Comparative Assessment of TRU Waste Forms and Processes

Volume II: Waste Form Data, Process Descriptions, and Costs

September 1982

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COMPARATIVE ASSESSMENT OF
TRU WASTE FORMS AND PROCESSES

VOLUME II: WASTE FORM DATA, PROCESS
DESCRIPTIONS, AND COSTS

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FOREWORD

This volume contains supporting information for the comparative assessment of the transuranic waste forms and processes summarized in Volume I. Detailed data on the characterization of the waste forms selected for the assessment, process descriptions, and cost information are provided. The purpose of this volume is to provide additional information that may be useful when using the data in Volume I and to provide greater detail on particular waste forms and processes. Volume II is divided into two sections and two appendixes. The first section provides information on the preparation of the waste form specimens used in this study and additional characterization data in support of that in Volume I. The second section includes detailed process descriptions for the eight processes evaluated. Appendix A lists the results of the MCC-1 leach test and Appendix B lists additional cost data.

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Waste Form Characterization Details

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WASTE FORM CHARACTERIZATION DETAILS

This section gives detailed descriptions of the preparation of the TRU waste and the seven waste forms evaluated. The chemical and physical characteristics of the waste forms are then discussed. Details of the MCC-1 leach test and the mechanical integrity test are provided.

WASTE MATERIALS USED IN COMPARATIVE ASSESSMENT

The various waste forms evaluated in this comparative study were all prepared from the same reference waste. This waste is actually a mixture of an ash produced in the Rocky Flats Plant (RFP) rotary-kiln incinerator and a sludge produced during the checkout phase of the RFP aqueous waste-stream decontamination facility. Reagent chemicals, primarily oxides, were added to the ash and sludge to yield a reference ash and a reference sludge whose compositions lay within the desired ranges. The reference ash and reference sludge were blended together to yield the reference waste. Because three times as much sludge as ash is anticipated to be produced at Rocky Flats, the reference waste contains the two components in a 3 to 1 ratio. For those tests that required plutonium-containing waste, a small quantity of another ash that contained Pu was added to the reference waste. Described below are the final adjustments to the ash and sludge and the preparation of the reference waste.

TRU REFERENCE ASH I

Reference Ash I was a combination of a nonradioactive RFP incinerator ash and several reagents mixed for 4 h in a ball mill. The batch makeup for the reference ash is listed in Table 1. Compositions of the RFP incinerator ash and the resulting TRU Reference Ash I, and

TABLE 1. Batch Makeup for TRU
Reference Ash I

<u>Components of TRU Reference Ash I</u>	<u>Amount, g</u>
Incinerator Ash	500.0
Al_2O_3	32.7
H_3BO_3	1.0
$\text{Ba}(\text{NO}_3)_2$	6.7
CaCO_3	58.0
Graphite	28.6
$\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	1.1
Fe_2O_3	2.5
KNO_3	16.7
MgO	49.8
Na_2CO_3	15.0
P_2O_5	37.8
SiO_2	57.5
Na_2SO_4	7.8
TiO_2	223.9
ZnO	2.9
$\text{ZrO}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}$	0.1
TOTAL	1042.1

the intended composition of the TRU reference ash, are shown in Table 2. (Compositions of the RFP sludge, reference sludge and intended reference waste are also listed; these are discussed in following sections.)

TRU REFERENCE SLUDGE III

Reference Sludge III was prepared by blending for 1 h 720.3 g of a nonradioactive RFP process sludge with 233.5 g of Fe_2O_3 and 346.1 g of SiO_2 in a ball mill.

An additional 5 wt% H_2O was needed to bring the TRU reference sludge batch to the intended level of 10 wt% H_2O . In order to reduce caking in the ball mill and to aid in the future blending of the reference waste batch, the H_2O addition was not made until the ash and sludge were blended together.

Table 2 shows the compositions of the RFP process sludge, the TRU Reference Sludge III, and the intended composition of the TRU reference sludge.

TRU REFERENCE WASTE III

The TRU Reference Waste III batch was prepared by mixing for 1 h one part Reference Ash I with three parts Reference Sludge III in a ball mill. To obtain the desired H_2O concentration of 7.5 wt%, a volume of distilled water, equal to 5 wt% of the Reference Sludge III component, was added, and the mixture was ball milled again for 1-1/2 h and then sieved to -12 mesh.

A total of 1200 g of the reference waste batch was spiked to 0.02 wt% Pu by adding 11.01 g of a second RFP incinerator ash that contained 2.2 wt% Pu. The Pu isotopic composition of this ash was ^{239}Pu --93.8%; ^{240}Pu --5.3%; and ^{241}Pu --0.4%. An even distribution of the plutonium-bearing ash throughout the reference waste was achieved by blending the two materials in an electric mortar grinder for 5 min and then shaking by hand in a large jar for 1/2 h.

A final chemical composition of the Reference Waste III batch is not available, but the intended composition is shown in Table 2. From this intended composition, a weight ratio of waste-as-batch to waste-as-oxides was estimated to be 1.18.

TABLE 2. Intended and Actual Compositions (expressed in wt% from ICP Analyses) of Reference Wastes

Component	RFP Incinerator Ash	TRU Reference Ash I	Intended Reference Ash I Composition	RFP Process Sludge	TRU Reference Sludge III	Intended Reference Sludge Composition	Intended Reference Waste III Composition	Analyzed Composition Reference Waste I
Al ₂ O ₃	28.9	16.7	18.6	2.46	1.49	1.48	5.76	5.74
B ₂ O ₃	0.05	0.09	<0.5	0.10	0.5	---	<0.5	<0.5
BaO	1.08	0.89	0.97	0.01	0.01	---	<0.5	<0.5
C(a)	---	9.00	9.7	---	---	---	2.43	2.79
CaO	1.41	3.56	4.0	13.6	7.56	7.61	6.71	6.28
Co ₂ O ₃	0.01	---	<0.5	---	0.01	---	<0.5	<0.5
Cr ₂ O ₃	0.15	0.10	<0.5	0.23	0.15	---	<0.5	<0.5
CuO	0.03	0.03	<0.5	0.06	0.05	---	<0.5	<0.5
Fe ₂ O ₃	2.23	1.20	1.43	9.38	22.8	21.9	16.8	13.39
K ₂ O	0.36	---	0.97	---	0.3	0.65	0.72	---
LiO ₂	---	---	---	0.02	0.01	---	---	---
MgO	0.68	4.83	5.34	6.27	2.95	3.50	3.97	3.37
MnO ₂	0.03	0.02	<0.5	0.04	0.02	---	<0.5	<0.5
MoO ₃	0.04	0.01	<0.5	---	0.01	---	<0.5	<0.5
Na ₂ O	1.14	1.17	1.82	11.20	7.05	6.19	5.1	5.6
NiO	0.06	---	<0.5	---	0.03	---	<0.5	<0.5
P ₂ O ₅	1.0	4.05	4.81	9.22	5.00	3.99	4.19	4.61
PbO	0.07	0.08	<0.5	---	---	---	---	---
SiO ₂	37.2	23.9	25.5	20.9	38.5	37.6	34.5	34.8
SrO	0.03	0.01	<0.5	0.27	0.15	---	<0.5	<0.5
TiO ₂	3.53	23.7	24.3	0.06	0.05	---	6.07	5.98
ZnO	2.65	1.84	1.67	0.05	0.04	---	0.50	0.69
ZrO ₂	0.05	0.04	<0.5	0.01	0.05	---	<0.5	<0.5
H ₂ O			---			10.0	7.5	16.46(c)
Other(b)						7.05	5.3	

(a) Determined with LECO CS44 carbon analyzer.

(b) Assumed to be carbonates, nitrates, and other volatiles.

(c) Determined from the weight loss of a sample held at 1050 °C for 3 h.

WASTE FORM FABRICATION

Seven waste forms were prepared for the characterization tests described in this report. These waste forms were:

- cast hydraulic cement
- cold-pressed hydraulic cement
- FUETAP cement
- borosilicate glass
- aluminosilicate glass
- cold-pressed/sintered silicate-ceramic
- recrystallized basalt glass-ceramic.

Most of the characterization tests were conducted on waste-form samples containing TRU Reference Waste III that contained plutonium (see preceding section). Fabrication of these samples is described here. Also, samples used in the mechanical integrity tests were prepared in the same manner, except that the reference waste did not contain plutonium. A second set of cement samples--cast hydraulic cement I and cold-pressed hydraulic cement I--was prepared with an earlier waste (Reference Waste 1 in Table 2) that contained smaller quantities of iron and zirconium than the TRU Reference Waste III. These cements were also leach-tested for 182 days at 40 and 90 °C.

CAST HYDRAULIC CEMENT II

The cast hydraulic cement II waste form was fabricated by adding 105 g of Reference Waste III (35 wt%) to 195 g of Portland Type II cement. After blending the 300 g of powder in an electric mortar grinder, 105 g of distilled water were added, and the batch was mixed to a paste by hand (water/solids = 0.35).

This paste was transferred to nine 2.5 cm dia x 5.0 cm high polystyrene sample vials. Each vial was vibrated to remove entrapped air, sealed with a polyethylene snap-on lid, and then set aside to cure at room temperature.

After curing for 31 days, the castings were removed from the sealed vials and cut into specimens for testing.

COLD-PRESSED HYDRAULIC CEMENT II

A 300 g batch of the cold-pressed hydraulic cement II waste form was prepared by blending equal weights of Reference Waste III and Portland Type II cement in an electric mortar grinder.

One-hundred-fifty grams of deionized water and the 300 g of waste-cement batch were mixed to a slurry by hand. From this slurry, 70 pellets (1.27 to 1.91 cm high) were pressed in a 1.27 cm dia die at 22,000 N (5000 lb) load. Butyl-stearate was used as the die lubricant.

The cold-pressed hydraulic cement II pellets were sealed into a plastic jar and allowed to cure at room temperature for 28 days before being cut into test specimens.

FUETAP CEMENT

The FUETAP samples were prepared at Oak Ridge National Laboratory. The formulation included 23 wt% Type I Portland Cement, 40% Reference Waste I, 15.5% Ottawa Sand, 0.5% Reax-LP (Westvaco), 1% D-65 (Dowell) and 20% water. Reax-LP and D-65 are proprietary set regulators. Due to time and material limitations, this formulation was not optimized for waste loading, porosity, compressive strength, or leachability. The cement, waste, Reax-LP, and sand were mixed together and the water and D-65 were stirred together. The dry mixture was then added to the liquid and the resulting grout was placed in Teflon[®]-lined molds. The molds were closed and autoclaved in saturated steam at 0.1 MPa and 100°C for 24 h. The samples were cooled and removed from the Teflon molds. Finally the samples were dewatered by heating 24 h at 250°C.

BOROSILICATE GLASS

A total of 400 g of glass batch for the borosilicate glass waste form was prepared by mixing several reagents to homogeneity in an electric mortar and grinder. The batch was sieved to -12 mesh and then reblended. Refer to Table 3 for the composition of this mixture. The ratio of glass batch weight to glass weight as oxide was 1.466.

A total of 398.6 g of the borosilicate glass batch was blended with 320.5 g of Reference Waste III in an electric mortar grinder. After melting, this blend produced a glass that was 50 wt% reference-waste-loaded as oxide.

Five borosilicate glass bars were produced by melting ~110 g glass batches in each of five unglazed porcelain crucibles at 1105°C. Each batch was melted for 2 h in an air atmosphere. The molten glass was poured into a 1.91 cm by ~7.6 cm long stainless steel mold that had been preheated on a metal hot plate.

Immediately after the bars had solidified (15 to 20 s), they were transferred to a preheated 500°C furnace and annealed at least 2 h in an air atmosphere before being furnace-cooled to room temperature.

TABLE 3. Chemical Makeup of the Borosilicate Frit Batch

Intended Composition		Batch Makeup	
Component	Wt% Oxide	Chemical Used	Weight Used, g
B ₂ O ₃	18.60	H ₃ BO ₃	90.10
CaO	12.09	CaCO ₃	58.86
CuO	4.64	Cu(OH) ₂	15.56
K ₂ O	3.71	KNO ₃	21.72
Li ₂ O	3.71	LiOH H ₂ O	28.43
MgO	2.96	MgO	8.07
Na ₂ O	7.44	Na ₂ CO ₃	34.70
SiO ₂	39.79	SiO ₂	108.52
TiO ₂	2.42	TiO ₂	6.60
ZrO ₂	4.64	ZrO(NO ₃) ₂ ·2H ₂ O	27.34

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ALUMINOSILICATE GLASS

The frit batch for the aluminosilicate glass waste form was prepared by mixing several reagent-grade chemicals in an electric mortar grinder, sieving to -12 mesh and reblending. The chemical makeup of this batch is given in Table 4. The ratio of batch weight to glass weight as oxides was calculated to be 1.208.

A 50 wt% waste-loaded (as oxide) aluminosilicate glass was fabricated. A total of 341 g of frit batch and 349 g of Reference Waste III was combined and blended in an electric mortar grinder. This yielded a 50% waste loading in the final glass product.

The mixture was melted in a platinum crucible at 1350°C for 2 h, and then five glass bars were poured in a 1.91 cm by ~7.6 cm stainless mold that had been preheated on a metal hot plate. After the edges of the bars had cooled to below "red heat," they were placed in a furnace at 500°C. The bars were held at this temperature for 2 h before being furnace-cooled to room temperature.

One aluminosilicate glass bar shattered while being cut into test specimens. As a result, the remaining bars were re-annealed by heating them from room temperature to 600°C at ~6°C/min. They were held at temperature for 3 h and then furnace-cooled.

COLD-PRESSED/SINTERED SILICATE CERAMIC

The cold-pressed/sintered silicate-ceramic waste form was prepared by ball milling for 12 h 70 g of bentonite and 35 g of the original unspiked Reference Waste III batch in ~250 mL of acetone. The mixture was air-dried and sieved to -70 mesh.

A total of 0.32 g of the RFP ash that contained 2.2 wt% Pu was blended with 104 g of the silicate-ceramic batch in an electric mortar grinder. This blend was equivalent to a 0.02 wt% Pu content in the reference waste. The final waste loading was 33 wt%.

Fifty-one pellets, each weighing ~2 g, were pressed from this batch in a 1.27 cm dia die at 8000 N (1800 lb) load using butyl-stearate as the die lubricant.

The pellets were sintered in an air atmosphere by heating at 300°C/h to 1000°C and holding at 1000°C for 2 h. The sintered pellets were then allowed to furnace-cool.

TABLE 4. Chemical Makeup of the Aluminosilicate Frit Batch

Intended Composition		Batch Makeup	
Component	Wt% Oxide	Chemical Used	Weight Used, g
Al ₂ O ₃	11.90	Al ₂ O ₃	34.53
CaO	14.38	CaCO ₃	74.45
K ₂ O	1.08	KNO ₃	6.72
MgO	2.83	MgO	8.20
Na ₂ O	5.75	Na ₂ CO ₃	28.53
SiO ₂	54.98	SiO ₂	159.20
TiO ₂	5.44	TiO ₂	15.79
ZrO ₂	3.63	ZrO(NO ₃) ₂ ·2H ₂ O	22.77

RECRYSTALLIZED BASALT GLASS-CERAMIC

A basalt glass-ceramic waste form with a 30% waste loading was prepared by mixing a total of 336 g of -40 mesh Pomona basalt (composition shown in Table 5) with 144 g of the TRU Reference Waste III batch in an electric mortar grinder.

The batch was melted in a platinum crucible in air for 2 h at 1400°C. Five bars were produced by pouring the molten glass in a stainless steel bar mold that had been preheated on a metal hot plate. When the edges of the bars had cooled to below "red heat," they were transferred to a 550°C annealing furnace. After 2 h at 550°C the bars were furnace-cooled.

The basalt glass-ceramic bars, which ranged in length from 2.5 to 10 cm, were recrystallized in a two-stage heat treatment. This was done by heating the bars in an air atmosphere from room temperature to 670°C at a heating rate of 4°C/min. After 1 h at 670°C, the temperature was increased to 920°C at 4°C/min, held 8 h, and then the bars were allowed to furnace-cool.

CAST HYDRAULIC CEMENT I

The cast hydraulic cement I specimens contained a 35 wt% loading of TRU Reference Waste I (see Table 2 for this waste composition). Portland Type II Cement (124 g) was blended with 64.83 g of Reference Waste I and 0.67 g of the RFP ash containing 2.2 wt% Pu. After the blend was mixed in the electric mortar grinder, 66.5 g of distilled water was added to the powders and the mixture was blended to a paste by hand (water/solids = 0.35).

The paste was then transferred to six plastic vials. The 5 cm high x 2.5 cm dia vials were then vibrated to remove any air pockets and sealed with snap-on plastic lids. After 7 days, the lids were removed. These samples were cut into test specimens 126 days after fabrication.

TABLE 5. ICP Analysis of
Pomona Basalt

<u>Component</u>	<u>Wt%</u>
Al ₂ O ₃	13.90
CaO	10.20
Fe ₂ O ₃	11.70
K ₂ O	0.50
MgO	6.68
MnO ₂	0.20
Na ₂ O	1.70
SiO ₂	51.60
TiO ₂	2.73

COLD-PRESSED HYDRAULIC CEMENT I

This waste form contained 50 wt% TRU Reference Waste I. Fifty grams of Portland Type II Cement, 49.5 g of Reference Waste I, and 0.5 g of the RFP ash containing 2.2 wt% Pu were mixed in an electric mortar grinder. Fifty milliliters of deionized H₂O was added to the solids, and the slurry was mixed by hand. From this material, 13 pellets, each about 1.3 cm high, were pressed at 22,000 N (5000 lb) load in a 1.27 cm dia die using butyl stearate as the die lubricant. The pellets were sealed in a glass jar for 127 days until they were cut into test specimens.

BASIC CHARACTERIZATION OF WASTE FORMS

To verify that each waste form had the designated composition and to provide basic data needed to interpret the results of the comparison tests, the chemical and microstructural compositions of each waste form were determined, and the density, porosity, and BET surface areas were measured.

CHEMICAL COMPOSITION

A sample of each waste form was crushed and fused in potassium hydroxide and in sodium peroxide. The fusions were dissolved and the resulting solutions were chemically analyzed with the inductive-coupled plasma spectrometer. Plutonium and americium concentrations were determined by alpha-energy analysis. Table 6 shows the results of these analyses. The concentrations of the nonradioactive species are expressed as weight percent of the oxide, and the actinide concentrations are shown as grams of metal per gram of waste form. The analyses of the cements (designated IIs) include the weight lost after heating to 800 °C as determined by thermogravimetric analysis. This loss is assumed to be water, but may also include CO₂.

PHYSICAL PROPERTIES

Several basic physical properties of the TRU waste forms have been determined and are shown in Table 7. The density and total open porosity were measured with a mercury porosimeter. The closed porosity was estimated from void areas observed on photomicrographs of cross sections of each waste form. Surface areas were too low for BET measurement for all forms except the cements. The large open porosities associated with the cements resulted in specimen surface areas ~50,000 times larger than the geometric surface area.

MICROSTRUCTURE

Waste form microstructural characterization can provide insight into a mechanistic interpretation of both chemical and physical durability tests. All seven TRU waste forms were characterized by semiquantitative X-ray diffraction (XRD), optical metallography (MET), alpha-autoradiography (α -AR), and scanning electron microscopy (SEM) that had energy dispersive analysis (EDAX) capabilities.

Phase compositions were determined primarily by correlating SEM-EDAX data with XRD crystal structure identification. Phase concentration estimates were obtained by semiquantitative XRD and verified in part by quantitative metallographic analysis. Phase morphology and apparent porosity were determined from micrographs obtained via MET and SEM. Plutonium distributions in the waste form and its host crystal phases were determined using SEM-EDAX and α -autoradiography.

TABLE 6. Composition of TRU Waste Forms, Wt% Oxide

Component	Borosilicate Glass	Aluminosilicate Glass	Basalt Glass- Ceramic	Silicate Ceramic	Cast Cement I	Cast Cement II	Cold- Pressed Cement I	Cold- Pressed Cement II	FUETAP Cement
Al ₂ O ₃	3.65	9.38	11.88	15.81	3.81	2.29	4.43	4.20	4.72
B ₂ O ₃	9.74	0.19	0.12	0.19	0.28	0.13	0.50	0.22	0.57
BaO	0.14	0.14	0.09	0.11	0.11	0.10	0.15	0.12	0.13
CaO	10.44	10.92	9.62	3.65	35.79	35.82	30.79	30.41	22.8
CuO	2.17	---	---	---	---	---	---	---	---
Fe ₂ O ₃	10.12	9.55	13.65	9.09	6.42	7.10	8.30	9.20	9.19
K ₂ O	1.97	0.80	0.58	0.39	---	---	---	---	---
Li ₂ O	1.89	---	---	---	---	---	---	---	---
MgO	3.18	3.05	5.41	2.89	1.77	1.55	2.12	2.05	2.3
MnO ₂	---	---	0.14	---	0.12	0.07	0.11	0.09	---
Na ₂ O	7.27	6.09	3.82	4.01	1.93	2.21	2.07	1.84	3.5
P ₂ O ₅	2.00	1.32	1.50	1.50	1.16	1.24	1.94	1.89	2.2
SiO ₂	39.81	44.37	46.26	55.14	22.81	23.05	25.52	25.15	38.4
SrO	0.07	0.07	0.05	0.07	0.08	0.08	0.09	0.09	0.08
TiO ₂	4.75	6.06	2.93	2.34	1.79	1.82	2.76	2.69	3.21
ZnO	0.29	0.25	0.16	0.27	0.20	0.14	0.23	0.27	0.35
ZrO ₂	1.09	0.51	---	---	---	---	---	---	---
Wt. Loss on Heating to 800 °C (a)	---	---	---	---	(c)	19.7	(c)	12.1	10.8
TOTAL	98.58	92.70	96.21	95.36	>76.27	95.30	>79.01	90.32	98.25
Pu	9.25E-5 ^(b)	9.19E-5	4.95E-5	6.30E-5	5.36E-5	5.59E-5	7.95E-5	7.77E-5	1.04E-4
²⁴¹ Am	1.78E-7	1.85E-7	9.73E-8	1.08E-7	9.03E-8	9.31E-8	1.45E-7	1.35E-7	---

(a) Determined by thermogravimetric analysis.

(b) Expressed as grams of metal per gram of waste form.

(c) Not determined.

TABLE 7. Density and Porosity of TRU Waste Forms

Waste Form	Density, g/cm ³	Open Porosity, %	Geometric Surface Area, cm ²	BET Surface Area, cm ² BDL (a)
Borosilicate Glass	2.80	0.5	4.06	BDL
Aluminosilicate Glass	2.80	0.2	4.04	BDL
Basalt Glass-Ceramic	2.93	0.3	4.03	BDL
Silicate Ceramic	2.49	0.9	3.96	400
Cast Cement I	1.63	23	4.03	2.1×10^5
Cast Cement II	1.63	22	3.99	2.2×10^5
Cold-Pressed Cement I	2.09		4.10	1.9×10^5
Cold Pressed Cement II	1.76	13	4.45	2.2×10^5
FUETAP Cement	1.69	7	3.75	2.1×10^5

(a) Below detection limit.

The results of this characterization are summarized below for each waste form:

- Aluminosilicate Glass:** Microscopic examination shows this material to be uniform and vitreous under magnifications as high as 3000X. Figure 1 is an optical micrograph and an autoradiograph of the same polished specimen. The micrograph shows the absence of crystalline microstructure in the glass. The large bubble is a casting artifact and not typical of the glass. The α -autoradiograph shows a good dispersion of Pu in this glass.
- Borosilicate Glass:** Glove-box X-ray diffraction analysis shows that this material is vitreous; however, microstructural examination shows a fine dispersion of micron-sized rod-shaped crystals that EDAX indicated were high in copper. X-ray diffraction analysis of a non-smearable sample on a unit outside the glove box (which has a much lower radioactive background) confirmed the presence of metallic Cu crystals in this glass as shown in Figure 2. Both MET and XRD analysis indicated that ~2 wt% of this phase was present in the sample. A second crystalline phase was also detected during microstructural examination. This phase was very rich in Zr and formed crystals ~100 μ m in dia. However, quantitative metallography indicates that this phase is present in the glass at <0.1 wt% and is thus undetectable by X-ray diffraction. This phase is shown in Figure 3. The light and dark areas of this crystalline assemblage represent a change in Zr to Si ratios--from 2 to 1 for the interior (light) areas to 1 to 1 for the dark areas that interface the glass. Figure 4 is an optical micrograph and an α -autoradiograph of a polished specimen of borosilicate glass. The micrograph shows the glass to have ~1% closed porosity. The α -autoradiograph of this sample shows that there is a good dispersion of Pu in the glass and that the Zr-rich crystals are somewhat enriched in Pu compared to the remainder of the glass sample.

(a) OPTICAL MICROGRAPH

1 mm

(b) α -AUTORADIOGRAPH

1 mm

FIGURE 1. Optical Micrograph and α -Autoradiograph of a Polished Specimen of Aluminosilicate Glass Showing an Absence of Crystals and a Good Dispersion of Plutonium in the Glass

FIGURE 2. SEM Micrograph of Micron-Sized Metallic Copper Crystals in Borosilicate Glass

Zr/Si RATIO

(a) 2 : 1

(b) 1 : 1

FIGURE 3. SEM Micrograph of a $(\text{Zr,Si})\text{O}_2$ Crystalline Assemblage in a Borosilicate Glass. (The light areas have less Si than the dark areas that interface with the glass.)

FIGURE 4. Optical Micrograph and α -Autoradiograph of Borosilicate Glass Showing $\sim 1\%$ Closed Porosity and a Good Dispersion of Plutonium in the Glass [Point A is a Zr-rich crystal (see Figure 3), which shows some Pu enrichment compared to the bulk glass.]

- Basalt Glass-Ceramic:** Different techniques have been used to identify several different crystalline phases in the basalt glass-ceramic. Metallographic examination shows a large number of fine and uniformly dispersed submicron-size augite crystals occupying perhaps a quarter of the glass volume. Microstructural examination on a scanning electron microscope shows only dendritic spinel $(\text{Mg, Ti, Fe})_2\text{O}_4$ crystals ranging from 2 to 7 μm in length and present at about 2 wt% in the glass (see Figure 5). X-ray diffraction analysis shows that the phase that is optically visible is $(\text{Ca, Na})(\text{Mg, Fe, Al})(\text{Si, Al})_2\text{O}_6$, which is present at an estimated 25 wt%. This phase is compositionally similar to the residual glass, and this may be the reason that it is unobservable by SEM. The α -autoradiograph of this sample, shown in Figure 6 along with the corresponding optical micrograph, indicates that the Pu is dispersed uniformly in the material. However, because the uniform dispersion is over a large number of small crystals, the crystallographic location of the Pu in the sample is uncertain.
- Cold-Pressed/Sintered Silicate-Ceramic:** Five crystalline phases were identified in this material, as shown in Figure 7. Two crystalline forms of SiO_2 were distinguishable by X-ray diffraction. These were quartz ($\alpha\text{-SiO}_2$) (~ 2 wt%) and low cristobalite (~ 18 wt%). Two iron oxide phases were observed in this ceramic also. Hematite ($\alpha\text{-Fe}_2\text{O}_3$) was present (~ 10 wt%), and a spinel-type crystal of the compositional form $(\text{Cr, Fe, Mg, Ni, Ti, Zn})(\text{Fe, Cr, Al})_2\text{O}_4$ was also noted

FIGURE 5. Micrograph of Crystalline Phases of Basalt Glass-Ceramic [The optical micrograph (a) shows a fine dispersion of micron-sized augite crystals invisible on the SEM micrograph (b) which reveals several spinel crystals only.]

FIGURE 6. An Optical Micrograph and its Corresponding α -Autoradiograph of a Polished Basalt Glass-Ceramic Section Showing an Absence of Large Crystals, Insignificant Porosity, and a Fine Dispersion of Pu in the Bulk Material

FIGURE 7. Crystalline Phase Identification in a Cold-Pressed/Sintered Silicate-Ceramic

(~6 wt%). The fifth crystalline phase observed was tentatively identified as CaMgP₂O₇ (~1 wt%). Both SiO₂ phases appear optically as dark, irregular shapes that are on the order of 2 to 20 μm in size. The iron oxide phases are optically bright shapes that range in size from a block-shaped 100 μm Fe₂O₃ crystal to micron-sized crystals of spinel. Crystals of CaMgP₂O₇ were observed with SEM to occur on the surfaces of a hematite crystal. While this phosphate phase is the most likely host for Pu, the presence of Pu in this or any other phase could not be confirmed with either SEM-EDAX or α-autoradiography. Excluding the SiO₂ and hematite, the great majority of the crystals observed in this ceramic were typically several microns or less in size. This is the principal reason that the phase in which the Pu is associated in this sample could not be determined. However, the α-autoradiograph does show the Pu to be definitely concentrated into selected areas of the sample, as shown in Figure 8.

- Cement:** Four crystalline phases have been identified in the cold-pressed material, and at least one more phase remains unidentified. Weight percents total ~10 wt% SiO₂, ~5 wt% each Ca₃SiO₅ and Ca₂Fe₂O₅, ~2 wt% Ca(OH)₂ and ~5 wt% of an unknown phase. The cast cement has the same phase assemblage, but the total weight percent for each phase is reduced by one-third in this material. Both cements have the aggregate microstructures expected of this type of material, but the microstructural similarities end there. The cast cement has closed porosity estimated at ~10 vol%. The cold-pressed cement has ~2 vol% closed porosity, as is shown for both materials in Figure 9. Alpha-autoradiographs for both these cements show that Pu is concentrated in some phase in these materials, but the phase involved

FIGURE 8. An Optical Micrograph and Its Corresponding α -Autoradiograph of a Polished Pressed/Sintered Silicate-Ceramic Sample Showing the Fine- and Regular-Featured Microstructure

FIGURE 9. Optical Micrographs Showing the Comparative Microstructure of a) Cast Cement and b) Pressed Cement

cannot yet be identified in these samples. Figures 10 and 11 show the optical micrographs and corresponding α -autoradiographs for the cast and pressed cements, respectively.

The FUETAP cement has two main phases-- SiO_2 and Fe_2O_3 (hematite). A third phase was tentatively identified as either $\text{Ca}(\text{PO}_3)_2$ or CaAl_4O_7 . Figure 12 shows the optical micrograph and corresponding α -autoradiograph for the FUETAP cement.

FIGURE 10. An Optical Micrograph of a Cast-Cement Sample and Its Corresponding α -Autoradiograph

FIGURE 11. An Optical Micrograph of a Pressed-Cement Sample and Its Corresponding α -Autoradiograph

FIGURE 12. An Optical Micrograph of a FUETAP Cement Sample and Its Corresponding α -Autoradiograph

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LEACH TEST AND CHEMICAL ANALYSIS METHODS

The seven waste forms were subjected to leach testing to provide a basis for comparing their relative chemical durabilities. The methodology used for the tests is presented in this section. The detailed results of these leach tests are contained in Appendix A.

LEACH TEST METHOD

The procedure used for obtaining data for comparing the chemical durabilities of the TRU waste forms is the MCC-1 Static Leach Test (MCC 1981). This test, developed by the Materials Characterization Center (MCC) at PNL, is designed to distinguish differences in leach behavior among waste forms and to permit an initial ranking of waste forms based on their leach resistance.

The test involves immersion of weighed specimens of known surface area in reference leachants in teflon leach vessels for fixed periods at closely controlled reference temperatures. The reference leachants are high-purity water (deionized water), silicate ground water, and brine. At the conclusion of the test period, the specimens are removed, rinsed, dried and weighed to determine weight loss. The leachate is acidified to 2 M HNO_3 in the leach vessel and heated at 90°C for 24 h to dissolve materials adsorbed on the leach vessel surfaces. From an analysis of the solution, the concentrations of leached elements are determined and the normalized losses and normalized depletion depths based on several elements are calculated.

The normalized loss (NL) in g/m^2 is calculated from:

$$(\text{NL})_i = \frac{M_i}{f_i \cdot \text{SA}}$$

where

f_i = the weight fraction of element i in the original specimen

M_i = mass of element i in the leachate in grams

SA = the geometric surface area of the specimen in m^2 .

For Pu, the normalized loss is calculated from:

$$(\text{NL})_{\text{Pu}} = \frac{A_{\text{Pu}} \cdot W_0}{A_0 \cdot \text{SA}}$$

where

A_{Pu} = the alpha activity in the leachate, disintegrations/min

A_0 = the total alpha activity in the original specimen, disintegrations/min

W_0 = the original specimen weight, g.

The normalized depletion depth in microns is calculated from:

$$(ND)_i = \frac{(NL)_i 10^3}{\rho}$$

where ρ = specimen density, kg/m^3 .

Status of MCC-1 Test at Start of Tests

The MCC-1 Static Leach Test was still undergoing revisions when the leach tests of all but the FUETAP TRU waste forms were begun (January 1981). The procedure used corresponded to that described in the January 1981 draft of the test. The only significant differences in the experimental conditions actually used and the current procedure that has been approved by the Material Review Board lie in the steps for cleaning the leach vessel. Some of the differences are:

Leach Vessel Cleaning. New leach vessels were not heated in air at 200°C for 1 wk prior to washing that is now required. The leach vessels were placed in boiling HNO_3 rather than in HNO_3 at 50°C , the temperature now specified in Step 3 of the cleaning procedure.

Removal of Plutonium Adsorbed on Leach Vessel Surface. In the MCC-1 test procedure, the specimen is removed at the end of the test, enough acid is added to the leach vessel to make the leachate 0.15 M , and the vessel is heated at 90°C for 12 h. We found that more than 90% of the plutonium released from the specimens was adsorbed on the leach vessel walls and that removal of the plutonium by acidifying the leachate to 0.15 M was incomplete. However, when the acidity of the leachate was increased into the range 1.0 to 6.0 M and the vessel was heated at 90°C for 24 h, >95% of the plutonium was dissolved. Therefore, the procedure was modified to adjust the acidity to 2.0 M H^+ . Reagent-grade nitric acid was used for the high-purity water and silicate ground-water leachants, and reagent-grade hydrochloric acid was used for the brine leachants. The vessels were held at 90°C for 24 h before the leachate was sampled for elemental analysis. This modification was also included in the blanks and the reference waste form tests.

After all the leach tests were completed it was discovered that the 2 M H^+ was still not sufficient to remove all the Pu from the leach vessel walls. A solution of 2 M HNO_3 and 0.1 M HF , however, did remove the Pu. Unfortunately, all of the leach solutions had been discarded and could not be reanalyzed. Therefore, the reported Pu values may be low by as much as a factor of three.

Test Matrix. The test matrix, shown in Table 8, did not completely follow any of the matrices recommended in the MCC-1 test procedure. The 90°C tests included matrix B and most of matrix D, except that the 364-day tests were not included, duplicate tests were run for 91 days, and triplicate tests were run for 182 days.

Analytical Techniques Used for Analysis of Leachates

Initially, the determination of Pu and Am in the leachates was by alpha-energy analysis of a 0.5 mL aliquot dried on stainless steel planchettes. Although quantitative results were obtained, it became apparent that an alternative method capable of the precise determination

TABLE 8. Test Matrix for Leach Tests of TRU Waste Forms

Leachant and Temperature	Number of Specimens						
	3 days	7 days	14 days	28 days	56 days	91 days	182 days
40 °C Water				3			3
Brine				1			1
Silicate Water				1			1
90 °C Water	1	1	1	3	2	2	3
Brine				3	2	2	3
Silicate Water				3	2	2	3

of Pu at concentrations as low as 10^{-11} moles/L in leachates of high ionic strength (e.g., salt brine), and which was simple and inexpensive, would be needed.

The method selected is a simple extraction liquid-scintillation technique originally developed for analyzing samples of animal tissue (Keough and Powers 1970). It utilizes direct extraction of Pu from 10 mL of the acidified leachate into a toluene solution of di-(2-ethylhexyl) phosphoric acid and scintillators (para-terphenyl and POPOP), and liquid scintillation counting of the alpha disintegrations. The extraction is made in the liquid scintillation vial, and counting is performed with both phases present. Brine samples were treated with sodium nitrite and heated. Sodium bromate was added before extraction. This treatment produced a luminescence in the samples that took several hours to subside before the samples could be counted. Because of low count rate, the measurement uncertainty for many samples was dominated by the background (~4 counts/min).

Determination of the nonradioactive elements was made by direct measurement of the leachate by ion-coupled plasma spectrometry. The instrument was calibrated twice daily using single-element standards obtained from Spex Industries Inc., Metuchen, New Jersey. Multi-element standards, prepared in the laboratory using these single element standards, were also used.

LEACH TEST DATA

Leachant Analysis

The leachants consisted of water, brine and silicate water. The nominal compositions are shown in Table 9.

The leachants were made up with high-purity deionized water. The chemicals used for the brine and silicate-water leachants were reagent grade. Each leachant was analyzed for metal-ion impurities by ICP. The pH was checked and adjusted to the specified values with dilute HCl or NaOH solutions before each leachant was used. Data describing each batch of leachant used in the 90 °C and 40 °C tests are given in Tables 10 and 11.

TABLE 9. Leachant Composition Used in Comparative Study

Leachant	Specifications
Water	Air-saturated water with a total impurity level <0.1 mg/L
Brine	MgCl ₂ --116 ± 11.6 g/L KCl--42 ± 4.2 g/L NaCl--90 ± 9 g/L pH--6.5 ± 0.1
Silicate Water	NaHCO ₃ --0.179 ± 0.0179 g/L SiO ₂ --0.058 ± 0.0058 g/L pH--7.5 ± 0.1

TABLE 10. Analysis of Leachants Used in 90°C Tests

Batch Number	Deionized Water		Silicate Ground Water		Brine	
	DI-1	DI-5	SL-2	SL-3	BC-1	BC 2
Date Made Up	01/02/81	02/17/81	02/02/81	03/30/81	01/27/81	03/30/81
Date Last Used	02/03/81	04/13/81	02/11/81	04/13/81	02/11/81	04/13/81
pH When Used	5.83	5.90	7.51	7.44	6.59	6.58
Element	Concentration, mg/L					
Al	---	---	---	---	---	---
Ca	---	---	---	---	20	20
Fe	---	---	---	---	---	---
K	---	---	---	---	27,500	26,400
Mg	---	---	---	---	29,600	32,300
Na	---	---	49	48.7	36,800	33,800
Si	---	---	24.7	25.5	---	---
Ti	---	---	---	---	---	---

(a) Below detection limit.

Equipment and Calibrations Used in Leach Tests

Table 12 lists the equipment used for the leach tests and the method and frequency of its calibration, where applicable.

Leachate Analyses

The tables in Appendix A list the normalized mass losses (NL_i) and the final pH for each test. For those tests with replication, the average normalized mass loss is reported along with the standard deviation. In all tests the sample surface area to volume of leachate ratio was 0.100 cm⁻¹.

TABLE 11. Analysis of Leachants Used in 40°C Tests

Batch Number	DI H ₂ O-I	DI H ₂ O-II	DI H ₂ O-III	Brine I ^(a)	Brine II	Brine III	Silicate IV	Silicate V	Silicate VI
Date Made Up	02/02/81	02/26/81	04/08/81	02/02/81	02/26/81	02/26/81	03/03/81	03/25/81	04/10/81
Last Date Used	02/06/81	03/02/81	04/14/81	02/06/81	03/02/81	03/27/81	03/12/81	03/27/81	04/14/81
pH When Used	---	---	---	6.5	6.5	6.6	7.6	7.5	7.6
Element	Concentration, mg/L								
Al	---	(b)	---	---	---	4.0	---	---	---
Ca	---	---	---	---	---	---	---	---	---
Fe	---	---	---	0.87	3.3	---	---	---	---
K	---	---	---	25,500	25,200	24,700	---	---	---
Mg	---	---	---	30,900	30,200	29,500	---	---	---
Na	---	---	---	35,000	33,300	34,300	44.8	48.7	47.4
Si	---	---	---	---	---	---	27.6	29.2	29.8
Ti	---	---	---	0.2	0.2	0.2	---	---	---

(a) Average of three determinations.

(b) Below detection limit.

TABLE 12. Equipment and Calibrations Used for Leach Tests

Item	40 °C Tests		90 °C Tests	
	Description	Calibration ^(a)	Description	Calibration ^(a)
Environmental Chamber	Blue M Model No. 0V-490A-Z mechanical convention oven	K-type thermocouples to Fluke digital thermometer model No. 2176A against Rubicon mV box every 6 months	Blue M model No. 472 A-Z forced-air-convection drying oven	K-type thermocouples calibrated against a platinum resistance thermometer by HEDL Standards Laboratory on December 18, 1980.
Temperature Recorder	Omniscribe® mV recorder Model No. B5227R-5, manufactured by Houston Instrument Company	K-type thermocouple against technique mV box every 6 months	Brown Honeywell Model Y(14) strip-chart recorder	Calibrated against standard voltage 6-months frequency by HEDL Standards Lab.
Balance	Mettler Model P-5	Calibrated against certified weights by HEDL Standards Lab--30-day frequency	Mettler Model H-51	Calibrated against certified weights by HEDL Standards Lab--30-day frequency.
pH Meter	Beckman Model SS-2 Expandomatic with Corning No. 22 34132-30 combination pH electrode	With buffer solution of pH4, pH7, pH10, every fourth sample	Beckman-Altex Model No. 4500	Calibrated against certified buffer solutions at pH4, pH7, and pH10. Frequency--each time used.
Micrometer	Starret No. 230RL outside micrometer calibrated to 0.001 in.	Starret® certificate of accuracy traceable to National Bureau of Standards, Washington, D.C.	Mitutoyo Model No. 505-626 dial caliper	Calibrated with Grade 3 block gauge.
Leach Vessels	60-mL PFS Teflon® vessels. Sovillex Catalog No. 0102-53 MOD		60-mL PFS Teflon® vessels. Sovillex Catalog No. 0102-53 MOD	

(a) All calibrations done by Hanford Engineering Development Laboratory (HEDL) Standards Laboratory are traceable to National Bureau of Standards through the primary Standards Laboratory, Dept. 2550, Sandia Laboratories, Albuquerque, New Mexico.

MECHANICAL INTEGRITY TESTS

The diametral compression test employed in this study follows procedures outlined in the Materials Characterization Center's Tensile-Strength Test (MCC-11) (MCC 1981). This test is used to measure the static tensile strength of brittle nuclear-waste solids. The test provides tensile-strength data that can be used to compare and to predict occurrence of fracture caused by tensile stresses. The test is applicable only to brittle materials such as glass, ceramics, concrete, and other materials that have tensile strengths that are less than one-third the value of their compressive strengths.

SAMPLE PREPARATION

Seven TRU waste-form materials were prepared and tested. The materials (previously described) were prepared for testing by either fabricating them to size or by core drilling them from larger samples. The samples were then centerless ground to produce uniform surface finishes and uniform roundness. Right circular cylinders with a length-to-diameter ratio of 0.5 were cut on a low-speed wafering saw using -200 mesh diamond blades. All specimens were within the tolerances specified by the MCC: round within a total tolerance zone of 0.025 mm, straight within a tolerance zone of 0.050 mm, the ends perpendicular to the cylinder axis within a tolerance zone of 0.075 mm, and the ends of the specimen parallel within a tolerance zone of 0.15 mm.

TEST PROCEDURE

In the tensile test used in this study, waste forms, in the form of right circular cylinders, are compressed along the vertical diametral plane by two platens, one of which moves at a constant speed relative to the other. As the load on the specimen increases, the tensile stresses imposed along the diametral plane reach the fracture strength of the material and the specimen splits. The fracture tensile strength is calculated from the load at the initiation of fracture and sample dimensions by the following equation:

$$T = 2P/\pi dt, \text{ MPa}$$

where P = applied force at initiation of fracture, N

d = specimen diameter, mm

t = specimen thickness, mm.

The samples tested in this study were placed between balsawood pads and loaded to fracture at a constant crosshead speed of 8×10^{-4} mm/s. The particular crosshead speed used in the test was sufficiently slow to approximate static stresses within the samples.

EXPERIMENTAL PROCEDURE

The experimental procedure was carried out in two parts. In the first part, the effect of the concentration of the reactants on the rate of reaction was studied. In the second part, the effect of the temperature on the rate of reaction was studied. The rate of reaction was measured by the volume of gas evolved per unit time.

Part I: Effect of Concentration

In the first part of the experiment, the effect of the concentration of the reactants on the rate of reaction was studied. The reactants were hydrogen peroxide and potassium iodide. The rate of reaction was measured by the volume of gas evolved per unit time. The results are shown in Table I.

Part II: Effect of Temperature

In the second part of the experiment, the effect of the temperature on the rate of reaction was studied. The reactants were hydrogen peroxide and potassium iodide. The rate of reaction was measured by the volume of gas evolved per unit time. The results are shown in Table II.

Discussion

The results of the experiment show that the rate of reaction increases with increasing concentration of the reactants and with increasing temperature. This is in agreement with the theoretical predictions.

Process Descriptions

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PROCESS DESCRIPTIONS

Volume I of this comparative assessment study evaluates, in part, the waste-immobilization processes. That evaluation is based on processing costs, equipment needs, maintenance requirements, and safety aspects. Those factors are derived from the process descriptions included here. The descriptions that follow represent a single conceptualized view of the eight processes and facilities, although we recognize that other conceptual designs are possible. The descriptions included, however, do provide reasonably safe and viable designs for the various processes considered in this comparative study.

EXPERIMENTAL

The first part of this experiment was devoted to the study of the effect of the concentration of the reactants on the rate of the reaction. The reaction was carried out in a closed system at a constant temperature of 25°C. The reactants were mixed in a beaker and the time taken for the reaction to complete was recorded. The concentration of the reactants was varied in a series of experiments and the effect on the rate of reaction was observed. The results showed that the rate of reaction increased with an increase in the concentration of the reactants.

100
90
80
70
60
50
40
30
20
10
0

BASES AND ASSUMPTIONS

The present study assumes that a facility will be designed, built, and operated to immobilize TRU wastes generated by a nuclear materials processing plant. The Rocky Flats Plant at Golden, Colorado, was selected as the reference study case. TRU wastes generated by this plant include high-specific activity (HSA) incinerator ashes, low-specific activity (LSA) incinerator ashes, dried process sludges, and other solid wastes, including spent glassware, pumps, and filters. In this study, it is assumed that only the ashes and the sludges are immobilized. Immobilization methods for the other TRU wastes are not considered at this time, although it is recognized that the cast-cement, FUETAP cement, and in-can glass melting processes may be suitable for immobilizing all wastes if equipment wastes are placed inside containers before the cement or glass is discharged into the containers.

Typical compositions of the ashes and the sludge are shown in Table 2, Volume I. The annual generation rate of these materials is shown below:

- HSA ash--10,000 kg/yr
- LSA ash--36,000 kg/yr
- process sludge--144,500 kg/yr.

The ashes are generated intermittently during the year when the incinerators are operated. The HSA ash is stored in 1-gal containers after it has been leached in a plutonium recovery process and dried. The LSA ash is stored in 55 gal drums. Both ashes are extremely lightweight, having densities of about 0.30 g/cm^3 . The ashes also tend to be somewhat hygroscopic. The lightweight and hygroscopic nature of the ashes will present some difficult handling problems in the solidification process. The ashes may also contain a small fraction of coarse material, including nuts and bolts, wire, and chunks of brick. This coarse material will be screened out during unloading into the process to prevent handling and processing problems in downstream operations. The screened coarse material will not be immobilized.

The process sludge is heavier, having a density of 1.1 g/cm^3 . The sludge is not excessively dusty and is considered relatively free-flowing. The process sludge is also stored in 55 gal drums. However, since the sludge is generated at a fairly high and continuous rate, there are advantages in avoiding the drumming step, as discussed on page 45.

Of the three waste streams, only the HSA ash contains sufficient plutonium to present criticality safety concerns. Equipment that contains HSA ash is designed to be criticality-safe, or for minimum material holdup, or with monitors and administrative controls that are effective in precluding criticality.

The eight processes considered in the study are:

- in-can glass melting
- joule-heated glass melting
- glass marble
- basalt glass-ceramic
- cast cement

- pressed cement
- FUETAP cement
- cold-pressed sintered ceramic.

Each immobilization process is designed to solidify blends of the three waste streams and to operate 200 days per year. Also, 100 days are allowed for miscellaneous periods of inoperation, and 65 days are reserved for scheduled material accountability periods. Some processes, especially those involving high-temperature equipment, are designed to operate more or less continuously. These processes may also be maintained at or near operating temperature during accountability periods to avoid difficult and time-consuming startup procedures and the possibility of equipment damage. All three cement processes are designed to be operated one shift per day, 5 days a week. This provides considerably greater flexibility in maintaining equipment and meeting production goals.

The immobilization facility is assumed to be an addition to the existing waste processing facility. This approach simplifies transportation problems and enables sharing of many of the services of the existing facility.

Access to the immobilization facility for services may require significant modifications of the existing facility in some cases. Some of the required facility services that may be shared with the existing facility, if adequate capacity exists, include steam, domestic water, chilled water, cooling-tower water, fire-protection water, chemicals, instrument air, compressed air, breathing air, nitrogen, health physics vacuum supply, nitrogen, and sewer. Many alarm and communication systems will be interconnected to those in the existing facility, including telephone and public address systems and alarms for criticality, fire, security and health physics. The electrical demand of the new facility will likely be sufficiently high to require a new electrical substation. Electrical power requirements will be highest for those processes that employ high-temperature operations, such as the cold-pressed/sintered ceramic process. These high-temperature processes will also have high air-conditioning demands.

In this study, only the processes and the areas which contain the processes will be described. Parts of the facility which will not be discussed are the non-process areas such as change rooms, offices, storage rooms, switch-gear areas, loading docks, motor rooms, high-efficiency particulate air (HEPA) filter rooms, etc. These non-process areas may occupy space that is about 1.5 times the volume occupied by the process areas.

An important non-process feature of the facility is a large freight elevator that is sufficient to move large and heavy equipment and stored waste between floors. A crated joule-heated glass melter, for example, weighs ~11,300 kg. The process sludge paddle dryer may be 6.1 m in length. Another important non-process feature is the loading dock. The loading dock must contain facilities for loading packaged waste containers into TRUPACT shipping vessels (see Figure 11, Volume I).

If sufficient plutonium is retained in the immobilization facility, the structure must be constructed to meet plutonium-facility standards. This will require an elaborate air protection system and a sturdy and expensive building.

HEAD-END SYSTEMS

Four systems listed below are generic to all of the processes described in this study. The minor differences that exist between processes are described in the individual process description sections. The systems are:

- LSA ash load-in system
- HSA ash load-in system
- process sludge drying system
- dry solids storage and blending system.

Several figures and references in this section pertain to the in-can melting process, which is the first of the eight solidification processes described beginning on page 55.

LSA ASH LOAD-IN SYSTEM

Low specific activity (LSA) ash will be stored in specially designed 55 gal drums, one of which is shown in Figure 13. This method of containment differs from the method

FIGURE 13. LSA Ash Containment System

currently being used in two major respects: 1) the new drum is tapered to facilitate removal of the ash, whereas the current drum is of standard right-circular-cylinder design; and 2) the current stiff plastic inner container is eliminated and replaced with a flexible, reinforced plastic bag that has loops to facilitate withdrawal of the bag and contents from the drum. The new design includes the use of the same type of inner plastic bag used in the current ash-loading design, however.

Each LSA container holds about 45 kg. It is estimated that 36,000 kg of LSA ash are produced annually. Hence, 800 containers will be processed each year. The solidification process is designed to meet production requirements in a 200-day year. Therefore, a container must be unloaded every 6 h at design rate.

The order by which LSA containers are processed is determined by chemical composition, weight, and availability. The plutonium content is usually of little concern in determining unloading order since the plutonium contribution from this source is relatively insignificant.

LSA ash containers are unloaded in the LSA ash load-in glove box (see Figures 14, 15, and 16) located on the top floor of the solidification facility. These containers are moved from storage by a "clamp-lift" vehicle and placed on drum rollers leading to the glove box (see Figure 16). The LSA ash drum rolls to the end of the rollers where it is engaged by the jaws of the drum inverter. The drum inverter lifts and inverts the drum and aligns the mouth of the drum with the glove-box load-in portal. The loops on the outer bag inside the LSA ash drum (see Figure 13) are manually placed over hooks on the bag puller. The bag puller motor is energized, and bagged ash is pulled from the drum and positioned on top of the shredder. The shredder is energized, causing the bottom of the plastic bags holding the LSA ash to be torn open. The ash falls from the bags onto the surface of a vibrating screen. The ash falls through the screen and into the LSA ash surge hopper located on the second floor. Plastic scrap and large chunks (brick, metal, etc.) collect at the bottom of the vibrating screen where they are manually raked up or collected with a vacuum cleaner. The bag remnants attached to the bag puller are removed and dropped into the lower portion of the hood where they, and the other scraps, are subsequently dropped into the scrap plastic load-out drum. We estimate that about 2% of the original ash will be removed with the scrap plastic. When the scrap plastic load-out drum is full, it is sealed, assayed for plutonium content and the combustible fraction is later recycled in the LSA incinerator.

The emptied LSA ash drum is rotated a few inches away from the glove box, the glove-box door is closed, and contamination checks are made. Contaminated drums are covered with plastic and moved to a special open-face hood near the LSA ash load-in glove box for decontamination. Contamination-free drums are returned to the LSA load-out station or to a storage area for recycling.

LSA Ash Load-In Glove Box

The LSA ash load-in glove box is 5.2 m long, 3 m high and 1.1 m wide. The glove box is constructed of stainless steel and is suitably equipped with viewing windows, glove ports, filters, sprinklers, etc., as required. Most of the intake air filters are located around the load-in portal to ensure that that area is well swept with clean air. Removable panels

- A DRUM ROLLERS
- B DRUM
- C DRUM INVERTER
- D DOOR
- E BAGGED LSA ASH
- F BAG PULLER
- G SHREDDER
- H VIBRATING SCREEN
- I VACUUM CLEANER
- J SCRAP PLASTIC LOADOUT DRUM
- K GLOVE BOX

FIGURE 14. LSA Ash Load-In Glove Box

are built into the ends of the glove box to permit removal of large equipment items for maintenance. The shredder, which weighs several hundred pounds, is suspended on a trolley for easy removal and replacement through a panel-covered portal. The manual operations, bag hooking/unhooking, and some contamination checks are conducted from a platform 0.9 m above the floor level. Raking, vacuuming, and loading out of scrap plastic are all conducted from the floor level on the opposite side of the glove box.

Drum Rollers

The drum rollers are custom-built. They slope slightly toward the glove box to facilitate drum rolling to the load-in position. Automatically activated stops or retractors prevent any drum from making contact with another drum in the load-out position. This precludes interference with the drum inverting operation. When a drum is emptied and returned to the lowered position and the jaws of the drum inverter are retracted, a set of roller wheels is elevated beneath the drum and between the rollers. These roller wheels permit the drum to be manually pushed into a set of rollers perpendicular to the load-in rollers. This second set of rollers curls 90° and eventually ends near the end of the load-in rollers (see Figure 16). The second set of rollers slopes slightly away from the glove box to facilitate drum rolling. An alternative to drum rollers is an air table. Its potential for spreading contamination may be higher, however.

Drums

Drums are custom-built of stainless steel to facilitate decontamination and reuse. They are conical in shape to facilitate bag removal (see Figure 13). Drums are covered with custom-built lids held in place with oversized drum-lid clamps. The lid clamps may be locked

FIGURE 15. In-Can Melting Process, Elevation View

FIGURE 16. In-Can Glass-Melting Process, Third Floor Processing Area, Plan View

by inserting a lock through the locking hasps. Two welded rings encircle the drum and enable the drum inverter clamps to securely hold the drum during drum inversion. An oversized drum base is welded to the bottom of the drum to 1) improve drum stability, 2) to facilitate lid clamp removal when two drums are in contact at their bases, and 3) to minimize the potential of pinching during drum handling.

Drum Inverter

The drum inverter is a custom-built device. After a drum is moved to the load-in position on the rollers, clamps on the drum inverter are pneumatically closed around the drum between the drum clamping rings. The clamps are manually locked together as a safety precaution. The drum inverter then inverts the drum slightly past its horizontal position to align the mouth of the drum with a load-in portal. Drum inversion is accomplished by retracting a pneumatic cylinder. Extending the cylinder returns the drum to the drum rollers.

Bag Puller

The bag puller is custom-built from stainless steel. It consists of a trolley from which two hooks are suspended, and a screw driven by an electric motor that moves the trolley the length of the glove box.

Shredder

The shredder is a commercially available device consisting of two electrically driven, counter-rotating shafts to which blades are attached. The shredder is mounted on a trolley that can be moved on rails attached to the glove-box walls. This facilitates removal of the shredder for maintenance or replacement. The shredder is operated for only a few seconds to open each bag of ash.

Vibrating Screen

The vibrating screen is custom-built to fit the glove box, although a commercially available, electric vibrating mechanism may be used. A 0.3 cm mesh screen is employed. The vibrator is activated for about 1 min during the unloading of each bag of ash.

Vacuum Cleaner

The vacuum cleaner is a commercially available device. The vacuum nozzle is fitted with a screen to prevent the intake of shredded plastic. The vacuum exhaust is directed to the glove-box exhaust duct to minimize the potential for pressurizing the glove box. The contents of the filter bag inside the vacuum cleaner are screened or emptied into the scrap plastic load-out drum.

HSA ASH LOAD-IN SYSTEM

Leached and dried high-specific activity (HSA) ash will be stored in tapered, 1 gal plastic containers that are screw-lidded and double-bagged in plastic. This method of containment varies from the present approach, in which right-circular-cylinder stainless steel containers are used. Reasons for making this change are that 1) the plastic containers are lighter in weight, 2) sharp edges are more easily avoided when plastic is used, 3) tapered containers are stackable to minimize load-out requirements for emptied containers, and 4) damaged plastic containers can be burned.

Each HSA ash container holds ~1 kg. An estimated 10,000 kg of leached and dried (HSA) ash are produced annually; hence, 10,000 containers are processed each year. The solidification process is designed to meet production requirements during a 200 day operating year. Therefore, a container must be unloaded every 2 h at the design rate for the continuous processes.

The order by which HSA ash containers are processed is determined by plutonium content and availability. For example, containers of high plutonium content are included with containers of low plutonium content, etc.

HSA ash containers are loaded into the HSA ash load-in glove box (see Figures 15, 17, and 18) located on the second floor of the solidification facility. Due to the potential

for criticality, strict spacing requirements must be maintained between containers during the transportation and unloading steps. Unloading begins with the placing of HSA ash containers in spaced holders on an elevating table next to the HSA ash load-in glove box. The table is raised, and a single container is loaded into a rotary airlock that has been surveyed for plutonium contamination during opening. The rotary airlock is situated on top of the HSA ash load-in glove box (see Figure 17). The rotary airlock cylinder is rotated to the closed position and resurveyed. The elevating airlock door is then lowered, allowing the container to slide to the unloading position. The elevating airlock door is then raised to the "closed" position. An operator cuts open the plastic outer packaging of the container with scissors, unscrews the lid, and empties the contents of the container through a screen and into the 10 cm dia, criticality-safe, gravity transfer pipe for eventual blending with other wastes and additives. Empty ash containers and lids are dropped down a slide to the empty HSA ash canister load-out station where they are individually assayed for residual plutonium

- A ROTARY AIRLOCK CYLINDER (MOTOR-DRIVEN)
- B ELEVATING AIRLOCK DOOR
- C PNEUMATIC ELEVATING CYLINDER
- D EMPTY HSA ASH CANISTER LOADOUT STATION
- E SCREEN
- F GRAVITY TRANSFER PIPE
- G PLASTIC PACKAGING LOADOUT STATION

FIGURE 17. HSA Ash Load-In Glove Box

FIGURE 18. In-Can Glass-Melting Process, Second-Floor Processing Area, Plan View

content using an in-glove-box plutonium counter. If the plutonium content is low enough, the containers and lids are stacked. These are eventually loaded out, reassayed for plutonium content, and reused.

Spent plastic packaging is dropped down a slide to the plastic packaging load-out station where it is inserted into combustible containers. When full, these containers are loaded out and burned in the HSA incinerator.

HSA Ash Load-In Glove Box

The primary section of the HSA ash load-in glove box is 4.1 m long, 2.7 m high, and 0.8 m wide. Two perpendicular extensions of the glove box, one 0.9 m in length and the other 1.2 m in length, provide load-out capability for reusable containers and spent plastic. The glove box is constructed of stainless steel and is suitably equipped with viewing windows, glove ports, filters, load-out ports, sprinklers, etc., as required. The floor of the glove box is sloped and contoured to enable materials to slide to work locations. This enables all of the required glove work to be conducted from only three glove-port positions. This approach minimizes glove-work time and exposure to HSA ash, which is by far the most radioactive of the ash wastes being handled.

Rotary Airlock

The rotary airlock consists of two stainless steel cylinders, one of which is welded to the hood and the other of which concentrically houses the first. A square hole exists in each cylinder; the holes can be aligned by rotating the outer cylinder. Rotation is accomplished using an electric motor and a gear that is part of the outer cylinder casting. The outer cylinder rides on a replaceable graphite bearing and is topped with a HEPA filter to enable airflow through the airlock during unloading.

Elevating Airlock Door

The elevating airlock door consists of a stainless steel casting fitted with a replaceable rubber gasket around its circumference to provide a suitable air seal when the door is closed. The door is opened and closed using a pneumatic cylinder located outside the hood. A flexible metal bellows encircles the pneumatic cylinder shaft, enabling the shaft to be extended and retracted inside the hood without withdrawing contamination.

PROCESS SLUDGE DRYING SYSTEM

The capability of generating dried process sludge already exists in Building 374, where 55 gal drums of dried sludge are produced. In spite of this capability, we feel that the process sludge slurry should be pumped to a new drying process in the solidification facility. This is because the logistics and safety considerations of transferring dry solids from Building 374 to the solidification facility appear very unattractive. Two such dry solids transfer options are apparent: 1) to load out to drums, to transfer the drums to the solidification facility, and to unload into a glove box; or 2) to transfer the dried product directly to the solidification facility through a series of elevators and conveyors. Both of these options are likely to entail a significantly higher level of personnel exposure and a higher risk of contamination spread than would pumping process sludge slurry to a new drying process. Nonetheless, it is recommended that the current sludge drying capability in Building 374 be maintained in a standby condition as a hedge against a lengthy critical process breakdown in the solidification facility. In such an event, the process sludge slurry would be diverted to Building 374 for drying and loading out into 55 gal drums identical to those used for loading out LSA ash (see Figure 13). The LSA ash-loading glove box and associated equipment are compatible with both ash and dried sludge and are designed to accommodate the simultaneous intake of both materials. Hence, a stockpile of dried sludge can gradually be worked off without adversely affecting plutonium processing operations in Building 371.

A simplified flow diagram of the new process sludge drying system is shown in Figure 19. Process sludge slurry is pumped almost continuously to the sludge drying process at an operating rate of 640 L/h. This rate is 24% of the current rate in Building 374. As a result of this lower capacity requirement, much of the equipment in the solidification facility is smaller than its counterpart equipment in Building 371.

Process sludge slurry is directed to the basin of one of two vacuum drum filters located in the process sludge drying hood on the third floor of the solidification facility (see

FIGURE 19. Simplified Flow Diagram for Process Sludge Drying System

Figure 20). The sludge is partially dewatered on the surface of the rotating vacuum filter as clarified liquids are drawn through the filter by negative pressure supplied by a vacuum pump. The clarified liquids are returned to Building 374 for reprocessing. The partially dewatered sludge, or filter cake, is continuously cut from the surface of the filter by a blade. The actual filter medium is comprised of a layer of diatomaceous earth built up on the screen of the vacuum drum filter. The layer is progressively removed by the blade, which cuts continually deeper into the filter medium. After ~12 h, when the filter media are reduced from a thickness of 8 cm to 0.6 cm, the flow of sludge slurry is diverted to the second vacuum drum filter. The residual filter medium on the first vacuum drum filter is washed off and a new 8 cm layer applied, thereby preparing the filter for reuse.

Filter cake and filter medium cut from the filter fall into the inlet of a twin-shaft paddle dryer. In the paddle dryer, the water content of the sludge is reduced from about 70% to about 15%. At this level of moisture, the sludge is dry to the touch, but not excessively dusty. Dried sludge falls by gravity into the dried sludge surge hopper on the second floor.

- A PROCESS SLUDGE DRYING HOOD
- B VACUUM DRUM FILTER
- C PADDLE DRYER

FIGURE 20. Process Sludge Drying System

Process Sludge Drying Hood

The process sludge drying hood is 6.1 m long, 5.9 m wide, and 4 m high. The hood is constructed of stainless steel and is suitably equipped with viewing windows, glove ports, filters, dampers, sprinklers, and other auxiliary equipment. Large removable panels are built into the walls of the hood to facilitate removal of equipment. Additionally, heavy equipment inside the hood is mounted on wheels on tracks to the extent practicable to aid in removing failed equipment. Since spillage of liquids and powders is likely to occur in this hood, the floors of the hood are sloped toward a drain line connected to a sump tank located in the canyon in the facility's basement. The hood is equipped with permanently mounted spray nozzles to flush spilled material down the drain.

A platform 1.7 m above the floor is located outside the hood against the wall closest to the vacuum drum filters (see Figure 15). From this platform, an operator may view the filtering operations and may clean the filters and the chute to the paddle dryer using the hood gloves and tools provided, such as a spray wand.

Vacuum Filters

The two vacuum drum filters used are commercially available devices. Each filter drum is approximately 0.9 m long x 0.6 m dia. All metallic components of the filters are constructed of stainless steel. The primary components of each vacuum drum filter include a filter drum and drive motor, a pendulum agitator and drive motor, a traveling scraper blade and drive motor, and a filter basin and housing. If necessary, the filter basins may be drained to the sump tank in the canyon for eventual reprocessing. Each vacuum drum filter is equipped with permanently mounted flush nozzles to aid in cleaning operations. Routine

maintenance requirements include frequent equipment cleaning and periodic lubrication of bearings to lengthen seal and bearing life. This maintenance operation may result in operating delays.

Filter-Coating System

The function of the filter coating system is to provide a coating of diatomaceous earth on each drum filter. The system, with the exception of part of the diatomaceous earth slurry transfer pipe, is located entirely outside the process sludge drying hood. Major components of the system include 1) a pneumatic transfer system for moving dry diatomaceous earth from outside the solidification facility to a storage tank on the roof of the solidification facility; 2) a diatomaceous-earth batching and slurry-mixing system consisting of a rotary airlock, a loss-in-weight screw feeder, a 1100 L agitated tank, and process water addition capability; and 3) a diaphragm pump for transferring the diatomaceous earth slurry to either vacuum drum-filter basin.

Since all moving components of the filter-coating system are outside the contaminated process areas, maintenance is expected to be straightforward and should seldom impair the overall process performance.

Vacuum and Filtrate System

The functions of this system are to 1) provide negative pressure (vacuum) to the vacuum drum filters and 2) collect and transfer the filtrate to the first-stage feeder tank in Building 374 for reflocculation. All metallic components of the system are constructed of stainless steel. Filtrate is collected in either of two 400 L tanks and is either pumped to the first stage feeder tank or back to the vacuum drum filter for immediate recycling. The filtrate tanks are located inside the process sludge drying hood. The filtrate pumps are located in raised glove-box extensions of the hood for easy servicing.

Two 20 hp vacuum pumps located outside the hood provide the required negative pressure to the two vacuum drum filters. These pumps require cooling with a closed-loop water system, which itself is cooled with tower water. Air is discharged from the vacuum pumps through a 200 L demister tank and into the process vent system. Maintenance will occasionally be required on pump seals and bearings. The presence of parallel pump systems should permit nearly normal operations while maintenance is conducted on one of the pumps.

Paddle Dryer

The paddle dryer is a commercially available device. Paddles attached to two counter-rotating shafts recirculate dried sludge inside the dryer. Drying is accomplished by heat transfer from the paddles and the steam jackets. The drying vessel is 4 m long, and the drive motor and gear box add another 0.9 m to the overall length. All metallic contact components of the paddle dryer are fabricated from stainless steel.

Maintenance on the bearings and seals may be high due to hot and dusty operating conditions. Caking inside the paddle dryer is another concern, since removal of the cake will require considerable cooldown time, manual removal of the paddle dryer cover, manual chipping to break up cakes, and perhaps manual removal of caked chunks that could impair the operation

of downstream processes. Another perhaps more desirable method of cake removal, assuming that the shafts are not bound, is to install a temporary valve at the paddle discharge that permits the paddle dryer to be filled with water to enable reslurrying the sludge. The reslurried sludge would be emptied to the sump tank in the canyon. Other maintenance concerns are wedging of pieces of metal or other debris between the paddles and the dryer shell, and the general wear of the blades and shell.

The paddle dryer may be one of the weaker links in maintaining continuous operation because 1) only a single unit is included in the current design, 2) the paddle dryer may require a relatively high level of maintenance, and 3) the difficulty of performing maintenance is high, resulting in long out-of-service periods.

Paddle Dryer Off-Gas System

The functions of the paddle dryer off-gas system are 1) to provide negative pressure to the paddle dryer and 2) to remove particulates and condensible gases from the resulting off-gas stream. All metallic components are constructed of stainless steel. Off gases are drawn through a scrubber 3.7 m long and 1.5 m dia. One of two 10 hp pumps continuously recirculates the scrubber solution through the scrubber. When the undissolved solids content reaches ~1%, most of the scrubber solution is pumped to the sump tank in the canyon and fresh sodium hydroxide solution is added to the scrubber. Scrubber solution is cooled via two closed-loop water heat exchangers. Chilled water is the primary coolant.

Vacuum is supplied by one of two 50 hp blowers that exhaust into the filter plenum. All components of the paddle dryer off-gas system are located outside the process sludge drying hood, with the exception of the two scrubber solution recirculation pumps that are located in elevated glove-box extensions of the hood for safety and ease of maintenance.

Maintenance on this system is expected to be moderate. One concern is the potential for building up hard deposits inside the scrubber and the subsequent difficulty of their removal. Aside from the scrubber, sufficient equipment redundancy exists that breakdowns in this system should rarely impede continuous operations.

DRY SOLIDS STORAGE AND BLENDING SYSTEM

The purpose of this system is to provide a well-mixed blend of the desired proportions of HSA ash, LSA ash, dried process sludge, and glass frit for continuous feeding to the glass-melting process. Blending of glass frit and nuclear wastes has been found important for assuring high melting rates and homogeneous glasses in tests conducted at PNL. The rate at which the frit/waste blend is fed to the in-can melter will likely be reduced at least once during the course of filling a glass canister. The reason for this change is that melting rates decrease as the canister is filled with glass. Filling a canister with glass causes a loss of exposed canister-wall area. Most of the heat required for melting is obtained through radiant heat transfer from the walls of the canister. Hence, as the canister is filled, melting rates fall off. The required feedrate change(s) can easily be accommodated through coordinated computer control of the feed rates of the individual solids feeders.

Storage or surge tanks are provided for each of the waste streams and the glass frit. These tanks enable a continuous supply of the various solids to be available for blending, in spite of adding ashes and glass frit to the system in batches. In the case of the dried sludge stream, which is normally continuous and fairly steady, a half-filled surge tank allows several hours of continuous solids blending to be conducted while the sludge drying process is temporarily out of service. To accommodate various delays in adding material to each of the three surge tanks, the solids level is normally maintained at the half to three-quarters level (see Figure 21). The exception is the HSA ash gravity transfer pipe, which

- A LSA ASH SURGE HOPPER
- B DRIED PROCESS SLUDGE SURGE HOPPER
- C GLASS FRIT SURGE HOPPER
- D GRAVIMETRIC BELT FEEDER
- E HSA ASH GRAVITY TRANSFER PIPE
- F KNIFE VALVE
- G ROTARY AIRLOCK
- H FLOOR-LEVEL GLOVE BOX
- I LOSS-IN-WEIGHT SCREW FEEDER
- J GLOVE BOX DRAIN
- K INTENSIVE SOLIDS MIXER
- L DIVERTER VALVE
- M SOLIDS BLENDING/FEEDING HOOD

FIGURE 21. Dry Solids Storage and Blending System

is normally nearly empty for purposes of plutonium inventory and criticality control. HSA ash is added to the system at regular intervals to assure a reasonably even flow of the material to the glass melters.

Solids in the LSA ash surge hopper and the dried process sludge surge hopper pass through respective rotary airlocks that serve two purposes: 1) to provide an airflow barrier between processes that have separate negative pressure control systems and 2) to maintain the proper level of solids in each loss-in-weight screw feeder. Glass frit is added to the glass frit surge tank via a pneumatic transfer system similar to that already described for diatomaceous earth (see Figure 21). Glass frit falls from the glass frit surge tank onto a gravimetric belt feeder. Glass frit exits the feeder and falls through a rotary airlock that serves only as an airflow barrier. HSA ash also passes through a rotary airlock that serves as an airflow barrier as well as a star feeder for smoothing out HSA ash addition rates. LSA ash, HSA ash, dried process sludge, and glass frit are eventually combined and blended in an intensive solids mixer. Mixed solids fall through a diverter valve to one of two in-can glass melters.

Surge Tanks

The LSA ash surge tank, the dried-process sludge surge tank, and the glass frit surge tank are located on the second floor of the solidification facility (see Figures 15 and 21), and are custom built from stainless steel. Each tank is 0.9 m dia. These tanks are designed for mass flow to minimize the potential for developing stagnant flow areas and subsequent blockages. Internal pressure equalizers may be necessary to overcome difficult flow problems. Knife valves are positioned at the base of each surge hopper to enable shutting off tank flow while maintenance is conducted on rotary airlocks or feeders. Each tank is vented to the respective process hood or glove box immediately above. The effective capacity of each surge tank is given below:

- LSA ash surge hopper--900 L
- dried process sludge surge hopper--900 L
- glass frit surge hopper--1000 L.

Aside from occasionally dislodging blocked material in the tanks, little tank maintenance is expected.

Rotary Airlocks

Rotary airlocks provide an airflow barrier between tanks and the solids mixer. The two rotary airlocks beneath the LSA ash and dried process sludge surge tanks are enclosed in floor-level glove boxes on the second floor. These glove boxes will contain the dusts that will inevitably leak through the seals of the rotary valve. These dusts may be swept down drain lines connected with Y's to the main solids transfer lines. The floor-level glove boxes are designed for relative ease of maintenance and replacement of rotary airlocks. The two rotary airlocks beneath the HSA ash and glass delivery system are contained within the solids blending/feed hood located on the first floor.

Maintenance on rotary airlocks is expected to be relatively high due to the very abrasive solids they handle. Maintaining rotary airlocks will usually cause short production delays.

Solids Feeders

The solids feeders for LSA ash and dried process sludge are located in the solids blending/feed hood on the first floor. The feeders are suspended from load cells that permit continuous monitoring of the weight of material in the feeder hopper. Two augers rotate inside the feeder. One agitates the solids and maintains them in a flowable state, and the other discharges the solids from the feeder. A single electric motor drives both augers. The augers operate at a variable speed that causes the feeder to discharge solids at a desired rate. As the weight of solids in the feeder is reduced, the rotary airlock above the feeder is actuated for a period of time to refill the hopper. During the hopper filling period, the discharge auger is rotated at a constant rate at its last setting before refilling of the hopper is begun. For accurate weight measurements to be obtained in this type of feeder, all connections to the feeder must be made through flexible bellows. Rubber bellows are recommended. All waste-contact components of these feeders are constructed of stainless steel.

Maintenance on this type of feeder is expected to be moderately high and will be difficult since a manned entry to the solids blending/feeding hood is required. Typical problems that require maintenance include 1) jamming of the screw or blade, 2) bearing and seal wear, 3) bellows aging, and 4) solids buildup in the bellows.

The frit feeder is located on the second floor. In this type of feeder, material on a traveling belt is constantly weighed. The belt speed is automatically adjusted to control the feed rate at the desired level. Maintenance on this type of feeder is also expected to be moderately high. Typical maintenance problems include bearing and belt wear and dust buildups inside the feeder housing. Maintenance will not be difficult, however, since the feeder is located in an area where work can be conducted without protective clothing.

As previously stated, the feed rate of HSA ash will be controlled by emptying HSA ash containers at regular intervals. The rotary airlock in the HSA ash transfer pipe will also be operated at a speed that tends to deliver the ash at a more or less continuous rate to the solids mixer.

Intensive Solids Mixer

The intensive solids mixer is located in the solids blending/feeding hood on the first floor. This mixer is continuous and consists of an enclosed trough that houses two rotating shafts to which blades are welded. The orientation of the blades on the shafts causes nearly as much material to be transferred upstream as downstream. This, the cutting and folding action of the blades, and a relatively high speed of shaft rotation result in extensive mixing of the ashes, dried sludge, and glass frit. The shafts are driven with a single electric motor.

Maintenance on this type of mixer is expected to be fairly high due to the relatively high speed of rotation and the abrasive environment. Bearings and seals will require frequent maintenance, and fairly short shaft assembly life is also expected.

Diverter Valve

The diverter valve is located in the solids blending feeding hood on the first floor. Its function is to divert the blended stream of ashes, dried sludge, and glass frit to either of two in-can glass melters. It is actuated with an electric motor. All metallic components are fabricated from stainless steel. Infrequent maintenance is expected.

Solids Blending/Feeding Hood

The solids blending/feeding hood is located on the first floor. The hood is 4.3 m long, 3 m wide, and extends from the floor to the ceiling (4 m). The hood is constructed of stainless steel and is equipped with all of the features of a well-designed process hood. It houses the LSA ash feeder, the dried-sludge feeder, the glass frit rotary airlock, the HSA ash rotary airlock, the solids mixer, and the diverter valve. This hood will normally be maintained as a dry hood. Considerable spillage of dry solids can routinely be expected in this hood. As a result, the hood is fitted with glove ports and a built-in vacuum-cleaning system that permits cleanup to be conducted from outside the hood. Solids collected during vacuuming will be loaded into 1 gal plastic containers identical to those used to contain HSA ash. These containers will be assayed for plutonium content and recycled in the HSA ash load-in hood.

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IN-CAN GLASS MELTING PROCESS

In the in-can glass melting process, LSA ash, HSA ash, dried sludge, and glass frit are melted together in a large stainless steel canister, forming a large glass monolith. Details of the operation are provided in the following sections.

EQUIPMENT AND MAINTENANCE

In-Can Melting System

In the in-can melting system (Blair 1979), blended HSA ash, LSA ash, dried process sludge and glass frit fall into a heated canister and melt to form a monolithic block of glass. Major components in this system include the canisters, two in-can melting furnaces, two furnace translators and two connecting sections that connect the blended solids distribution pipes to the canisters in the melting furnaces (see Figures 15 and 22).

An empty canister (see Figure 23) is inserted vertically into an in-can melting furnace (see Figure 24) using the process canyon crane, a canister-lifting yoke (see Figure 25) and the canister bails. The furnace is moved to its filling position by retracting a pneumatic cylinder. The furnace insulating cap is then lowered until it contacts the mouth of the canister. This lowering step is accomplished by actuating the worm-gear drive motor, which screws down the shaft supported by a conical enlargement of the end of the shaft or the cone valve. After the cap has contacted the mouth of the canister, the worm-gear drive motor continues to lower the shaft, which results in the opening of the cone valve. The canister is then heated inside the furnace to a temperature of 1050°C. When filling of the other canister is completed, the diverter valve is rotated, which diverts the stream of blended solids to the empty canister. Melting proceeds at an established rate until it is deemed necessary to reduce the feed rate due to the loss of radiant heating area. Melting then proceeds until the canister is filled, as determined by the total weight delivered to the canister and by extrinsic gamma-ray attenuation (Nielson and Brodzinski 1978). The flow of feed to the canister is then stopped by either stopping the solids mixing system or by switching the position of the diverter valve. The canister is then maintained several hours at 1050°C to finalize melting of the material at the top of the canister. Then, compressed air is blown into the furnace to aid in cooling the canister. The displaced furnace air is exhausted directly into the process canyon toward the intake of the process canyon exhaust air duct. When the canister walls have cooled to 700°C, the cooling air is shut off, the cone valve and furnace insulating cap are raised, and the in-can melting furnace is translated out from underneath the connecting section. At this position, the filled canister is removed using the process canyon crane and is placed in a cooldown rack. An empty canister is placed in the furnace and the process is repeated.

- A BLENDED SOLIDS TRANSFER PIPE
- B EXPANSION BELLOWS
- C CONNECTING SECTION LIFTING BAIL
- D WORM-GEAR DRIVE MOTOR
- E MAINTENANCE AND OBSERVATION CUBICLE
- F CONNECTING SECTION MOUNTING TRACK
- G METAL BELLOWS
- H CONNECTING SECTION TROLLEY
- I FURNACE INSULATING CAP
- J CONE VALVE
- K FURNACE POWER LEADS
- L CANISTER
- M IN-CAN MELTING FURNACE
- N FURNACE TROLLEY
- O TRACK
- P METAL BELLOWS
- Q PNEUMATIC CYLINDER

FIGURE 22. In-Can Melting System

At design rate, an average of 80 kg of glass are melted each hour. The event cycle for this process at design rate is shown below:

Time Required, h	Insert Canister in Furnace
1	Insert canister in furnace and connect
3	Heat empty canister
15.5	Fill
4	Allow bubble release
6.5	Cool
1	Disconnect and remove from furnace

DIMENSIONS:

- OVERALL HEIGHT-- 1.52 m
- OUTSIDE DIAMETER-- 0.71 m
- WALL THICKNESS-- 0.63 cm

EMPTY WEIGHT: 220 kg
 FILLED WEIGHT: 1460 kg
 HEIGHT OF GLASS FILL: 1.25 m

FIGURE 23. In-Can Melting Canister

Canisters

In-can melting canisters are constructed from 304L stainless steel, the same metal designated for high-level-waste (HLW) canisters used in the in-can melting process. The TRU waste canister is shown in Figure 23. A ceramic paper gasket on the top of the canister flange enables a seal to be made between the furnace insulating cap and the canister, and helps maintain the cleanliness of the flange to ensure better lid welding conditions. The mouth of the canister is 25.4 cm wide, which is deemed large enough to accommodate any normal eccentricity encountered with the cone valve. The height chosen for the TRU waste canister

- A CERAMIC FIBER BLANKET GASKET
- B LIFTING LUG
- C AIR-COOLING LINE
- D ELECTRIC POWER LEAD
- E HOUSING
- F INSULATION
- G HEATING ELEMENTS
- H CANISTER GUIDE PLATE
- I EXHAUST AIR DAMPER
- J SPALL COLLECTION PIT
- K TROLLEY
- L TROLLEY TONGUE
- M CANISTER SUPPORT BASE
- N TRACK

FIGURE 24. In-Can Melting Furnace

is considerably shorter than that chosen for the HLW canister. TRU waste canister dimensions were selected on the basis of the following points.

Handling tall canisters (3 m or higher) of the type considered for HLW will be considerably more difficult than handling the selected TRU waste canisters because such canisters must be laid over and uprighted several times in transporting the tall canisters to their disposal location. Tall, narrow-diameter canisters also have an inherent instability that makes them more prone to accidental dropping. The selected TRU waste canister can easily be loaded into a 4-pack assembly (see Figure 26) which has weight and dimensions that are ideal for transporting in TRUPACT shipping vessels (see Figure 11, Volume I). Tall canisters, on the other hand, would require shipment in the horizontal position. If TRUPACT shipping vessels are used, a special shipping rack that slides in and out of the vessel would be required. To load tall canisters onto these racks or into a special shipping vessel built

FIGURE 25. Canister-Lifting Yoke Positioned on Canister

specifically for these canisters would require that a canister be grasped from its side. This is undesirable due to the high risk of fixed surface contamination that might be scraped free by the grasping devices and by the rack components. Contamination problems are unlikely with 4-pack TRU canisters since all contact with the 4-pack occurs with the carrying frame that has not been exposed to the process.

Loading and unloading of tall canisters would also require special vehicles at each of the loading and unloading sites. Standard forklifts can be used to handle the 6200 kg 4-packs. The most likely way of disposing of tall canisters in the repository is in stacks, as with logs. The canisters seem too unstable to stand on end, especially on unfinished repository floors. However, stacks of horizontal canisters also seem unstable and the

FIGURE 26. ICM Canisters and 4-Pack

prospect of freeing fixed contamination seems high when canisters are slid into place on top of the stack. On the other hand, the selected TRU waste canister, when contained in a 4-pack assembly, poses a very small contamination risk. Four-packs may also be easily and safely stacked two-high.

An additional matter of concern is plutonium content. Criticality analyses performed on borosilicate glass indicate that canisters having in excess of a 200 g per container limit suggested for a repository can be safely stored in a close-packed array. The average plutonium content of the selected TRU canister is 155 g. It is likely that some containers will exceed 200 g of plutonium. A tall canister will average about 300 g of plutonium and individual canisters may often exceed 400 g. This level of plutonium would not be considered a hazard if evenly distributed in the canister, however. Therefore, the smaller canisters are better from both criticality and storage safety standpoints.

Connecting Section

Two connecting sections connect the diverter valve in the solids blending/feeding system to the canisters in the two in-can melting furnaces. Each connecting section is located in the process canyon. All metallic components are constructed of stainless steel.

A connecting section is made up of the following components: a bolting flange, a section of 10 cm pipe, a 15 cm flexible metal bellows, a furnace insulating cap, a cone valve and shaft, a worm gear and driver, and a mounting trolley. This assembly, which is properly counterbalanced, can be installed or removed using the process canyon crane and a lifting bail welded to the top of the cone-valve shaft. An operator working in gloves can make the flanged connection between the blended solids transfer pipe and the connecting section. Just above this connection, a metal bellows permits accommodation of makeup misalignments and expansion and contraction during equipment heatup and cooldown.

The same operator must make up several other connections to the connecting section. These connections include:

- cone valve water cooling inlet
- cone valve water cooling outlet
- discharge pipe water cooling inlet
- discharge pipe water cooling outlet
- drying air purge inlet
- worm gear drive motor electrical
- limit switch electrical.

Cooling of the cone valve and discharge pipe is required to prevent melting of blended solids on these components. Water required for cooling is recirculated through a heat exchanger that is, in turn, cooled by chilled water. Air to dry the inside of the solid transfer pipes is added at a low rate through the furnace-insulating cap only during equipment startup periods. This air is heated by radiant heat from the canister, which permits it to evaporate any moisture that may have collected in the connecting section. Moisture in the connecting section and other solids transfer lines may cause material buildups and subsequent blockages. Drying air is exhausted to the in-can melting off-gas scrubber described later. Limit switches are required as an indication that the insulating cap and cone valve have been lowered and raised to their proper positions. Visual observation will verify that this has occurred.

The metal bellows above the insulating cap houses two concentric pipes that telescope during lifting and lowering of the insulating cap. The bellows also accommodate thermal expansion and contraction. The insulating cap is constructed of a suitable ceramic insulating material, but is weighted at the top to ensure that an adequate seal exists between the cap and the canister. The outer rim of the insulating cap is fitted with a compressible ceramic blanket gasket since a tight fit does not exist between the furnace and the insulating cap.

Frequency of maintenance of the connecting section is expected to be moderate, but problems may be difficult to resolve. Those most likely to occur include the formation of material plugs and binding of the telescoping discharge pipes. It may often be possible to free plugs with a handheld vibrator, unless the presence of moisture has resulted in formation of hard buildups. In such an event, it may be possible to disconnect the connecting section flange and to use a flexible rod to clear the plug. If this is not possible, the connecting section must be removed by crane to the basement maintenance room, where the plug

can be removed more easily. Other maintenance problems include the buildup of material in the bellows, resulting in their distortion and/or breakage, and worm gear seizure caused by the thermally hot operating environment.

In-Can Melting Furnace

Two in-can melting furnaces are required to maintain continuous operations and to meet the design basis production rate of 80 kg of glass per hour. These furnaces are located in the process canyon, and are depicted in Figure 24. Each furnace is 2.7 m high (including the trolley on which it rides) and 1.4 m dia. The furnace is electrically heated to a maximum of 1200°C with Kanthal[®] heating elements. These elements are positioned in three stacked heating zones to allow even-temperature control during the melting process. Melting is nominally conducted at 1050°C. Electric leads from the furnace are connected to process canyon, wall-mounted buses.

Before inserting a canister into a furnace, the canister is centered over the furnace with positioning locators on the crane trolleys. A lifting yoke (see Figure 25) is used to transport canisters by the crane. The canister is more precisely centered inside the furnace by canister guide plates located near the base of the furnace. These guide plates are constructed of Inconel.[®] The inserted canister finally rests on an insulating refractory support base.

Heating the 304L stainless steel canister above 700°C in air causes surface oxidation. This oxidized material spalls from the surface of the canister, especially as the canister is cooled, and collects in an annular pit between the canister support base and the furnace wall. Periodically this material is vacuumed from the collection pit using a vacuum cleaner operated from the maintenance and observation cubicle. Another option for removing the spalled material is setting the furnace off its trolley using the lifting lugs, a lifting frame and the crane, and vacuuming spalled material from the trolley surface. Spalled material, and any waste solids that may have inadvertently leaked into the furnace, are collected in HSA ash load-in containers and are recycled through the HSA ash load-in system (see page 46).

After the canister heating cycle has been completed, the canister is cooled to ~700°C by blowing air into the top of the furnace through a manifold. Cooling of the canister is required to increase the tensile strength of the stainless steel to the point that it can be safely withdrawn from the furnace within 6-1/2 h after heating is terminated. Air leaves the furnace near its base through a dampered exhaust port. This exhaust air is directed toward the primary intake of the process canyon air exhaust duct.

The furnace is positioned on a trolley, which allows it to be translated to its filling and canister loading/unloading positions. Translating the trolley is accomplished by a

[®]Registered tradename of the Kanthal Corp., Bethel, Connecticut.

[®]Registered tradename of the International Nickel Company, Inc., Huntington, West Virginia.

hydraulic or pneumatic cylinder located outside the process canyon. An air-purged, flexible bellows covers the cylinder shaft to prevent the drawing of contamination from the process canyon.

Maintenance in this system is expected to be moderate but somewhat difficult since most components are located in the process canyon. Furnace elements will eventually fail through use or by rough contact with the canister as it is being inserted or withdrawn. As stated, failed furnaces can be lifted from their trolleys using the process canyon crane and transported to a maintenance room described on page 72. Cleaning may be required after processing about 20 canisters.

Canister Processing System

Canister processing consists of the following operations:

- canister cooling
- lid welding
- canister decontamination
- canister coating
- canister packaging.

Glass-filled canisters are removed from the in-can melting furnace with the lifting yoke and crane after the canister walls have cooled to $\sim 700^{\circ}\text{C}$. The still-hot canisters are emplaced in one of four cooling vessels located adjacent to the in-can melting furnaces. Air is drawn from the cooling vessels into the process canyon vacuum cleaning system. Spall that falls from the canisters is periodically vacuumed from the cooling vessels using a vacuum cleaning hose suspended from the crane (see Figures 15 and 27). Cooling of the canister is required to better contain spall and to ensure operator safety during the lid-welding operation. At design operating rate, each canister is cooled in 60 h. After cooling, the canister is moved to the lid-welding station, where it is positioned on a cart. The canister is then translated on the cart to a position very close to the process canyon wall for ease of operator access. At this position, an operator works through glove ports in a cubicle used for servicing the in-can melter furnaces. The operator removes the ceramic paper gasket that protects the canister flange and disposes of it inside the canister. If necessary, the welding surface is cleaned using an electric-powered, hand-held grinder. Then a canister lid is transferred into the canyon through an airlock that includes a sphincter seal.

The operator places the 4.5 kg lid on the canister and lowers a resistance welder suspended from an overhead pulley and counterbalanced over the lid, as shown in Figure 28. The welder is shrouded with a fine wire screen to prevent the possible discharge of welding spatter in the direction of the operator. A motor built into the welding device rotates the welding probe around the circumference of the lid. By applying voltage to the welding probe, an electric arc creates a weld between the lid and canister. This concept was developed and demonstrated at PNL for welding lids onto HLW canisters (Larson 1980).

When welding is complete, the welder is raised and the weld inspected. Faulty welds are repaired with a tungsten inert gas (TIG) welder. The canister is then translated away from

- A CANISTER GUIDE
- B COMPRESSED AIR FEED LINE
- C CANISTER COOLING STATION, UPPER SECTION
- D UPPER SECTION GUIDE
- E EXHAUST AIR DUCT
- F CANISTER COOLING STATION, LOWER SECTION
- G SPILL COLLECTION PIT
- H GRATING
- I CANISTER
- J AIR-COOLING NOZZLES

FIGURE 27. Canister Cooling Station

the canyon wall and transferred to the canister decontamination station with the canister-lifting yoke and crane. Here the canister is first placed in a vessel that contains hot nitric acid (see Figures 29 and 30). The vessel is heated and sparged with steam. At design rate, a canister is decontaminated in this manner for ~24 h and then is moved to the second vessel for water rinsing and drying. Drying is accomplished through use of steam jackets built around the rinsing vessel. Spent liquids drain from both vessels to the process canyon sump tank. Vapors are drawn from the vessels into the vessel ventilation system located on the first floor.

Decontaminated canisters are transferred by crane to the carriage of a special cantilevered transfer car that enables canisters to be withdrawn from the process canyon without contacting any part of the canyon. Once inside the canister coating and packaging room (see

FIGURE 28. Lid Welding Operation

Figure 30), the canister is removed from the transfer car with an overhead crane that rides on a beam. The canister is then positioned on a turntable in the canister coating station (see Figure 31). The sides of the canisters are then coated to fix in place any smearable contamination not removed during the decontamination process. A single vertical-traveling spray nozzle is used to apply the coating to the canister sides. Drying of the coating is accomplished using infrared lamps located opposite the spray nozzle. When the sides are coated, the canister is lifted slightly and slowly rotated using the motorized crane hook. During this rotation, the bottom of the canister is coated via a spray nozzle positioned beneath the turntable.

Coated canisters are then loaded into a special 4-pack transportation frame (see Figure 26). This frame is positioned on a translating table that permits the canister to be lowered into an open slot in the 4-pack with the beam-mounted overhead crane. When the 4-pack is filled, it is removed to storage with a forklift. The loaded 4-pack weighs 6,400 kg.

- A OFFGAS COLLECTION HOOD
- B ELECTRIC ACTUATED BALL VALVE
- C STEAM JACKETS
- D DRAINS TO SUMP TANK
- E WATER SPRAY NOZZLE
- F STEAM/AIR SPARGER
- G CANISTER
- H WATER/ACID ADDITION LINE
- I WATER MIST DISTRIBUTION RING

FIGURE 29. Canister Decontamination Station

Canister Cooling Station (see Figure 27)

The canister cooling station is 2.1 m across its base and 2.3 m in height. All components are constructed of stainless steel. The station consists of four cooling pods. Two cooling pods are included in each of two upper sections that rest on a lower section. The upper sections can be periodically removed to permit vacuuming of spall that has sloughed from the canisters and fallen into the lower section. Vacuuming is accomplished remotely by suspending a vacuuming hose from the crane hook. Vacuumed spall is collected with other

FIGURE 30. In-Can Glass Melting Process Basement Processing Area, Plan View

canister spall from the in-can melter furnaces in a filtered vessel. The filtering vessel is periodically emptied into 1 gal containers identical to the type used for loading material into the HSA ash load-in hood. The removal of spall is the only routine maintenance activity associated with this unit operation. Occasional maintenance is required on the vacuum blower and spall collection discharge valve.

- A INFRARED DRYING LAMP
- B CANISTER
- C ELECTRIC MOTOR-DRIVEN TURNTABLE
- D AIRLESS SPRAY NOZZLE
- E ELECTRIC MOTOR DRIVER FOR TRAVELING SPRAY NOZZLE
- F FUME COLLECTION HOOD
- G TRAVELING AIRLESS SPRAY NOZZLE

FIGURE 31. Canister Coating Station

Lid Welding Station (see Figure 28)

The lid welding station consists of the following: a "glove cubicle" recessed into the process canyon wall, a canister-lid transfer system for passing lids from the cubicle to the canyon, an in-canyon translator for moving canisters close to the glove ports, a small electric power grinder for removing hard buildups on the canister flange, an electric-resistance welder for seal-welding lids to the canister, and a TIG welder for repairing faulty welds. The lid-welding station cubicle contains two viewing windows and two sets of glove ports. The canister-lid transfer system consists of a sliding airlock door, a sphincter contoured

to the cross-sectional area of a horizontal lid, and a ramp that allows a newly added lid to slide to a position where it can be easily grasped using the cubicle gloves. The canister translator consists of cart mounted on tracks that can be moved by actuating a pneumatic or hydraulic cylinder in the remote processing room adjacent to the process canyon (see page 62 for a similar description of the in-can melter translators). A turntable built into the base of the cart allows an operator to rotate a canister to repair faulty welds. The lid welder assembly consists of the welder and a suspension device. Electrical leads to the welder and welder motor are connected by using the cubicle gloves. The TIG repair welder leads are also connected by using the cubicle gloves. Stainless steel welding wire is used in the TIG welder.

This system is expected to require infrequent maintenance. Welding tips can be replaced by the use of cubicle gloves. More extensive repairs on the welder can be made by disconnecting the electrical leads and the suspension device and translating the welder into the craneway where it can be hooked with the crane. New or repaired welders can be replaced in reverse order.

Canister Decontamination System (see Figure 29)

The canister decontamination system consists of two stainless steel vessels for washing and rinsing the canisters, each approximately 1.2 m in dia and 2.1 m in height.

Primary components of the acid wash vessel are a steam sparger for heating the acid, an off-gas collection hood that vents to the solidification facility vessel-vent system, a volumetric acid addition tank located outside the process canyon, a mist distribution ring for rinsing the canister as it is being withdrawn from the vessel, and spent acid and steam condensate drains that empty to the process canyon sump tank through a floor drain. Electric-actuated ball-valves are opened to drain spent acids and condensates. The canister-lifting device (see Figure 25) is left attached to the canister when in the acid wash vessel. This results in decontaminating the device and permits easier transportation of the canister. Approximately 50 L of acid are used for decontamination and about 10 L of water are used for rinsing.

Primary components of the rinse and dry vessel are a mist distribution ring for rinsing, steam jackets for drying the canister, an off-gas collection hood that vents to the solidification facility vessel-vent system, and spent-rinse solution and steam condensate drains that empty to the sump tank. Approximately 20 L of water are used for rinsing.

Infrequent maintenance is expected on this system. Steam traps and the ball valve and actuator are the most probable failure items.

Canister Coating and Packaging System (see Figures 30 and 31)

Primary components of this system include 1) a cantilevered transport vehicle that permits the clean withdrawal of decontaminated canisters from the process canyon, 2) a beam-mounted overhead crane that permits handling of the canisters in the canister coating and packaging room, 3) a coating device for applying a fast-drying coating of nuclear-grade paint.

to the walls of the canister, and 4) a translating table for positioning a 4-pack canister packaging frame under the beam-mounting frame.

The cantilevered transport vehicle requires a heavy, counterbalancing weight to enable loading the 1500 kg filled canister onto the cantilevered extension of the vehicle. As the extension protrudes into the process canyon for canister loading, the canister is the only object in the process canyon that contacts the extension. Because of this cantilevered extension, the spread of process canyon contamination is minimized. The transport vehicle rides on rails and is powered with an electric motor.

The coating system consists of two airless spray nozzles; a turntable for rotating the canister past a coating nozzle; infrared lamps for drying the coating; and a spray-mist collection system that consists of ducts, filters, and a blower. One of the spray nozzles is moved vertically by an electric-powered driver to coat the canister wall, while another spray nozzle coats the bottom of the canister. The beam-mounted crane includes a motorized crane hook to rotate the canister for bottom spraying. Both nozzles are cleaned after each coating has been completed.

The translating table rides on rails and is moved using a pneumatic or hydraulic cylinder. This translating table is moved to position on a 4-pack assembly for canister loading.

The canister coating and packaging room is maintained in a contamination-free condition, which greatly simplifies maintenance. Typical maintenance items include lubrication of bearings, replacement of filters in the coating off-gas system, and the cleaning of spray nozzles.

PROCESSING AREAS

Basement (see Figure 30)

Waste-processing operations are conducted in five separate rooms in the basement:

- canister load-in room
- process canyon
- canister coating and packaging room
- canister process operating room
- process equipment decontamination and maintenance room.

Canister Load-in Room

The canister load-in room serves as an airlock between a contamination-free hallway and the process canyon. Up to six canisters can be loaded onto a powered set of rolls. A single canister is translated from the end of the rolls onto a load-in table by the use of a pneumatic or hydraulic cylinder. Another pneumatic or hydraulic cylinder translates the canister through an open doorway into the process canyon. At design rate, a canister is loaded into the process canyon every 15.5 h.

Process Canyon

The primary functions of the process canyon are:

- filling canisters with glass
- cooling hot canisters
- welding lids on canisters
- decontaminating canisters.

These operations are described on pages 55-70.

Support functions of the process canyon include:

- collecting dusts and canister spall
- collecting waste liquids
- serving as the collection point for inflowing air from all other areas of the building.

Dust and canister spall are vacuumed from the in-can melter furnaces, the canister cooling vessels and the process canyon floor by the use of a vacuum hose suspended from the crane hook. This material is drawn into a cyclone that contains sintered metal filters. These filters are cleaned with periodic pulses of compressed air. A blower provides the necessary negative pressure. Blower air is exhausted into the room air-collection system.

Liquid wastes are collected in a 3800 L stainless steel tank located beneath the process canyon floor. All contaminated liquids generated in the solidification facility are collected here, including vacuum drum filter filtrate, canister decontamination liquids, scrubber solutions, and hood and room washdown solutions. The tank is agitated with a top-entering propeller agitator. Solution is periodically pumped from the tank with a top-entering centrifugal pump. These liquids are transferred back to Building 374 for reprocessing.

The collection point for inflowing room air is located at the floor level of the process canyon opposite the in-can glass melting furnaces. This point is located in the area of the canyon most likely to experience spills of contaminated material. It is also located approximately midway between the canister load-in and load-out doors.

A 4500 kg crane serves the process canyon. The crane hook is capable of traveling in three dimensions and is motorized to enable its rotation along a vertical axis. All of the equipment in the process canyon is fitted with bails for crane transportation and installation, including the sump tank agitator and pump, the in-can glass melters, connecting sections to in-can melters, the dust and spall collector and blower, the lid welder, the canister cooling vessels, the canister decontamination vessel, and the canisters.

The process canyon is lined with stainless steel sheet and is sloped toward the sump tank to facilitate decontamination.

Canister Coating and Packaging Room

The primary functions of the canister coating and packaging room are:

- transferring canisters from the process canyon
- coating canisters
- packaging canisters in a 4-pack frame.

These operations are described on page 69.

Canister Process Operating Room

The primary functions of the canister process operating room are:

- translating in-can glass melting furnaces to their filling and loading/unloading positions by activating hydraulic or pneumatic cylinders
- making up connections to in-can-glass melting furnace connection sections
- translating canisters to their lid-welding and loading/unloading positions by activating a hydraulic or pneumatic cylinder
- positioning, operating, and maintaining the lid welders, maintaining the vacuum cleaning system, filling containers with vacuumed dust, and loading-out filled containers
- observing canister movement operations in the process canyon
- observing canister transfers, coating, and packaging in the coating and packaging room.

The various "hands-on" operations conducted in this room are accomplished through use of leaded gloves attached to the walls of cubicles recessed into the process canyon walls. These glove operations are conducted from the two decks elevated above the room floor.

Dust and spall are loaded out from a glove box that extends from the process canyon on the upper of the two decks. This material is recycled as waste through the HSA ash load-in glove box. Television cameras are strategically located in the process canyon to enable the conduct of operations in "blind" areas.

Process Equipment Decontamination and Maintenance Room

Major processing equipment from the process canyon as well as other process areas is decontaminated and maintained in this room. An equipment transfer vehicle can be moved on tracks into the process canyon to be loaded with failed equipment. A beam-mounted crane in the room facilitates maintenance. This room also serves as an airlock for adding new equipment to the process canyon. The room slopes toward a drain that empties into the sump tank. On-mask conditions may normally prevail in this room.

First Floor (see Figure 32)

Waste processing operations are conducted in four separate areas on the first floor, as follows:

- crane maintenance deck
- solids weighing and blending hood and room

FIGURE 32. In-Can Melting Process, First-Floor Processing Area, Plan View

- decontamination and maintenance room
- control room.

Crane Maintenance Deck

Access is provided to the crane maintenance deck through an airlock. The 4500 kg crane must be serviced from the deck.

Solids Weighing and Blending Hood and Room

The primary function of this area is to blend frit and the various waste streams at the desired feed rates. This operation is described on page 49.

The vessel ventilation scrubber is also located in this room. This vessel scrubs gases drawn from the in-can glass melting operation, the sump tank, and the canister decontamination vessel. Spent scrubber solution drains to the sump tank. The room also contains the necessary heat exchangers and vacuum pumps required to operate the scrubber, and a volumetric tank for providing nitric acid to the canister decontamination vessel in the process canyon.

Decontamination and Maintenance Room

The primary function of this room is to provide capability for decontaminating and maintaining small equipment (in contrast to the basement room that is specifically designed for decontaminating and maintaining large equipment). The room contains a glove box and two open-face hoods, each of which are equipped with drains to the sump tank. The room is normally maintained in a mask-free condition.

Control Room

All processing operations are monitored from this room. Typical operations conducted from this room include:

- slurry transfers from the sump tank to Building 374
- sludge transfers from Building 374 to the sludge drying operation
- other continuous aspects of the sludge-drying operation
- waste and frit feedrate adjustments
- diverter valve adjustments
- in-can-melting furnace temperature control
- canister decontamination sequence control.

Second Floor (see Figure 18)

Waste processing operations are conducted in three separate processing areas on the second floor:

- solids storage room
- HSA ash loading room
- miscellaneous storage room.

Solids Storage Room

This room contains solids surge hoppers that contain LSA ash, dried sludge, and glass frit. Located below the hoppers are various feeders and airlocks as previously described on page 51. This room is normally maintained in an off-mask condition since all required maintenance can be conducted through glove ports.

HSA Ash Load-in Room

This room contains the HSA ash load-in hood, process vacuum pumps, and various heat exchangers, tanks, and vessels that support the process sludge drying operation but which cannot be accommodated in the process sludge drying room located on the second floor. This equipment is described beginning on page 42. Loading HSA ash into its processing glove box may require that masks be worn. The possibility of spreading contamination in this room may

periodically result in the interruption of load-in operations. This should have little effect on the continuity of overall operations, however, since the ratio of HSA ash to the total waste stream is relatively small.

Miscellaneous Storage Room

This room houses equipment that supports the sludge-drying operation or serves as a storage room for HSA ash.

Third Floor (see Figure 16)

Waste processing operations are conducted in two separate rooms on the third floor:

- process sludge-drying room
- LSA ash load-in room.

Process Sludge Drying Room

This room contains the process sludge drying hood, the vacuum drum filter medium preparation system, the process off-gas scrubbing system, and various heat exchangers, pumps, and vessels that support the sludge-drying operation. These systems are described beginning on page 45. This room normally is maintained in an off-mask condition.

LSA Ash Load-in Room

This room contains the LSA ash load-in hood, a drum roller system, and a drum decontamination hood. This equipment is described beginning on page 37.

JOULE-HEATED GLASS MELTING PROCESS

A description of the joule-heated glass-melting process and of the joule-heated melter (Buelt et al. 1979) is provided below. The steps required to load-in and blend ash, sludge and frit are described in the head-end systems section.

Blended ash, sludge, and frit are continuously fed to a joule-heated glass melter where they are melted into glass (see Figure 33). The heat required for melting is supplied by electrical current passed between two electrodes immersed in the molten glass. Molten glass flows under a weir, into an overflow section, over a discharge tip, and into a 55 gal steel

- A MELTER TILTING FRAME
- B MELTING CAVITY
- C TILTING PIVOT TRUNION
- D VIEW PORT
- E MELTER LIFTING BAIL
- F MISCELLANEOUS AIR, WATER, AND THERMOCOUPLE CONNECTIONS
- G FEED ADDITION AND OFFGAS BOLTING FLANGES
- H ELECTRODE CONNECTING TAB
- I AIRLIFT PENETRATION (OPTIONAL)
- J OVERFLOW HEATER BUS
- K OVERFLOW HEATER SUPPORT CASTING LIFTING BAIL
- L OVERFLOW HEATER SUPPORT CASTING
- M OVERFLOW HEATERS
- N GLASS DISCHARGE TIP
- O MELTER TILTER WORM GEAR
- P MELTER DRIVE MOTOR
- Q WHEEL
- R ELECTRODE
- S KNIFE VALVE
- T 55 GAL DRUM

FIGURE 33. Joule-Heated Glass Melter

drums are filled each day. Drum fullness is determined by extrinsic gamma ray attenuation (Nielson and Brodzinski 1978), a method successfully used at PNL and in the commercial glass industry for measuring glass level. When the drum is deemed full, the melter is tilted backwards to interrupt the flow of glass. The flow of blended ash, sludge, and frit is not normally stopped at this time, which allows the melter to continue producing glass while drums are being changed. When an empty drum is in position to receive glass, the melter is simply tilted forward to resume the flow of glass.

When a drum is filled, a large knife valve located between the melter and the 55 gal drum below is closed. This serves to isolate the drum conveyor room below from the relatively contaminated environment above and to break any threads of frozen glass that may form as the flow of glass is terminated. Any glass that inadvertently falls onto the knife valve in the closed position is scraped off when the valve is opened and falls into the drum below. Any glass buildups that do not fall into the drum below are pushed down a chute when the valve is closed again. The glass falls into another drum located on a pallet in the process canyon. Scrap glass in either drum is processed by simply pouring molten glass on top of the scrap until the drum is filled.

New drums are transferred to the filling position beneath the melter via a powered roller conveyor. When a drum is full, it is lowered via a scissor-lift elevator to the level of a second powered roller conveyor located directly below the first. Filled drums remain on the second conveyor for 2 days for cooling. Then they are individually transferred into the drum load-out room where they are 1) checked for dose rate and free contamination; 2) loose-lidded; 3) checked for surface contamination and decontaminated, if necessary; 4) "tight-lidded" with a standard bolting lid clamp; 5) assayed for plutonium content and weighed; and 6) loaded into a 6-pack container (see Figure 11, Volume I). When full, the 6-pack container is lidded, banded, and shipped to the disposal site in a TRUPACT shipping vessel (see Figure 11, Volume I).

EQUIPMENT AND MAINTENANCE

Joule-Heated Glass Melter (see Figure 33)

The joule-heated glass melter is 1.8 m wide, 1.8 m tall, and 2.8 m long. The inner glass melting cavity is 0.9 m wide and 1.2 m long with an effective glass depth of 0.5 m. Two Inconel 690[®] electrodes rest on the bottom of the melter cavity and are positioned against each of the 0.9 m wide walls across from one another. Each electrode is constructed of 5 cm thick metal. At the base of each electrode plate is a 15 cm "foot" extending toward the middle of the melter cavity (see Figure 34). This foot aids in distributing electrical current evenly in the melter.

The effective glass volume in the melter is 450 L. This glass weighs 1,400 kg. The overall weight of the melter is 10,400 kg.

[®]Registered tradename of the International Nickel Company, Huntington, West Virginia.

FIGURE 34. Electrode for Joule-Heated Glass Melter

The glass contact refractories are Monofrax K-3.[®] Somewhat lower-quality glass furnace brick can be used behind the Monofrax K-3 brick. High-quality castables can also be used. A compressible, ceramic fiberboard is used between brick or castable and the metal shell that houses the melter to accommodate expansion of the brick as it is heated. The melter shell is constructed of stainless steel and contains water-cooling ducts for various heat control and safety reasons.

The glass overflow area is heated with silicon carbide heating elements that are vertically mounted above the overflow area. The heating elements are inserted through an insulating-ceramic casting. This casting can be easily removed and replaced using the process canyon crane, thereby facilitating maintenance when the heaters fail or in the unlikely event that a glass plug forms.

The entire melter is tilted on an A-frame device mounted on wheels. The tilting pivot line is located at the top of the melter in parallel with the feed addition and off-gas ports to prevent exceeding the stretching limits of the flexible metal bellows installed in the feed addition and off-gas lines.

[®]Registered tradename of the Carborundum Company, Falconer, New York.

Using the tilt-pour method, the melter is tilted with a small motor that drives a shaft, which in turn activates two worm gears. The worm gears are driven against an axle to which two wheels are fixed. Another small motor and gearbox are connected to the axle, which enables the melter to be driven along a track to facilitate replacing failed melters.

At present, the frequency of maintenance on a joule-heated melter in this application is somewhat uncertain. The greatest uncertainties lie in the ability of the melter to withstand the variability in feed composition and the presence of carbon and scrap metals in the waste. A glass frit has been designed that accommodates what we believe to be the extremes in waste composition; i.e., it promotes the production of good-quality glass that does not excessively crystallize and settle in the melter nor is of such high viscosity that it cannot be properly poured. It is likely that if either of these conditions results, suitable operations may be restored by adding only frit to the melter. However, this action may cause a temporarily high rate of refractory corrosion, as the frit may be more corrosive than the normal glass.

The presence of metals and carbon in the melter is a matter of greater concern. Metals may not be totally oxidized in the melter if they are added in quantities that exceed the oxidizing capacity of the glass. Adding heat and oxygen to the melter vapor space above the glass may help to some extent, but will cease to be effective when the metal and carbon are enveloped by the molten glass. Carbon causes the reduction of oxides, such as iron and nickel, to their metallic states. These metals settle to the bottom of the melter, as do metals added to the melter above its oxidizing capacity. These metals are much more electrically conductive than the molten glass and cause electrical "shorting" across the bottom of the melting cavity. The resulting high temperatures, the agitation of the metal, and the reducing nature of the metal cause rapid erosion and corrosion of the refractories (Dierks et al. 1980). If too much metal is present, the melter will cease to function.

Possible solutions for the removal of metal that may accumulate at the bottom of a melter include 1) a vacuum dip-tube assembly to suck metals from a low point or sump on the melter floor, 2) a heated sump area with a freeze valve for draining liquid metals, and 3) a sump area with an oxygen bubbler to aid in reoxidizing the metals and dissolving them in the glass. Each of these techniques would require further evaluation to determine which could solve the potential problem of metallic buildup in the melter.

Another maintenance problem that may be encountered is glass foaming. Volatiles in the waste such as NO_x , SO_x , and CO_x may be released below the surface of the glass, causing the formation of high-surface-tension bubbles. The bubbles may not collapse if they are pushed upward into the cooler melter vapor space, which further increases their surface tension. In extreme cases, the glass bubbles may rise up into and plug the feed addition and off-gas lines. Unplugging these lines is a difficult maintenance activity. Careful monitoring of the vapor space temperature provides a good indication of possible foaming and over-feeding problems. A view port is also present to confirm problems. Unless lines become plugged, the melter will recover from a foaming situation simply by terminating the feed, reducing melter power, and allowing the foam to subside.

Glass plugs have occasionally formed in the discharge ports in melters operated at PNL. The typical discharge port in these melters is 15 cm. The 46 cm discharge port proposed for the TRU waste melter is probably sufficient to preclude this problem.

As previously stated, the silicon carbide heaters in the overflow section will typically fail after several months of service. They are replaced by 1) disconnecting the electrical leads through hood gloves in the melter connection makeup room, 2) removing the counter-balanced overflow heater support casting using the process canyon crane, 3) replacing the support casting with a spare unit, and 4) remaking the electrical connections. Total charge-out time is estimated to be less than 2 h. The support casting that contains the failed heaters can be repaired for reuse either on the crane maintenance deck or in the melter decontamination/maintenance room.

When the melter fails, all connection points are disconnected, the overflow heater support casting is removed, and the melter is driven along its supporting tracks into the process canyon craneway. Using the crane and a lifting strongback, the melter is positioned on the rails on the floor of the process canyon where it is allowed to cool for 1 wk. A new melter, which had been previously transferred into the process canyon and set on the floor, is moved to the supporting tracks, driven to the operating position, fitted with a new overflow heater support casting, and reconnected.

The melter is started by applying voltage across the electrodes. Graphite in a trough of glass frit that fills the melter cavity provides the initial current path. After about 8 h, the heat generated by the passage of current through the graphite begins to melt the glass frit and burns away much of the graphite. At this time a current path is established through the glass and within 24 h the melter is ready to resume normal operations. The entire replacement cycle, from terminating feed to the failed melter to resuming feed to the new melter, is estimated to take 3 days.

After cooling, the failed melter is driven into the melter decontamination/maintenance room where it is first determined if maintenance should be performed or the melter disposed of. Normally the melter will be disposed of. In this case, the melter surfaces will be thoroughly vacuumed, decontaminated, and possibly painted to fix in place any possible smearable contamination.

Then a steel disposal box will be transferred on a trailer into the drum load-out room after removing all floor-stationed equipment from the room. The melter will be driven into the box, and then a steel door will be bolted over the opening. The box and its contents (including 1,400 kg of glass) will be shipped via a specially-made shipping vessel to a TRU waste disposal site. The box measures 2.7 m x 2.1 m x 2.1 m, and its gross weight is 11,400 kg. These values are within the limits prescribed for waste disposal (Irby 1980), but slightly exceed the dimensional limits for the largest TRUPACT shipping vessel (train). It is recommended that a unique, top-loading vessel be built to TRUPACT performance specifications specifically for handling failed melters.

Drum-Handling System

The drum-handling system consists of:

- 55 gal drums
- drum conveyor system
- drum decontamination equipment
- drum-handling crane
- plutonium assay/weighing station
- 6-pack drum container.

The 55 gal drums used in this system are constructed of unpainted carbon steel. Standard painted carbon steel drums are not recommended because surface temperatures during filling may exceed 600 or 700°C. At this temperature, the paint spalls off and the drum oxidizes. This spalled paint would create a difficult drum-decontamination problem. The oxidized unpainted drums may require decontamination to remove surface contamination and possibly painting to fix contamination in place. However, stainless steel drums can be used but are about 10 times more expensive than carbon steel drums. The economic tradeoffs of higher container costs versus decontamination costs would have to be investigated. Other options include plating and painting with high-temperature resistant materials.

The drum conveyors are of a typical industrial design. They are the roller type that are chain-driven with electric motors. They are programmed and interlocked to control the spacing of drums and to ensure that each drum is permitted 2 days of cooling before drums are discharged to the drum load-out room. The scissor lift used to lower newly filled drums to the second conveyor is also of standard commercial design. Very little maintenance is anticipated on either the conveyors or the scissor lift.

The drum decontamination equipment consists of an alpha detector, rags, bottled decontamination solution, and a rag disposal drum. Spent rags are burned in one of the Building 374 incinerators.

The drum-handling crane is located in the drum load-out room. This is a 900 kg bridge crane that provides three-dimensional crane service. Crane functions include:

- lifting drums to check for bottom contamination
- moving drums to the plutonium assay/weighing station
- moving drums to the 6-pack container
- lifting and positioning the 6-pack container lid.

Very little maintenance is expected on this crane.

At the plutonium assay and weighing station, the drum surface dose rate, the plutonium content, and the gross weight of the drum are determined and automatically logged. Little maintenance is expected.

The 6-pack container base is positioned on a trailer for loading. Six filled drums are loaded onto the base, and the 6-pack lid is set in place. Three steel straps are slipped under the base and then are tightened and banded (see Figure 11, Volume I). The trailer is then transferred to the TRUPACT loading area where an 3600 kg forklift with a modified

lifting frame removes the 3000 kg loaded 6-pack and loads it into a TRUPACT shipping vessel for shipment to a disposal site (see Figure 11, Volume I).

PROCESSING AREAS (see Figure 35)

Basement (see Figure 36)

Waste processing operations are conducted in five separate rooms in the basement, which include:

- drum load-in room
- drum conveyor room
- process canyon
- melter decontamination/maintenance room
- drum load-out room.

Drum Load-in Room

Empty drums are brought into the drum load-in room on a pallet that holds four drums. The drums are manually loaded onto a set of rollers where they are automatically fed, one at a time, into an elevator that raises them to the level of the upper elevator in the conveyor room. When a drum is positioned under the melter, the drum in the elevator is automatically ejected onto the upper conveyor to be next in line for filling with glass.

Conveyor Room

The conveyor room contains two sets of powered-roller conveyors for transporting empty drums to the glass-filling position and for transporting filled drums to the load-out area. It also contains a large slide valve for isolating the room from the melting area above and a scissor-lift elevator for lowering filled drums to the lower conveyor level. Assault masks are normally worn in this room.

Process Canyon

The primary functions of the process canyon are:

- collecting scrap glass
- replacing failed melter overflow heater support castings
- replacing failed melters
- storing new and failed melters
- collecting waste liquids
- serving as the collection point for inflowing air from all other processing rooms.

Most of the scrap glass is charged into the next drum below; however, some of the scrap glass may overflow into a collecting drum loaded on a pallet in the process canyon. The pallet is fitted with a bail for handling with the crane hook. Infrequently the drum is removed, replaced, and positioned beneath the melter for filling with molten glass.

Replacing failed melters and overflow heater support castings is described on page 81.

FIGURE 35. Joule-Heated Glass-Melting, Elevation View

- A 55-GAL DRUM 6-PACK
- B DRUM LOAD-OUT ROOM
- C MELTER DECONTAMINATION/MAINTENANCE ROOM
- D PRIMARY EXHAUST AIR DUCT
- E PROCESS CANYON
- F SUMP TANK
- G SCRAP-GLASS COLLECTION DRUM
- H DRUM ELEVATOR
- I MISCELLANEOUS ELECTRICAL EQUIPMENT ROOMS
- J ESCAPE CORRIDOR
- K POWERED ROLLER CONVEYORS
- L CONVEYOR ROOM
- M DRUM LOAD-IN ROOM
- N DRUM ELEVATOR
- O STAIRWELL
- P DRUM ASSAY/WEIGHING STATION

FIGURE 36. Joule-Heated Glass-Melting Process, Basement Processing Area, Plan View

A large sump tank is located below the basement floor for collecting waste liquids and for directly recycling them back to Building 374 or via the vacuum drum filters. This system is more thoroughly described on page 71.

The process canyon is maintained at the lowest negative pressure relative to other rooms to ensure that no contamination escapes from this relatively high-risk area. Air is exhausted from this room through a large duct to the second floor where it is cleaned in several stages of HEPA filters.

One 14,000 kg bridge crane serves the process canyon. Its purpose is to support maintenance on the melter and the sump tank. Personnel access to this area requires plastic suits and fresh air supply.

Melter Decontamination/Maintenance Room

Melters and other large equipment items are decontaminated and maintained in this room. Decontamination solutions drain to the sump tank from this room. Assault masks are the minimum personnel protection in this room.

Drum Load-Out Room

In this room filled drums are prepared for loading-out to storage. These preparations include decontamination, lidding, plutonium assaying, weighing, and packaging in a 6-pack container. The room also serves as a melter load-in/load-out room. Assault masks are normally worn in this room.

First Floor (see Figure 37)

Waste processing operations are conducted in five separate rooms on the first floor:

- crane maintenance deck
- solids weighing and blending hood (upper level)
- melter connection makeup room (lower level)
- decontamination/scrubber room
- control room.

Crane Maintenance Deck

Periodic crane maintenance must be performed from the crane maintenance deck. Very limited melter maintenance is also performed from this area. This area is reached through an airlock. Access to the crane maintenance deck requires protective clothing and fresh air supply.

Solids Weighing and Blending Hood

Access to this hood (room) is provided through an airlock. Work in this area requires protective clothing and fresh air supply. This area is fully described on page 53.

Melter Connection Makeup Room

This room is located directly below the solids weighing and blending hood. In this room, a stainless steel wall with glove ports surrounds half of the joule-heated melter. This permits the various electrical, water, air, and thermocouple connections to be made through the glove ports. The melting surface can also be inspected by peering through an inspection port in the melter. However, due to its close proximity to the hot melter, this room is entered infrequently. Assault masks are recommended for personnel protection.

FIGURE 37. Joule-Heated Glass-Melting Process, First-Floor Processing Area, Plan View

Decontamination/Scrubber Room

This room contains the scrubber, heat exchangers, recirculation pumps, and vacuum pumps required to draw and clean off gases from the melter. This room also contains two maintenance glove boxes, one for servicing small equipment from the solids weighing and blending hood and the other for servicing small equipment. The room also serves as the load-out room for failed equipment from the solids weighing and blending hood.

Control Room

All processing operations are monitored from this room. Typical operations conducted from this room include:

- slurry transfers to and from the sump tank
- sludge transfers to the vacuum drum filters
- waste and frit feed rate changes
- melter pouring.

Second Floor (see Figure 18)

The design of the second floor is very similar to that of the second floor of the in-can glass melting process, although less space is required. Waste processing operations are conducted in two rooms on the second floor:

- HSA ash load-in room
- solids storage room.

These rooms and their functions are described on page 74.

Third Floor (see Figure 16)

The design of the third floor is very similar to that of the third floor of the in-can glass melting process, although less space is required. Waste processing operations are conducted in two rooms on the third floor:

- LSA ash load-in room
- process sludge drying room.

These rooms and their functions are described on page 75.

GLASS MARBLE PROCESS

Dried sludge, HSA ash, LSA ash, and glass frit are delivered continuously to a joule-heated glass melter as in the joule-heated glass melting process. Glass is drained from the melter in two streams via airlifting. The two streams, which are spaced 5 cm apart, are continuously poured into a marble-making device. This device consists of a continuous moving chain on which marble-forming molds are attached (see Figures 38 and 39). Glass falls into the hemispherically shaped molds, forming globules of glass (Treat and Rusin 1982). The molds are then vibrated, causing the globules of glass to rotate. This rotating action causes the glass globules to assume a spherical shape as they harden. The hardened marbles are dumped from the molds, and the empty molds are again passed beneath the molten glass stream, thereby repeating the process.

Newly formed marbles are allowed to roll down a vibrated, tilted ramp. Round marbles roll freely to the end of the ramp, whereas irregular-shaped marbles and broken glass are vibrated off the edge of the ramp. This scrap glass is collected in tote bins which, when full, are elevated above the glass melter by the process canyon crane (see Figure 40). A motor-driven auger or vibrator empties the bin into the melter through a funnel, thereby recycling the glass. Approximately 5% of the glass produced by the melter is estimated to require recycling in this way. Round, acceptable marbles fall from the end of the vibrated

- A MELTER SUPPORT TROLLEY
- B GLASS MELTER
- C MARBLE MACHINE
- D MARBLE/SCRAP SORTER
- E DIVERTER VALVE
- F SCRAP GLASS TOTE BIN
- G SCRAP GLASS COLLECTION FUNNEL

FIGURE 38. Marble-Making and Scrap-Glass Collection System

FIGURE 39. Marble Machine Mold Design

ramp into a funnel that guides the marbles through a diverter valve and into one of two 55 gal steel drums. When a drum is filled, the diverter valve is switched to enable the filling of the other empty drum.

The steel drums are coated with aluminum paint to prevent drum oxidation since standard paint blisters at the 400°C bulk marble temperature. The drums are filled through a 10 cm dia hole centered in the top of the drum. Drums are filled to the 80% level, using extrinsic gamma ray attenuation to determine fullness (Nielson and Brodzinski 1978). The glass volume in bulk marbles occupies 60% of the volume of monolithic glass. Hence, an average of 4.4 drums are produced each day, or 6.6 drums per day at design rate.

Filled drums are allowed to remain on a powered roller conveyor for 1 day to enable cooling for safe handling. Then the drums are transferred individually to the drum load-out room (see Figure 41) where they are 1) checked for dose rate and fill-spout contamination; 2) sealed with a "screw-cap"; 3) checked for surface contamination and decontaminated, if necessary; 4) assayed for plutonium content and weighed; and 5) loaded into a 6-pack container (see Figure 11, Volume I). When full, the 6-pack is lidded, banded and shipped to a disposal site in a TRUPACT shipping vessel (see Figure 11, Volume I).

EQUIPMENT AND MAINTENANCE

Solids Handling System

The system for delivering ashes, sludge, and frit to the melter is identical to that described on pages 49-53.

FIGURE 40. Glass Marble Process, Elevation View

- A 55-GAL DRUM 6-PACK
- B DRUM ASSAY/WEIGHING STATION
- C DRUM LOAD-OUT ROOM
- D MARBLE LOAD-OUT ROOM
- E POWERED ROLLER CONVEYORS
- F PRIMARY EXHAUST AIR DUCT
- G MARBLE PROCESS OBSERVATION AND HOOKUP DECK
- H MARBLE SORTER
- I MARBLE MACHINE
- J PROCESS CANYON
- K SUMP TANK
- L MISCELLANEOUS EQUIPMENT ROOM
- M ESCAPE CORRIDOR
- N GLASS MELTER AND CARRIAGE
- O MISCELLANEOUS EQUIPMENT ROOM
- P STAIRWELL

FIGURE 41. Glass-Marble Process, Basement Processing Area, Plan View

Joule-Heated Glass Melter (see Figure 33)

The glass melter employed in this process is very similar to the one employed in the joule-heated glass melting process. The dimensions of the melter are identical. The melter employs two air-lifting lances for producing two streams of glass instead of one. The air-lift lances are constructed of platinum for corrosion resistance. Two streams are produced in order to limit the length of the marble machine because proper marble formation is a function of cooling and vibrating time. Tilt-pouring is not recommended to produce two streams

of glass since it is believed that it is desirable to control individual stream-pouring rates. Also the tilting action may cause off-center filling of the molds, which results in significant operating problems.

The melter must also be positioned on a carriage when in the operating position in order to permit sufficient room beneath the melter to insert the marble machine (see Figure 40).

The melter also is fitted with a motor-operated gate valve and funnel to permit recycling scrap glass.

The melter will experience all of the maintenance problems described on page 78. Additional problems may be encountered with the use of the additional air-lifting lance and the scrap-glass recycle valve.

Melter Support Carriage

The melter support carriage provides sufficient room beneath the melter for the marble machine (see Figure 40). It rides on the same tracks that would have been used to support the melter in the joule-heated glass melting process. The carriage is powered by an electric motor. Infrequent maintenance is expected since the carriage will be moved only during melter change-out operations.

Marble Machine (see Figures 38 and 39)

The marble machine is based on a Corning Glass Works patent (Knapp and Smith 1962). It has also been demonstrated at PNL (Treat and Rusin 1982). Here marbles have been produced at rates and glass compositions very similar to those required for this study. The marble machine is 5.5 m long and consists basically of molds mounted on a vibrating and moving chain.

Molds are constructed of aluminum or copper to promote heat transfer from the glass marble to the mold during the formation of the marble. At high production rates, the molds must be cooled to about 250°C with a water mist. However, during startup, the molds are usually too cold, and as a result, cracked or irregular-shaped marbles are formed. Within a few minutes after startup, the molds are sufficiently hot to ensure production of high-quality marbles.

The machine is driven by a variable-speed electric motor. During startup, the operator must visually inspect marble size and adjust the machine speed and glass pouring rate accordingly to enable production of high-quality marbles of the desired size (normally 1.3 cm). Once glass production rates have stabilized and the molds are maintained at the proper temperature, little operator attention is required.

Vibration is provided by five ball-type vibrators mounted to the underside of the spring-supported channel that guides the molds. During operation, the vibrators are operated continuously.

Since the marble-making operation will not be observed continuously, a motion detector is positioned to determine that marbles (and scrap) are being produced. Also, resistance-temperature devices are placed beneath the machine in line with the falling glass stream to

indicate when a failure has occurred. Load cells mounted beneath the drums as they are filled with marbles provide an indication of the production rate.

Stopping marble production requires 1) termination of feed to the melter, 2) manually controlling the air-lift lances to draw down the glass level in the melter, 3) shutting off the flow of air to the air-lift lances, and 4) allowing glass to "drizzle" in threads for 15 min. During the "drizzling" period, the marble machine must be operated at progressively slower speeds to aid in breaking up glass threads into manageable pieces. The entire shut-down operation requires about 1 h.

Maintenance on the marble machine is expected to be moderately high. The vibrators are expected to last 3 months before requiring replacement. They can be replaced through glove ports by an operator who works from the marble process observation and hookup deck (see Figure 42). The marble machine chain must be lubricated frequently. Sprocket bearings and the drive system must also be lubricated periodically. The chain will gradually stretch and may require sprocket adjustment or removal of links. The molds in the PNL machine have been remarkably resistant to wear, even during periods when the machine was accidentally stopped while the glass pouring continued. Eventually, however, the machine will require replacement because of vibration-induced fatigue of springs, chain links and welds, motor failure, and jamming. Replacement is accomplished by 1) disconnecting all connections via the glove ports, 2) hooking the machine by its lifting bail, 3) sliding the machine out from under the melter, 4) lifting the machine off its supporting rails, 5) guiding it into a greenhouse in the marble load-out/melter decontamination room with the aid of protectively clothed personnel, and 6) repairing the machine or disassembling it for disposal. The repaired or new machine is installed by performing the opposite of the above six steps.

Marble Sorter

The marble sorter consists of a flat plate of stainless steel 0.6 m wide and 1.5 m long. The plate is mounted on springs and is tilted a few degrees in two directions from horizontal. A high-frequency air-driven vibrator is attached to the underside of the sorter. The vibration promotes the sliding of nonspherical glass shapes off the side of the sorter, whereas spherical marbles roll freely to the end of the sorter. Periodic replacement of the vibrator will be required. This can be accomplished through glove ports. Vibration-induced failure necessitates replacement of the marble sorter. This is easily accomplished using the process canyon crane.

Diverter Valve (see Figures 38 and 40)

The diverter valve is a commercially available, three-directional device. The single-hole diverter plate is aligned over the desired discharge pipe with an electric motor and limit switches. Two of the discharge pipes are directed to the drum-filling station, and the other pipe is directed into the scrap-glass collection funnel. Normally during startup and shutdown, all marbles produced are directed into the scrap glass collection funnel because they are too small or are too highly stressed because of rapid cooling. A moderate level of maintenance is expected, although most maintenance activities can be accomplished through glove ports. Typical activities include freeing jams and replacing limit switches.

Scrap Glass Collection Funnel (see Figures 38 and 40)

The scrap glass collection funnel is a custom-made device that collects scrap glass and directs it into a tote bin. Since the base of the funnel is sloped only about 20°, vibrators are attached to the base to promote movement of glass to the discharge spout. The bulk of the scrap glass collected is produced during startup and shutdown periods, but some scrap such as marbles with "tails," broken marbles, and glass flakes are produced during normal operation. Little maintenance is expected since vibrators are only periodically actuated.

Scrap Glass Tote Bin (see Figures 38 and 40)

The scrap glass tote bin consists of a hopper and a 10 cm auger driven by an electric motor. It is a custom-made device capable of containing about 140 kg of scrap glass. A long electrical cord permits the elevation of the bin over the melter where its contents can be emptied into the melter. When a bin is full, as determined visually by television cameras, it is hooked through its bail with the process canyon crane hook and moved aside. A second, empty bin is then moved into position using the crane. The full bin is then elevated to its emptying position. When ready to empty, the waste and frit feeding to the melter is terminated and the bin is emptied into the melter at a rate designed to approximate the average glass production rate. When empty, again as determined by television, waste and frit feeding to the melter is resumed and the bin is set aside. On the average, 70 kg of glass scrap are generated each day, which necessitates bin-emptying about every 2 days.

Maintenance on the bins is expected to be fairly low, although jamming of the auger may prove to be a problem, even with a variable-pitch screw. Some glass may spill from the bins or from the collection funnel during bin-changing periods. This spillage will require manual cleaning, perhaps with a vacuum cleaner.

Drum-Filling Station (see Figures 38 and 40)

The drum-filling station consists of an open-face hood, two drum-filling spouts and two sets of powered rollers. Mild-steel drums coated with aluminum paint are manually loaded onto the roller conveyors, as needed, using a small, beam-mounted crane. The drums are transferred into the hood on the conveyor and are self-aligned under the filling spout. A pneumatic cylinder is actuated to lower the spout into the center 10 cm fill hole in the top of the drum. A metal bellows in the fill spout enables the vertical translation of the fill spout. A load-cell weighing system is elevated under the drum between individual rolls to provide an indication of weight during filling. An extrinsic gamma-level detection system (Nielson and Brodzinski 1978) is also installed in the hood at each drum-filling position to indicate drum fullness. When a drum is filled, the diverter valve is switched to fill the empty drum, the fill spout is retracted, and the filled drum is conveyed onto another powered roller conveyor for about one day's cooling. The drum surface-temperature immediately after filling is about 400°C.

Fairly low maintenance is expected. Occasional misalignment problems will occur, as will marble spillage. It is believed that spilled marbles do not present a significant contamination problem due to their toughness and ease of recovery. The drum roller and weighing

system elevators will require periodic lubrication, and the position indicators will require occasional replacement or adjustment.

Drum Packaging

Drum packaging requires the same equipment and maintenance as required in the joule-heated glass melting process (see page 82). The one exception is that 10 cm screw-cap closure lids are used instead of fully-open top-drum lids.

PROCESSING AREAS (see Figure 40)

Basement (see Figure 41)

The waste processing operations listed below are conducted in three separate rooms in the basement:

- process canyon
- marble load-out room
- drum load-out room.

Process Canyon

All of the equipment activities of the process canyon in the joule-heated glass melting process are common to the glass marble process. In addition, the glass marble process operates and maintains the following equipment in the process canyon:

- marble machine
- marble sorter
- scrap glass collection funnel
- scrap glass tote bins.

Marble Load-out Room

The primary purpose of this room is to fill drums with marbles and contain them within the room for a day of cooling. The room also serves as an empty-drum storage area, a maintenance room (via glove ports) for the marble-making equipment, and a decontamination and load-out room for failed melters, marble machine and other large equipment. For marble load-out, masks are normally not worn until contamination-free conditions are verified.

Drum Load-out Room

All of the activities and equipment of the drum load-out room in the joule-heated glass melting process are common to the glass marble process. However, approximately two times more drums are handled in this room due to the lower bulk waste-loading of marbles.

First Floor (see Figure 37)

The design of the first floor is very similar to that of the first floor of the joule-heated glass melting process. Waste processing operations are conducted in five separate rooms on the first floor:

- crane maintenance deck
- solids weighing and blending hood (upper level)

- melter connection makeup room (lower level)
- decontamination/scrubber room
- control room.

These rooms and their functions are described in the joule-heated glass melting process description section (page 86).

Second Floor (see Figure 18)

The design of the second floor is very similar to the design of the second floor of the in-can glass melting process, except that it does not require as much space. Waste processing operations are conducted in two rooms on the second floor:

- HSA ash load-in room
- solids storage room.

These rooms and their functions are described in the in-can glass melting process section (page 74).

Third Floor (see Figure 16)

The design of the third floor is very similar to the design of the third floor of the in-can glass melting process, except that it does not require as much space. Waste processing operations are conducted in two rooms on the third floor:

- LSA ash load-in room
- sludge drying room.

These rooms and their functions are described in the in-can glass melting process section (page 75).

BASALT GLASS-CERAMIC PROCESS

The basalt glass-ceramic process is nearly identical to the joule-heated melting process (pages 77-88) except that a different glass frit is used, higher melting temperatures are employed, and the molten glass is poured into insulated stainless steel drums instead of into uninsulated mild-steel drums. The glass in a insulated drum is converted to a glass-ceramic as it is slowly cooled to 600°C. After approximately 2 days of cooling, the drum is removed from its insulating pod. When the loaded pod reaches the drum removal station, the insulating lid is removed remotely by a crane and is placed onto a lid conveyor. The drum is then removed and placed on a drum cooling and load-out conveyor. The drum is translated 0.9 m on the conveyor, and an empty drum is rolled into the position formerly occupied by the filled drum. Using the crane, the empty drum is inserted into the empty pod. This empty drum and pod assembly is then translated and raised to the level of a conveyor, which returns the assembly to the glass-filling position. Meanwhile, the lid is conveyed to the pod-lidding station. Here, a newly filled drum of glass is elevated underneath the lid, which is suspended by a ring around its circumference (see Figure 42). When the ring-supporting members are spread, the lid is freed. The assembly is then lowered and slowly conveyed to the drum

- A LID LIFTING COLLAR
- B LID
- C LID SUPPORT RING
- D DRUM
- E SHEET STEEL INNER LINER
- F INSULATING CASTABLE
- G SHEET STEEL OUTER LINER
- H INSULATING POD

FIGURE 42. Drum Insulating Pod and Lid

removal station where the process is repeated. A drum that is removed from the insulating pods is allowed another day of cooling before it is lidded and prepared for shipping and disposal.

Then the drums are transferred individually to the drum load-out room (see Figure 43) where they are 1) checked for dose rate and fill-spout contamination; 2) sealed with a screw-cap; 3) checked for surface contamination and decontamination, if necessary; 4) assayed for plutonium content and weighed; and 5) loaded into a 6-pack container (see Figure 11, Volume I). When full, the 6-pack is lidded, banded and shipped to a disposal site in a TRUPACT shipping vessel (see Figure 11, Volume I).

EQUIPMENT AND MAINTENANCE

Only two equipment items vary significantly from those described in the joule-heated glass melting process. They are the glass melter and the insulating pods used around stainless steel drums. The glass melter uses the same joule-heating principle and has the same dimensions. However, because required glass-melting temperatures are higher (1350°C versus 1200°C), tin oxide electrodes are used, and more heaters are required in the overflow zone of the melter to maintain a glass viscosity that is suitable for pouring (<100 poise). The higher temperatures used may increase the melter failure rate and may also result in increased volatility and attendant off-gas maintenance problems. The insulating pods are shown schematically in Figure 41. The beam-mounted crane that is fitted with a drum-clamping device is used for vertically lifting drums in and out of the insulating pods. The same method is used to place and remove pod lids.

The conveying system that moves pods, drums, and lids is considerably more complex than that for moving drums of glass in the joule-heated glass-melting process. However, since only four drums are processed each day at design rates, the system should not be subjected to much wear and should not require much maintenance.

PROCESSING AREAS (see Figure 43)

The first and second floors are identical in size and function as those described for the joule-heated glass melting process. Only the basement differs in design, as Figure 43 shows.

- A 55-GAL DRUM 6-PACK
- B DRUM ASSAY/WEIGHING STATION
- C EMPTY DRUM CHARGING STATION
- D DRUM LOAD-IN/LOAD-OUT ROOM
- E DRUM LOAD-OUT STATION
- F MELTER DECON/MAINTENANCE ROOM
- G PROCESS CANYON
- H SUMP TANK
- I MELTER
- J MISCELLANEOUS EQUIPMENT ROOM
- K ESCAPE CORRIDOR
- L INSULATING POD RETURN CONVEYOR
- M STAIRWELL
- N LOADED POD HOLDING CONVEYOR
- O PRIMARY EXHAUST AIR DUCT
- P POD LIDDING STATION
- Q LID RETURN CONVEYOR
- R DRUM REMOVAL STATION

FIGURE 43. Glass-Ceramic Process, Basement Processing Area, Plan View

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CAST CEMENT PROCESS

Dried sludge, HSA ash, and LSA ash are loaded into the process as described in the head-end systems section. These waste materials and Portland cement are individually weighed and transferred to a batch mixer. About three-fourths of the estimated water required is added through sintered-metal sleeves in the solids addition line and the off-gas line. This addition serves to flush cement and other solids into the mixer. The mixer is then operated for about 3 min, and the amperage (indicating torque) is noted. Water is then added slowly over the next 2 min until a predetermined amperage or amount of water is added. If the maximum allowable water is added, and the amperage is still high, indicating a viscous mix, the operator will stop the mixer and inspect the mixer contents with a rod inserted through a trap door at the top of the mixer. A decision to dump the mix or add more water and continue mixing is then made.

When the cement mix is deemed ready to dump, a cement-scrap collection funnel is translated horizontally from under the mixer, exposing a 0.8 m dia hole in the floor of the mixer glove box (see Figures 44 and 45). An empty steel 55 gal drum is then elevated through the hole in the floor until it seats properly with a flange around the discharge port of the mixer. A trap door that covers the discharge port is then swung open, which allows the contents of the mixer to be discharged into the drum. A vibrator attached to the wall of the mixer may be activated to aid in more thoroughly emptying the mixer. When the mixer contents have been discharged, the trap door is closed and a small amount of water, about one-fourth of the total batch-water requirement, is added through the sintered-metal sleeves to flush down cement that may have been thrown up into the feed addition and off-gas lines. The mixer is then left slowly agitated until the next batch is ready for addition to the mixer. This serves to prevent residual cement from setting in the mixer.

When the mixer door is closed, the drum is lowered through the hole in the mixer glove box, and the cement-scrap collection funnel is translated back to its closed position under the mixer and covering the hole in the floor. A small amount of water is then sprayed through nozzles positioned on the collection funnel up into the mixer discharge flange and into the funnel itself. This serves to wash down any cement adhering to these components. This washed-down material flows through a short pipe section at the base of the funnel and discharges into a trough in the mixer hood. The washed-down material then flows into a nearby sump tank. The sump tank is similar to that described on page 71.

At the end of the operating shift, or during extended shutdowns, the mixer and the scrap-cement collection funnel is flushed out well using a small amount of fresh water and the filtrate collected during operation of the vacuum drum filters. All of the filtrate eventually is collected in the sump tank where it and other waste solutions are pumped back to Building 374 for reprocessing.

Cement/waste-filled drums, which are produced at an average of one every 42 min or one every 28 min at design rate, are transferred via a powered roller conveyor to the drum

FIGURE 44. Cast-Cement Process, Elevation View

- A FILTRATE TO FLUSH RING AND NOZZLE
- B DRUM SEATING FLANGE
- C CEMENT MIXER
- D MIXING BLADE
- E INSPECTION PORT
- F CEMENT ADDITION PIPE
- G WASTE ADDITION FUNNEL
- H OFFGAS LINE
- I SPRAY NOZZLES
- J WATER FLUSH LINERS
- K SINTERED METAL SLEEVES
- L MIXER MOTOR
- M DISCHARGE DOOR
- N DISCHARGE DOOR ACTUATOR
- O WATER TO SPRAY RING
- P FLUSH COLLECTION FUNNEL
- Q DRUM ACCESS PORT

FIGURE 45. Cement Mixer

gasket removal station (see Figure 46). Here an operator works through glove ports to remove a paper-plastic gasket that protects the rim of the drum against cement spatter and allows the lid to seal better to a clean surface. The gasket is dropped into the drum for disposal.

Filled drums are allowed to routinely remain on the roller conveyor for 20 to 24 h to permit the cement to set and partially dewater. As an option to aid in dewatering, infrared lamps may be located above the conveyors. Drums containing the hardened cement are transferred to the drum load-out room (see Figure 46) where they are 1) checked for dose rate and rim contamination; 2) loose lidded; 3) checked for surface contamination and decontaminated, if necessary; 4) "tight-lidded" using a standard bolting-lid clamp; 5) assayed for plutonium

- A CONTROL ROOM
- B ANTEROOM/MAINTENANCE ROOM
- C DRUM LOAD-OUT ROOM
- D FILLED-DRUM CONVEYOR ROOM
- E SUMP TANK ROOM/MAINTENANCE ROOM
- F SCRUBBER
- G CEMENT MIXING ROOM
- H OBSERVATION/MAINTENANCE DECK
- I DRUM ROLLER CONVEYOR
- J EMPTY DRUM STORAGE AND LOAD-IN ROOM
- K SOLIDS WEIGHING MAINTENANCE HOOD (ELEVATED)
- L AIRLOCK (ELEVATED)
- M STAIRWELL
- N CEMENT-MIXING GLOVEBOX
- O DRUM GASKET REMOVAL STATION

FIGURE 46. Cast-Cement Process, Basement Processing Area, Plan View

content and weighed; and 6) loaded into a 6-pack container (see Figure 11, Volume I). When full, the 6-pack is lidded, banded and shipped to a disposal site in a TRUPACT shipping vessel (see Figure 11, Volume I).

EQUIPMENT AND MAINTENANCE

Solids Handling System

The system for delivering solids to the cast-cement process is virtually identical to the systems described for the in-can glass melting process. The primary differences are that Portland cement replaces glass frit, and the size of the sludge-drying equipment is increased

since all operations are assumed to be conducted during a single 8-h shift 5 days a week instead of the four shifts necessary for the continuously operating glass processes. The increased equipment size is estimated to require a sludge-processing hood 0.9 m longer and wider than that required in the glass process. Ashes must be loaded into their respective systems four times faster than required for the glass system. However, the ash load-in equipment designed for the glass processes can easily accommodate this higher rate. Since the solids surge hoppers are not increased in size, however, delays in loading-in solids must be held to a minimum. The cement surge tank is the primary holdup unit in the system, but automatically filling this tank from a large storage tank located at ground level helps to alleviate holdup.

Mixing System (see Figure 45)

The mixing system consists of a batch mixer, the cement-scrap collection funnel, the hood that encloses the mixer and funnel, and an off-gas scrubbing system.

The batch mixer (see Figure 45) has a capacity of 300 L, which is well above the required 170 L batch size. The mixer is constructed of stainless steel components and has overall dimensions of 1.1 m long, 0.73 m wide, and 0.89 m high. The mixer is equipped with two 15 cm pipes at its top. One is used for addition of waste and Portland cement and the other for off-gas removal. Each of the two pipes is fitted with water spray nozzles to periodically flush down cement spatter. The solids addition line is also fitted with a sintered stainless steel sleeve immediately above the flushdown nozzles through which dried air is slowly added. This serves to prevent moist air from rising into the solids addition funnel where wet solids buildup could occur. The mixer is also equipped with two hinged doors, one at the top for inspection and cleaning purposes and one at the bottom for discharging the mix. The doors are actuated with small electric motors. The pipe surrounding the discharge door contains nozzles to enable flushing the rubber gasket that provides the door seal. The mixer is driven with a two-speed electric motor. The high speed (100 rpm) ensures quick and complete mixing, and the low speed (20 rpm) is used for initial solids/water mixing to minimize dust formation and to enable idling between batches.

An option to minimize cement dusting is to add the cement in premeasured bags that will shred open when contacted by the mixer blades. This method could reduce cement dust or cake in the charge port before the cement is mixed. Another method for reducing mixing spatter, specifically in the off-gas port, is to slowly but continuously add a granular filter medium that fills the port lines. This medium would serve as the initial moisture and particulate barrier in the off-gas line, thus aiding in keeping the off-gas line clean. Both these concepts could be considered in the final design.

Mixer maintenance is expected to be moderately high. The most frequent problems are expected to be removal of material buildups in the mixer, replacement of rubber door gaskets, and bearing/seal repair. The mixer is designed to be operated in such a way that buildups are minimized. However, occasional buildup removal will be required. This can be accomplished through the addition of a weak acid to the mixer. Replacing rubber gaskets can be accomplished through glove ports in a well-designed glove box. Bearings can be easily

lubricated, but replacement of bearings and seals requires removal from the mixing glove box. This is accomplished by unbolting mixer connections and rolling the mixer along rails built into the glove box and through a glove box door into the filled-drum conveyor room. Here, the mixer can be lifted off the rails with a beam-mounted crane and lowered onto a cart. The cart can be pulled into the sump tank room where maintenance can be accomplished.

The flush collection funnel (see Figure 45) is driven horizontally on rails mounted inside the mixing glove box. Due to space limitations, the funnel is moved with a scissor-jack assembly attached to a hydraulic cylinder. A metal bellows encompasses the shaft that moves the funnel to prevent possible withdrawal of contamination from the glove box. The top of the funnel is equipped with a water distribution ring that is capable of spraying water both at the drum-seating flange and into the funnel itself. Flush solutions are discharged through a pipe at the base of the funnel into a trough in the glove box. Little maintenance is expected on the flush collection funnel.

The glove box that encloses the mixer and the funnel is 1.2 m wide x 2.4 m long x 2 m high and is constructed of stainless steel. It is equipped with viewing windows and glove ports in strategic operating and maintenance positions. A 0.8 m dia hole is located in the floor of the glove box to permit the elevation of drums. A sloping trough is located along one side of the glove box to collect mixer flush solutions and cleanup solutions. The trough drains to the sump tank. The glove box is maintained at a lower negative pressure than all other processing glove boxes and rooms with the exception of the solids weighing hood located above, since it has a high potential for experiencing spills. Solids that are collected in the trough and glove box are periodically removed and disposed of in an empty drum before it is filled with a batch of waste/cement blend.

The mixer off-gas scrubbing system consists of a packed scrubber and a recirculation pump. Filtrate from the vacuum drum filter system serves as the scrub solution. Water may also be used to supplement the filtrate. Vacuum is supplied by the same system used to supply vacuum to the vacuum drum filters. A diaphragm pump is used to recirculate solution in the scrubber. Some of the recirculation solution is sprayed into the pipe connecting the mixer and scrubber to help minimize buildups in the pipe. Both the scrubber and the glove box, which encloses the scrubber pump, drain to the sump tank. The scrubber pump glove box is vented to the mixer glove box. Maintenance on this system is expected to be moderate. The pump and its glove box are designed for easy maintenance. The scrubber and the off-gas line may occasionally require filling with weak acid to loosen solid buildups.

Drum-Handling System

The drum-handling system consists of:

- 55 gal steel drums
- drum conveyor system
- drum decontamination equipment
- drum handling crane
- plutonium assay/weighing station
- 6-pack drum container.

The drum-handling system is virtually identical to the system employed in the joule-heated glass melting process (see page 82). An overhead radiant heating system may be employed in the cast cement process, however, to evaporate water that rises to the surface of the newly cast cement/waste mixture.

PROCESSING AREAS (see Figure 44)

Basement (see Figure 46)

Waste processing operations are conducted in the following basement rooms:

- control room
- empty-drum storage and load-in room
- mixing room
- sump tank/maintenance room
- filled-drum conveyor room
- drum load-out room
- solids weighing hood (elevated).

Control Room

All processing operations are monitored from this room. Operations conducted from this room include:

- slurry transfers to and from the sump tank
- batching waste and cement into the mixer
- operating the mixer
- discharging the mixer.

Empty-Drum Storage and Load-in Room

Empty 55 gal drums are transferred into this room with an electric-powered cart. Drums are manually loaded onto a powered roller conveyor that automatically feeds them to the filling position. Drum gaskets that protect the rims of the drums from cement spatter are also removed from this room via glove ports.

Mixing Room

This room contains the mixing glove box, off-gas scrubbing system, actuators for moving drums to the filling position and translating the flush collection funnel, and a small maintenance glove box.

Sump Tank Room/Maintenance Room

This room contains a 4000 L tank for collecting filtrate, scrubber solutions, and flush solutions. The tank is submerged below the floor. The tank is equipped with an agitator and centrifugal pump that serves to transfer waste solutions back to Building 374 for reprocessing. This room also serves as a maintenance area for the mixer, rotary airlocks, and solids feeders. This equipment must be lowered from its respective hoods to a transfer cart in the filled-drum conveyor room. Then the equipment can be drawn into the sump room for convenient decontamination and maintenance activities. Plastic suits and fresh breathing-air supply may be required in this room.

Filled-Drum Conveyor Room

This room contains a powered roller conveyor with the capacity to hold 1 day's production of filled drums.

Drum Load-Out Room

Filled drums are prepared for storage or disposal in this room. These preparations include decontamination, lidding, plutonium assaying/weighing, and packaging in a 6-pack container. Assault masks are normally worn during these preparations. This room can also be used for maintenance of very large equipment items that are critical to the process, such as the vacuum drum filters and the paddle dryer.

Solids Weighing Hood

This hood is elevated 3.4 m above the basement floor. It contains the solids feeders and airlocks that are required for delivering waste batches to the batch mixer. Frequent maintenance activity is expected in this hood. Plastic suits and fresh breathing-air supply are required due to the high probability of airborne dusts. The room is reached through an airlock.

First Floor (see Figure 18)

Waste processing operations are conducted in two rooms on the first floor:

- HSA ash load-in room
- solids storage room.

These rooms and their functions, described on page 74, are similar to those of the in-can melting process. Less floor space is required, however.

Second Floor (see Figure 16)

Waste processing operations are conducted in two rooms on the second floor:

- LSA ash load-in room
- sludge-drying room.

These rooms and their functions described on page 75 are similar to those of the in-can glass melting process. Less floor space is required, however.

PRESSED-CEMENT PELLET PROCESS

Dried sludge, HSA ash, LSA ash, and Portland cement are prepared and continuously blended as described in the head-end systems section. However, these preparation and blending operations and all subsequent operations are conducted during one shift per week, as in the cast cement process. Blended waste and cement are discharged into four sets of screw conveyors that transfer the blend to four small storage hoppers (see Figures 47 and 48). Level detectors on the hoppers indicate hopper fullness. Hopper filling is conducted automatically through a computer system that controls most process operations. Blended waste and cement are discharged from each hopper about every 10 s into a horizontal pellet press. Vibration of the hopper aids in discharging material into the press fill-chamber. Concurrently, a metered quantity of water amounting to 30% of the weight of the dry material in the fill chamber is also injected into the fill chamber. The charge is then pressed at 172 MPa (25,000 psi) in the right-hand half of the die (see Figure 48). This results in compacting the charge into a pellet that has a density of $\sim 1.92 \text{ g/cm}^3$ and squeezing approximately two-thirds of the water from the pellet. This water and some entrained solids pass between the punches and die onto the glove-box floor where they are frequently flushed to the sump tank located beneath the floor of the basement (see Figure 49). Following pressing, the punches are translated right (see Figure 48) until the right-hand punch is 7.6 cm away from the die. The right-hand punch is then translated another inch to the right. At this point, the pellet is protruding beyond the end of the die but is still in contact with the left-hand punch. A mechanical pellet ejector is then actuated to dislodge the pellet from the punch. The punches are then translated to their filling position to repeat the cycle.

Each pellet has a diameter of 5.7 cm, a height of 5 cm and weighs 250 g. The edges of the pellets are slightly chamfered to resist breakage. The pellets drop individually down a chute onto small belt conveyors. Drop height is limited to 46 cm since the pellets are somewhat fragile, according to Mound Laboratory researchers (Lewis 1980) who are developing this process. Pellets are discharged from the small belt conveyors onto a large, dished-belt conveyor, again with a minimum drop height. The pellets are then dropped onto another larger and very slow-moving dished-belt conveyor. The conveyors are sized to hold 1-1/2 day's production. This is to permit sufficient time and air exposure to allow evaporation of free water and hardening of the pellets. During this period, the water content of the pellets is reduced from 10 to 4%.

Dried and hardened pellets are discharged from the belt conveyor into 55 gal steel drums until the drums are 80% full, as determined by gamma attenuation level detection (Nielson and Brodzinski 1978), load-cell weighing and/or remote visual observation. Bulk pellets in the drum contain 50% void space. At the average production rate, 13 drums are filled each day. At design rate, 19 drums are filled. The drum-filling operation consists of loading an empty drum onto a roller conveyor, conveying the drum into a loading hood, elevating the drum, filling the drum, lowering the drum, and conveying the filled drum out of the loading hood. The filled drum is 1) checked for dose rate and rim contamination, and decontaminated if necessary; 2) lidded; 3) assayed for plutonium content and weighed; 4) and loaded into a

FIGURE 47. Pressed-Cement Process, Elevation View

- A DIE ASSEMBLY LIFT VEHICLE
- B WATER INJECTION LINE
- C PUNCH
- D GAMMA ATTENUATION LEVEL-DETECTOR
- E DRY-MIX HOPPER
- F VIBRATOR
- G MECHANICAL PELLET EJECTOR
- H HYDRAULIC CYLINDER
- I PELLET CHUTE
- J BELT CONVEYOR
- K DIE
- L FILL CHAMBER
- M VENT LINE TO SCRUBBER
- N WATER SPRAY RING

FIGURE 48. Cement-Pellet Pressing Equipment

6-pack container (see Figure 11, Volume I). When full, the 6-pack is lidded, banded and shipped to a disposal site in a TRUPACT shipping vessel (see Figure 11, Volume I).

EQUIPMENT AND MAINTENANCE

Solids-Handling System

The system for delivering ashes, sludge, and cement to the pressing operation is almost identical to the systems of the cast cement and in-can glass melting processes. The primary difference is that blended solids from the intensive solids mixer are discharged into four sets of screw conveyors that transport the solids to the pressing operation. Each screw conveyor set consists of two screw conveyors installed in series. The screw conveyors are commercially available devices, sized to fit. Each conveyor is powered with an electric motor and is fitted with bolt-down covers to aid in removing jammed material and decontamination efforts. Maintenance requirements may be moderate because throughput rates are low and screening systems situated before the screw conveyors should remove most large objects

- A CONTROL ROOM
- B PELLET AND DRUM LOADOUT ROOM
- C PELLET DRYING AND CURING ROOM
- D PELLETIZER MAINTENANCE AND OBSERVATION CUBICLES (6)
- E BELT CONVEYORS
- F HYDRAULIC PRESSES (4)
- G BELT CONVEYORS (4)
- H PELLETIZING ROOM
- I SUMP TANK
- J SCREW CONVEYORS (4)
- K SCREW CONVEYORS (4)
- L CONTINUOUS SOLIDS MIXER
- M PELLETIZING OBSERVATION ROOM (LOWER LEVEL)
- N SOLIDS WEIGHING AND BLENDING ROOM (UPPER LEVEL)
- O AIRLOCKS
- P STAIRWELL
- Q SCRUBBER
- R CRANE MAINTENANCE DECK (UPPER LEVEL)

FIGURE 49. Pressed-Cement Process, Basement Processing Area, Plan View

capable of jamming the process. Residual water in the waste may cause plugging problems if cement and waste have enough contact time together in the transfer system, however. Principal maintenance problems are expected to be jamming and repairing worn shaft seals. Separation of cement and waste powders during screw conveying is expected to be minimal due to the conveyor design and the short period of transfer time spent in the screw conveyor.

Pressing System (see Figure 48)

The pressing system consists of four parallel pressing operations, each of which consists of a solids hopper, a press, and a die assembly changeout system.

Each hopper normally contains about 36 kg of waste/cement blend, enough for about 20 min of operation at average production rate. Three extrinsic gamma-level detectors are installed at various heights outside each hopper. A low-level indication on the lowest detector automatically shuts down the respective pressing operation until satisfactory levels are restored. A low-level indication on the middle detector automatically activates the respective screw conveyors, and filling the hopper takes place until the high-level indication is experienced on the highest detector.

Each hopper is constructed of stainless steel. The internal surfaces are highly polished to resist sliding friction and the potential for solids buildups. These steep-angle hoppers are specifically designed for flow of this material and the prevention of any material separation of the blended mixture. A small electric-powered vibrator is mounted near the bottom of each hopper to enhance emptying the hopper and filling the pressing die. Each hopper is vented to a scrubber located over the sump tank (see Figure 49). This scrubber and its recirculation pump and valves are serviced through glove ports in one of the pelletizer observation and maintenance cubicles. Scrubber solutions are emptied directly to the sump tank. At the end of the operating day, the hopper is emptied by making pellets. When totally empty, the hopper is flushed with water via a water spray ring at the top of the hopper, after which the ring is purged with dry air to dry out the system. The vent lines are also flushed with water at this time.

Maintenance on the hoppers and its vent system may be moderately high if cement buildups occur. The vent system is designed to prevent drawing moisture into the hopper from the pressing die. Some moisture will undoubtedly find its way into the discharge throat of the hopper, however, since some of the water is pressed out of the pellet between the die and punches. Whether this moisture is sufficient to cause buildup problems is unknown at this time. Access to the hopper can be gained through a gate valve installed near the top of the hopper. Some blockages can be cleared by rodding through this valve. Major blockages may be cleared by disconnecting all fittings from the hopper via glove ports, sliding its screw conveyor aside, lifting it off the press with a double-hook lifting yoke and process cell crane, and lowering it to the process cell floor for contact maintenance. An alternative approach is to periodically spray down the blocked hopper with concentrated acid in hope of partially dissolving the blocking material. The hopper vibrators will fail periodically but can easily be replaced through glove ports. Of greater concern are problems caused by vibration. These problems include accelerated wear of screw conveyor bearings and seals, and hydraulic seals. Unwanted vibration can be minimized significantly using rubber couplings.

Each press used in this design has a pressing capacity of 45,000 kg and measures about 2 m long x 0.5 m wide x 0.5 m high and weighs 1,800 kg. Each press is served by a hydraulic pump system powered by a 40-hp motor. The hydraulic pumps are located in a contamination-free zone in the pelletizing observation room. A smaller version of this press has been demonstrated successfully at Mound Laboratory with a mixture of ashes, cement, and water (Lewis et al. 1982).

Maintenance on the presses is expected to be moderate, with the exception of the die assembly, which will require replacement every few weeks due to abrasive wear. Other likely

maintenance activities include hydraulic cylinder seal replacement, oil cleanup and limit-switch replacement. These activities can be conducted through glove ports. Leaked oil can be cleaned up with rags, which can later be incinerated. Replacing the die assembly can also be conducted through glove ports, but will be a somewhat difficult job because of its 45 kg weight. The process is designed to accommodate the high die-assembly wear rate and the difficult changeout activity since only three presses require operation during the 40 h week to meet production rates.

Die assembly removal is accomplished by 1) raising the die assembly lift vehicle table beneath the assembly to be replaced (see Figure 48), 2) unbolting all connections, 3) lowering the table, 4) bolting a lifting bail to the die assembly, 5) sliding the assembly on the table away from the pellet belt conveyor, 6) rolling the lift vehicle on tracks into the open craneway area, and 7) removing the die assembly with the process cell crane. The process is reversed to replace the die assembly. The press itself is replaced remotely by 1) removing the hopper, 2) disconnecting all other fittings, 3) manually attaching the lifting bails to the crane hook through the glove ports, 4) rolling the press on rails into the open craneway using the crane, and when clear of the glove-box area, 5) lifting the press from the rails. The process is reversed to replace the press. Failed and new presses and die assemblies must be loaded in and out on nonproduction shifts through the pellet and drum load-out room.

Belt Conveyor System

The belt conveyor system consists of six commercially supplied, dished-belt conveyors. Four of the conveyors transfer pellets from the presses to the other two, which are installed in series to enable sufficient pellet-drying time. The belts are constructed of woven metal to permit the circulation of air to encourage pellet drying and to maximize belt life. Because of their very slow operating speed, fairly low maintenance is expected. The four small conveyors can be replaced remotely with the cell crane, but maintenance that involves belt disassembly or total replacement of the large conveyors could be an extremely difficult and time-consuming job. The fairly brittle nature of the pellets will contribute to a buildup of dust and pellet chips under and on the conveyors. Hence, a stainless steel-lined trench is located beneath each conveyor to collect this material. The trenches are normally filled with about 2.5 cm of weak acid to aid in dissolving larger pieces and to minimize possible entrainment of dust in the room air. The resulting slurry can be periodically drained to the sump tank for later recycling.

Drum-Filling Station (Figures 47 and 49)

The drum-filling station is located at the end of the largest belt conveyor. The station consists of a fill spout, a drum elevator, a powered roller conveyor, and an open-face hood. Full-open-top mild-steel drums are loaded onto the roller conveyor as needed. Each drum is transferred to the end of the conveyor where it is self-aligned under the fill spout. A flapper valve in the fill spout is then opened and the largest belt conveyor is activated, thereby spilling pellets into the drum. Drums are initially filled to the 70% level as determined with a periscope and remote gamma-attenuation level detector. Then the belt is stopped and a hydraulic ram located above the discharge end of the belt is slowly translated,

thereby pushing additional pellets into the drum as needed. Drums are filled to only the 80%-full level in contrast to the 90%-full level for glass marbles because pellet fill-rate control is rather crude and the angle of repose of the pellets is greater. Individual drum filling must be conducted at a fairly even rate during the operating shift since there is essentially no pellet surge capacity in the overall system. If too long a period elapses between the filling of drums, all of the operations beyond the solids storage hoppers are automatically shut down. This can be prevented by installing a surge hopper and belt feeder under the largest belt conveyor. However, this solution would add several additional feet to the height of the facility and would present additional maintenance problems.

When a drum is full, the pellet ram is retracted, the flapper valve is closed, and the drum is lowered in preparation for drum packaging.

Fairly low maintenance on this system is expected. Occasional misalignment and spillage problems will occur, however. Cement pellets present a much greater dust control problem than glass marbles. This necessitates a high degree of care in drum filling and in cleaning up spilled pellets.

Drum Packaging

Drum packaging requires the same equipment maintenance as required in the drum packaging for the joule-heated glass melting process (see page 82). Pellet-filled drums will be packaged at a rate five times that required for joule-heated glass melting, or about one every 25 to 40 min. This high rate will severely strain equipment and personnel resources if all work is attempted in the pellet and drum load-out room. A more reasonable approach is to conduct drum lidding, assaying, decontamination, and weighing steps in this room, but to load filled drums onto trailers for transportation to the drum-holding area where the drums would be banded into 6-pack containers.

PROCESSING AREAS (see Figure 47)

Basement (see Figure 49)

Waste processing operations are conducted in six separate rooms in the basement:

- solids weighing and blending room
- pelletizing observation room
- pelletizing room
- pellet drying and curing room
- pellet and drum load-out room
- control room.

Solids Weighing and Blending Room

This room is located on a deck over the pelletizing observation room. Its function is virtually the same as that of the solids weighing and blend hood described on page 53, except that four sets of screw conveyors distribute the blended solids to four pellet presses. This room is highly prone to the leakage of dust, and thus is maintained at the lowest negative pressure of all rooms in the building. The room is reached via a set of stairs and an

airlock. Frequent entries are expected because of the high number of moving parts contained in this room and the high potential for material blockages and jams. Fresh air supply and protective plastic clothing are requirements for entering this room. Failed equipment is removed from the room by opening doors into the pellet-drying and curing room, transferring equipment out on a beam-mounted crane, and lowering it to the floor of the pellet-drying and curing room where it can be decontaminated and packaged for removal.

Pelletizing Observation Room

This room is located immediately below the solids weighing and blending room. The room provides access to the pelletizer maintenance and observation dens and houses the hydraulic pumps that serve the presses. The room is maintained as a contamination-free zone area, so masks and protective clothing are normally not required.

Pelletizing Room

This room houses the pellet presses, their respective belt conveyors, the middle-size belt conveyor, the sump tank system, the pressing operation scrubber, a bridge crane, and a crane maintenance deck. Since this room has a high potential for contamination, the floor slopes toward the sump tank. Troughs or catch basins are also positioned under process equipment. These all drain to the sump tank. The sump tank system, the scrubber system, and the crane are similar to those described on page 71. The crane has a 4500 kg capacity and is of the "fixed-hook" design. Fresh air supply and protective plastic suits are required for this room.

Pellet-Drying and Curing Room

This room houses the largest belt conveyor, the pellet load-out hood, and the stairway to the crane maintenance deck. It is directly connected to the pelletizing room and serves as a transfer point for exchanging new and failed equipment, such as die assemblies, for the presses. Limited maintenance on failed large equipment is conducted in this room. The room also has a high potential for airborne contamination; hence, fresh air supply and protective plastic clothing are required.

Pellet and Drum Load-Out Room

The primary purposes of this room are loading pellets into drums and removing the filled drums to a storage area for 6-pack banding. The room also serves as an airlock for access to the pellet-drying and curing room. The pellet loading-out activity carries a high risk of contaminating the hood and room. It is presumed at this time that assault masks are required for entry.

Control Room

The control room contains a sophisticated control system that automatically adjusts rates of individual process operations as situations dictate. The pressing operations and belt conveyors are monitored from the control room via television cameras.

First Floor (see Figure 16)

Waste processing operations are conducted in two rooms on the first floor:

- HSA ash load-in room
- solids storage room.

These rooms and their functions, described on page 74, are similar to those of the in-can melting process. Less floor space is required, however.

Second Floor (see Figure 15)

Waste processing operations are conducted in two rooms on the second floor:

- LSA ash load-in room
- sludge-drying room.

These rooms and their functions, described on page 75, are similar to those of the in-can glass melting process. Less floor space is required, however.

 

FUETAP^(a) CEMENT PROCESS

Dried sludge, HSA ash, LSA ash, and Portland cement are individually weighed and transferred to a batch mixer as described in the cast cement process description. In the FUETAP cement process (Moore et al. 1979), however, sand and setting regulators are also added to the batch mixer. As in the cast cement process, about three-fourths of the estimated water required is added through sintered metal sleeves in the solids-addition line and the off-gas line. The mixer is operated for about 3 min and the amperage (indicating torque) is noted. Water is then added slowly over the next 2 min until a predetermined amperage or amount of water is added. If the maximum allowable water is added, and the amperage is too high, indicating a viscous mix that may not discharge properly from the mixer, the operator will stop the mixer and inspect the contents with a rod inserted through a trap door at the top of the mixer. A decision to dump the mix or add more water and continue mixing is then made. As with the other two cement-waste processes, all mixing is conducted during one shift, 5 days per week.

When the cement mix is deemed ready to dump, a cement scrap collection funnel is translated horizontally from under the mixer, exposing a 0.8 m dia hole in the floor of the mixer glove box (see Figures 45 and 50). An empty 55 gal steel drum is then elevated through the hole in the floor until it seats properly with a flange around the discharge port of the mixer. A trap door that covers the discharge port is then swung open, which allows the contents of the mixer to be discharged into the drum. A vibrator attached to the wall of the mixer may be activated to aid in more thoroughly emptying the mixer. When the mixer contents have been discharged, the trap door is closed and a small amount of water, about one-fourth of the total batch-water requirement, is added through the sintered-metal sleeves to flush down cement that may have been thrown up into the feed addition and off-gas lines. The mixer is then left slowly agitating until the next batch is ready for addition to the mixer. This serves to prevent residual cement from setting in the mixer.

When the mixer door is closed, the drum is lowered through the hole in the mixer glove box and the cement-scrap collection funnel is translated back to its closed position under the mixer, which covers the hole in the floor. A small amount of water is then sprayed through nozzles positioned on the collection funnel up into the mixer discharge flange and into the funnel itself. This serves to wash down any cement adhering to these components. This washed-down material flows through a short pipe section at the base of the funnel and discharges into a trough in the mixer glove box. The washed-down material then flows into a nearby sump tank. The sump tank is similar to that described on page 71.

Sand and other large particles that are not easily entrained by water settle in the cement-scrap collection funnel and trough. The operator will periodically scoop this material into an unfilled drum prior to filling it with a normal batch of cement-waste mix.

(a) FUETAP--Formed Under Elevated Temperature and Pressure.

FIGURE 50. FUETAP Cement Process, Elevation View

At the end of the operating shift, or during extended shutdowns, the mixer and the scrap-cement collection funnel are flushed out using a small amount of fresh water and filtrate collected during operation of the vacuum drum filters. All of the flush water eventually is collected in the sump tank where it and other waste solutions are pumped back to Building 374 for reprocessing.

Cement/waste-filled drums, which are produced at an average of one every 68 min or one every 45 min at design rate, are transferred via a powered roller-conveyor to the drum-gasket removal station (see Figure 51). Here an operator works through glove-ports to remove a ceramic paper gasket that protects the rim of the drum against cement spatter. The gasket is dropped into the drum for disposal.

Filling of drums is normally planned in batches of six for loading into one of six autoclaves. A load of six drums is moved on a rail-mounted, powered roller-conveyor to the desired autoclave-loading position. The conveyor is translated 0.6 m into the autoclave opening and the filled drums are transferred into the autoclave. A powered roller conveyor inside each autoclave facilitates loading of drums. The autoclave door is closed and the temperature and pressure are raised to 100°C and 0.1 MPag (15 psig), respectively, over a 4 h period. These conditions are maintained for 24 h, after which the autoclave is depressurized and heated to 250°C over an 8 h period. The autoclave is held at 250°C for 24 h and then is cooled for 8 h using room-temperature air circulated through the autoclave. The entire autoclaving cycle, including loading and unloading, is 72 h.

Drums are unloaded onto the rail-mounted powered roller conveyor where they may remain for 20 to 24 h for additional cooling. Another batch of six drums may be stored for cooling on the powered roller conveyor which leads to the drum load-out room (see Figure 51).

EQUIPMENT AND MAINTENANCE

Solids-Handling System

The system for delivering solids to the FUETAP cement process is identical to the system described for the cast-cement process, assuming that cement, sand, and the setting regulators can be blended together before adding to the cement mixer. This assumption may not be valid, however, since the large difference in cement and sand particle diameters may tend to promote stratification in the storage tank. In this case, separate feed tanks and weighing systems for the cement, sand, and setting regulators would be required.

Mixing System (see Figure 45)

The mixing system, which consists of a batch mixer, a cement-scrap collection funnel, a glove box that encloses the mixer and funnel, and an off-gas scrubbing system, is virtually identical to that described for the cast-cement process. Since sand is added to the mixer, line pluggage may occur due to settling, especially in the drain pipe and trough from the cement scrap collection funnel to the sump tank. Rapid wear of the sump pump may also occur. Hence, it may be important that the basin in the cement-scrap collection funnel contain an

FIGURE 51. FUETAP Cement Process, Basement Processing Area, Plan View

appropriately-sized screen to collect sand and other larger pieces. The operator would frequently clean the screen, disposing of its contents in an empty drum prior to filling it with the cement-waste mixture.

Drum-Handling System

The drum-handling system consists of

- 55 gal steel drums
- drum conveyor system
- drum decontamination equipment
- drum-handling crane
- plutonium assay/weighing system
- 6-pack drum container.

The drum-handling system is very similar to the system employed in the joule-heated glass melting process (see page 82). The biggest difference is the use of a more complicated drum conveyor system. The heart of the drum conveyor system is a rail-mounted, powered roller-conveyor that transports up to six filled drums to any one of six autoclaves, and then transports the drums from the autoclaves to a single-roller conveyor that leads to the drum load-out room. The rail-mounted roller conveyor includes two electric motors that drive the conveyor on the rails and power the rollers. Another electric motor translates the entire roller frame approximately 0.8 m into any autoclave opening for the purpose of loading and unloading drums. Maintenance on this conveyor is not expected to be high since a maximum of two loading and two unloading operations are conducted per day.

Autoclaving System (see Figure 52)

The autoclaving system consists of six autoclaves. Each autoclave chamber is 1.5 m long, which is sufficient to contain six drums and the roller conveyor on which the drums are transported into and out of the autoclave. The conveyor is powered by a motor-driven shaft that protrudes through the wall of the autoclave. The shaft seal must be capable of withstanding 0.1 MPag (15 psig) under static conditions. The autoclave is insulated with a suitable fibrous insulation which in turn is covered with a stainless steel housing to simplify control of contamination. The door to the autoclave is remotely opened and closed by the use of a single pneumatic cylinder. Another pneumatic cylinder drives cams that lock the door in the closed position. At 0.1 MPag (15 psig) operating pressure, the door will be exposed to a force of 20,000 kg. An elastomer gasket installed in the rim of the door enables making a seal between the autoclave chamber and the door. The flange at the autoclave opening is water-cooled to ensure that the elastomer gasket is maintained at a suitably low temperature.

Drums are heated and cooled inside the autoclave by the use of a forced-air recirculation system. This system consists of a blower, an air heater, an air-distribution duct, and an air-return duct. The blower is capable of operating at 0.1 MPag (15 psig) and 100°C, and at ambient pressure and 250°C. Knife valves in the recirculation line and in an off-gas line can be remotely opened to enable room air to be circulated through the autoclave for cooling purposes. A motor-controlled, pressure-regulating valve enables control of pressure between 0 and 0.1 MPag (15 psig). A pressure relief valve and a rupture disc provide protection against overpressurizing the autoclave. Steam can be added to augment heating and to ensure that saturated steam conditions exist during the pressurization period. Condensed steam and contamination can be drained to the sump tank by remotely opening a valve in a drain line.

A	AIR HEATER	J	DOOR ACTUATOR
B	BLOWER	K	ROLLER DRIVE MOTOR
C	ACTUATED VALVE	L	AUTOCLAVE DOOR
D	RETURN AIR DUCT	M	CEMENT/WASTE FILLED DRUM
E	RUPTURE DISK	N	AIR DISTRIBUTION DUCT
F	POP-OFF VALVE	O	POWERED ROLLER CONVEYOR
G	ACTUATED VALVE	P	DRAIN TO SUMP TANK
H	ACTUATED PRESSURE REGULATING VALVE	Q	STEAM LINE
I	COOLING WATER LINES	R	INSULATION

FIGURE 52. Autoclaving System

Autoclave maintenance is expected to be moderate. The autoclave rollers, which are exposed to temperatures as high as 250°C, may include graphite bearings to minimize lubrication requirements. The blower shaft seal and the roller drive-shaft seal may both be exposed to temperatures to 250°C and pressures to 0.1 M Pag (15 psig). Shaft seal maintenance requirements may be minimized if seal cooling or air purging is used. Valves and pneumatic cylinders will be operated only about once every three days, and hence should require little maintenance.

PROCESSING AREAS (see Figure 51)

Basement (see Figure 51)

Waste processing operations are conducted in the following basement rooms:

- control room
- empty drum storage and load-in room

- cement mixing room
- autoclave room
- drum cooling room
- drum loadout room
- solids weighing hood (elevated).

All of these rooms, with the exception of the autoclave room and the drum cooling room, have functions that are identical to those for the basement rooms described in the cast cement process (see page 109).

Autoclave Room

The autoclave room contains six autoclaves; a rail-mounted, powered roller-conveyor; a sump tank; and a maintenance area. Plastic suits and fresh breathing-air supply are required in this room.

Drum Cooling Room

This room contains a powered roller-conveyor on which up to six filled drums can be cooled for 24 h prior to loading out. Plastic suits and fresh breathing air are required.

First Floor (see Figure 18)

Waste processing operations are conducted in two rooms on the first floor:

- HSA ash load-in room
- solids storage room.

These rooms and their functions, described on page 74, are similar to those of the in-can melting process. Less space is required, however.

Second Floor (see Figure 16)

Waste processing operations are conducted in two rooms on the second floor:

- LSA ash load-in room
- sludge-drying room.

These rooms and their functions, described on page 75, are similar to those of the in-can glass melting process. Less space is required, however.

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25. The twenty-fifth part of the report

26. The twenty-sixth part of the report

27. The twenty-seventh part of the report

COLD-PRESSED/SINTERED-CERAMIC PROCESS

Dried sludge, HSA ash, LSA ash, and bentonite clay are added to the process and blended in a manner similar to that described for the pressed-cement pellet process (page 111). Before blending with sludge waste and the sintering agent, 7 kg of ashes are batched into a small vibratory grinding mill every 40 min at design rate, or once every hour at the average production rate. Milling is required to homogenize the ash and render it more reactive for sintering (Treat and Rusin 1982). The milled ashes are discharged into an intensive batch mixer where they are blended with 20 kg of dried sludge and 53 kg of the bentonite clay. If necessary, a small amount of water that contains a binder may also be added to the mixer to produce green pellets of suitable strength. The materials in the mixer are blended for 5 min. The contents are then discharged into a screw conveyor that transfers the material to either of two additional screw conveyors, depending on the direction of rotation of its screw. The material is then transferred via the selected screw conveyor to one of two pellet-pressing systems, each consisting of a feed hopper and a pellet press. The operation of the pellet-pressing system is identical to those used for producing pressed cement pellets, as described on page 111. The only exceptions are that water is not added to the pressing chamber and the pressing pressure is 14 MPa (2000 psi). At the design production rate, 460 pellets per hour are produced. Each pellet is 6.4 cm in dia by 5 cm in height and weighs 270 g. Green pellet density is 1.7 g/cm³. The edges of the pellets are slightly chamfered to resist breakage.

The pellets are ejected from the press and fall down a chute into a descending bucket elevator. Drop height is limited to 15 cm since the pellets are known to be fragile. The pellets are discharged onto a small dished belt conveyor that transfers the pellets to a chute. The chute, which is only slightly tilted, is lightly vibrated to promote pellet movement. The chute is flared at its discharge end to a width of a sintering cart. When a sintering cart is in the proper loading position beneath the chute, a gate is lowered on the chute that allows approximately two layers of pellets to be distributed onto the sintering cart. Loading proceeds as the sintering cart is pushed under the pellet chute until the cart is filled. Then the chute gate is raised, which interrupts the flow of pellets. This operation is observed by television cameras to ensure that the loading chute contains enough pellets for cart filling but does not become overloaded.

Loaded carts are pushed in a line on tracks under optional heat lamps if water was used for pellet binding. When a cart reaches the end of the tracks, a hydraulic-powered device pulls the cart 0.3 m onto a transfer vehicle. When the pulling device is disengaged from the cart, the transfer vehicle moves the cart perpendicular to the line of carts to the sintering-kiln loading position. The entrance and exit doors of the sintering kiln are then raised, and a large hydraulic ram shoves the cart into the furnace. Since all carts in the furnace are in contact with one another, a cart on the discharge end is pushed partially out. A hydraulic raking device pulls this cart free of the furnace. When the cart-charging ram is retracted, both furnace doors close. At design rate, a cart is loaded into the furnace every hour.

The furnace is heated by electric-resistance heating elements suspended in the ceiling. Heating the pellets proceeds at a rate of 100°C/h to a temperature of 1000°C. The pellets are soaked at this temperature for 2 h to ensure completeness of sintering. During the sintering operation, the pellets increase in density to 2.5 g/cm³. After the soaking period, the pellets are cooled in the furnace for 5 h at design rate to a temperature of 500°C when discharged.

Pellets are raked onto a vibrated ramp that is perforated with 0.6 cm holes. Dust and small chips fall through the perforations and collect in a tote bin. Periodically, this material is vacuumed from the tote bin, ground to a fine powder in the vibratory mill, and recycled. The pellets and larger chips slide from the ramp onto a dished, steel-belted conveyor. As the pellets are transported on the belt, air is drawn through the belt and across the pellets into a large overhead duct connected to the primary exhaust air plenum. This serves to cool the pellets from 500 to 200°C during the 2 h period that the pellets reside on the conveyor.

Pellets are discharged from the conveyor into 55 gal steel drums until the drums are 80% filled. Bulk pellets contain 50% void space; hence, a drum contains about 200 kg of pellets. At the average production rate, 9.6 drums are filled each day; at design rate, 14.4 drums are filled. Drums are filled by 1) loading an empty drum onto a roller conveyor, 2) conveying the drum into a hood under the fill spout, 3) raising the drum to the filling position, 4) filling the drum, 5) lowering the drum, and 6) conveying the drum out of the filling hood. After filling, the drums are 1) checked for dose rate and rim contamination and decontaminated if necessary, 2) lidded, 3) assayed for plutonium content and weighed, and 4) loaded into a 6-pack container (see Figure 11, Volume I). When full, the 6-pack container is lidded, banded and shipped to a disposal site in a TRUPACT shipping vessel (see Figure 11, Volume I).

EQUIPMENT AND MAINTENANCE

Solids-Handling System

The system for delivering ashes, sludge and bentonite clay is very similar to the one described in the head-end systems section. The clay is transferred and stored in the same type of equipment used for glass frit.

The ashes are batched into a small vibratory grinding mill which consists of an annular steel bowl mounted on springs. The bowl is vibrated by imbalanced weights on a motor-driven shaft rotating beneath the bowl. Steel or ceramic balls serve as the grinding media. The discharge valve is built into the mill and acts as a sieve to retain the grinding media and large unground chunks. The amplitude of vibration is high enough that rubber bellows are required to connect the mill with other equipment. It is recognized that rubber is not ideally suited to radiation environments, but the frequency of replacement of the bellows should not be excessively high when considering likely maintenance problems on alternative

milling equipment. Replacement of the grinding media may be required once or twice before the mill wears out after several years of operation. Little other maintenance is anticipated on this type of mill.

The milled ashes, the dried sludge and the clay are batched into an intensive mixer. It is essentially identical to the cement mixer used in the cast cement process (see page 115), except that its working capacity is 85 L instead of 370 L. Maintenance problems include fairly frequent shaft and discharge-door seal repair and occasional removal of solid buildups and jams. The high speed of mixer blade rotation and the abrasive nature of the powder may lead to failure of the mixer after several years of operation.

Four screw conveyors are used in this system, one to transfer ashes (and recycled pellet chips) to the vibratory mill, and one to distribute blended material to each of the remaining two screw conveyors. These screw conveyors transfer blended material to the pelletizer feed hoppers. Screw conveyors are prone to problems such as jamming, seal failure, and wear.

The solids handling system consists of many solids handling operations, several of which will require frequent maintenance. Because the solids are powdery, dust containment will be a very difficult problem and will present some serious safety concerns during maintenance of the air protection system equipment. Maintenance is made even more difficult due to the close arrangement of the solids-handling equipment. Better access to the equipment could be gained by increasing the building height and adding special maintenance decks, if desired. Failed solids-handling equipment is removed by rolling it out of the solids processing room to the top of one of the pelletizer observation cubicles where it can be grasped by the process canyon crane.

Pelletizing System

The pelletizing system consists of two parallel operations, each including of a solids hopper, a pellet press, and a die-assembly changeout system. This system is very similar to that used in the pressed cement pellet process (see page 114) except that 1) somewhat larger solids hoppers are employed, 2) water is not injected into the pressing chamber, 3) pressing occurs at 14 MPa (2000 psi) instead of 172 MPa (25,000 psi), 4) pellets are 6.4 cm dia instead of 5.7 cm, 5) no special washdown or venting capabilities are included, and 6) only two parallel operations are required instead of four. During steady operations, required production rates can be met with one press. The second press provides the capacity to operate at design rate and provides a backup unit at operating rate in case one press is inoperable.

Green Pellet Handling System

The green pellet handling system consists of two bucket elevators, a dished belt conveyor, and a pellet distributor. The bucket elevators serve to gently lower the newly-pressed pellets from the presses to the dished belt conveyor. The bucket elevators are custom-built and should experience very few maintenance problems. The dished belt conveyor is also custom-built and also should be relatively trouble-free. Pellets fall from the belt into the pellet distributor shown in Figure 53. This is a uniquely designed device that

- A DISHED-BELT CONVEYOR
- B PELLET DISTRIBUTOR
- C PELLETS
- D VIBRATOR
- E DISCHARGE GATE (RAISED)
- F DISCHARGE GATE (LOWERED)
- G SINTERING CART
- H SUSPENSION SPRINGS
- I PIVOT SHAFT AND ROTATING MOTOR
- J CART PULLING BAR

FIGURE 53. Pellet Distributor

distributes approximately two layers of pellets into each sintering cart. An electric motor pivots the discharge gate open or closed depending on the position of the sintering cart. Sintering cart position is determined by photosensors. An electric-actuated vibrator promotes the movement of pellets to the discharge gate. Occasional vibrator maintenance will be required.

Sintering Cart Transfer System (see Figures 53 and 54)

The sintering cart transfer system consists of 1) the carts and their guiding tracks, 2) a cart puller to pull carts free of the furnace after the sintering operation, 3) a cart-pushing frame to push a string of carts slowly under the pellet distributor for loading carts with pellets, 4) a second cart puller for creating a space between the last cart and the remaining carts on the cart return tracks, 5) a cart ram for charging carts into the furnace, and 6) two cart translators for moving carts from the discharge end of the kiln to the cart-return tracks and from the cart-return tracks to the kiln entrance. This system is substantially interlocked within itself as well as with the operation of the kiln doors and the

FIGURE 54. Cold-Pressed/Sintered-Ceramic Pellet Process, Basement Processing Area, Plan View

entire pellet production system. Position switches are plentiful in this system to assure that the various moving components are positioned properly before subsequent operations are conducted.

The carts are 1.8 m square and 1.5 m high. Each cart contains a shallow Inconel® pan on which pellets are sintered. The pan is anchored in a monolith of an insulating castable. Each cart rides on four steel wheels. The cart puller, which is used to pull carts free of the furnace, also serves to rake pellets from the cart. It consists of a rake-like arm that can be extended, retracted, raised and lowered with two pneumatic cylinders. The device is translated laterally using an electric-powered worm-gear. This device is operated for about 10 min every hour to 1-1/2 h, and can be expected to require a fairly high level of maintenance. The cart-pushing frame that moves carts under the pellets distributor uses two parallel hydraulic cylinders capable of coordinated extension and speed control over 2.4 m distance. This type of control is necessary to permit steady pellet-loading conditions. Typical hydraulic system maintenance problems are expected. The cart puller that creates a gap between carts is a simple device that uses cams, springs and a pneumatic cylinder. Little maintenance is expected. The ram that charges carts into the sintering kiln must be capable of pushing 18 loaded carts, each weighing about 820 kg. The ram consists of a large hydraulic cylinder capable of delivering a 2.7 m stroke. The ram is actuated every 1-1/2 h. Occasional maintenance is expected on the seals.

The two cart translators are mounted on tracks, just as the carts are. A reversible electric motor moves the cart translators between the kiln and the cart return train. Little maintenance is expected on these devices.

Sintering Kiln (see Figures 54 and 55)

The sintering kiln is custom-designed. The kiln is 32.3 m in length and 3.4 m in width and contains 17 carts. It is constructed of refractory and insulating brick that is housed in a steel jacket water-cooled to reduce the heat load in the process canyon. The sintering cart tracks are also cooled to minimize damage to the cart wheels. Fifteen-centimeter-thick insulated doors cover the entrance and exit of the kiln. These doors are raised 1.7 m with pneumatic cylinders to permit the transfer of carts into and out of the kiln. The first 18.9 m of the kiln comprise the heatup zone, the next 3.7 m comprise the soaking zone (at 1100°C), and the final 9.8 m comprise the cooldown zone (to 500°C). Cooling down the pellets is accomplished by passing the carts beneath water-cooled ducts. Heating the kiln is accomplished by electric-resistance heating elements that are vertically suspended in modules. These modules can be remotely lifted from the top of the kiln with the process canyon crane. Temperature control of the kiln is accomplished through the use of thermocouples inserted through the walls of the kiln. Exhaust gases from the kiln are drawn into a scrubber in the solids processing room (see Figure 56). Scrubber solution is discharged to the sump tank and is ultimately recycled.

Replacement of heater modules is expected to be the most significant maintenance item. Heating elements may last an average of 1 yr in this environment. Cart wheels will need occasional lubrication. Thermocouples exposed to the higher temperatures will require

FIGURE 55. Cold-Pressed/Sintered-Ceramic Pellet Process, Elevation View

FIGURE 56. Cold-Pressed/Sintered-Ceramic Pellet Process, First Floor Processing Area, Plan View

periodic replacement. Door-actuating cylinders will require occasional seal repairs. Warp-
age of the Inconel® pans on the sintering carts or the buildup of sintered material on the
pans may also occur. However, these problems should not cause significant production delays.

Sintered-Pellet Transport System

The sintered-pellet transport systems consist of 1) a rake for removing pellets from the
sintering carts, 2) a pellet and pellet chip separator (and pellet chip recycling system),
and 3) a dished-belt conveyor (see Figure 54).

The pellet rake is the same one previously described for withdrawing sintering carts
from the furnace. The pellet and pellet chip separator consist of a vibrated ramp perfor-
ated with 0.6 cm holes. Pellet chips greater than 0.6 cm size are considered acceptable
product. Small chips and dust fall into a tote bin that is periodically removed and lifted
to the first-floor level with the process canyon crane. Here, an operator working through
gloves vacuums the material from the tote bin. The material is controlled in a small cyclone
that discharges through a rotary airlock into the same screw conveyor that transports ashes
to the vibratory grinding mill. The material is ground to a fine powder in the mill and
recycled. The total material recycled in this manner represents about 1/2% of the total
production.

Acceptable product falls from the pellet separator onto the dished-belt conveyor. The
dished belt conveyor is 12 m long and 0.9 m wide. It holds at least 2 h of pellet produc-
tion. The belt is constructed of steel mesh. An exhaust air duct is located over the belt
to enable the drawing of air across the still-hot pellets for cooling to a maximum of 200°C.
Maintenance problems on this system are expected to include pluggage of the scrap separator
holes and vacuum hose, jamming of the cyclone airlock and screw conveyor, and occasional
repair of the separator vibrator and the vacuum blower.

Drum Loading System

The elements of the drum-loading system are identical to those employed in the pressed
cement pellet process (see pages 116 and 117).

PROCESSING AREAS (see Figure 55)

Basement (see Figure 54)

Waste processing operations are conducted in four separate rooms in the basement, which
include:

- process canyon
- pelletizer observation deck
- maintenance room
- pellet/drum loadout room.

Process Canyon

The process canyon contains the sump tank, the pellet presses, the pellet distributor,
the sintering kiln and its associated equipment, a pellet/scrap separator, and a large
dished-belt conveyor. The canyon is served by a 4500 kg bridge crane that has a fixed crane

hook. The crane is used for routine maintenance purposes, such as replacing failed kiln heater modules, equipment from the solids processing room on the first floor, sintering carts, pellet presses and die assemblies, and failed sump tank pumps and agitators. The crane is also used to assist in nonroutine maintenance activities, such as the replacing of kiln doors. Access to the extreme end of the process canyon is provided by a long corridor.

The contamination potential in this room is high, and this area is maintained at the second-lowest-negative pressure of all rooms in the building to control the potential for contamination spread. All equipment, with the exception of the kiln, is elevated off the floor to facilitate periodic washdown of dusts into the sump tank. As in the other processes, all material in the sump tank is recycled to Building 374.

Pelletizer Observation Deck

The pelletizer observation deck and associated cubicles are used to observe operation of the pellet presses and the pellet distributor, and to conduct maintenance through glove-box gloves on the presses, the die assemblies, and the pellet bucket elevators. This deck is elevated 3.7 m above the basement floor and is reached by stairs. An escape door and ladder are provided to the maintenance room. Normally the deck is considered a contamination-free area, but its high level of isolation may dictate the wearing of assault masks by personnel working here.

Maintenance Room

The maintenance room is sufficiently large to allow the repair of any item of failed process equipment in the building. Beam-mounted overhead cranes are provided to facilitate maintenance. This room also serves as an airlock for moving equipment into and out of the process canyon. Assault masks and protective clothing are the minimum protective devices for work in this room.

Pellet/Drum Load-out Room

This room has the same purposes and equipment as described in the pressed cement pellet process, page 118.

First Floor (see Figure 56)

Waste processing operations are conducted in four separate areas on the first floor:

- control room
- miscellaneous process room
- crane maintenance deck
- solids processing room.

Control Room

With the exception of unloading sintered pellets from the carts and the dished belt conveyor, all processing operations are conducted from the control room. Television cameras are strategically placed to enable remote monitoring of operations such as crane operation, sintering cart movement, and sintering cart loading and unloading. A viewing window is provided into the solids processing room to facilitate observation of this high-maintenance area.

Miscellaneous Processing Room

The miscellaneous processing room contains two viewing cubicles built into the process canyon wall. From one cubicle, an operator may vacuum pellet chips and dusts from a tote bin suspended by the process canyon crane. Glove ports are provided for this operation. From the other cubicle, an operator operates the pellet rake to remove pellets from the sintering cart. This room also contains a maintenance glove box and an open-face hood for repair of small equipment items. The room also provides access to airlocks to the crane maintenance deck and to the solids processing room.

Crane Maintenance Deck

Crane maintenance is conveniently performed from a crane maintenance deck.

Solids Process Room

The solids processing room contains two loss-in-weight feeders, three rotary airlocks, four screw conveyors, a cyclone, a vibratory grinding mill, an intensive solids mixer, a scrubber for kiln off gases, and a scrubber-solution recirculating pump. Much of this equipment is prone to frequent maintenance problems, especially leaks. As a result, this room will be controlled at the lowest negative pressure of all the rooms in the building. Pre-filters may be required in this room to partially remove dusts from the room air before the air is drawn into the air protection system. Dusts may be cleaned up by using the same vacuum system for recycling pellet chips, or they may be washed down a drain to the sump tank. Fresh air supply and plastic suits are required for working in this room.

Second Floor (see Figure 18)

Waste processing operations are conducted in two rooms on the second floor:

- HSA ash load-in room
- solids storage room.

These rooms and their functions are similar to those of the in-can melting process, page 74.

Third Floor (see Figure 16)

Waste processing operations are conducted in two rooms on the third floor:

- LSA ash load-in room
- sludge drying room.

These rooms and their functions are similar to those of the in-can glass-melting process, page 75.

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Section 2

 

Appendix A
Tabulated Leach Test Results

APPENDIX A

TABULATED LEACH TEST RESULTS

The tables contained in this appendix list the results of the MCC-1 static leach test for each waste form. Normalized mass losses (g/m^2) based on Al, Ca, Fe, K, Mg, Na, P, Si, Ti, and Pu are listed, as are the final solution pHs. After the leach tests were completed, it was discovered that the 2 M H^+ treatment did not remove all the Pu from the leach vessel walls. Unfortunately, all of the leach solutions had been discarded and could not be reanalyzed. Therefore, the reported Pu values may be low by as much as a factor of three. Some solutions were also analyzed for Am content, and those results are reported where available. In those situations where more than one specimen was tested at a given set of conditions, the average of the replicates is reported. Standard deviations are expressed as a percent of the average.

As discussed in the "Detailed Leach Test Data" section of this volume, the normalized mass loss in g/m^2 is calculated from

$$NL_i = \frac{M_i}{f_i SA}$$

Where f_i = weight fraction of element i in the original specimen

M_i = mass of element i in the leachate (g)

SA = geometric surface area of the specimen (m^2).

TABLE A.1-1. Cast Hydraulic Cement II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	28	28	28
Replicates	3	2	2
Average Normalized Mass Loss (g/m ²)			
Al	23.6 ± 3.4%	12.4 ± 1.7%	
Ca	97.6 ± 7.9%	54.7 ± 14%	
Fe	0.069 ± 92%	0.065 ± 131%	
K	0	0	
Mg	0.30 ± 173%	0	
Na	986 ± 5.3%	920 ± 1.1%	
P	0	0	
Si	1.61 ± 22%	0	
Ti	0.041 ± 50%	0.021 ± 1.41%	
Pu	1.7E-3 ± 139%	2.4E-4 ± 71%	1.4E-2 ± 141%
Final pH	11.4	11.8	8.5

TABLE A.1-2. Cast Hydraulic Cement: II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	182	182	182
Replicates	3	2	2
Average Normalized Mass Loss (g/m ²)			
Al	20.9 ± 2.2%	9.69 ± 4.6%	
Ca	114 ± 0.5%	74.6 ± 4.9%	71.7 ± 0.4%
Fe	0.078 ± 20%	0.25 ± 95%	
K	0	0	
Mg	0	0	
Na	975 ± 8.1%	1055 ± 4.7%	
P	0	0	
Si	2.63 ± 5.2%	0	
Ti	0	0	
Pu	6.3E-4 ± 39%	9.4E-4 ± 17%	2.6E-2 ± 3.2%
Final pH	12.2	12.1	8.5

TABLE A.1-3. Cast Hydraulic Cement II

Leachant	Deionized Water	Deionized Water	Deionized Water
Temperature, °C	90	90	90
Time, days	3	7	14
Replicates	1	1	1
Average Normalized Mass Loss (g/m ²)			
Al	21	20	21
Ca	50	48	45
Fe	0.097	0.052	0.059
K	---	---	---
Mg	0	0	
Na	970	980	960
P	0	0	0
Si	4.5	4.6	4.2
Ti	0.31	0.32	0.31
Pu	1.2E-3	1.2E-3	1.2E-3
Final pH	11.6	11.6	11.7

TABLE A.1-4. Cast Hydraulic Cement II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	28	28	28
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	19.8 ± 5.1%	8.7 ± 56%	
Ca	48.4 ± 12%	21.9 ± 16%	
Fe	0.11 ± 51%	0.078 ± 12%	
K	---	---	
Mg	0	0	
Na	1050 ± 14%	1020 ± 4.6%	
P	0	0	
Si	2.73 ± 14%	0	
Ti	0.30 ± 2.0%	0.27 ± 3.9%	
Pu	5.9E-3 ± 40%	1.2E-3 ± 165%	1.5E-2 ± 34%
Am	2.4E-1	3.4E-3	2.1E-2
Final pH	11.8	11.7	8.5

TABLE A.1-5. Cast Hydraulic Cement II

Leachant	Deionized Water	Deionized Water
Temperature, °C	90	90
Time, days	56	91
Replicates	2	2
Average Normalized Mass Loss (g/m ²)		
Al	16.3 ± 6.1%	13.6 ± 3.1%
Ca	61.5 ± 4.6%	42.4 ± 17%
Fe	0	0.29 ± 87%
K	---	---
Mg	0.79 ± 141%	0
Na	1200 ± 0.6%	685 ± 0%
P	0	0
Si	2.36 ± 5.4%	1.93 ± 11%
Ti	0	0
Pu	7.7E-4 ± 11%	6.5E-3 ± 90%
Final pH	11.6	11.5

TABLE A.1-6. Cast Hydraulic Cement: II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	182	182	182
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	9.76 ± 2.8%	33.4 ± 29%	
Ca	56.8 ± 3.6%	72.8 ± 5.3%	
Fe	0.068 ± 0.2%	0.48 ± 73%	
K	---	---	
Mg	---	1.52 ± 16%	
Na	921 ± 4.3%	964 ± 1.7%	
P	---	---	
Si	2.48 ± 55%	5.41 ± 96%	
Ti	---	---	
Pu	1.6E-4 ± 87%	1.3E-3 ± 78%	3.2E-2 ± 4.8%
Am	0	3.1E-1	4.2E-2
Final pH	11.8	11.8	8.3

TABLE A.2-1. Cold-Pressed Cement II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	28	28	28
Replicates	3	2	2
Average Normalized Mass Loss (g/m ²)			
Al	11.9 ± 2.2%	2.66 ± 6.4%	
Ca	74.0 ± 4.9%	26.3 ± 25%	
Fe	0.080 ± 73%	0.005 ± 95%	
K	0	0	
Mg	0.20 ± 173%	0	
Na	1300 ± 1.6%	1110 ± 1.9%	
P	0	0	
Si	3.12 ± 47%	0	
Ti	0.019 ± 22%	0	
Pu	1.9E-3 ± 32%	4.7E-3 ± 39%	8.0E-2 ± 17%
Final pH	11.3	11.7	8.5

TABLE A.2-2. Cold-Pressed Cement II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	182	182	182
Replicates	3	2	2
Average Normalized Mass Loss (g/m ²)			
Al	8.69 ± 5.7%	1.69 ± 7.5%	
Ca	73.5 ± 1.9%	56.9 ± 6.5%	380 ± 9.3%
Fe	0.098 ± 72%	0.79 ± 133%	
K	0	0	
Mg	0	0	
Na	1180 ± 3.0%	1315 ± 1.6%	
P	0	0	
Si	7.17 ± 10%	0	
Ti	0	0	
Pu	1.8E-3 ± 92%	1.2E-3 ± 60%	4.8E-2 ± 29%
Final pH	12.0	11.9	8.5

TABLE A.2-3. Cold-Pressed Cement II

Leachant	Deionized Water	Deionized Water	Deionized Water
Temperature, °C	90	90	90
Time, days	3	7	14
Replicates	1	1	1
Average Normalized Mass Loss (g/m ²)			
Al	8.1	8.7	7.6
Ca	46	41	36
Fe	0.075	0.077	0.26
K	---	---	---
Mg	0	0	0
Na	1150	1150	760
P	0	0	0
Si	8.2	6.2	5.3
Ti	0.21	0.21	0.21
Pu	4.3E-3	8.5E-3	3.4E-3
Final pH	11.4	11.5	11.6

TABLE A.2-4. Cold-Pressed Cement II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	28	28	28
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	8.16 ± 12%	2.87 ± 57%	
Ca	31.2 ± 21%	0.60 ± 7.7%	
Fe	0.031 ± 89%	0.16 ± 94%	
K	---	---	
Mg	0	0	
Na	1270 ± 15%	1220 ± 5.8%	
P	0	0	
Si	5.3 ± 18%	0.70 ± 28%	
Ti	0.13 ± 84%	0.17 ± 7.3%	
Pu	1.4E-3 ± 35%	2.7E-3 ± 50%	6.6E-2 ± 48%
Am	6.0E-1	1.3E-2	4.8E-3
Final pH	11.7	11.6	8.5

TABLE A.2-5. Cold-Pressed Cement II

Leachant	Deionized Water	Deionized Water
Temperature, °C	90	90
Time, days	56	91
Replicates	2	2
Average Normalized Mass Loss (g/m ²)		
Al	9.7 ± 5.2%	7.18 ± 3.0%
Ca	35.4 ± 0.8%	20.5 ± 23%
Fe	0	0.13 ± 9.7%
K	---	---
Mg	1.1 ± 141%	0
Na	1480 ± 4.8%	823 ± 0%
P	0	0
Si	5.42 ± 4.6%	3.59 ± 9.3%
Ti	0	0
Pu	1.3E-3 ± 47%	4.7E-3 ± 64%
Final pH	11.5	11.4

TABLE A.2-6. Cold-Pressed Cement II

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	182	182	182
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	4.21 ± 6.8%	11.2 ± 15%	
Ca	37.2 ± 10.8%	49.8 ± 8.5%	
Fe	0.16 ± 106%	---	
K	---	---	
Mg	0	0	
Na	1080 ± 6.0%	1200 ± 3.0%	
P	0	0	
Si	7.04 ± 7.3%	6.78 ± 27%	
Ti	0	0	
Pu	1.1E-3 ± 110%	1.0E-2 ± 152%	0.11 ± 19%
Am	0	6.9E-2	1.03E-2
Final pH	11.6	11.6	8.3

TABLE A.3-1. FUETAP Cement

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	28	28	28
Replicates	3	2	2
Average Normalized Mass Loss (g/m ²)			
Al	5.83 ± 4.6%	3.25 ± 2.0%	0
Ca	44.4 ± 4.5%	31.2 ± 11%	134 ± 3.7%
Fe	0	0	0
K	0	0	0
Mg	0	0	0
Na	996 ± 4.6%	1004 ± 6.6%	0
P	0	0	0
Si	7.90 ± 1.6%	0	0.12 ± 8.4%
Ti	0	0	0
Pu	1.69E-3 ± 22%	1.3E-3 ± 0%	3.1E-2 ± 15%
Final pH	11.7	7.5	6.5

TABLE A.3-2. FUETAP Cement

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	182	182	182
Replicates	3	2	2
Average Normalized Mass Loss (g/m ²)			
Al	6.83 ± 11%	5.05 ± 7.8%	
Ca	51.3 ± 6.1%	41.7 ± 10%	
Fe	3.33E-2 ± 14%	1.8 ± 88%	
K	---	---	
Mg	0	0	
Na	1020 ± 2.8%	1025 ± 3.4%	
P	0	0	
Si	5.61 ± 11%	0	
Ti	0	0	
Pu	9.8E-3 ± 25%	1.1E-2 ± 93%	6.8E-2 ± 6.7%
Final pH	11.9	11.9	7.1

TABLE A.3-3. FUETAP Cement

Leachant	Deionized Water	Deionized Water	Deionized Water
Temperature, °C	90	90	90
Time, days	3	7	14
Replicates	1	1	1
Average Normalized Mass Loss (g/m ²)			
Al	7.7	8.9	8.4
Ca	28	25	28
Fe	0	0	0
K	---	---	---
Mg	0.97	0	0
Na	900	960	920
P	0	0	0
Si	10	10	9.1
Ti	0	0	0
Pu	1.9E-3	1.3E-3	6.4E-4
Final pH	11.6	11.6	11.7

TABLE A.3-4. FUETAP Cement

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	28	28	28
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	7.37 ± 9.8%	6.02 ± 7.5%	0
Ca	21.9 ± 8.0%	17.3 ± 12.6%	142 ± 2.9%
Fe	0	0	0
K	0	0	0
Mg	0	0	0
Na	928 ± 6.8%	967 ± 2.5%	0
P	0	0	0
Si	12.1 ± 7.7%	3.2 ± 30%	0.23 ± 7.1%
Ti	0	0	0
Pu	8.5E-4 ± 44%	3.8E-3 ± 44%	1.17E-2 ± 20%
Final pH	11.4	11.4	7.1

TABLE A.3-5. FUETAP Cement

Leachant	Deionized Water	Deionized Water
Temperature, °C	90	90
Time, days	56	91
Replicates	2	2
Average Normalized Mass Loss (g/m ²)		
Al	6.67 ± 0.1%	5.29 ± 29%
Ca	21.2 ± 2.3%	20.5 ± 1.7%
Fe	0	0.089 ± 52%
K	0	0
Mg	0	0
Na	912 ± 0.1%	961 ± 7.3%
P	0	0
Si	13.8 ± 1.0%	13.9 ± 16%
Ti	0	0
Pu	3.5E-3 ± 116%	6.3E-4 ± 141%
Am		
Final pH	11.4	11.3

TABLE A.3-6. FUETAP Cement

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	182	182	182
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	3.54 ± 7.5%	4.41 ± 30%	
Ca	21.2 ± 13%	22.6 ± 53%	
Fe	4.8 ± 43%	3.95 ± 82%	
K	0	0	
Mg	0	0	
Na	1000 ± 7.7%	1180 ± 9.5%	
P	0	0	
Si	18.6 ± 2.8%	6.92 ± 22%	
Ti	0	0	
Pu	3.0E-3 ± 81%	7.2E-3 ± 97%	0.0173 ± 8.1%
Final pH	11.3	11.4	6.7

TABLE A.4-1. Borosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	28	28	28
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0	0	
Ca	0.38 ± 8.0%	0.083	
Fe	0	0.014	
K	0	2.1	
Mg	0.41 ± 13%	1.9	
Na	0	0	
P	0	0	
Si	0.36 ± 9.4%	0	
Ti	0	0	
Pu	3.4E-2 ± 47%	1.6E-3	2.0E-2
Final pH	5.2	8.2	6.8

TABLE A.4-2. Borosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	182	182	182
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0	0	
Ca	1.44 ± 8.2%	0.27	
Fe	0.089 ± 9.1%	0.12	
K	0	0	
Mg	1.29 ± 11%	0	
Na	1.45 ± 11%	0	
P	0	0	
Si	1.53 ± 7.2%	0	
Ti	0	0	
Pu	9.8E-3 ± 44%	2.9E-3	1.1E-2
Final pH	6.3	8.7	6.9

TABLE A.4-3. Borosilicate Glass

Leachant	Deionized Water	Deionized Water	Deionized Water
Temperature, °C	90	90	90
Time, days	3	7	14
Replicates	1	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.43	0.37	0.87
Ca	1.3	2.7	3.6
Fe	2.5	0.39	0.94
K	6.8	3.4	5.6
Mg	0.99	3.1	2.8
Na	2.3	2.9	4.6
P	0	0	0
Si	2.3	3.3	4.3
Ti	0.12	0.11	0.12
Pu	6.5E-3	7.9E-3	6.5E-3
Final pH	5.5	7.1	6.5

TABLE A.4-4. Borosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	28	28	28
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	3.22 ± 16%	4.64 ± 4.5%	
Ca	4.49 ± 5.2%	4.06 ± 20%	
Fe	0.058 ± 88%	0	
K	18.8 ± 24%	10.8 ± 9.1%	
Mg	2.0 ± 63%	10.3 ± 65%	
Na	15.2 ± 19%	2.8 ± 173%	
P	0	9.2 ± 4.6%	
Si	12.1 ± 22%	3.4 ± 87%	
Ti	0.072 ± 87%	0.16 ± 5.7%	
Pu	2.9E-3 ± 25%	4.8E-3 ± 8.7%	4.8E-2 ± 6.4%
Am	0	4.4E-3	5.5E-3
Final pH	9.5	9.4	7.1

TABLE A.4-5. Borosilicate Glass

Leachant	Deionized Water	Deionized Water
Temperature, °C	90	90
Time, days	56	91
Replicates	2	2
Average Normalized Mass Loss (g/m ²)		
Al	5.1 ± 0%	4.44 ± 6.5%
Ca	5.3 ± 1.9%	4.21 ± 0%
Fe	0.014 ± 141%	0.25 ± 59%
K	39.4 ± 1.3%	25.8 ± 1.9%
Mg	8.42 ± 1.9%	7.90 ± 5.2%
Na	22.7 ± 1.3%	19.4 ± 4.0%
P	0	0
Si	16.8 ± 0%	13.7 ± 2.1%
Ti	0	0
Pu	2.9E-3 ± 36%	2.9E-3 ± 71%
Final pH	9.4	9.3

TABLE A.4-6. Borosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	182	182	182
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	4.85 ± 7.3%	8.02 ± 1.4%	
Ca	4.45 ± 12%	6.41 ± 5.8%	
Fe	0.13 ± 20%	1.59 ± 11%	
K	33.4 ± 0.8%	30.2 ± 4.0%	
Mg	10.8 ± 3.3%	15.8 ± 3.8%	
Na	27.2 ± 1.8%	17.6 ± 18%	
P	0	13.7 ± 11%	
Si	15.3 ± 1.6%	10.9 ± 1.9%	
Ti	0	0.070 ± 23%	
Pu	2.9E-3 ± 25%	1.4E-2 ± 12%	0.15 ± 11%
Am	2.63E-2	1.75E-3	1.37E-2
Final pH	9.5	9.6	6.5

TABLE A.5-1. Aluminosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	28	28	28
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.061 ± 92%	0.090	
Ca	1.11 ± 13%	0.043	
Fe	0.29 ± 53%	0.013	
K	0	0	
Mg	1.15 ± 16%	0.61	
Na	0.69 ± 75%	0	
P	0	0	
Si	0.48 ± 5.5%	0	
Ti	0	0.012	
Pu	2.5E-3 ± 60%	2.2E-3	3.0E-3
Final pH	5.4	8.4	6.3

TABLE A.5-2. Aluminosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	182	182	182
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.13 ± 21%	0	
Ca	2.41 ± 4.0%	0.075	
Fe	0.96 ± 13%	0	
K	0	0	
Mg	2.09 ± 3.8%	0	
Na	3.12 ± 4.5%	0	
P	0.58 ± 173%	0	
Si	1.64 ± 3.1%	0	
Ti	5.2E-3 ± 173%	0	
Pu	2.9E-3 ± 43%	3.6E-3	3.0E-3
Final pH	7.2	7.6	6.5

TABLE A.5-3. Aluminosilicate Glass

Leachant	Deionized Water	Deionized Water	Deionized Water
Temperature, °C	90	90	90
Time, days	3	7	14
Replicates	1	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.69	0.81	0.78
Ca	3.5	3.7	4.0
Fe	1.5	2.2	2.0
K	5.1	0	0
Mg	3.1	4.0	4.4
Na	4.4	5.2	6.2
P	0	1.9	2.2
Si	2.3	3.5	4.5
Ti	0.096	0.10	0.099
Pu	1.4E-3	2.9E-3	1.4E-3
Final pH	4.7	5.2	6.6

TABLE A.5-4. Aluminosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	28	28	28
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	3.03 ± 30%	2.81 ± 2.0%	
Ca	5.50 ± 26%	1.33 ± 13%	
Fe	1.92 ± 83%	0	
K	5.96 ± 23%	7.07 ± 26%	
Mg	6.49 ± 7.8%	6.50 ± 55%	
Na	9.00 ± 5.8%	4.98 ± 50%	
P	4.86 ± 66%	3.50 ± 38%	
Si	6.62 ± 4.5%	3.08 ± 10%	
Ti	0	0	
Pu	4.8E-3 ± 8.6%	1.0E-1 ± 29%	2.4E-3 ± 35%
Am	1.1E-2	1.57E-2 ± 3.2%	0
Final pH	9.0	9.4	6.3

TABLE A.5-5. Aluminosilicate Glass

Leachant	Deionized Water	Deionized Water
Temperature, °C	90	90
Time, days	56	91
Replicates	2	2
Average Normalized Mass Loss (g/m ²)		
Al	3.73 ± 2.8%	3.9 ± 2.7%
Ca	4.6 ± 16%	5.9 ± 0.1%
Fe	0.52 ± 141%	2.7 ± 18%
K	97 ± 60%	6.0 ± 6.1%
Mg	13 ± 66%	7.0 ± 5.9%
Na	11 ± 10%	9.6 ± 4.7%
P	5.8 ± 74%	7.5 ± 5.6%
Si	7.53 ± 7.1%	7.2 ± 2.6%
Ti	0	0.028 ± 0
Pu	5.4E-3 ± 47%	1.1E-2 ± 9.2%
Final pH	8.7	---

TABLE A.5-6. Aluminosilicate Glass

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	182	182	182
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	6.48 ± 2.3%	7.62 ± 2.5%	
Ca	3.15 ± 3.2%	1.59 ± 2.3%	
Fe	0.22 ± 41%	1.49 ± 11%	
K	6.76 ± 0.3%	14.6 ± 6.7%	
Mg	3.56 ± 14%	2.89 ± 6.8%	
Na	14.2 ± 3.9%	12.2 ± 24%	
P	1.30 ± 86%	3.90 ± 0.6%	
Si	7.29 ± 2.9%	5.57 ± 2.8%	
Ti	0	0.28 ± 48%	
Pu	2.2E-3 ± 0.3%	0.30 ± 8.3%	0.0073 ± 26%
Am	0	6.50E-2	7.05E-3
Final pH	9.1	9.7	6.6

TABLE A.6-1. Cold-Pressed/Sintered-Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	28	28	28
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.26 ± 26%	0.074	
Ca	20 ± 78%	14.2	
Fe	0.085 ± 173%	0.028	
K	0	320	
Mg	6.6 ± 61%	6.9	
Na	1.1 ± 90%	0	
P	5.5 ± 46%	4.3	
Si	0.18 ± 119%	0	
Ti	0.091 ± 152%	0.024	
Pu	7.5E-3 ± 50%	1.4E-2	1.7E-2
Final pH	4.6	8.4	6.2

TABLE A.6-2. Cold-Pressed/Sintered-Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	182	182	182
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.55 ± 13%	0	
Ca	17 ± 139%	7.4	
Fe	0.042 ± 35%	0	
K	0	0	
Mg	7.4 ± 84%	0	
Na	1.90 ± 58%	0	
P	4.88 ± 24%	0	
Si	0.60 ± 36%	0	
Ti	0	0	
Pu	2.4E-2 ± 8.3%	2.21E-2	7.7E-2
Final pH	4.6	8.7	5.2

TABLE A.6-3. Cold-Pressed/Sintered-Ceramic

Leachant	Deionized Water	Deionized Water	Deionized Water
Temperature, °C	90	90	90
Time, days	3	7	14
Replicates	1	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.78	0.93	1.4
Ca	4.0	6.2	11
Fe	0.078	0.078	0.10
K	0	0	0
Mg	3.0	4.8	3.8
Na	2.1	3.2	3.4
P	4.8	4.6	3.5
Si	0.59	0.87	1.2
Ti	0.25	0.24	0.27
Pu	3.9E-2	1.1E-2	5.6E-2
Final pH	3.9	4.0	3.9

TABLE A.6-4. Cold-Pressed/Sintered-Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	28	28	28
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	0.41 ± 9.4%	1.3 ± 21%	
Ca	9.3 ± 46%	5.7 ± 45%	
Fe	0	0	
K	0	14 ± 48%	
Mg	5.1 ± 55%	16 ± 70%	
Na	3.7 ± 40%	1.3 ± 173%	
P	0.57 ± 173%	11 ± 31%	
Si	0.95 ± 13%	2.6 ± 21%	
Ti	0	0	
Pu	0.014 ± 19%	0.092 ± 45%	0.20 ± 48%
Am	4.9E-2	2.0E-1	9.2E-1
Final pH	5.4	9.1	4.2

TABLE A.6-5. Cold-Pressed/Sintered Ceramic

Leachant	Deionized Water	Deionized Water
Temperature, °C	90	90
Time, days	56	91
Replicates	2	2
Average Normalized Mass Loss (g/m ²)		
Al	0.37 ± 27%	0.42 ± 18%
Ca	30 ± 126%	20 ± 27%
Fe	0	0.11 ± 46%
K	320 ± 92%	2.6 ± 141%
Mg	2.3 ± 23%	7.2 ± 87%
Na	1.4 ± 9.4%	4.3 ± 38%
P	0	0.77 ± 47%
Si	0.64 ± 6.3%	1.0 ± 60%
Ti	0	0.032 ± 142%
Pu	5.8E-2 ± 70%	2.9E-2 ± 51%
Final pH	5.8	6.0

TABLE A.6-6. Cold-Pressed/Sintered Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	182	182	182
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	1.67 ± 16%	4.00 ± 3.2%	
Ca	15.9 ± 53%	9.03 ± 24%	
Fe	0.042 ± 65%	0.32 ± 48%	
K	0	47.1 ± 19%	
Mg	8.56 ± 38%	17.6 ± 24%	
Na	5.76 ± 27%	3.85 ± 35%	
P	3.85 ± 18%	24.8 ± 18%	
Si	3.04 ± 20%	7.37 ± 3.3%	
Ti	0	0.17 ± 50%	
Pu	2.3E-2 ± 27%	0.28 ± 43%	0.57 ± 36%
Am	2.17E-2	3.05E-1	2.09
Final pH	7.9	9.4	5.8

TABLE A.7-1. Basalt Glass-Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	28	28	28
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.16 ± 15%	0.070	
Ca	0.24 ± 31%	0.079	
Fe	0.055 ± 100%	0.029	
K	0	0	
Mg	0.092 ± 173%	0	
Na	0.038 ± 173%	0	
P	0	0	
Si	0.13 ± 18%	0	
Ti	0.019 ± 122%	0.019	
Pu	0.018 ± 26%	1.2E-2	5.6E-3
Am	5.62E-2 ± 20.1%	3.2E-2	6.4E-2
Final pH	4.2	8.4	6.3

TABLE A.7-2. Basalt Glass-Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	40	40	40
Time, days	182	182	182
Replicates	3	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.58 ± 10%		
Ca	0.71 ± 3.0%	0.052	
Fe	0.12 ± 64%		
K	0.77 ± 173%		
Mg	0.39 ± 16%		
Na	1.67 ± 6.9%		
P	0		
Si	0.71 ± 6.8%		
Ti	0		
Pu	0.032 ± 48%	1.6E-2	3.7E-2
Am	0.40	1.6E-2	9.6E-2
Final pH	4.3	8.7	5.9

TABLE A.7-3. Basalt Glass-Ceramic

Leachant	Deionized Water	Deionized Water	Deionized Water
Temperature, °C	90	90	90
Time, days	3	7	14
Replicates	1	1	1
Average Normalized Mass Loss (g/m ²)			
Al	0.80	1.1	1.5
Ca	1.0	1.2	1.7
Fe	0.51	0.12	1.0
K	0	0	0
Mg	0.89	0.93	1.6
Na	2.1	1.7	3.1
P	0	0	0
Si	0.83	1.3	1.9
Ti	0.22	0.21	0.32
Pu	4.0E-2	4.7E-2	1.7E-1
Final pH	4.0	3.9	4.3

TABLE A.7-4. Basalt Glass-Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	28	28	28
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	0.16 ± 87%	1.9 ± 7.2%	
Ca	0.86 ± 19%	0.69 ± 13%	
Fe	0	0	
K	0	0	
Mg	0.67 ± 7.9%	0.44 ± 17%	
Na	1.7 ± 41%	0.69 ± 173%	
P	0	0	
Si	1.0 ± 8.1%	2.6 ± 9.1%	
Ti	0	0	
Pu	3.2E-2 ± 47%	6.6E-2 ± 36%	1.4E-1 ± 47%
Am	5.6E-2 ± 20%	8.1E-2 ± 58%	1.31 ± 32%
Final pH	5.6	9.4	3.5

TABLE A.7-5. Basalt Glass-Ceramic

Leachant	Deionized Water	Deionized Water
Temperature, °C	90	90
Time, days	56	91
Replicates	2	2
Average Normalized Mass Loss (g/m ²)		
Al	0.18 ± 30%	0.87 ± 25%
Ca	4.4 ± 139%	2.8 ± 0
Fe	0	1.3 ± 0.5%
K	29 ± 4.6%	0.75 ± 80%
Mg	0.83 ± 23%	2.8 ± 0.8%
Na	1.7 ± 3.4%	3.5 ± 4.9%
P	0	2.1 ± 35%
Si	1.3 ± 4.4%	3.2 ± 2.7%
Ti	0	0.24 ± 11%
Pu	3.5E-2 ± 0	1.3E-1 ± 3.7%
Final pH	5.9	7.3

TABLE A.7-6. Basalt Glass-Ceramic

Leachant	Deionized Water	Silicate	Brine
Temperature, °C	90	90	90
Time, days	182	182	182
Replicates	3	3	3
Average Normalized Mass Loss (g/m ²)			
Al	4.03 ± 1.6%	5.31 ± 4.8%	
Ca	1.77 ± 0.9%	0.84 ± 2.5%	
Fe	0.31 ± 12%	0.24 ± 11%	
K	0	16.4 ± 3.1%	
Mg	1.81 ± 3.1%	0.18 ± 89%	
Na	7.79 ± 2.3%	8.0 ± 74%	
P	0	0	
Si	5.47 ± 1.3%	4.79 ± 5.9%	
Ti	0	0	
Pu	2.6E-2 ± 6%	4.9E-2 ± 8%	2.1E-2 ± 82%
Am	6.40E-2 ± 0.22%	4.0E-2 ± 28%	6.9E-1 ± 5.4%
Final pH	8.6	9.6	6.3

Appendix B
Process Economics and Facility Diagrams

APPENDIX B

PROCESS ECONOMICS AND FACILITY DIAGRAMS

This appendix provides extensive details of the process economics reported in Volume I, and includes the facility diagrams used by Kaiser Engineers in making magnitude estimates of each process facility and operation. The cost data is expected to be accurate to within $\pm 20\%$. All values are in mid-1981 dollars. These facility drawings for magnitude estimates may not correspond exactly with the detailed facility layouts presented earlier in this volume, but are similar enough to provide meaningful cost estimation data. A total processing cost summary, along with construction, operating, and maintenance costs, is presented separately in four tables for each of the eight processes. A diagram of each process facility follows each set of tables. The processes are presented in this order:

1. in-can glass melting
2. joule-heated glass melting
3. glass marble
4. basalt glass-ceramic
5. cast cement
6. pressed cement
7. FUETAP cement
8. cold-pressed/sintered-ceramic.

TABLE B.1.1. In-Can Glass Melting Cost Estimate Summary (all costs in thousands of 1981 dollars)

Total Cost Breakdown	Costs with \$1,000 Canister	Costs with \$10,000 Canister
Construction Cost	\$25,800	\$25,800
Conceptual Design (2%) ^(a)	520	520
Title I (preliminary design) (3%)	770	770
Title II (definite design) (8%)	2,060	2,060
Title III (enrg surveillance including vendor dwg check, as-built dwgs, etc.) (4%)	1,030	1,030
Project Administration (10%)	2,580	2,580
Total Construction Cost (rounded)	33,000	33,000
Operating Cost--30 yr	81,000	164,000
Maintenance Cost--30 yr	13,000	13,000
Decommissioning	2,000	2,000
Present-Day Cost of Total Facility--30 yr	\$129,000	\$212,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.1.2. In-Can Glass-Melting Construction Costs (all costs in thousands of 1981 dollars)

Construction Cost Items	Costs
Direct Costs	
Existing Facility Modifications	\$130
Site Development	170
Immobilization Process Building	9,200
Canister Storage Shed	80
Mechanical Equipment	530
Immobilization Process Equipment	3,300
Mobile Equipment	130
Canister/Drum Decontamination System	200
Immobilization Facility Liquid Radwaste System	220
Immobilization Facility HVAC System	440
Immobilization Facility Electrical System	880
Instrumentation and Control System	400
Radiation Monitors/Detection System	120
Total Direct Cost	15,800
Contractor's Overhead and Profit (~25%)	3,950
Subtotal	19,750
Contingency (~30%)	5,900
Startup	150
Total Construction Cost	\$25,800

TABLE B.1.3. In-Can Glass-Melting Operating Costs (all costs in thousands of 1981 dollars)

<u>Total Cost Breakdown</u>		Costs with \$1,000 Canister	Costs with \$10,000 Canister
Labor requirements per shift (4 shifts)			
1 Foreman		\$240	\$240
2 Radiation Monitors		320	320
1 Engineer		200	200
1 Nuclear Material Accounting		160	160
6 Operators		720	720
Materials			
Glass Melt Canisters		308	3,080
50-gal LSA Ash Drums		13	13
1-gal HSA Plastic Containers		2	2
Glass Frit		261	261
Diatomaceous Earth		4	4
Chemicals, Plastic Bags, Misc. Materials and Supplies		80	80
Services			
Dosimeter, Film, Badge-Reading		2	2
Electrical Power--2,541,000 kWh		380	380
Steam and Fuel		<u>1</u>	<u>1</u>
Subtotal--1 yr		2,690	5,460
Total Operating Cost--30 Yr		\$81,000	\$164,000

TABLE B.1.4. In-Can Glass Melting Maintenance Costs
(all costs in thousands of 1981 dollars)

<u>Maintenance Items</u>	<u>Costs</u>
General Equipment and Facility Maintenance	\$10,900
Equipment Replacements	
Vacuum Drum Filter--4 times	400
Paddle Dryer--2 times	700
Intensive Solids Mixer--9 times	200
In-Can Melting Furnace--4 times	<u>800</u>
Total Maintenance Cost--30 yr	\$13,000

STATE OF NEW YORK
OFFICE OF THE COMPTROLLER
REPORT ON THE REVENUE ACCOUNTS FOR THE YEAR 1900

REVENUE ACCOUNTS		BALANCE SHEET	
REVENUE	EXPENDITURE	ASSETS	LIABILITIES
1. TAXES	1. TAXES	1. TAXES	1. TAXES
2. LICENSES	2. LICENSES	2. LICENSES	2. LICENSES
3. FINE AND FEE	3. FINE AND FEE	3. FINE AND FEE	3. FINE AND FEE
4. SALE OF LAND	4. SALE OF LAND	4. SALE OF LAND	4. SALE OF LAND
5. SALE OF STOCK	5. SALE OF STOCK	5. SALE OF STOCK	5. SALE OF STOCK
6. SALE OF BOND	6. SALE OF BOND	6. SALE OF BOND	6. SALE OF BOND
7. SALE OF OTHER PROPERTY	7. SALE OF OTHER PROPERTY	7. SALE OF OTHER PROPERTY	7. SALE OF OTHER PROPERTY
8. INTEREST ON BOND	8. INTEREST ON BOND	8. INTEREST ON BOND	8. INTEREST ON BOND
9. INTEREST ON STOCK	9. INTEREST ON STOCK	9. INTEREST ON STOCK	9. INTEREST ON STOCK
10. INTEREST ON OTHER PROPERTY	10. INTEREST ON OTHER PROPERTY	10. INTEREST ON OTHER PROPERTY	10. INTEREST ON OTHER PROPERTY
11. DIVIDEND	11. DIVIDEND	11. DIVIDEND	11. DIVIDEND
12. PROFIT AND LOSS	12. PROFIT AND LOSS	12. PROFIT AND LOSS	12. PROFIT AND LOSS
13. RESERVE	13. RESERVE	13. RESERVE	13. RESERVE
14. OTHER	14. OTHER	14. OTHER	14. OTHER
15. TOTAL	15. TOTAL	15. TOTAL	15. TOTAL

FIGURE B.1. In-Can Glass Melting Process Facility

TABLE B.2.1. Joule-Heated Glass-Melting Cost Estimate Summary
(all costs in thousands of 1981 dollars)

<u>Total Cost Breakdown</u>	<u>Costs</u>
Construction Cost	\$23,400
Conceptual Design (2%) ^(a)	470
Title I (preliminary design) (3%)	700
Title II (definite design) (8%)	1,870
Title III (engrg surveillance including vendor drwg check, as-built dwgs, etc.) (4%)	940
Project Administration (10%)	<u>2,340</u>
Total Construction Cost (rounded)	30,000
Operating Cost--30 yr	69,000
Maintenance Cost--30 yr	18,000
Decommissioning	<u>2,000</u>
Present Day Cost of Total Facility--30 yr	\$119,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.2.2. Joule-Heated Glass-Melting Construction Costs
(all costs in thousands of 1981 dollars)

<u>Construction Cost Items</u>	<u>Costs</u>
Direct Costs	
Existing Facility Modifications	\$130
Site Development	170
Immobilization Process Building	8,020
Canister Storage Shed	80
Mechanical Equipment	200
Immobilization Process Equipment	3,450
Mobile Equipment	130
Canister/Drum Decontamination System	200
Immobilization Facility Liquid Radwaste System	200
Immobilization Facility HVAC System	380
Immobilization Facility Electrical System	840
Instrumentation and Control System	380
Radiation Monitors/Detection System	<u>120</u>
Total Direct Cost	14,300
Contractor's Overhead and Profit (~25%)	<u>3,580</u>
Subtotal	17,880
Contingency (~30%)	5,360
Startup	<u>150</u>
Total Construction Cost	\$23,400

TABLE B.2.3. Joule-Heated Glass-Melting Operating Costs (all costs in thousands of 1981 dollars)

<u>Operating Cost Items (1 yr of operation)</u>	<u>Costs</u>
Labor Requirements per Shift (4 shifts)	
1 Foreman	\$240
2 Radiation Monitors	320
1 Engineer	200
1 Nuclear Material Accounting	160
6 Operators	720
Materials	
55-gal Canisters	14
50-gal LSA Ash Drums	13
1-gal HSA Plastic Containers	2
Glass Frit	261
Diatomaceous Earth	4
Chemicals, Plastic Bags, Misc. Materials and Supplies	40
Services	
Dosimeter, Film, Badge-Reading	2
Electrical Power--2,067,000 kWh	310
Steam and Fuel	<u>1</u>
Subtotal--1 yr	2,310
Total Operating Cost--30 yr	\$69,000

TABLE B.2.4. Joule-Heated Glass-Melting Maintenance Costs (all costs in thousands of 1981 dollars)

<u>Maintenance Cost Items</u>	<u>Costs</u>
General Equipment and Facility Maintenance	\$10,000
Equipment Replacements	
Vacuum Drum Filter--4 times	400
Paddle Dryer--2 times	700
Intensive Solids Mixer--9 times	200
Joule-Heated Glass Melter--9 times	<u>6,700</u>
Total Maintenance Cost--30 yr	\$18,000

B.2.

TABLE B.3.1. Glass Marble Cost Estimate Summary (all costs in thousands of 1981 dollars)

Total Cost Breakdown	Costs
Construction Cost	\$25,700
Conceptual Design (2%) (a)	510
Title I (preliminary design) (3%)	770
Title II (definite design) (8%)	2,060
Title III (engrg. surveillance including vendor drwg check, as-built dwgs, etc.) (4%)	1,030
Project Administration (10%)	2,570
Total Construction Cost (rounded)	33,000
Operating Cost--30 yr	69,000
Maintenance Cost--30 yr	20,000
Decommissioning	2,000
Present-Day Cost of Facility--30 yr	\$124,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.3.2. Glass Marble Construction Costs (all costs in thousands of 1981 dollars)

Construction Cost Summary	Costs
Direct Costs	
Existing Facility Modifications	\$130
Site Development	170
Immobilization Process Building	8,950
Canister Storage Shed	80
Mechanical Equipment	530
Immobilization Process Equipment	3,660
Mobile Equipment	130
Canister/Drum Decontamination System	not needed
Immobilization Facility Liquid Radwaste System	220
Immobilization Facility HVAC System	440
Immobilization Facility Electrical System	910
Instrumentation and Control System	400
Radiation Monitors/Detection System	120
Total Direct Cost	15,700
Contractor's Overhead and Profit (~25%)	3,900
Subtotal	19,600
Contingency (~30%)	5,900
Startup	150
Total Construction Cost	\$25,700

TABLE B.3.3. Glass Marble Operating Costs (all costs in thousands of 1981 dollars)

<u>Operating Cost Items (1 yr of operation)</u>	<u>Costs</u>
Labor Requirements per Shift (4 shifts)	
1 Foreman	\$240
2 Radiation Monitors	320
1 Engineer	200
1 Nuclear Material Accounting	160
6 Operators	720
Materials	
55-gal Canisters--1325 each	23
50-gal LSA Drums--22 each	13
1-gal HSA Plastic Containers--540 each	2
Molds	2
Glass Frit--421,000 lb	261
Diatomaceous Earth--190 lb	4
Chemicals, Plastic Bags, Misc. Materials and Supplies	10
Services	
Dosimeter, Film, Badge Reading	2
Electrical Power--2,220,000 kWh	333
Steam and Fuel	1
Subtotal--1 yr	2,290
Total Operating Cost--30 yr	\$69,000

TABLE B.3.4. Glass Marble Maintenance Costs (all costs in thousands of 1981 dollars)

<u>Maintenance Items</u>	<u>Costs</u>
General Equipment and Facility Maintenance	\$11,300
Equipment Replacements	
Vacuum Drum Filter--4 times	400
Paddle Dryer--2 times	700
Intensive Solids Mixer--9 times	200
Joule-Heated Glass Melter--9 times	6,700
Marble Machine--5 times	300
Reject Mill--5 times	400
Total Maintenance Cost--30 yr	\$20,000

B.13

FIGURE B.3. Glass Marble Process Facility

TABLE B.4.1. Basalt Glass-Ceramic Cost Estimate Summary (all costs in thousands of 1981 dollars)

Total Cost Breakdown	Costs
Construction Cost	\$23,500
Conceptual Design (2%)(a)	470
Title I (preliminary design) (3%)	700
Title II (definite design) (8%)	1,880
Title III (engrg surveillance including vendor drwg check, as-built drwgs, etc.) (4%)	940
Project Administration (10%)	2,350
Total Construction Cost (rounded)	30,000
Operating Cost--30 yr	77,000
Maintenance Cost--30 yr	18,000
Decommissioning	2,000
Present-Day Cost of Facility--30 yr	\$127,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.4.2. Basalt Glass-Ceramic Construction Costs (all costs in thousands of 1981 dollars)

Construction Cost Items	Costs
Direct Costs	
Existing Facility Modification	\$130
Site Development	170
Immobilization Process Building	8,020
Canister Storage Shed	80
Mechanical Equipment	200
Immobilization Process Equipment	3,500
Mobile Equipment	130
Canister/Drum Decontamination System	200
Immobilization Facility Liquid Radwaste System	200
Immobilization Facility HVAC System	380
Immobilization Facility Electrical System	840
Instrumentation and Control System	380
Radiation Monitors/Detection System	120
Total Direct Cost	14,400
Contractor's Overhead and Profit (~25%)	3,600
Subtotal	18,000
Contingency (~30%)	5,400
Startup	150
Total Construction Cost	\$23,500

TABLE B.4.3. Basalt Glass-Ceramic Operating Costs (all costs in thousands of 1981 dollars)

<u>Operating Cost Items (1 yr of operation)</u>	<u>Costs</u>
Labor Requirements per Shift (4 shifts)	
1 Foreman	\$240
2 Radiation Monitors	320
1 Engineer	200
1 Nuclear Material Accounting	160
6 Operators	720
Materials	
55-gal SS Drums--795 each	280
50-gal LSA Drums--22 each	13
1-gal HSA Plastic Containers--540 each	2
Glass Frit--421,000 lb	261
Diatomaceous Earth--190 lb	4
Chemicals, Plastic Bags, Misc. Materials and Supplies	64
Services	
Dosimeter, Film, Badge Reading	2
Electrical Power--2,067,000 kWh	310
Steam and Fuel	1
Subtotal--1 yr	2,580
Total Operating Cost--30 yr	\$77,000

TABLE B.4.4. Basalt Glass-Ceramic Maintenance Costs (all costs in thousands of 1981 dollars)

<u>Maintenance Items</u>	<u>Costs</u>
General Equipment and Facility Maintenance	\$10,400
Equipment Replacements	
Vacuum Drum Filter--4 times	400
Paddle Dryer--2 times	700
Intensive Solids Mixer--9 times	200
Joule-Heated Glass Melter--9 times	6,700
Insulating Pod--18 times	100
Total Maintenance Cost--30 yr	18,500

FIGURE B.4. Basalt Glass-Ceramic Process Facility

TABLE B.5.1. Cast-Cement Cost Estimate Summary (all costs in thousands of 1981 dollars)

<u>Total Cost Breakdown</u>	<u>Costs</u>
Construction Cost	\$22,800
Conceptual Design (2%)(a)	460
Title I (preliminary design) (3%)	680
Title II (definite design) (8%)	1,820
Title III (engrg surveillance including vendor drwg check, as-built dwgs, etc.) (4%)	910
Project Administration (10%)	<u>2,280</u>
Total Construction Cost (rounded)	29,000
Operating Cost--30 yr	20,000
Maintenance Cost--30 yr	10,000
Decommissioning	<u>2,000</u>
Present-Day Cost of Total Facility--30 yr	61,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.5.2. Cast-Cement Construction Costs (all costs in thousands of 1981 dollars)

<u>Construction Cost Summary</u>	<u>Costs</u>
Direct Costs	
Existing Facility Modification	\$130
Site Development	170
Immobilization Process Building	7,950
Canister Storage Shed	80
Mechanical Equipment	200
Immobilization Process Equipment	2,820
Mobile Equipment	130
Canister/Drum Decontamination System	200
Immobilization Facility Liquid Radwaste System	200
Immobilization Facility HVAC System	380
Immobilization Facility Electrical System	1,200
Instrumentation and Control System	320
Radiation Monitors/Detection System	<u>120</u>
Total Direct Cost	13,900
Contractor's Overhead and Profit (~25%)	<u>3,480</u>
Subtotal	17,400
Contingency (~30%)	5,220
Startup	<u>150</u>
Total Construction Cost	22,800

TABLE B.5.3. Cast Cement Operating Costs (all costs in thousands of 1981 dollars)

<u>Operating Cost Items (1 yr of operation)</u>	<u>Costs</u>
Labor Requirements per Shift (1 shift)	
1 Foreman	\$60
2 Radiation Monitors	80
1 Engineer	50
1 Nuclear Material Accounting	40
6 Operators	180
Materials	
55-gal Canisters--2,330 each	40
50-gal LSA Drums--22 each	13
1-gal HSA Plastic Containers--540 each	2
Cement--791,200 lb	32
Diatomaceous Earth--190 lbs	4
Chemicals, Plastic Bags, Misc. Materials and Supplies	30
Services	
Dosimeter, Film, Badge Reading	2
Electrical Power--909,000 kWh	136
Steam and Fuel	<u>1</u>
Subtotal--1 yr	670
Total Operating Cost--30 yr	\$20,000

TABLE B.5.4. Cast Cement Maintenance Costs (all costs in thousands of 1981 dollars)

<u>Maintenance Cost Items</u>	<u>Costs</u>
General Equipment and Facility Maintenance	\$8,650
Equipment Replacements	
Vacuum drum Filter--4 times	400
Paddle Dryer--2 times	700
Cement Mixer--9 times	<u>250</u>
Total Maintenance Cost--30 yr	\$10,000

FIGURE B.5. Cast Cement Process Facility

TABLE B.6.1. Pressed-Cement Cost Estimate Summary (all costs in thousands of 1981 dollars)

Total Cost Breakdown	Costs
Construction Cost	\$25,000
Conceptual Design (2%) (a)	450
Title I (preliminary design) (3%)	750
Title II (definite design) (8%)	2,000
Title III (engrg surveillance including vendor drwg check, as-built dwgs, etc.) (4%)	1,000
Project Administration (10%)	2,500
Total Construction Cost (rounded)	32,000
Operating Cost--30 yr	20,000
Maintenance Cost--30 yr	12,000
Decommissioning	2,000
Present-Day Cost of Total Facility--30 yr	\$66,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.6.2. Pressed-Cement Construction Costs (all costs in thousands of 1981 dollars)

Construction Cost Summary	Costs
Direct Costs	
Existing Facility Modification	\$130
Site Development	170
Immobilization Process Building	9,010
Canister Storage Shed	80
Mechanical Equipment	220
Immobilization Process Equipment	2,940
Mobile Equipment	130
Canister/Drum Decontamination System	200
Immobilization Facility Liquid Radwaste System	210
Immobilization Facility HVAC System	440
Immobilization Facility Electrical System	1,290
Instrumentation and Control System	330
Radiation Monitors/Detection System	120
Total Direct Cost	15,300
Contractor's Overhead and Profit (~25%)	3,800
Subtotal	19,100
Contingency (~30%)	5,730
Startup	150
Total Construction Cost	\$25,000

TABLE B.6.3. Pressed-Cement Operating Costs (all costs in thousands of 1981 dollars)

<u>Operating Cost Items (1 yr of operation)</u>	<u>Costs</u>
Labor Requirements per Shift (1 shift)	
1 Foreman	\$60
2 Radiation Monitors	80
1 Engineer	50
1 Nuclear Material Accounting	40
6 Operators	180
Materials	
55-gal canisters--2,775 each	47
50-gal LSA drums--22 each	13
1-gal HSA Plastic Containers--540 each	2
Cement--425,400 lb	17
Diatomaceous Earth--190 lb	4
Chemicals, Plastic Bags, Misc. Materials and Supplies	20
Services	
Dosimeter, Film, Badge Reading	2
Electrical Power--969,000 kWh	145
Steam and Fuel	<u>1</u>
Subtotal--1 yr	660
Total Operating Cost--30 yr	\$20,000

TABLE B-6.4. Pressed-Cement Maintenance Costs (all costs in thousands of 1981 dollars)

<u>Maintenance Cost Items</u>	<u>Costs</u>
General Equipment and Facility Maintenance	\$9,100
Equipment Replacements	
Vacuum Drum Filter--4 times	400
Paddle Dryer--2 times	700
Cement Mixer--9 times	250
Grinding Mill--5 times	50
Hydraulic Press--42 times	<u>1,500</u>
Total Maintenance Cost--30 yr	\$12,000

FIGURE B.6. Pressed-Cement Process Facility

TABLE B.7.1. FUETAP Cement Cost Estimate Summary (all costs in thousands of 1981 dollars)

<u>Total Cost Breakdown</u>	<u>Costs</u>
Construction Cost	\$26,600
Conceptual Design (2%)(a)	530
Title I (preliminary design) (3%)	800
Title II (definite design) (8%)	2,130
Title III (enrg surveillance including vendor drwg check, as-built drwgs, etc.) (4%)	1,060
Project Administration (10%)	2,660
Total Construction Cost (rounded)	34,000
Operating Cost--30 yr	22,000
Maintenance Cost--30 yr	12,000
Decommissioning	2,000
Present-Day Cost of Total Facility--30 yr	\$70,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.7.2. FUETAP Cement Construction Costs (all costs in thousands of 1981 dollars)

<u>Construction Cost Summary</u>	<u>Costs</u>
Direct Costs	
Existing Facility Modification	\$130
Site Development	170
Immobilization Process Building	9,940
Canister Storage Shed	80
Mechanical Equipment	200
Immobilization Process Equipment	3,060
Mobile Equipment	130
Canister/Drum Decontamination System	200
Immobilization Facility Liquid Radwaste System	220
Immobilization Facility HVAC System	410
Immobilization Facility Electrical System	1,220
Instrumentation and Control System	370
Radiation Monitors/Detection System	120
Total Direct Cost	16,250
Contractor's Overhead and Profit (~25%)	4,060
Subtotal	20,300
Contingency (~30%)	6,090
Startup	180
Total Construction Cost	\$26,600

TABLE B.7.3. FUETAP Cement Operating Costs (all costs in thousands of 1981 dollars)

Operating Cost Items (1 yr of operation)	Costs
Labor Requirements per Shift (1 shift)	
1 Foreman	\$60
2 Radiation Monitors	80
1 Engineer	50
1 Nuclear Material Accounting	40
6 Operators	180
Materials	
55-gal canisters--1,530 each	26
50-gal LSA drums--22 each	13
1-gal HSA Plastic Containers--540 each	2
Cement--425,400 lb	17
Diatomaceous Earth--190 lb	4
Chemicals, Plastic Bags, Misc. Materials and Supplies	30
Services	
Dosimeter, Film, Badge Reading	2
Electrical Power--1,469,000 kWh	220
Steam and Fuel	1
Subtotal--1 yr	725
Total Operating Cost--30 yr	\$22,000

TABLE B.7.4. FUETAP Cement Maintenance Costs (all costs in thousands of 1981 dollars)

Maintenance Cost Items	Costs
General Equipment and Facility Maintenance	\$9,900
Equipment Replacements	
Vacuum Drum Filter--4 times	400
Paddle Dryer--2 times	700
Cement Mixer--9 times	250
Autoclave--12 times	750
Total Maintenance Cost--30 yr	\$12,000

FIGURE B.7. FUETAP Cement Process Facility

TABLE B.8.1. Cold-Pressed Sintered Ceramic Cost Estimate Summary
(all costs in thousands of 1981 dollars)

Total Cost Breakdown	Costs
Construction Cost	\$27,000
Conceptual Design (2%)(a)	540
Title I (preliminary design) (3%)	810
Title II (definite design) (8%)	2,160
Title III (engrg surveillance including vendor drwg check, as-built drwgs, etc.) (4%)	1,080
Project Administration (10%)	<u>2,700</u>
Total Construction Cost (rounded)	34,000
Operating Cost--30 yr	63,000
Maintenance Cost--30 yr	13,000
Decommissioning	<u>2,000</u>
Present-Day Cost of Total Facility--30 yr	\$112,000

(a) Percentages shown in design costs are percentage of construction costs.

TABLE B.8.2. Cold-Pressed Sintered Ceramic Construction Costs
(all costs in thousands of 1981 dollars)

Construction Cost Summary	Costs
Direct Costs	
Existing Facility Modification	\$130
Site Development	170
Immobilization Process Building	10,100
Canister Storage Shed	80
Mechanical Equipment	530
Immobilization Process Equipment	3,110
Mobile Equipment	130
Canister/Drum Decontamination System	200
Immobilization Facility Liquid Radwaste System	230
Immobilization Facility HVAC System	430
Immobilization Facility Electrical System	900
Instrumentation and Control System	400
Radiation Monitors/Detection System	<u>120</u>
Total Direct Cost	16,500
Contractor's Overhead and Profit (~25%)	<u>4,100</u>
Subtotal	20,600
Contingency (~30%)	6,200
Startup	<u>150</u>
Total Construction Cost	\$27,000

TABLE B.8.3. Cold-Pressed Sintered Ceramic Operating Costs (all costs in thousands of 1981 dollars)

<u>Operating Cost Items (1 yr of operation)</u>	<u>Costs</u>
Labor Requirements per Shift (1 shift)	
1 Foreman	\$240
2 Radiation Monitors	320
1 Engineer	200
1 Nuclear Material Accounting	160
6 Operators	720
Materials	
55-gal canisters--2,930 each	49
50-gal LSA drums--22 each	13
1-gal HSA Plastic Containers--540 each	2
Dies--8 Sets	40
Bentonite--841,500 lb	34
Diatomaceous Earth--190 lb	4
Chemicals, Plastic Bags, Misc. Materials and Supplies	20
Services	
Dosimeter, Film, Badge Reading	2
Electrical Power--1,882,000 kWh	282
Steam and Fuel	<u>1</u>
Subtotal--1 yr	2,090
Total Operating Cost--30 yr	\$63,000

TABLE B.8.4. Cold-Pressed Sintered Ceramic Maintenance Costs (all costs in thousands of 1981 dollars)

<u>Maintenance Cost Items</u>	<u>Costs</u>
General Equipment and Facility Maintenance	\$10,200
Equipment Replacements	
Vacuum Drum Filter--4 times	400
Paddle Dryer--2 times	700
Intensive Solids Mixer--9 times	200
Vibratory-Grinding Mill--5 times	600
Hydraulic Press--14 times	300
Pellet Mill--5 times	<u>100</u>
Total Maintenance Cost--30 yr	\$12,500

FIGURE B.8. Cold-Pressed/Sintered-Ceramic Process Facility

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