DPSTD-77-13-3

Preliminary Technical Data Summary No. 3 for the
DEFENSE WASTE PROCESSING FACILITY

Compiled by L. F. Landon
Engineering Technology Division
Savannah River Laboratory

May 1980

Issued by E. I. du Pont de Nemours & Co. (Inc.)
Savannah River Laboratory
Aiken, SC 29801

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Objectives (L. F. Landon)*

This Preliminary Technical Data Summary (PTDS No. 3) presents an update on the best information presently available for the purpose of establishing the basis for the design of a Defense Waste Processing Facility (DWPF). The objective of this project is to provide a facility to fix the radionuclides present in Savannah River Plant (SRP) high-level liquid waste in a high-integrity form (glass). The issue of this document is to be considered preliminary since the research and development effort will be an ongoing activity during the early stages of plant design. The document will continue to be updated as new information is obtained.

Additional basic data evolved from the continuing research and development programs and flowsheet optimization studies will supersede the data presently contained in this document. As individual data packages are formalized, the Technical Information Service of the Savannah River Laboratory will issue revisions to each individual assigned a copy of Preliminary Technical Data Summary No. 3. Additional Technical Data Summaries will be issued when deemed appropriate.

The major changes in this issue relative to PTDS No. 2 (DPSTD-77-13-2, June 1979) are as follows:

1. Material balance flowsheets have been updated based on the following revised process data:

    - The three-wash sludge washing scheme has been changed to a dewatering step followed by two washes.
    - The water content of the centrifuge sludge cake has been reduced from 6.2 to 3.0 lb H_2O/lb of solids.
    - Solids recovery for each centrifuge pass has been increased from 97 to 98%.
    - Solids recovery for the gravity settling operation has been increased from 98 to 99%.

---

* Contributor. Questions concerning material in this Preliminary Technical Data Summary should be addressed to contributor whose name appears after a heading.

- Total solids content of spray-dryer feed has been increased from about 6% to 17 wt %.

2. Volumetric underflow recycle for the gravity settling operation has been decreased from 10 to 7%.

3. The parallel-train concept of ion exchange columns for cesium and strontium recovery has been reduced to a single-train concept consisting of two cesium ion exchange columns and one strontium ion exchange column, all in series.

4. The clarified supernate fraction of the waste following treatment by ion exchange will be incorporated into concrete and stored onsite as large monoliths in an intermediate-depth land burial site.

5. The canister overpack and associated equipment and offsite shipping facilities are eliminated from the scope of this document.

6. The capacity of the glass-waste interim-storage facility has been increased to 6500 canisters.

7. The canisters will undergo a two-step decontamination procedure in Mechanical Cells A and B. A nitric acid-sodium fluoride solution will be used in the first step followed by an oxalic acid cleaning step.

8. Sludge settling rate in Gravity Settler increased from 10 to 20 inches/hour.

Additional alternatives to the technical bases presented here will continue to be evaluated as potentially valuable contributions toward improved operability and/or reduced cost of the facility. These alternatives will be handled on an individual basis if and when a clear-cut advantage becomes apparent.

1.2 Background (L. F. Landon)

Since 1953, the Savannah River Plant (SRP), near Aiken, South Carolina, has been producing special nuclear materials, primarily plutonium and tritium, for defense purposes. The SRP facilities were constructed and operated by the Du Pont Company initially for the Atomic Energy Commission (AEC), now the Department of Energy (DOE). The SRP site occupies an area of about 300 square miles along the Savannah River, about 25 miles downstream from Augusta, Georgia. SRP includes a nuclear fuel fabrication plant, three production reactors, two fuel reprocessing plants, and a facility for producing heavy water.

The SRP operations produce high-level radioactive waste in the chemical processing of fuel and target elements after irradiation in the SRP nuclear reactors. This waste is stored in large underground tanks as an alkaline liquid with a precipitated sludge until the decay heating has abated appreciably. Then the supernatant liquid is evaporated and returned to the tanks to form a salt cake to reduce volume and mobility.

In 1971, the Division of Waste Management and Transportation was formed in the AEC and published initial plans for the long-term management of defense waste. For SRP, the plan was storage of liquid waste in a deep-mined cavern under the SRP site. In November 1972, the AEC deferred further study of that storage option in favor of an investigation of the conversion of SRP waste to a high-integrity solid. The status of the technology, technical data base, proposed design criteria, and estimated risks for the deep-mined cavern were summarized in a Technical Assessment [1].

As a first step in evaluating waste forms for Savannah River waste, a survey was made of all pertinent forms and processes, and the applicability of these waste forms and processes to SR waste was evaluated [2]. One of the principal conclusions of this evaluation was that the presence of the soluble salts ($NaNO_3$, Na_2CO_3, etc.) presented significant difficulties if these salts had to be incorporated into a high-integrity form such as glass or concrete. A process for segregating the soluble salts from the radionuclides was suggested based on physical separation of the insoluble sludge and supernate via centrifugation and filtration and separation of soluble radionuclides in the supernate (principally Cs-137) by ion exchange.

Subsequent laboratory studies showed that the separation of nuclides from soluble salts was feasible [3], that concrete was an acceptable waste form [4], but that glass had the highest integrity (principally greater leach resistance in water and absence of off-gassing when heated [5].

Concurrent with initial small-scale research in the Savannah River Laboratory (SRL), conceptual studies were carried out as a joint effort between SRL, SRP, and the Du Pont Engineering Department to evaluate the feasibility and cost of selected options. These studies included evaluation of basic parameters such as waste form, disposal mode for the solid radioactive waste form and the decontaminated salts, processing rates, etc.

During this same period, SRL also made an overall evaluation of the costs and risks of all options for long-term management of Savannah River waste. This overall evaluation included options such as onsite bedrock storage and continued tank storage as well as solidification [6].

In 1977, the following reference process was chosen:

- Incorporation of radionuclides in glass and offsite shipment to a Federal repository.
- Return of the decontaminated supernate as damp salt cake to onsite bulk storage.
- Processing all >5-year-old waste.

In August 1978, a Preliminary Technical Data Summary (PTDS No. 1) was issued which presented the best information that was currently available for the purpose of establishing the basis for design of a Defense Waste Processing Facility [7]. This document was updated and reissued in June 1979 (DPSTD-77-13-2). The current reference process flowsheet is shown schematically in Figure 1.1.

1.3 Design Criteria and Basic Assumptions (L. F. Landon)

1. The waste processing facility will be located at a new site (200-S Area) on the SRP site in reasonable proximity to the F and H-Area Interim Waste Storage Facilities.
2. The waste processing facility is designed for an average attained rate of 9 gpm equivalent feed on a reconstituted basis.
3. The aged waste will be separated into two fractions, a supernate fraction and a sludge-slurry fraction, for feed to the DWPF. The supernate fraction is composed of decanted supernate and redissolved salt cake. The sludge-slurry fraction is prepared by slurrying the in-tank, settled-sludge.
4. The waste will be processed to obtain a borosilicate glass (containing essentially all the radioactivity) and a concrete-salt matrix (containing very low concentrations of radioactivity).
5. The chemical composition of the waste feed to the DWPF is based on past analyses of supernate and sludge samples obtained from existing waste storage tanks. For planning purposes perfect blending of the two waste fractions at the time of plant startup is assumed in calculating material balances.

6. Clarified supernate following ion exchange, will be incorporated into concrete and stored as a concrete matrix in a new intermediate-depth land burial facility. The clarified supernate fraction of the waste feed will be sufficiently decontaminated such that the radionuclide content of the saltcrete will conform to the projected NRC waste classification C.

7. The radionuclide composition of the waste is based on the following:

   - Reactor operation for the late 1980's.
   - Irradiated fuel is cooled for 180 days before processing.
   - The high-heat and low-heat waste streams generated during fuel reprocessing are blended in the proportion they are generated.

8. The only current regulatory requirement for the glass waste form is that it be a solid. Possible future criteria and regulations regarding the uniformity of the glass, maximum heat output, leachability limits, chemical composition, etc., may alter the scope of the project.

9. The glassform will be stored onsite in an air-cooled vault.

10. The radioactive borosilicate glass will be contained in a 2-ft-diameter, 10-ft-long steel canister. Approximately 3260 lbs of glass will be loaded into each canister filling it to approximately 80%.

11. Selection of materials of construction, particularly for items that would be very difficult to replace (such as embedded piping) should assume the DWPF will eventually be decontaminated with nitric acid.

12. This document does not address the technical bases for preparation of the feed to the DWPF (sludge slurrying, salt cake dissolution, waste tank cleaning, and excess oxalic acid digestion).

1.4 References

1. R. F. Bradley and J. C. Corey. Technical Assessment of Bedrock Waste Storage at the Savannah River Plant. USERDA Report DP-1438, E. I. du Pont de Nemours & Company (Inc.), Savannah River Laboratory, Aiken, SC (November 1976).

2. R. M. Wallace, H. L. Hull, and R. B. Bradley. Solid Forms for Savannah River Plant High-Level Waste. USERDA Report DP-1335, E. I. du Pont de Nemours & Company (Inc.), Savannah River Laboratory, Aiken, SC (December 1973).

3. A. S. Jennings. Plan for Solidification of Savannah River Plant High-Level Waste. Report CONF-771102-4, American Institute of Chemical Engineers, New York (1978).

4. J. A. Stone. Evaluation of Concrete as a Matrix for Solidification of Savannah River Plant Waste. USERDA Report DP-1448, E. I. du Pont de Nemours & Company (Inc.), Savannah River Laboratory, Aiken, SC (June 1977).

5. J. A. Kelley. Evaluation of Glass as a Matrix for Solidification of Savannah River Plant Waste. USERDA Report DP-1382, E. I. du Pont de Nemours & Company (Inc.), Savannah River Laboratory, Aiken, SC (May 1975).

6. Alternatives for Long-Term Management of Defense High-Level Radioactive Waste - Savannah River Plant. Report ERDA-77-42 (Two volumes), U.S. Energy Research and Development Administration, Washington, DC (May 1977).

7. Preliminary Technical Data Summary for the Defense-Waste Processing Facility. USDOE Report DPSTD-77-13, E. I. du Pont de Nemours & Company (Inc.), Savannah River Laboratory, Aiken, SC (August 1978).

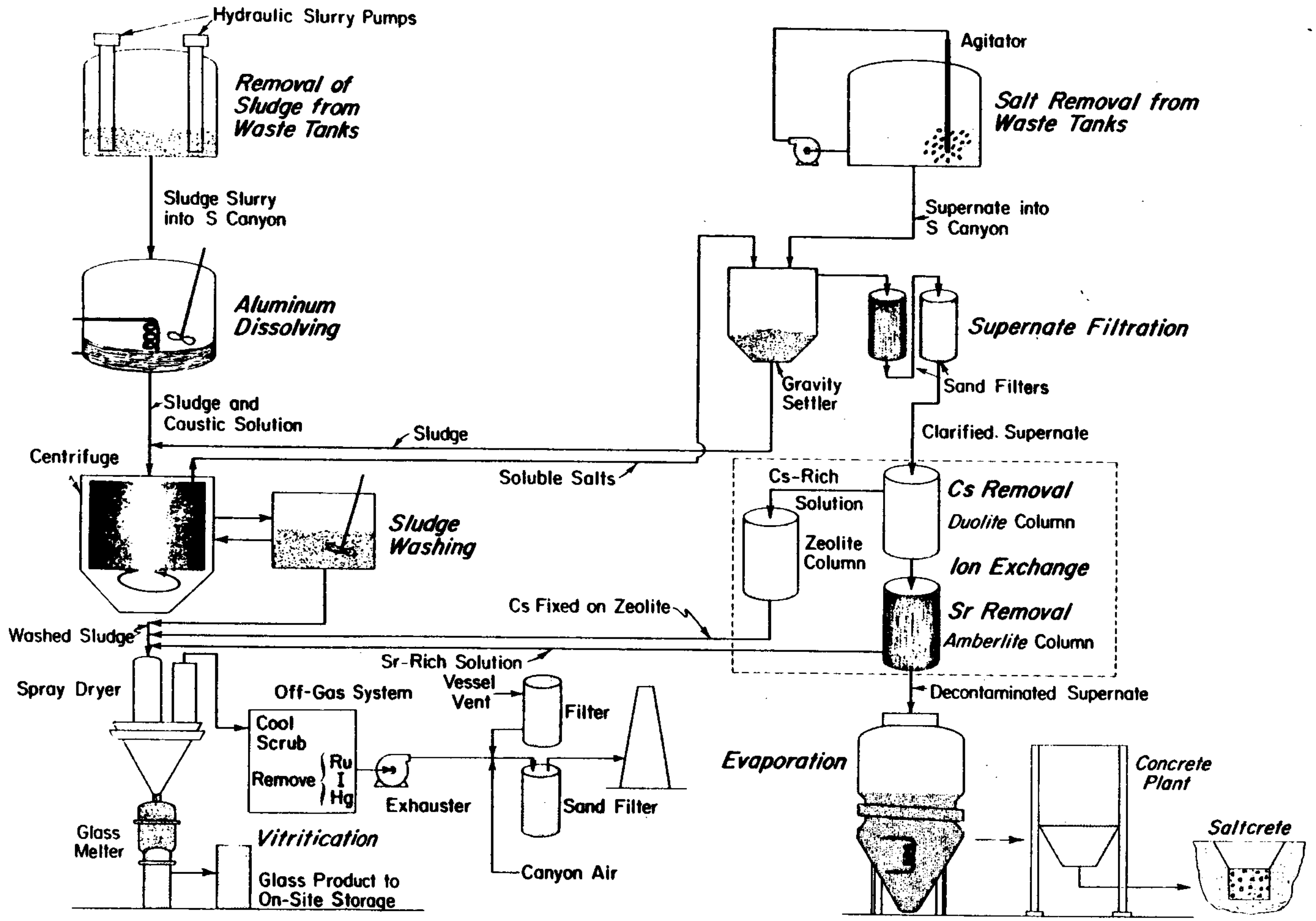


FIGURE 1.1 SRP Defense Waste Processing Reference Flowsheet

2. FEED DESCRIPTION

2.1 General

The high- and low-heat acidic waste generated from the separations processes (Appendix 13.1) are neutralized with sodium hydroxide prior to transfer to interim storage. Neutralization of the wastes causes precipitation of insoluble compounds (sludge) of stable and radioactive fission products, actinide elements, and elements added in the processes, primarily Fe, Mn, Al, and Hg. The neutralized wastes are transferred to selected underground waste tanks, according to their heat contents. After the wastes have aged (during which the insoluble fraction of the waste settles out) [1,2], the supernates are transferred to an evaporator for dewatering. The concentrate from the evaporator is transferred to cooled waste tanks where the cooling causes the salt to crystallize. Fresh neutralized waste has been added to the sludge heel in some tanks, and there has been some mixing of high- and low-heat waste sludges. In other cases sludge has been removed from several tanks and transferred to others. Tanks from which sludge has been removed have been used to retain salt from the concentration of supernate. Thus, sludge composition and characteristics are variable and are not only a function of sludge source and age, but are affected by waste management practices. Variations can occur not only from tank to tank but also within a tank as a function of location and depth.

2.2 Feed Composition

2.2.1 Chemical Composition (A. J. Hill, J. R. Wiley)

Table 2.1 summarizes the chemical composition of the soluble and insoluble fractions of the two waste streams that comprise the feed to the processing facility. The detailed bases for calculating these compositions are presented in Chapter 4 and Appendix 13.2.

2.2.2 Radionuclide Composition (J. R. Chandler)

The concentration of radionuclides in the supernate and sludge-slurry feed streams for 5 and 15-year-old waste are tabulated in Tables 2.3 through 2.10. The distribution of radionuclides between gravity-settled, in-tank sludge and supernate are tabulated in Table 2.11. The bases for radionuclide composition calculations are outlined in detail in Chapter 7.

2.3 Sludge Description (A. J. Hill, J. A. Stone)

2.3.1 General[1]

Insoluble solids represent 7.3 volume percent of the neutralized wastes transferred from the Separation Facilities to the waste tank farm. During aging, the sludge settles to the bottom of the waste tank. About three-fourths of the settled sludge is compacted into a sticky, dark brown, gelatinous mass. The remainder is loosely settled, finely divided material of essentially the same composition. Sludge, as sampled, is a mixture of water soluble salts, insoluble solids, and interstitial liquid. Following centrifugation and drying, approximately 70-80% of the sludge is a complex mixture of oxides and hydroxides of manganese, iron, and aluminum, plus uranium, mixed fission products, and actinides.

2.3.2 Characteristic Types of Sludge

The plant feed represents a weighted average or composite composition based on individual tank analyses. It is important to recognize that this composition assumes perfect blending of the sludge in storage in both areas and that reported sludge analyses from a given tank approximate the composition of the entire tank.

2.3.3 Chemical Components of Sludge

The representative elemental composition of SRP sludge is listed in Table 2.12. More detailed analyses for sludges from several SRP tanks are shown in Appendix 13.3 and Reference 3.

2.3.4 Physical Properties

2.3.4.1 Density

A density of 1.369 g/cc for in-tank settled sludge was used in calculating the reference feed.

2.3.4.2 Viscosity

The viscosity of sludge suspensions in supernate have been measured as a function of the volume ratio of sludge to supernate. For these tests synthetic supernate and synthetic sludge were used to represent the characteristics of early samples of sludge from Tanks 12 and 14. The results are shown in Figure 2.1.

Viscosity data on actual sludge are summarized in Table 2.13. Apparently, viscosities of 1:1 mixtures of centrifuged sludge and supernate may vary from 10 to 100 cp depending on the sludge type.

2.3.4.3 Settling Velocity

In early studies of the properties of sludge [5], a sample from Tank 12H was slurried with supernate (specific gravity = 1.25) and allowed to settle. The observed settling rate for the major portion of the sludge was 6 in./hr while that of the finer material was 1 in./hr. The settled volume of sludge was 25% of the total mixture and the volume of sludge after centrifugation was about half the settled volume [5]. Settling rates in dilute sodium hydroxide for early samples of sludge from Tanks 2 and 9 are shown in Figure 2.2. The as-received sludge was stirred vigorously in a graduated cylinder and allowed to settle. The sludges settled with a very sharp interface between sludge and supernate, with no tail of fines extending into the interface [4]. However, this sharp interface was not observed following sludge transfer from Tank 11H to 13H (Figure 2.3). The settling behavior will be dependent on the specific gravity of the supernate. The data in Figure 2.2 should be applied only to settling behavior in wash water or in dilute tank rinses.

In recent settling tests with washed Tank 16H sludge, repetitive tests showed good reproducibility of sludge settling rates. The sludge settled fairly rapidly at first, but the settling rate diminished with time. The initial volume ratio of water/sludge was 9:1. Average settling rates were about 15 in./hr for the first 10 minutes, about 4 in./hr for the first hour, and about 0.3 in./hr for 16 hours. No significant change in the volume of settled sludge was observed after 16 hours.

2.4 Supernate Description (R. S. Ondrejcin)

2.4.1 General

Supernate solution from about half of the waste tanks at SRP has been sampled and characterized [6,7]. Table 2.14 lists the concentration of major components of the supernate. Detailed analyses for major chemical components in supernate samples taken since 1972 are shown in Appendix 13.4 Minor ions which have also been identified in the supernate are PO_4^{3-}, Cl^-, CrO_4^{2-}, and NH_4^+. Trace metals in the supernate are Fe, Hg, Ag, Pb, and U. Analyses of trace elements are available in Reference 6.

2.4.2 Density

A density of 1.242 g/cc for in-tank supernate was used for calculating reference feed. See Appendix 13.1 for a detailed description for calculating the density of supernate.

2.4.3 Viscosity

The viscosity of the reference waste tank supernate is about 2 cp.

TABLE 2.1

Chemical Composition of Soluble and Insoluble Fraction of DWPF Feed (Dry Basis)

	lb/hr	
	Solubles	Insolubles
Sludge-Slurry Feed[a]	144.2	103.1
Supernate Feed[b]	1975	1.302

Soluble Solids, wt %		Insoluble Solids, wt %	
$NaNO_3$	4.69+01[c]	$Fe(OH)_3$	3.85+01
$NaNO_2$	1.80+01	$UO_2(OH)_2$	2.91
$NaAlO_2$	9.71	$CaCO_3$	3.82
$NaOH$	7.24	$Ni(OH)_2$	4.42
Na_2CO_3	7.54	Na_2O	1.93
Na_2SO_4	1.01+01	$NaNO_3$	1.14
$Na_2C_2O_4$[d]	1.23-01	Na_2SO_4	6.15-01
$NaCl$	3.05-01	MnO_2	7.58
NaF	1.99-02	$Hg(OH)_2$	1.16
$Na[HgO(OH)]$	6.08-02	$NaCl$	1.23
		NaF	1.29-01
		C	1.31
		$Al(OH)_3$	3.44+01
		SiO_2	5.62-01
		HgI_2	3.13-01

---

a. Actual sludge contains 1.95 lb suspended solids per gallon with a specific gravity of 1.37. Dissolved salts are present at $\sim$29% by weight, exclusive of suspended solids. Sludge-slurry feed is prepared by slurrying with water such that the resulting volume is twice the sludge volume.

b. Supernate feed is constituted to $\sim$29 wt % salt solution by dissolving the salt cake in the tank with recycle water.

c. Modified scientific notation used throughout this report. For example, 4.69+01 is equivalent to 4.69×10^1; i.e., 46.9.

d. Not accounted for in supernate fraction of sludge-slurry feed.

Table 2.2 (Deleted)

TABLE 2.3
ISOTOPIC CONTENT (g/gal) OF SUPERNATE
FEED STREAM – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	5.89525E-08	PD104	5.45252E-05	TE129	7.82654E-25	SM148	4.93794E-05
CR 51	7.20001E-27	PD105	4.29982E-04	TE129M	8.46959E-22	SM149	1.92622E-05
CO 60	2.45861E-07	PD106	2.74278E-04	TE130	7.11931E-04	SM150	2.73170E-04
SE 77	2.34317E-06	PD107	1.32501E-04	I127	8.15234E-05	SM151	2.45551E-05
SE 76	5.90207E-06	PD108	7.74233E-05	I129	3.40422E-04	SM152	9.85978E-05
SE 79	1.45546E-05	PD110	2.63963E-05	I131	4.87467E-73	SM154	1.75028E-05
SE 80	3.46955E-05	AG109	4.32231E-05	CS133	4.71463E-02	EU151	6.35689E-07
SE 82	7.00294E-05	AG110	2.00491E-08	CS134	3.32156E-04	EU152	3.41649E-08
RB 85	7.31481E-05	CD110	3.73666E-06	CS135	5.86465E-03	EU153	3.36439E-05
RB 87	1.79578E-04	CD111	1.76417E-05	CS136	1.56331E-47	EU154	3.76144E-06
SR 86	2.60386E-04	CD112	1.21651E-05	CS137	4.16426E-02	EU155	1.67267E-06
SR 89	3.13389E-15	CD113	6.32857E-07	BA134	1.44997E-03	EU156	1.55721E-42
SR 90	3.74776E-04	CD114	1.98455E-05	BA136	1.51652E-04	TB159	5.42166E-07
Y 89	3.48578E-04	CD115M	2.68641E-19	BA136M	1.37176E-54	TB160	2.63071E-16
Y 90	9.75206E-08	CD116	9.17082E-06	BA137	7.72570E-03	TL208	2.68247E-17
Y 91	6.66434E-14	SN116	6.51607E-07	BA137M	6.34522E-09	U232	3.90574E-10
ZR 90	5.15140E-05	SN117	3.37478E-06	BA138	5.09188E-02	U234	1.20448E-06
ZR 91	4.09184E-04	SN118	2.62604E-06	BA140	5.87559E-46	U235	4.05306E-05
ZR 92	4.19938E-04	SN119	3.52166E-06	LA139	1.13767E-03	U236	2.92622E-05
ZR 93	7.29932E-04	SN120	3.65353E-06	LA140	2.06285E-48	U238	1.41040E-03
ZR 94	4.66272E-04	SN121M	1.46951E-09	CE140	1.12136E-03	NP236	2.14331E-12
ZR 95	7.68847E-13	SN122	4.08299E-06	CE141	3.34602E-21	NP237	2.04587E-05
ZR 96	4.68026E-04	SN123	6.57041E-11	CE142	1.05489E-03	PU236	1.93078E-10
NB 95	8.89325E-13	SN124	6.11712E-06	CE144	8.20636E-06	PU237	6.15945E-22
NB 95M	5.38151E-16	SN125	4.94325E-64	PR141	1.05132E-03	PU238	7.15915E-05
MO 95	5.09149E-04	SN126	1.41136E-05	PR143	4.72394E-45	PU239	1.86605E-04
MO 96	2.06666E-06	SB121	3.79571E-06	PR144	3.46272E-10	PU240	3.20852E-05
MO 97	4.86733E-04	SB123	4.80387E-06	PR144M	1.73133E-12	PU241	1.35769E-05
MO 98	4.91314E-04	SB124	1.08577E-17	ND142	3.73495E-06	PU242	2.54196E-06
MO100	5.34808E-04	SB125	2.14273E-06	ND143	1.25493E-03	AM241	5.13625E-06
TC 99	1.66231E-02	SB126	6.71291E-14	ND144	1.07845E-03	AM242	2.87562E-14
RU100	1.50895E-04	SB126M	5.10195E-16	ND145	6.93789E-04	AM242M	2.40517E-09
RU101	1.44092E-02	TE122	1.55474E-07	ND146	5.63026E-04	AM243	4.70564E-08
RU102	1.26265E-02	TE124	7.24783E-06	ND147	4.16571E-55	CM242	1.72361E-11
RU103	4.07205E-17	TE125	1.65511E-05	ND148	3.25682E-04	CM243	1.75277E-10
RU104	6.23417E-03	TE125M	8.20366E-06	ND150	1.30493E-04	CM244	3.27954E-09
RU106	5.10101E-05	TE126	7.19572E-07	PM147	6.91562E-05	CM245	6.28714E-11
RH103	1.33393E-04	TE127	2.44395E-13	PM148	1.12282E-21	CM246	2.81232E-12
RH103M	8.00689E-20	TE127M	6.98094E-11	PM148M	1.25211E-19	CM247	1.14468E-14
RH106	4.78396E-11	TE128	1.96634E-04	SM147	2.22793E-04	CM248	2.61397E-16

TABLE 2.4
ISOTOPIC CONTENT (g/gal) OF SUPERNATE FEED STREAM – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.34971E-08	RH103M	1.37415E-47	TE127	1.99912E-23	SM150	2.73170E-04
CR 51	2.02560E-66	RH106	5.01282E-14	TE127M	5.71033E-21	SM151	2.27904E-05
CO 60	6.57651E-13	PD104	5.45252E-05	TE128	1.96634E-04	SM152	9.85978E-05
SE 77	2.34317E-06	PD105	4.29982E-04	TE129	9.42054E-58	SM154	1.75028E-05
SE 78	5.90207E-06	PD106	2.80588E-04	TE129M	1.01945E-54	EU151	1.72727E-06
SE 79	1.45570E-05	PD107	1.32501E-04	TE130	7.11931E-04	EU152	2.00383E-08
SE 80	3.46955E-05	PD108	7.74233E-05	I127	8.15235E-05	EU153	3.36439E-05
SE 82	7.00294E-05	PD110	2.63963E-05	I129	3.40421E-04	EU154	1.67911E-06
BR 85	7.31431E-05	AG109	4.32231E-05	CS133	4.71463E-02	EU155	3.94298E-07
RB 87	1.79578E-04	AG110	8.68945E-13	CS134	1.04453E-05	TB159	5.42166E-07
SR 88	2.60386E-04	CD110	3.75665E-06	CS135	5.86463E-03	TB160	1.63081E-31
SR 89	2.74720E-36	CD111	1.76417E-05	CS137	3.30772E-02	TL208	5.73507E-17
SR 90	2.92849E-04	CD112	1.21651E-05	BA134	1.74157E-03	U232	5.16646E-10
Y 89	3.48578E-04	CD113	8.32857E-07	BA136	1.51652E-04	U234	1.20444E-06
Y 90	7.62023E-08	CD114	1.98459E-05	BA137	1.62910E-02	U235	4.05300E-05
Y 91	1.15019E-32	CD115M	5.97311E-44	BA137M	5.04007E-09	U236	2.92622E-05
ZR 90	1.28205E-04	CD116	9.17082E-06	BA138	5.09188E-02	U238	1.41040E-03
ZR 91	4.09184E-04	SN116	6.51607E-07	LA139	1.13767E-03	NP236	2.14318E-12
ZR 92	4.19938E-04	SN117	3.37478E-06	CE140	1.12136E-03	NP237	2.04586E-05
ZR 93	7.29927E-04	SN118	3.62604E-06	CE141	5.30388E-55	PU236	1.69760E-11
ZR 94	4.66272E-04	SN119	3.52166E-06	CE142	1.05488E-03	PU237	4.93512E-46
ZR 95	1.25723E-29	SN120	3.65353E-06	CE144	1.11708E-09	PU238	6.61539E-05
ZR 96	4.68026E-04	SN121M	1.27916E-09	PR141	1.05132E-03	PU239	1.86551E-04
NB 95	1.45260E-29	SN122	4.08299E-06	PR144	4.71356E-14	PU240	3.20513E-05
NB 95M	8.79994E-33	SN123	2.57020E-19	PR144M	2.35673E-16	PU241	8.47257E-06
MO 95	5.09149E-04	SN124	6.11712E-06	ND142	3.73495E-06	PU242	2.54194E-06
MO 96	2.06666E-06	SN126	1.41135E-05	ND143	1.25493E-03	AM241	1.01151E-05
MO 97	4.86733E-04	SB121	3.79590E-06	ND144	1.08665E-03	AM242	2.74742E-14
MO 98	4.91314E-04	SB123	4.80395E-06	ND145	6.93789E-04	AM242M	2.29796E-09
MO100	5.34808E-04	SB124	5.90894E-36	ND146	5.63026E-04	AM243	4.70122E-08
TC 99	1.66226E-02	SB125	1.69159E-07	ND148	3.25682E-04	CM242	5.56478E-12
RU100	1.50895E-04	SB126	6.71286E-14	ND150	1.30493E-04	CM243	1.37435E-10
RU101	1.44092E-02	SB126M	5.10192E-16	PM147	4.92240E-06	CM244	2.23659E-09
RU102	1.26265E-02	TE122	1.55474E-07	PM148	2.67771E-48	CM245	6.28201E-11
RU103	6.98953E-45	TE124	7.24783E-08	PM148M	2.98603E-46	CM246	2.80820E-12
RU104	6.23417E-03	TE125	2.19460E-05	SM147	2.87026E-04	CM247	1.14488E-14
RU106	5.34504E-08	TE125M	6.47640E-09	SM148	4.93794E-05	CM248	2.61396E-16
RH103	1.33393E-04	TE126	7.19835E-07	SM149	1.92622E-05		

TABLE 2.5
ISOTOPIC CONTENT (Ci/gal) OF SUPERNATE FEED STREAM – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	5.69875E-04	SN123	7.05606E-07	CE144	2.61808E-02	U236	1.89277E-09
CR 51	6.62605E-22	SN126	4.01010E-08	PR143	3.17835E-40	U238	4.74015E-10
CO 60	2.78994E-04	SB124	1.90069E-13	PR144	2.61818E-02	NP236	2.82332E-14
SE 79	1.01533E-06	SB125	2.24646E-03	PR144M	3.14175E-04	NP237	1.44182E-08
RB 87	1.57274E-11	SB126	5.61413E-09	ND144	1.27660E-15	PU236	1.02570E-07
SR 89	8.85125E-11	SB126M	4.01010E-08	ND147	3.36888E-50	PU237	7.43564E-18
SR 90	5.30323E-02	TE125M	1.47664E-03	PM147	6.41564E-02	PU238	1.22526E-03
Y 90	5.30461E-02	TE127	6.45470E-07	PM148	1.84578E-16	PU239	1.15964E-05
Y 91	1.63352E-09	TE127M	6.58979E-07	PM148M	2.67630E-15	PU240	7.29517E-06
ZR 93	2.95860E-06	TE129	1.63089E-17	SM147	5.07009E-12	PU241	1.36979E-03
ZR 95	1.61495E-08	TE129M	2.56864E-17	SM148	1.49283E-17	PU242	9.70113E-09
NB 95	3.48201E-08	I129	5.94166E-08	SM149	4.62734E-18	AM241	1.76289E-05
NB 95M	2.05098E-10	CS134	3.91591E-11	SM151	6.25860E-04	AM242	2.32537E-08
TC 99	2.81817E-04	CS135	6.76164E-06	EU152	6.18836E-06	AM242M	2.33703E-08
RU103	1.30498E-12	CS136	1.15537E-42	EU154	1.01653E-03	AM243	9.39112E-09
RU106	1.70437E-01	CS137	3.61259E 00	EU155	6.04696E-04	CM242	5.70770E-08
RH103M	2.61253E-12	BA136M	3.69717E-43	EU156	8.57935E-38	CM243	9.04578E-09
RH106	1.70437E-01	BA137M	3.41751E 00	TB160	2.97083E-12	CM244	2.65262E-07
PD107	6.82159E-08	BA140	4.28737E-41	TL208	7.89875E-09	CM245	1.08222E-11
AG110	9.45216E-05	LA140	1.14653E-42	U232	8.39298E-09	CM246	8.63840E-13
CD115M	6.84483E-15	CE141	9.53168E-17	U234	7.52260E-09	CM247	1.06192E-18
SN121M	8.69614E-08	CE142	2.53263E-11	U235	8.75922E-11	CM248	1.10894E-18

TOTAL ACTIVITY 8.00 00 Ci/gal

TOTAL HEAT GENERATION, watts/gal

Primary	6.22-03
Gamma	1.60-02

TABLE 2.6
ISOTOPIC CONTENT (Ci/gal) OF SUPERNATE FEED STREAM – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.23806E-04	SN121M	7.56972E-06	PR144	3.56394E-06	NP236	2.82315E-14
CO 60	7.46279E-05	SN123	2.11667E-15	PR144M	4.27665E-08	NP237	1.44181E-08
SE 79	1.01522E-06	SN126	4.01006E-08	ND144	1.28632E-15	PU236	9.01829E-09
RB 87	1.57274E-11	SB124	1.02438E-31	PM147	4.56652E-03	PU237	5.95764E-42
SR 89	6.34690E-32	SB125	1.77348E-04	PM148	4.40181E-43	PU238	1.13220E-03
SR 91	4.14393E-02	SB126	5.61409E-09	PM148M	6.38243E-42	PU239	1.15931E-05
Y 90	4.14501E-02	SB126M	4.01007E-08	SM147	6.53185E-12	PU240	7.28746E-06
Y 91	2.81926E-28	TE125M	1.16732E-04	SM148	1.49283E-17	PU241	8.54807E-04
ZR 93	2.95858E-06	TE127	5.27987E-17	SM149	4.62734E-18	PU242	9.70102E-09
ZR 95	2.64080E-25	TE127M	5.39038E-17	SM151	5.80880E-04	AM241	3.47174E-05
NB 95	5.69385E-25	TE129	1.96305E-50	EU152	3.62958E-06	AM242	2.22171E-08
NB 95M	3.35379E-27	TE129M	3.09177E-50	EU154	4.53783E-04	AM242M	2.23285E-08
TC 99	2.81808E-04	I129	5.94186E-08	EU155	1.89691E-04	AM243	9.38229E-09
RU103	2.23962E-40	CS134	1.35371E-02	TB160	1.84166E-27	CM242	1.84276E-08
RU106	1.78591E-04	CS135	6.76161E-06	TL208	1.68874E-08	CM243	7.09283E-09
RH103M	4.48364E-40	CS137	2.86952E 00	U232	1.11021E-08	CM244	1.80904E-07
RH106	1.78591E-04	BA137M	2.71456E 00	U234	7.52178E-09	CM245	1.08133E-11
PD107	6.82159E-08	CE141	1.51089E-50	U235	8.75922E-11	CM246	8.62574E-13
AG110	4.09665E-09	CE142	2.53263E-11	U236	1.89277E-09	CM247	1.06192E-18
CD115M	1.52191E-39	CE144	3.56381E-06	U238	4.74015E-10	CM248	1.10894E-18

TOTAL ACTIVITY 5.69 00 Ci/gal

TOTAL HEAT GENERATION, watts/gal

Primary	3.30-03
Gamma	9.71-03

TABLE 2.7
ISOTOPIC CONTENT (g/gal) OF SLUDGE-SLURRY FEED STREAM – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.70466E-07	PD104	4.83295E-03	TE129	6.93722E-23	SM148	1.22578E-02
CR 51	6.38187E-25	PD105	3.81124E-02	TE129M	7.50720E-20	SM149	4.78161E-03
CO 60	9.95035E-05	PD106	2.43112E-02	TE130	6.31034E-02	SM150	6.78112E-02
SE 77	2.07692E-04	PD107	1.17445E-02	I127	7.22599E-03	SM151	6.09551E-03
SE 78	5.23142E-04	PD108	6.86257E-03	I129	3.01740E-02	SM152	2.44757E-02
SE 79	1.29043E-03	PD110	2.33969E-03	I131	4.32077E-71	SM154	4.24485E-03
SE 80	3.07531E-03	AG109	3.83117E-03	CS133	1.89362E-02	EU151	2.57273E-04
SE 82	6.20719E-03	AG110	1.77709E-06	CS134	1.21367E-04	EU152	1.38270E-05
RB 85	2.76799E-02	CD110	3.31206E-04	CS135	2.35553E-03	EU153	1.36162E-02
RB 87	6.79539E-02	CD111	1.56371E-03	CS136	6.27902E-48	EU154	1.52231E-03
SR 88	9.85327E-02	CD112	1.07828E-03	CS137	1.67257E-02	EU155	6.76956E-04
SR 89	1.18589E-12	CD113	7.38220E-05	BA134	5.82338E-04	EU156	6.30229E-40
SR 90	1.41819E-01	CD114	1.75904E-03	BA136	6.09109E-05	TB159	1.34586E-04
Y 89	1.31905E-01	CD115M	2.38115E-17	BA136M	5.50966E-55	TB160	6.53043E-14
Y 90	3.69028E-05	CD116	8.12874E-04	BA137	3.10302E-03	TL208	2.37766E-15
Y 91	2.52185E-11	SN116	1.61754E-04	BA137M	2.54855E-09	U232	1.58071E-07
ZR 90	2.08485E-02	SN117	6.37749E-04	BA138	2.04515E-02	U234	4.87471E-04
ZR 91	1.65603E-01	SN118	9.00120E-04	BA140	2.35992E-46	U235	1.64031E-02
ZR 92	1.69955E-01	SN119	8.74210E-04	LA139	2.82413E-01	U236	1.18429E-02
ZR 93	2.95415E-01	SN120	9.06945E-04	LA140	5.12079E-46	U238	5.70811E-01
ZR 94	1.88708E-01	SN121M	3.64787E-07	CE140	2.78364E-01	NP236	8.67431E-10
ZR 95	3.11164E-10	SN122	1.01355E-03	CE141	8.30610E-19	NP237	8.27994E-03
ZR 96	1.89417E-01	SN123	2.12750E-08	CE142	2.61861E-01	PU236	7.81415E-08
NB 95	3.59518E-10	SN124	1.51850E-03	CE144	2.03713E-03	PU237	2.49282E-19
NB 95M	2.17798E-13	SN125	1.22710E-61	PR141	2.60977E-01	PU238	2.89741E-02
MO 95	1.92667E-01	SN126	3.50353E-03	PR143	1.17266E-42	PU239	7.55218E-02
MO 96	7.82046E-04	SB121	9.42239E-04	PR144	8.59578E-08	PU240	1.29854E-02
MO 97	1.84184E-01	SB123	1.19250E-03	PR144M	4.29781E-10	PU241	5.49478E-03
MO 98	1.85918E-01	SB124	2.69530E-15	ND142	9.27157E-04	PU242	1.02877E-03
MO100	2.02377E-01	SB125	5.31908E-04	ND143	3.11523E-01	AM241	2.07872E-03
TC 99	1.02264E-01	SB126	1.66640E-11	ND144	2.67712E-01	AM242	1.16381E-11
RU100	9.28294E-04	SB126M	1.26650E-13	ND145	1.72225E-01	AM242M	9.73410E-07
RU101	8.86437E-02	TE122	1.37807E-05	ND146	1.39764E-01	AM243	1.90445E-05
RU102	7.76770E-02	TE124	6.42426E-06	ND147	1.03409E-52	CM242	6.97572E-09
RU103	2.50546E-16	TE125	1.46704E-03	ND148	8.08465E-02	CM243	7.09371E-08
RU104	3.83520E-02	TE125M	7.27146E-06	ND150	3.23934E-02	CM244	1.32728E-06
RU106	3.13809E-04	TE126	6.37807E-05	PM147	1.71672E-02	CM245	2.54450E-08
RH103	8.20622E-04	TE127	2.16624E-11	PM148	2.78727E-19	CM246	1.13819E-09
RH103M	4.92577E-19	TE127M	6.18769E-09	PM148M	3.10821E-17	CM247	4.63352E-12
RH106	2.94305E-10	TE128	1.74291E-02	SM147	5.53057E-02	CM248	1.05791E-13

TABLE 2.8
ISOTOPIC CONTENT (g/gal) OF SLUDGE-SLURRY FEED STREAM – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	9.68593E-09	RH103M	8.45365E-47	TE127	1.77197E-21	SM150	6.78112E-02
CR 51	1.79543E-64	RH106	3.08384E-13	TE127M	5.06147E-19	SM151	5.65743E-03
CO 60	2.66162E-05	PD104	4.83295E-03	TE128	1.74291E-02	SM152	2.44757E-02
SE 77	2.07692E-04	PD105	3.81124E-02	TE129	8.35009E-56	SM154	4.34485E-03
SE 78	5.23142E-04	PD106	2.48705E-02	TE129M	9.03615E-53	EU151	6.59052E-04
SE 79	1.29029E-03	PD107	1.17445E-02	TE130	6.31034E-02	EU152	8.10982E-06
SE 80	3.07531E-03	PD108	6.86257E-03	I127	7.22600E-03	EU153	1.36162E-02
SE 82	6.20719E-03	PD110	2.33969E-03	I129	3.01739E-02	EU154	6.79564E-04
RB 85	2.76799E-02	AG109	3.83117E-03	CS133	1.89362E-02	EU155	1.59578E-04
RB 87	6.79539E-02	AG110	7.70207E-11	CS134	4.19536E-06	TB159	1.34586E-04
SR 88	9.85327E-02	CD110	3.32976E-04	CS135	2.35552E-03	TB160	4.04830E-29
SR 89	8.50361E-34	CD111	1.56371E-03	CS137	1.32854E-02	TL208	5.08340E-15
SR 90	1.10817E-01	CD112	1.07828E-03	BA134	6.99501E-04	U232	2.09095E-07
Y 89	1.31905E-01	CD113	7.38220E-05	BA136	6.09108E-05	U234	4.87457E-04
Y 90	2.88357E-05	CD114	1.75904E-03	BA137	6.54329E-03	U235	1.64931E-02
Y 91	4.35242E-30	CD115M	5.29438E-42	BA137M	2.02434E-09	U236	1.18429E-02
ZR 90	5.18864E-02	CD116	8.12874E-04	BA138	2.04515E-02	U238	5.70811E-01
ZR 91	1.65603E-01	SN116	1.61754E-04	LA139	2.82413E-01	NP236	8.67378E-10
ZR 92	1.69955E-01	SN117	8.37749E-04	CE140	2.78364E-01	NP237	8.27992E-03
ZR 93	2.95412E-01	SN118	9.00120E-04	CE141	1.31662E-52	PU236	6.87045E-09
ZR 94	1.88708E-01	SN119	8.74210E-04	CE142	2.61861E-01	PU237	1.99732E-43
ZR 95	5.08821E-27	SN120	9.06545E-04	CE144	2.77301E-07	PU238	2.67735E-02
ZR 96	1.89417E-01	SN121M	3.17536E-07	PR141	2.60977E-01	PU239	7.55000E-02
NB 95	5.87891E-27	SN122	1.01355E-03	PR144	1.17008E-11	PU240	1.29717E-02
NB 95M	3.56147E-30	SN123	6.38023E-17	PR144M	5.85031E-14	PU241	3.42898E-03
MO 95	1.92667E-01	SN124	1.51850E-03	ND142	9.27157E-04	PU242	1.02876E-03
MO 96	7.82046E-04	SN126	3.50350E-03	ND143	3.11523E-01	AM241	4.09371E-03
MO 97	1.84184E-01	SB121	9.42286E-04	ND144	2.69749E-01	AM242	1.11192E-11
MO 98	1.85918E-01	SB123	1.19252E-03	ND145	1.72225E-01	AM242M	9.30018E-07
MO100	2.02377E-01	SB124	1.46682E-33	ND146	1.39764E-01	AM243	1.90265E-05
TC 99	1.02260E-01	SB125	4.19917E-05	ND148	8.08465E-02	CM242	2.25215E-09
RU100	9.28294E-04	SB126	1.66639E-11	ND150	3.23934E-02	CM243	5.56221E-08
RU101	8.86437E-02	SB126M	1.26649E-13	PM147	1.22193E-03	CM244	9.05181E-07
RU102	7.76770E-02	TE122	1.37807E-05	PM148	6.64709E-46	CM245	2.54242E-08
RU103	4.29989E-44	TE124	6.42426E-06	PM148M	7.41247E-44	CM246	1.13652E-09
RU104	3.83520E-02	TE125	1.94523E-03	SM147	7.12509E-02	CM247	4.63352E-12
RU106	3.28822E-07	TE125M	5.74049E-07	SM148	1.22578E-02	CM248	1.05791E-13
RH103	8.20622E-04	TE126	6.38041E-05	SM149	4.78161E-03		

TABLE 2.9
ISOTOPIC CONTENT (Ci/gal) OF SLUDGE-SLURRY FEED STREAM – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.64784E-03	SN123	1.75208E-04	CE144	6.49907E 00	U236	7.66034E-07
CR 51	5.87312E-20	SN126	9.95458E-16	PR143	7.88989E-38	U238	1.91841E-07
CO 60	1.12913E-01	SB124	4.71823E-11	PR144	6.49930E 00	NP236	1.14264E-11
SE 79	8.99955E-05	SB125	5.57657E-01	PR144M	7.79902E-02	NP237	5.83525E-06
RB 87	5.95139E-09	SB126	1.39364E-06	ND144	3.16902E-13	PU236	4.15117E-05
SR 89	3.34940E-08	SB126M	9.95459E-06	ND147	8.36285E-48	PU237	3.00932E-15
SR 90	2.00679E 01	TE125M	1.31062E-01	PM147	1.59260E 01	PU238	4.95881E-01
Y 90	2.00732E 01	TE127	5.72125E-05	PM148	4.58192E-14	PU239	4.69324E-03
Y 91	6.18139E-07	TE127M	5.84099E-05	PM148M	6.64359E-13	PU240	2.95247E-03
ZR 93	1.19739E-03	TE129	1.44557E-15	SM147	1.25859E-09	PU241	5.54374E-01
ZR 95	6.53594E-06	TE129M	2.27676E-15	SM148	3.70577E-15	PU242	3.92620E-06
NB 95	1.40922E-05	I129	5.26669E-06	SM149	1.14868E-15	AM241	7.13468E-03
NB 95M	8.30062E-08	CS134	1.57282E-01	SM151	1.55362E-01	AM242	9.41114E-06
TC 99	1.73371E-03	CS135	2.71580E-06	EU152	2.50452E-03	AM242M	9.45832E-06
RU103	8.02813E-12	CS136	4.64052E-43	EU154	4.11407E-01	AM243	3.80073E-06
RU106	1.04851E 00	CS137	1.45099E 00	EU155	3.25673E-01	CM242	2.30999E-05
RH103M	1.60720E-11	BA136M	1.48496E-43	EU156	3.47220E-35	CM243	3.66097E-06
RH106	1.04851E 00	BA137M	1.37264E 00	TB160	7.37473E-10	CM244	1.07355E-04
PD107	6.04646E-06	BA140	1.72201E-41	TL208	7.00123E-07	CM245	4.37990E-09
AG110	8.37811E-03	LA140	2.85110E-40	U232	3.39678E-06	CM246	3.49609E-10
CD115M	6.06705E-13	CE141	2.36612E-14	U234	3.04427E-06	CM247	4.29777E-16
SN121M	2.15871E-05	CE142	6.28694E-09	U235	3.54499E-08	CM248	4.48806E-16

TOTAL ACTIVITY 7.70 01 Ci/gal

TOTAL HEAT GENERATION, watts/gal
Primary 2.21-01
Gamma 1.62-02

TABLE 2.10
ISOTOPIC CONTENT (Ci/gal) OF SLUDGE-SLURRY FEED STREAM – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	9.36309E-04	SN121M	1.87909E-05	PR144	8.84705E-04	NP236	1.14257E-11
CO 60	3.02031E-02	SN123	5.25437E-13	PR144M	1.06163E-05	NP237	5.83523E-06
SE 79	8.99859E-05	SN126	9.95450E-06	ND144	3.19313E-13	PU236	3.64984E-06
RB 87	5.95139E-09	SB124	2.56773E-29	PM147	1.13358E 00	PU237	2.41115E-39
SR 89	2.40173E-29	SB125	4.40244E-02	PM148	1.09270E-40	PU238	4.58217E-01
SR 90	1.56810E 01	SB126	1.39363E-06	PM148M	1.58436E-39	PU239	4.69189E-03
Y 90	1.56851E 01	SB126M	9.95452E-06	SM147	1.62146E-09	PU240	2.94935E-03
Y 91	1.06684E-25	TE125M	1.03468E-02	SM148	3.70577E-15	PU241	3.45953E-01
ZR 93	1.19738E-03	TE127	4.67993E-15	SM149	1.14868E-15	PU242	3.92615E-06
ZR 95	1.06877E-22	TE127M	4.77787E-15	SM151	1.44196E-01	AM241	1.40507E-02
NB 95	2.30439E-22	TE129	1.73998E-48	EU152	1.46895E-03	AM242	8.99159E-06
NB 95M	1.35733E-24	TE129M	2.74046E-48	EU154	1.83653E-01	AM242M	9.03668E-06
TC 99	1.73366E-03	I129	5.26669E-06	EU155	7.67706E-02	AM243	3.79716E-06
RU103	1.27780E-39	CS134	5.43714E-03	TB160	4.57169E-25	CM242	7.45794E-06
RU106	1.09867E-03	CS135	2.71579E-06	TL208	1.49685E-06	CM243	2.87058E-06
RH103M	2.75830E-39	CS137	1.15254E 00	U232	4.49320E-06	CM244	7.32145E-05
RH106	1.09867E-03	BA137M	1.09030E 00	U234	3.04418E-06	CM245	4.37632E-09
PD107	6.04645E-06	CE141	3.75061E-48	U235	3.54499E-08	CM246	3.49097E-10
AG110	3.63116E-07	CE142	6.28694E-09	U236	7.66034E-07	CM247	4.29777E-16
CD115M	1.34898E-37	CE144	8.84674E-04	U238	1.91841E-07	CM248	4.48805E-16

TOTAL ACTIVITY 3.61 01 Ci/gal

TOTAL HEAT GENERATION, watts/gal

Primary	1.23-01
Gamma	5.88-03

TABLE 2.11

Percent of Radionuclides in Gravity-Settled In-Tank Sludge[a]

Group Ident.	Radionuclides	%
I	Cs-Ba	6.8
II	Tc, Ru-Rh	52.8
III	Ag, Cd, I, Cr, Se, Pd, Te, Tl	94.2
IV	La, Ce-Pr, Pm, Nd, Sm, Sn-Sb, Tb	97.8
V	Sr-Y, Rb, Mo	98.6
VI	U, Pu, Am, Cm, Np, Co, Zr-Nb, Eu	98.7

---

a. See Appendix 13.9.

TABLE 2.12

Representative Elemental Composition of SRP Reference Sludge

Element	Wt %	Element	Wt %
Fe	20.1	Na	2.50
Al	11.9	Si	0.26
Mn	4.79[a]	NO_3^-	0.83
U	2.28	SO_4^{2-}	0.42
Ca	1.53	Cl	0.75
Ni	2.80	F	0.058
Hg	1.13	C	1.31

---

a. Includes the manganese used during digestion of the sodium oxalate generated during tank cleaning.

TABLE 2.13

Viscosity of SRP Sludge

Condition	n, cp	Temp, °C
Sample from Tank 12H Settling Tests	10	25
Sample from Tank 12H, Centrifuged and Mixed with Equal Volume Supernate[4]	70	25
Sample from Bottom of Tank 14H, Centrifuged and Mixed with Equal Volume Supernate[5]	15	-

TABLE 2.14

Concentration of Major Chemical Components in Reference SRP Supernate

Component	Molarity
$NaOH$	0.75
$NaNO_3$	2.2
$NaNO_2$	1.1
$NaAlO_2$	0.5
Na_2CO_3	0.3
$NaSO_4$	0.3

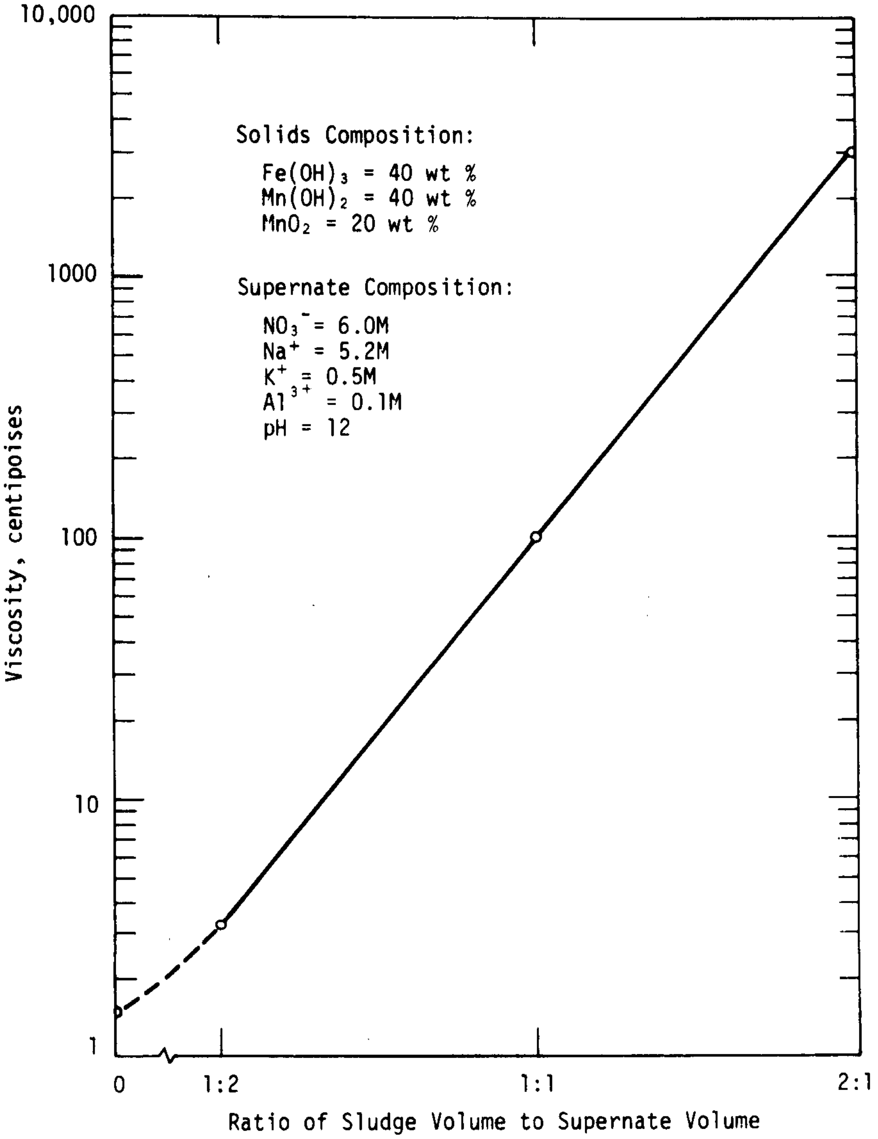
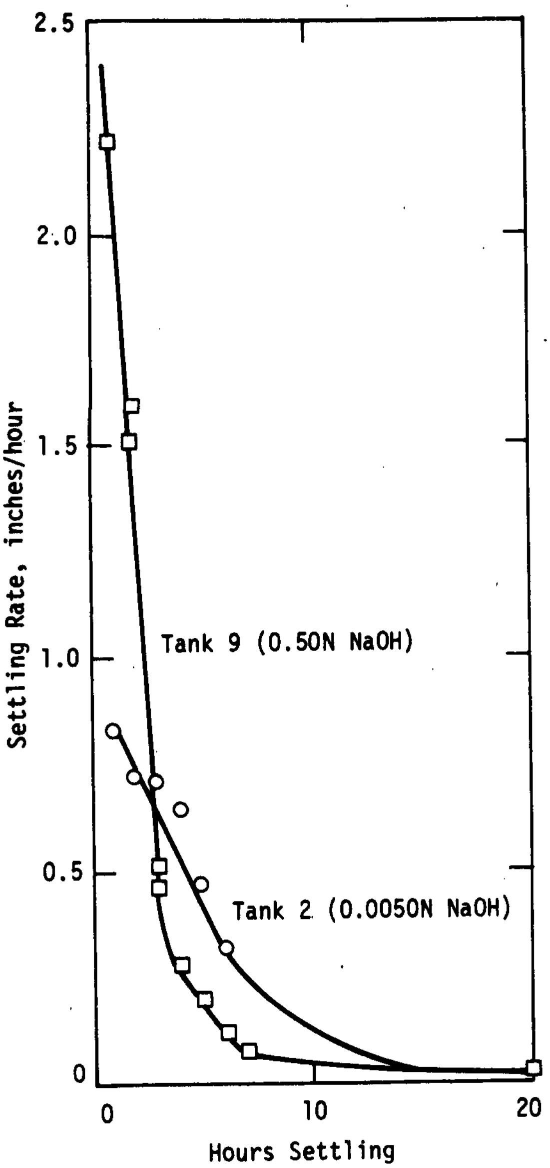


FIGURE 2.1. Effect of Sludge Concentration on Viscosity of Sludge Suspensions



Time, hr	Interface Height		Rate, in./hr
	ml	in.	
	Tank 2		
0	175	6.95	
1	154	6.12	0.83
2	136	5.40	0.72
3	118	4.69	0.71
4	102	4.05	0.64
5	90	3.58	0.47
6	82	3.26	0.32
22.5	53	2.10	~0.02
46.5	52	2.06	
118.5	51	2.02	
	Tank 9		
0	180	7.14	
1	124	4.92	2.22^a
2	85	3.37	1.55^a
3	72	2.88	0.49^a
4	65	2.58	0.28
5	60	2.38	0.20
6	57	2.26	0.12
7	55	2.18	0.08
19	40	1.59	~0.02

^{a}Average of two.

FIGURE 2.2. SRP Sludge Settling Rates

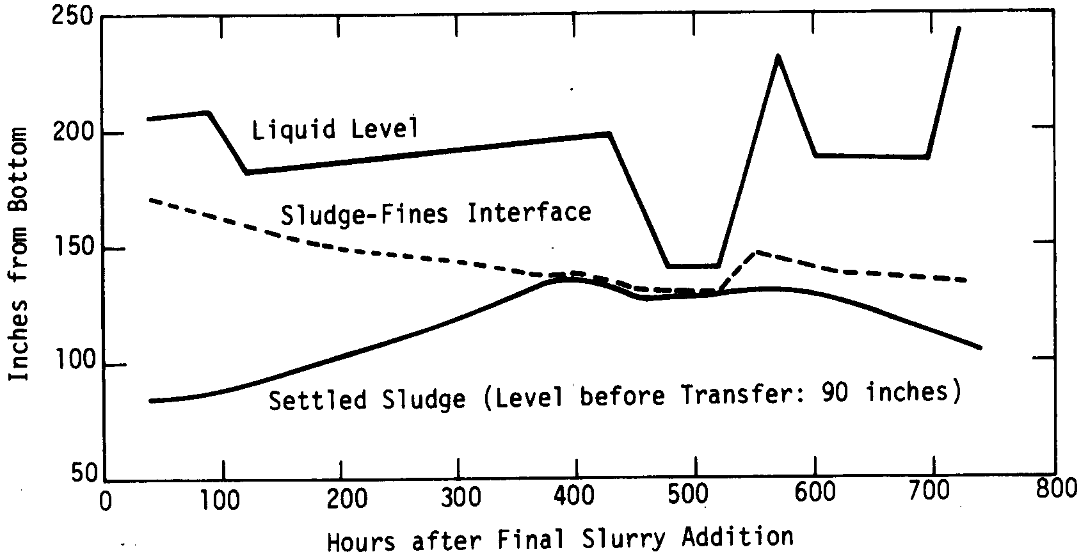


FIGURE 2.3. Sludge Settling in Waste Tank No. 13

2.5 References

1. SRP Radioactive Waste Sludge. Memorandum, H. M. Kelley to J. A. Porter. Internal Report DPST-73-222, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (January 1973).

2. R. M. Wallace, H. L. Hull, and R. F. Bradley. Solid Forms for Savannah River High-Level Wastes. USERDA Report DP-1335, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (December 1973).

3. J. A. Stone. Detailed Analyses of SRP High-Level Waste Sludges. Internal Report DPST-76-425, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (February 1961).

4. Examination of Solids from Tank 12H. Memorandum M. D. Snyder to V. P. Thayer. Internal Report DPST-61-186, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (February 1961).

5. M. D. Snyder. Examination of Solids from Waste. Internal Report DPST-61-121, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (January 1961).

6. R. S. Ondrejcin. Chemical Compositions of Supernate Stored in SRP High Level Waste Tanks. USERDA Report DP-1347, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (August 1974).

7. J. R. Wiley and R. M. Wallace. Removal of Cesium from Savannah River Plant Waste Supernate. USERDA Report DP-1388, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (July 1975).

3. PRODUCT DESCRIPTION

3. PRODUCT DESCRIPTION

3.1 Glass

The purpose of this section is to describe the composition and properties of SRP high level waste glass. As currently planned, the waste glass product will be produced by melting composite dried sludge and glass frit in a Joule-heated ceramic melter. The molten glass will be poured into a 2 x 10 ft canister. This section addresses only the properties of the vitrified product and not those of the entire package. The subjects discussed herein are glass composition and general properties, sulfate phase separation, thermal stability, leachability, and radiation stability.

3.1.1 Composition and General Properties

3.1.1.1 Chemical Composition (M. J. Plodinec)

Table 3.1 lists the major components in the glass waste form based on a composite feed. The composition of the reference glass frit, Frit 131, is listed in Table 3.2.

3.1.1.2 Radionuclide Composition (J. R. Chandler)

The isotopic content and total heat generation rate for the reference waste glass are tabulated in Tables 3.3 and 3.4. The effect of storage period is shown in Figures 3.1 and 3.2. Based on 3260 lbs of waste glass per reference canister, the total activity and heat generation per canister are 1.84×10^5 Ci and 541 watts for 5-year aged waste and 1.04×10^5 Ci and 310 watts for 15-year aged waste.

3.1.1.3 Physical Properties (M. J. Plodinec)

3.1.1.3.1 Solidified Glass

Several important physical properties of the solid glass waste form are compiled in Table 3.5. For most of these, no experimental value has been determined for glasses containing SRP waste. Thus, reasonable values for similar systems reported in the literature have been included. Mechanical properties of glass have been reviewed in Reference 2.

3.1.1.3.2 Models of Physical Properties of SRP Waste Glass[a]

Models were developed to enable prediction of the thermal conductivity, specific heat, density, coefficient of expansion, refractive index, and viscosity of SRP waste glass as functions temperature. Physical properties for the reference glass product of containing composite sludge are summarized in this section. Details of the development of these models are summarized in Appendix 13.5.

Thermal Conductivity

The calculated effective thermal conductivity, as a function of temperature, is shown in Table 3.6.

Heat Capacity

Table 3.7 summarizes the calculated mean and true heat capacity of glass containing calcined composite sludge as a function of temperature.

Density

The calculated density of glass containing calcined composite sludge as a function of temperature is summarized in Table 3.8. The strain point temperature is defined as the temperature at which the viscosity of glass is about 3.2×10^8 poises.

Coefficient of Expansion

The coefficient of expansion (β_m) calculated for composite glass containing 27.5 wt % sludge at 20°C to 90°C is 2.54×10^{-5} 1/°C. The coefficient of expansion increases slowly and is nearly constant from 25°C to just below the strain point temperature (596°C). A rapid and large increase in the coefficient occurs, starting just below the strain point temperature. The calculated mean cubic expansion coefficient from above the strain point temperature to the melting temperature is 7.62×10^{-5} 1/°C.

---

[a] Data reported in this section and in Tables 3.6, 3.7, 3.8, and 3.9 were calculated based on Frit 21. Physical properties will be recalculated using the revised waste glass composition containing Frit 131.

Refractive Index

The refractive index (n_D) calculated for composite glass containing 27.5 wt % sludge with Frit No. 21 is 1.585 at 25°C. Changes in the refractive index of glass caused by temperature, are small up to the annealing point (temperature at which the viscosity is about 10^{13} poises) of the glass.

Viscosity

The viscosity (η) calculated for composite glass containing 25 wt % sludge in Frit No. 21 is tabulated in Table 3.9 over a temperature range of 850°C to 1225°C.

3.1.1.4 Microstructure (M. J. Plodinec)

The vitrified product will contain several phases. The amount of each phase will vary with sludge type, but all will probably be present to some extent.

- The glassy phase is the most important and present by far in the largest amount. This phase acts as the host matrix for the other phases and will determine most of the properties of the final waste form.

- Often nepheline ($NaAlSiO_4$) or other alkali aluminosilicate phases will be present, especially for sludges high in aluminum. These phases result from devitrification of glasses and are easily formed. This may reduce the impact strength of the glass and make it more leachable.

- Also present will be insoluble metal oxides of the formula MN_2O_4 where M is a bivalent cation (such as Fe^{2+}, Mn^{2+}, Ni^{2+}) and N is a trivalent one (such as Fe^{3+}, Mn^{3+}). These materials, called spinels, are of limited solubility in the glassy phase and will probably concentrate toward the bottom of the canister [5,6]. Spinels are usually less leachable than the glassy phase, but can cause the glass to crack if subjected to severe thermal gradients. As the aluminum content of the sludge increases the amount of spinel crystals decreases.

- One other phase may be present as well. RuO_2 has limited solubility in borosilicate glasses and may form microcrystals in the product [5]. The presence or absence of this phase will be determined mainly by the homogeneity of the feed to the glass melter [7].

3.1.2 Thermal Stability (M. J. Plodinec)

In this section, the thermal stability of the glass waste form is described. Varied thermal treatments can cause devitrification and/or thermal shock. The influence of both on the integrity of the reference glass waste form are considered. In addition, the affects of varied waste composition in the glass form on devitrification are described. It is important to recognize that there has been no waste glass form quality criteria established by the NRC at this time. Consequently, the significance of devitrification and thermal shock cannot be properly evaluated.

3.1.2.1 Devitrification

During cooling of glass melts below the liquidus,* crystals may form depending on the composition of sludge mixed with the glass frit and the rate of cooldown. This process of crystal formation is called devitrification. The presence of these crystals can alter the glass waste form's chemical [8] and mechanical behavior and consequently have an impact on the integrity of the glass waste form. The crystalline phase will likely have a higher leachability than the original glass [9-11]. Also, the residual glass phase, through removal of a network former by crystallization, will result in a glass waste form that is mechanically weaker and consequently subject to more extensive fracture in the event of a mechanical accident [11,12].

The rate of devitrification will depend on the composition of the sludge mixed with glass frit. Previous studies have shown that sludges high in aluminum devitrify more quickly but the presence of uranium and nickel inhibits devitrification [13,14]. Table 3.10 summarizes the temperature at which maximum devitrification occurs in glass samples containing a variety of single major sludge components [14].

Nepheline ($NaAlSiO_4$) and other alkali aluminosilicates are always expected to be present [14]. For sludges high in iron, the spinel phase (insoluble metal oxides of the formula MN_2O_4, where M is a bivalent cation and N is a trivalent cation) will always form in the melt [15]. To minimize the formation of either phase, blending the "high aluminum" sludges (the basis for calculating the composite feed) is advantageous in that the aluminum apparently hinders formation of the spinel phase and the iron reduces the rate of nepheline formation.

---

* The lowest temperature at which no crystals exist.

Minimizing the length of time that the waste glass form is in the temperature range of 500°C to 900°C will minimize devitrification. At temperatures near the melting temperature the viscosity of the glass is so low and the solubility of most crystalline material is so high that no crystal formation or growth occurs (spinels formed during melting, however, will still be present). At about 900°C however, the rate of solution of crystals has decreased so much that devitrification may begin [15]. As the glass is cooled below 900°C, the rate of devitrification increases to a maximum between 550 and 900°C. Further cooling results in viscosities too high for effective material transport and consequently a decrease in the rate of devitrification results. During interim and terminal storage, the rate of devitrification will be extremely low and can be ignored.

3.1.2.2 Thermal Shock

The maximum temperature gradient the waste glass form can withstand without fracturing from thermal shock is about 100°C. This estimate is based on a formula derived by Everett [16].

$$\Delta Tmax = \frac{P(1-S)}{\alpha E}$$

where P = tensile strength
E = Young's modulus
S = Poisson's ratio
α = Thermal expansion coefficient

During the presently expected cooldown rate, thermal shock will effect a tenfold increase in surface area of the glass. Stresses may occur during cooling at the glass-filled canister interface; however, this is not expected to be a problem. Even if the stress in the canister reaches the yield point, the canister would compensate by yielding since it is a malleable material.

3.1.3 Leachability (M. J. Plodinec)

Leachability is one of the parameters that is used to evaluate the integrity of a particular waste form. It is usually expressed as the quantity of waste form that dissolves per unit area into a surrounding medium per unit time (g/cm^2-day). By assuming that radionuclides are uniformly distributed throughout the waste form, leachability data allow calculation of the quantity of radionuclides that could be released into the surrounding medium over a period of time. To date, no criteria for leachability of waste glass has been established by any governmental agency. However, leachabilities of most vitreous products are 10^{-5} to 10^{-7} g/cm^2-day and these values are used as a guideline to determine acceptable leach resistance of a waste form [17]. The glass used in the leachability tests described in the following two sections utilized either Frit 18 or 21, neither at which is the current reference frit.

3.1.3.1 Leachability of Glass Containing Simulated Sludge

Extensive laboratory investigations have been conducted at SRL to evaluate the effect of simulated SRP sludge components on the distilled water leachability of borosilicate glass [17,18]. The majority of these tests utilized glass frit 18.

Figure 3.3 summarizes that portion of data where Frit 21 was used [18]. Glass samples containing U_3O_8, NiO, MnO_2, or CaO all had higher leachabilities than glass without these components. At low concentrations, Fe_2O_3 and Al_2O_3 increased leachability but at higher concentrations (about 12 wt %), the leachability of glasses containing Fe_2O_3 and Al_2O_3 was comparable to that of Frit 21 alone. The substitution of 4 wt % LiO_2 (to 1 the lower viscosity) for Na_2O had no effect on leachability of the glass.

Brine leaching of glass containing simulated waste is also being studied to evaluate the durability of the glasses under possible salt bed storage conditions. Leaching at 20-25°C and 90°C has been studied thus far.

Glass containing Cs-137 tracer was leached for 67 days in brine at ambient temperatures. The cumulative leachabilities clearly differ with glass composition as shown in Figure 3.4. The glasses made with high Fe sludge leached more rapidly than those made with high Al sludge. Glasses containing composite sludge with an intermediate composition have intermediate leachabilities.

Glass leach rates in 90°C brine decrease with time as do those for room temperature tests. The leachabilities are, however, a factor of approximately 5 greater at 90°C. Testing at 90°C also revealed that distilled water is a more severe leachant than brine.

3.1.3.2 Leachability of Glass Containing Actual Sludge

Leach rate data are shown in Tables 3.11, 3.12, and 3.13. Tests of the effect of pH on leaching were begun and have continued >200 days. Cumulative fractions leached based on Sr-90 analysis are shown in Figures 3.5 and 3.6 of this report. In pH = 4 buffer, the leach rate increased after about 50 days, the whereas in the other solutions the leach rate remained nearly constant. The increased leaching may be caused by the acetate ion in the pH = 4 buffer rather than an actual pH effect [1]. Cs-137 and Pu activity in the buffered solutions are being measured to determine glass leaching based on these isotopes.

3.1.4 Sulfate Phase Separation (J. R. Wiley)

Sulfate is the only constituent of SRP waste which is present in significant amounts that is not compatible with borosilicate glass. If the sulfate solubility limit (about 1 wt %) is exceeded, alkali metal sulfates segregate into a separate phase on the surface of the glass during melting. This is undesirable because the sulfate phase is water-soluble and rich in radioactive cesium.

Laboratory tests included measurement of the solubility of sulfates in glass made with simulated sludge in Frit 21 [17,20]. Solubilities ranged to 1.25 wt % for Na_2SO_4 in Frit 21. For glass loaded with 35 wt % sludge, the sulfate level in the sludge itself could be about 2.8 wt % before a sulfate phase would segregate. Typical, washed, SRP sludges contain only about 0.5 wt % sulfate [19].

Washed sludges from seven SRP tanks were successfully incorporated with Frit No. 21 glass without sulfate segregation [20,21].

3.1.5 Radiation Stability (N. E. Bibler)

During long term storage, the glass waste form will be continuously irradiated by beta-gamma emissions from fission products and by alpha emissions from transuranic nuclides. Properties of the glass that may potentially be affected by these radiations are leachability, stored energy, density and microstructure. The accumulation of helium in the glass from neutralization of alpha particles is of additional concern in that helium accumulation in the glass network may cause stresses and/or diffused helium may result in pressure buildup in the canister freeboard.

The estimated dose received during long-term storage (2 x 10^5 years) is calculated to be 4.8 x 10^{10} rads from beta-gamma and 7.4 x 10^{10} rads from alpha radiation. Results of radiolysis studies with Co-60 gamma, Cm-244 alpha, and Pu-238 alpha radiations on glass and simulated wastes indicate that these radiations will have minimal and insignificant effects on the leachability and stored energy of the glass.

The maximum expansion of glass during storage is expected to be less than 1.0% due to alpha irradiation. Tests have not been performed to determine if beta and gamma radiation will cause positive expansion of the glass. However, at identical doses, the effect of beta-gamma irradiation would be less than that due to alpha emissions.

After 2 x 10^5 years storage, approximately 0.09 cm^3 He (STP) will have been produced for each cm^3 of glass. Assuming the helium diffuses through the glass, the gas pressure in the free volume of the canister could be about 6 psi assuming a 20% freeboard.

A more detailed summary of the specific effects of radiation on glass is in Appendix 13.6.

3.1.6 Canister Specifications (J. P. Howell, W. N. Rankin)

3.1.6.1 Reference Requirements

Regulatory requirements for the permanent storage of defense-generated waste have not been established. The DW glassform will be stored on-site in an interim storage facility.

Even though provisions are being made for long-term storage on-site, the design of the canister should not preclude the possibility of its shipment to a geologic repository at a later date.

Several draft documents are being written as criteria for Commercial Nuclear Waste. Among these documents are: "Interim Waste Package Performance and Acceptance Criteria," ONWI-33(4), "Rockwell Hanford Operations Commercial Waste and Spent Fuel Packaging Program Package Design Criteria, RHO-CD-772, "Interim Report: Commercial Waste Packaging Studies," RHO-ST-10. These documents along with "The Cask Designers Guide," Federal Shipping Regulations, CFR-Title 10-Part 71.42 NRC-NUREG 0274, "Determination of Performance Criteria for High-Level Solidified Nuclear Waste," and NRC Regulatory Guide 7.6, "Stress Allowables for the Design of Shipping Cask Containment Vessels," can be used for guidelines in the design of the container but should not be construed as given regulations at this time.

The package should be designed in accordance with the American Society of Mechanical Engineers (ASME Boiler and Pressure Vessel [BPV] Code, Division I, Section III, Class 3). Exceptions should be obtained fcr pressue testing, x-ray inspection, and other sections of this code which placed undue and unnecessary restraints on the design.

3.1.6.2 Canister

The reference design canister, shown in Figure 3.7 is made of Type 304L stainless steel with a wall thickness of about 3/8 inch; it weighs about 1100 pounds. Although 304L stainless steel is the reference material at this time, the use of a refined grade of low carbon steel such as calcium treated, ASTM-A516 (Grade 65-70) (plate) and ASTM-A707 (flanges) should not be precluded.

The objectives of the canister are to provide:

- a form for solidifying the waste glass
- containment during Interim Storage
- a surface for decontamination
- a means for handling the glass form

The reversed dished head at the canister bottom allows the canister to be set down on flat surfaces. The double flanged nozzle atop the glass canister is intended to facilitate attachment to the continuous glass melter for containment of molten glass vapors and particulate contamination. The top flange is intended to be the electrical grounding surface for the five inch resistance plug weld which seals the throat opening and insures that the canister is leaktight from liquid entry during decontamination. The weld must also be leaktight to prevent the escape of plutonium or other radioactive particulate matter from the container into the canyon or interim storage facility.

The entire canister surface finish should be specified as a 2B finish as defined by ASTM Specification A-480, "General Requirement for Flat Roll Stainless and Heat Resisting Steel Plate, Sheet, and Strip Steel." This surface finish is necessary prior to heating to insure uniformity in decontaminating the container after processing.

3.1.6.3 Materials of Construction Compatibility (W. N. Rankin)

Type 304L stainless steel is the recommended canister alloy for cast vitrified waste [22]. This recommendation is based on long-term heating tests for up to 20,000 hours (2.3 years) at temperatures that bracket the temperature expected during interim storage [25]. In these tests the lifetime of canisters of cast vitrified waste stored in air was predicted. The thickness of reactions observed between vitrified waste/canister alloy, and canister alloy/environment similar to that expected during interim storage was extrapolated to estimate the time required for penetration of the reference design (3/8-inch thick) canister.

Data from tests up to 20,000 hours (2.3 years) indicate that oxidation would penetrate a 3/8-inch-thick low carbon steel canister in about 200 years of storage in a surface facility, and its strength would be reduced in a much shorter period. A 3/8-inch-thick canister of Type 304L stainless steel would not be penetrated for more than 8000 years in a surface facility.

Differences in canister lifetime, predicted from the data fro these tests, are attributable to the difference in corrosion resistance of the candidate alloys. Both Type 304L stainless steel and low carbon steel reacted similarly with vitrified waste. But, Type 304L stainless steel is much more resistant to atmospheric corrosion in a radiation field than low carbon steel. The lifetime of canisters constructed from other compositions of austenitic stainless steels would be expected to be similar. Past experience indicates that other compositions of austenitic stainless steels have similar compatibility with molten vitrified waste, which is a much more severe condition [27].

3.1.7 Heat Generation Rate and Temperature Profile

3.1.7.1 Heat Generation Rate (J. R. Chandler)

Tables 3.3 and 3.4 summarize the heat generation data for the reference glass waste form. For 5 and 15 year aged waste feed, the total heat generation rate in a glass-filled canister is 541 and 310 watts, respectively.

3.1.7.2 Temperature Profile (M. H. Tennant)

Heat transfer models were developed to predict glass temperature profiles during the glass melt pour, canister cooling, helium leak testing and encapsulation [31]. Based on these models, the following overall process characteristics were determined.

Bases:[a] Melt Temperature at Pour - 1150°C

Radioactive Decay Heat - 1 kw/canister

Fill Rate - about 183 lb/hr (based on design capacity of melter-2.2T/d)

Canister Glass Capacity at Fill - about 3260 lbs

- At the end of the fill period (about 17 hours), the maximum glass temperature will remain in excess of 800°C. Figure 3.8 describes the temperature distribution of the glass at the end of fill.

- Subsequently, 11-15 additional hours are required to reduce the glass temperature to below the devitrification temperature (about 500°C). Figure 3.9 shows the maximum glass centerline temperature and the maximum canister surface temperature as a function of elapsed time after fill for three cooling modes (natural air convection, forced air convection and water cooling).

- Helium leak testing and canister encapsulation processes will raise the temperature of the glass near the canister surface but will have little effect upon the glass centerline temperature as depicted in Figure 3.10.

- Equilibrium temperatures (radioactive decay heat controlling) will be 120°C glass centerline and 60°C at canister surface. See Figure 3.11 for the temperature profile throughout the canister at steady state.

Additional thermal analysis data for canister processing are described in Reference 31.

3.1.8 Regulatory Aspects of Solidified Glass (E. J. Hennelly)

Currently, there are no Federal regulations that specify the required properties of solidified high-level waste and its container. NRC has studies under way and expects to have preliminary drafts of proposed regulations available for review and comment in 1979. Section 11 provides a broader view of regulatory matters and indicates some of the items that may require measurement or control in order to meet possible regulations.

---

[a] This analysis assumes a radionuclide heat generation rate of 1000 watts. Although this rate is no longer applicable (Section 3.1.7.1), the temperature data in Figures 3.8 and 3.9 are still valid since the sensible heat content is controlling. However, the temperature data in Figure 3.11 ("steady state") are no longer applicable, being high by approximately 1.5.

3.2 Saltcrete

3.2.1 Composition and General Properties

3.2.1.1 General

Following treatment by ion exchange resin to remove cesium, strontium, and plutonium, the water-soluble portion of SRP waste (supernate) will be solidified in concrete to reduce the leachability of the salt. The concrete would then be buried in soil trenches below the ground surface. The solidified product (saltcrete) can be characterized by its chemical properties and its residual radioactivity.

3.2.1.2 Chemical Properties (J. R. Wiley)

Chemical properties of saltcrete will be determined by its major components (Table 3.14) [28]. Many other ions are present in trace concentrations [29]. Those which have been identified include PO_4^{3-}, CrO_4^{2-}, and NH_4^+. Trace metals include Fe, Hg, Ag, Pb, and U. Trace components do not contribute to chemical behavior of the bulk salt. However, some are biological hazards.

3.2.1.3 Residual Radioactivity (J. R. Chandler)

The isotopic content and associated decay heat in 5 and 15 year saltcrete are tabulated in Tables 3.15 and 3.16.

3.2.2 Radiation Stability (N. E. Bibler)

During long-term storage, saltcrete will be continuously irradiated from decay of the residual radionuclides. The only significant effect of this irradiation will be to produce gases. Because of the small yields of these gases and the small amounts of radioactivity present, the amount of gases produced will be insignificant.

TABLE 3.1

Chemical Composition of Reference Glass Waste Form

Oxide	Source*	Amount, wt %
Li_2O	F	4.08
B_2O_3	F	10.5
TiO_2	F	0.718
CaO	F + S	0.843
Na_2O	F + S	13.7
SiO_2	F + S	42.2
Fe_2O_3	S	11.8
Al_2O_3	S	2.38
MnO_2	S	3.39
U_3O_8	S	1.09
NiO	S	1.45
Zeolite	S	2.60
MgO	F	1.43
ZrO_2	F	0.357
La_2O_3	F	0.357
O Solids	F + S	3.03
NR Salt	S	0.0984
Density		2.37 g/cc @ 1100°C 2.5 g/cc @ 120°C

---

* F = Frit; S = composite sludge;

TABLE 3.2

Chemical Composition of Glass Frit 131

Oxide	Wt %
SiO_2	57.9
Na_2O	17.7
TiO_2	1.0
$B_{23}O$	14.7
Li_2O	5.7
MgO	2.0
ZrO_2	0.5
La_2O_3	0.5

TABLE 3.3
ISOTOPIC CONTENT (Ci/lb) OF WASTE GLASS – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
CR 51	2.81671E-20	SN126	4.78804E-06	PR144	3.12610E 00	U238	9.23308E-08
CO 60	5.43439E-02	SB124	2.26942E-11	PR144M	3.75125E-02	NP236	5.49941E-12
SE 79	4.31608E-05	SB125	2.68227E-01	ND144	1.52427E-13	NP237	2.80845E-06
RB 87	2.86411E-09	SB126	6.70327E-07	ND147	4.02244E-48	PU236	1.99990E-05
SR 89	1.61515E-08	SB126M	4.78806E-06	PM147	7.66028E 00	PU237	1.44979E-15
SR 90	9.67721E 00	TE125M	6.28557E-02	PM148	2.20386E-14	PU238	2.38898E-01
Y 90	9.67973E 00	TE127	2.74384E-05	PM148M	3.19550E-13	PU239	2.26105E-03
Y 91	2.98080E-07	TE127M	2.80127E-05	SM147	6.05366E-10	PU240	1.42241E-03
ZR 93	5.76293E-04	TE129	6.93279E-16	SM148	1.78244E-15	PU241	2.67080E-01
ZR 95	3.14568E-06	TE129M	1.09191E-15	SM149	5.52504E-16	PU242	1.89152E-06
NB 95	6.78244E-06	CS134	1.09924E 00	SM151	7.47275E-02	AM241	3.43384E-03
NB 95M	3.99501E-08	CS135	1.89807E-05	EU152	1.20540E-03	AM242	4.52947E-06
TC 99	7.80997E-04	CS136	3.24324E-42	EU154	1.58006E-01	AM242M	4.55217E-06
RU103	3.61542E-12	CS137	1.01410E 01	EU155	1.56743E-01	AM243	1.82925E-06
RU106	4.72190E-01	BA136M	1.03784E-42	EU156	1.67113E-35	CM242	1.11177E-05
RH103M	7.23793E-12	BA137M	9.59333E 00	TB160	3.54716E-10	CM243	1.76198E-06
RH106	4.72192E-01	BA140	1.20352E-40	TL208	3.35775E-07	CM244	5.16690E-05
PD107	2.89985E-06	LA140	1.37135E-40	U232	1.63463E-06	CM245	2.10799E-09
AG110	4.01810E-03	CE141	1.13808E-14	U234	1.46518E-06	CM246	1.68263E-10
CD115M	2.90972E-13	CE142	3.02396E-09	U235	1.70617E-08	CM247	2.06847E-16
SN121M	1.03832E-05	CE144	3.12598E 00	U236	3.68664E-07	CM248	2.16006E-16
SN123	8.42735E-05	PR143	3.79496E-38				

TOTAL ACTIVITY 5.64 01 Ci/lb

HEAT GENERATION, watts/lb
Primary 1.17-01
Gamma 4.89-02

TABLE 3.4
ISOTOPIC CONTENT (Ci/lb) OF WASTE GLASS — 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
CO 60	1.45364E-02	SN123	2.52730E-13	ND144	1.53586E-13	NP237	2.80844E-06
SE 79	4.31562E-05	SN126	4.78800E-06	PM147	5.45243E-01	PU236	1.75838E-06
RB 87	2.86411E-09	SB124	1.23505E-29	PM148	5.25576E-41	PU237	1.16164E-39
SR 89	1.15817E-29	SB125	2.11753E-02	PM148M	7.62063E-40	PU238	2.20753E-01
SR 90	7.56174E 00	SB126	6.70323E-07	SM147	7.79902E-10	PU239	2.26040E-03
Y 90	7.56371E 00	SB126M	4.78802E-06	SM148	1.78244E-15	PU240	1.42090E-03
Y 91	5.14453E-26	TE125M	4.96217E-03	SM149	5.52504E-16	PU241	1.66669E-01
ZR 93	5.76288E-04	TE127	2.24443E-15	SM151	6.93570E-02	PU242	1.89150E-06
ZR 95	5.14387E-23	TE127M	2.29140E-15	EU152	7.06987E-04	AM241	6.76243E-03
NB 95	1.10908E-22	TE129	8.38866E-49	EU154	8.83902E-02	AM242	4.32755E-06
NB 95M	6.53271E-25	TE129M	1.32120E-48	EU155	3.69488E-02	AM242M	4.34925E-06
TC 99	7.80973E-04	CS134	3.80004E-02	TB160	2.19894E-25	AM243	1.82753E-06
RU103	6.20482E-40	CS135	1.89806E-05	TL208	7.17880E-07	CM242	3.58942E-06
PU106	4.94782E-04	CS137	8.05512E 00	U232	2.16253E-06	CM243	1.38158E-06
RH103M	1.24218E-39	BA137M	7.62006E 00	U234	1.46513E-06	CM244	3.52373E-05
RH106	4.94782E-04	CE141	1.81653E-48	U235	1.70617E-08	CM245	2.10627E-09
PD107	2.89984E-06	CE142	3.02396E-09	U236	3.68684E-07	CM246	1.68017E-10
AG110	1.74149E-07	CE144	4.25520E-04	U238	9.23308E-08	CM247	2.06847E-16
CD115M	6.46960E-38	PR144	4.25533E-04	NP236	5.49907E-12	CM248	2.16005E-16
SN121M	9.03826E-06	PR144M	5.10632E-06				

TOTAL ACTIVITY 3.20 01 Ci/lb

HEAT GENERATION, watts/lb
Primary 6.70-02
Gamma 2.82-02

TABLE 3.5

Physical Properties of Glass Waste Forms

Property	Value	Reference
Thermal Conductivity at 100°C	0.55 pcu/hr-ft-°C	Table 3.6
Heat Capacity at 100°C	0.22 pcu/lb-°C	Table 3.7
Fractional Thermal Expansion	1.1×10^{-5}°K	d
Young's Modulus[a]	9×10^6 psi	1
Tensile Strength	9×10^3	1
Compressive Strength	1×10^5 psi	4
Poisson's Ratio[b]	0.2	1
Density at 100°C	2.49 g/cc	Table 3.8
Softening Point	500 to 550°C	d

---

a. Young's modulus, or the modulus of elasticity, measures the stiffness of the material, e.g., carbon steel is about 30×10^6 psi.

b. Poisson's ratio can be thought of as the ratio of equatorial to axial strain, under an applied axial stress.

c. Experimentally determined. Range is 2.35 to 3.25.

d. Experimentally determined.

TABLE 3.6

Calculated Effective Thermal Conductivity of the Reference Glass Waste Form

Temp, °C	k_{eff}, pcu/hr-ft-°C	Temp, °C	k_{eff}, pcu/hr-ft-°C
0	0.54	750	0.81
100	0.55	800	0.95
200	0.56	850	1.11
300	0.58	900	1.29
400	0.59	950	1.50
500	0.60	1000	1.73
600	0.61	1050	1.99
655	0.62	1100	2.26
700	0.69	1150	2.55

TABLE 3.7

Calculated True and Mean Heat Capacity of the Reference Glass Waste Form

	Heat Capacity, pcu/lb-°C	
Temp, °C	Cm(Mean)*	Cp(True)
0	0.177	0.177
100	0.200	0.220
200	0.218	0.250
300	0.232	0.271
400	0.244	0.286
500	0.253	0.298
600	0.262	0.307
700	0.269	0.314
800	0.275	0.320
900	0.280	0.324
1000	0.285	0.328
1100	0.289	0.332
1200	0.292	0.334

---

* Reference temperature - 0°C.

TABLE 3.8

Calculated Density of the Reference Glass Waste Form

Temp., °C	Density, gm/cc	Temp., °C	Density, gm/cc
25	2.495	700	2.440
100	2.490	800	2.421
200	2.484	900	2.403
300	2.478	1000	2.385
400	2.471	1100	2.367
500	2.465	1150	2.358
596	2.459*	1200	2.349
600	2.458	1300	2.330

---

* Density of glass at strain point temperature.

TABLE 3.9

Calculated Viscosity of the Reference Glass Waste Form

Temp., °C	η, poise	Temp., °C	η, poise
850	1930	1050	92.6
875	1080	1075	74.4
900	656	1100	61.0
925	425	1125	50.9
950	291	1150	43.0
975	208	1175	36.9
1000	154	1200	32.0
1025	118	1225	28.1

TABLE 3.10

Effect of Sludge Components on Devitrification of Waste Glass [14]

Component, wt %	T_D, °C	Heated One Month at 600°C Relative Amount of Devitrification[a]	Phase Formed
None	623	S	b
CaO (1.2)	632	S	b
NiO (2.4)	645	S	b
U_3O_8 (5.5)	c	S	b
MnO_2 (6.6)	608	S-M	Mn_3O_4[d]
Al_2O_3 (21.1)	576	XL	$NaAlSiO_4$
Fe_2O_3 (19.3)	620	L	Fe_3O_4[d]

---

a. S = Small; M = Moderate; L = Large; XL = Essentially complete.

b. Too little to detect by x-ray diffraction.

c. None observed at T <850°C.

d. Though listed as C_3O_4 (C = Fe or Mn) they probably contain Ti, Na, and Li, in a spinel structure.

TABLE 3.11

Glass Leach Rates Based on Cs-137

Glass Type[a]	Leach Rate (g/cm^2-day)[b] 1	2	4	7	14	21	35	50	74	100 (days)
21-35-4.6	3.7-07[c]	8.8-07	7.5-08	7.6-08	3.1-08	9.5-08	7.7-08	1.5-08	1.0-07	9.4-09
21-35-5A	2.2-07	2.0-07	3.0-07	2.0-07	1.3-07	1.0-07	5.2-08	1.4-08	2.2-08	3.6-08
21-35-5B	3.8-07	3.8-07	1.1-06	6.1-07	2.9-06	-	1.8-07	4.1-08	1.8-08	6.5-09
21-35-13A	3.3-07	2.4-07	6.3-07	2.7-07	1.5-07	3.0-06	1.1-07	-	1.5-08	3.5-08
21-35-13B	2.9-07	1.4-07	2.7-07	4.5-07	2.8-05	3.6-06	5.7-07	2.7-07	1.1-07	9.4-08
21-35-13C	1.6-07	1.3-08	1.2-07	2.2-07	1.2-07	2.4-04	2.7-06	7.2-08	3.1-08	3.2-08
21-35-15	3.8-07	2.6-07	3.5-07	3.9-07	9.6-07	1.6-06	1.6-07	3.9-08	1.2-07	6.6-08
21-35-16	5.2-06	8.0-07	1.6-06	4.0-07	6.2-07	9.5-06	4.8-07	1.7-07	4.2-07	2.1-07

---

a. Glass is designated by: Frit number - wt % sludge - SRP waste storage farm sludge source (Tank).
b. Leach rate = grams of waste form/cm^2-day.
c. Leach rates are given in exponential form, i.e., 3.7-07 = 3.7 x 10^{-7}.

TABLE 3.12

Glass Leach Rates Based on Pu

	Leach Rate (g/cm^2-day)[b]									
Glass Type[a]	1	2	4	7	14	21	35	50	74	100 (days)
21-35-4.6	2.2-08[c]	2.9-07	5.2-07	1.5-08	4.4-09	1.4-08	4.8-09	4.8-09	2.1-09	1.9-09
21-35-5A	3.7-06	3.4-07	1.8-06	4.2-07	9.7-08	8.2-08	3.6-08	2.4-08	4.2-08	1.6-08
21-35-5B	7.8-07	2.8-07	4.0-07	7.7-07	9.6-08	-	1.9-07	4.0-08	1.9-08	1.5-08
21-35-13A	6.4-07	1.4-06	7.3-06	1.2-06	5.5-07	-	5.4-07	-	2.7-07	4.8-08
21-35-13B	2.5-06	2.2-06	1.8-06	2.8-06	1.3-06	8.9-07	5.1-07	6.1-07	8.6-08	9.2-08
21-35-13C	3.5-07	-	3.1-07	1.9-07	2.0-07	8.5-07	1.5-07	1.1-07	3.2-09	9.2-09
21-35-15	3.6-06	1.4-06	6.4-07	7.3-07	7.8-07	6.9-07	5.9-07	3.7-07	2.6-07	4.6-08
21-35-16	1.2-06	3.5-07	5.0-07	1.9-07	1.4-07	2.5-07	9.0-08	9.2-08	7.4-08	1.2-08

---

[a] Glass is designated by: Frit number - wt % sludge - SRP waste storage farm sludge source (Tank).

[b] Leach rate = grams of waste form/cm^2-day.

[c] Leach rates are given in exponential form, i.e., 2.2-08 = 2.2×10^{-8}.

TABLE 3.13

Glass Leach Rates Based on Sr-90

Glass Type[a]	Leach Rate $(g/cm^2\text{-day})$[b] 1	2	4	7	14	21	35	50	74	100 (days)
21-35-4.6	7.6-07[c]	2.8-07	1.2-07	4.6-08	1.7-08	8.6-09	5.5-09	5.4-09	3.5-09	1.0-08
21-35-5A	9.7-07	1.3-06	1.5-06	1.1-06	7.4-07	3.4-07	1.1-07	6.9-08	8.3-08	1.1-07
21-35-5B	8.2-07	1.7-06	1.4-06	1.8-06	1.3-06	-	1.9-07	7.2-08	4.3-08	1.6-07
21-35-13A	2.1-06	2.2-06	2.9-06	1.9-06	1.3-06	8.6-07	4.5-07	-	1.6-07	1.4-07
21-35-13B	2.7-07	4.0-07	1.7-06	1.6-06	9.1-07	6.7-07	3.5-07	3.3-07	2.1-07	2.2-07
21-35-13C	1.7-07	2.2-07	3.5-07	2.4-07	1.6-07	2.8-07	8.9-08	6.5-08	4.2-08	5.6-08
21-35-15	7.7-07	4.4-07	5.8-07	6.9-07	4.0-07	2.3-07	8.1-08	5.3-08	3.8-08	1.1-07
21-35-16	3.1-07	1.9-07	1.5-07	1.4-07	1.0-07	8.8-08	5.3-08	5.1-08	4.1-08	4.4-08

---

a. Glass is designated by: Frit number - wt % sludge - SRP waste storage farm sludge source (Tank).
b. Leach rate = grams of waste form/cm^2-day.
c. Leach rates are given in exponential form, i.e., 7.6-07 = 7.6×10^{-7}.

TABLE 3.14

Major Chemical Constituents of Saltcrete

Compound	wt %
$NaNO_3$	5.89
$NaNO_2$	2.10
NaOH	3.07
$NaAlO_2$	1.29
Na_2CO_3	1.40
Na_2SO_4	1.18
$Na_2C_2O_4$	.0169
NaCl	.0419
NaF	.00274
$Na[H_gO(OH)]$	.00837
H_2O	29.2
Cement	55.8

TABLE 3.15
ISOTOPIC CONTENT (nCi/g) OF SALTCRETE[a] – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	6.34654E 01	SN126	1.99701E-03	PR144	b	U235	6.95511E-07
CR 51	6.11867E-17	SB124	9.46534E-09	PR144M	b	U236	1.50939E-05
CO 60	<2.00000E-02[b]	SB125	1.11872E 02	ND144	6.35739E-11	U238	3.83333E-06
SE 79	9.37672E-02	SB126	2.79581E-04	ND147	1.67768E-45	NP236	2.28348E-10
RB 87	2.37934E-07	SB126M	1.99701E-03	PM147	3.20975E 01[c]	NP237	1.16117E-04
SR 89	1.33796E-09	TE125M	1.36555E 02	PM148	9.19177E-12	PU236	9.23283E-06
SR 90	5.37767E-01[c]	TE127	5.96103E-02	PM148M	1.33278E-10	PU237	6.73794E-16
Y 90	5.37902E-01[c]	TE127M	6.08577E-02	SM147	2.52488E-07	PU238	1.10910E-01
Y 91	2.46923E-08	TE129	1.50616E-12	SM148	7.43413E-13	PU239	1.04390E-03
ZR 93	2.39290E-02	TE129M	2.37217E-12	SM149	2.30439E-13	PU240	6.59680E-04
ZR 95	b	I129	9.77107E-02	SM151	3.11675E 01	PU241	1.24046E-01
NB 95	b	CS134	b	EU152	5.00512E-02	PU242	8.78971E-07
NB 95M	1.65882E-06	CS135	7.96098E-05	EU154	b	AM241	1.42495E-01
TC 99	2.70189E 01[c]	CS136	1.36030E-41	EU155	6.50833E 00	AM242	1.88064E-04
RU103	1.49206E-07	CS137	2.67939E 01[c]	EU156	6.93890E-34	AM242M	1.89008E-04
RU106	1.94871E 04	BA136M	4.35298E-42	TB160	1.47945E-07	AM243	7.59553E-05
RH103M	1.49354E-07	BA137M	2.53469E 01[c]	TL206	3.12841E-18	CM242	4.61625E-04
RH106	1.94871E 04	BA140	5.04783E-40	TL207	4.64359E-08	CM243	7.31615E-05
PD107	6.29927E-03	LA140	5.71961E-38	TL208	7.24558E-04	CM244	2.14544E-03
AG110	b	CE141	4.74673E-12	TL209	2.95168E-12	CM245	8.75294E-08
CD115M	6.32073E-10	CE142	1.26123E-06	U232	6.74560E-05	CM246	6.98671E-09
SN121M	4.33061E-03	CE144	b	U233	7.99384E-09	CM247	8.58880E-15
SN123	3.51486E-02	PR143	1.58280E-35	U234	2.10680E-04	CM248	8.96900E-15

a. *The isotopic concentrations were computed by a computer model which simulates the flow of isotopes through the reference process. Unless otherwise noted, no credit was taken for decontamination by the ion exchange flowsheet except for cesium, plutonium, and strontium.*

b. *Based on chemical analyses (see footnote c) the total contribution from these isotopes is <0.5 n Ci/g.*

c. *These values were determined analytically after actual SRP waste supernate was clarified and treated by the reference ion exchange process (see "Reference Process for Disposal of SRP Waste Salt." Internal memorandum, B. W. Benjamin–P. L. Roggenkamp to S. Mirshak, November 16, 1979). Concentrations computed by the computer model are documented in appendix 13.7.*

TABLE 3.16
ISOTOPIC CONTENT (nCi/g) OF SALTCRETE[a] – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.60612E 01	SN123	1.05408E-10	ND144	6.40575E-11	U238	3.83333E-06
CO 60	<2.00000E-02[b]	SN126	1.99699E-03	PM147	2.28463E 00[c]	NP236	2.28334E-10
SE 79	9.37572E-02	SB124	5.15115E-27	PM148	2.19205E-38	NP237	1.16648E-04
RB 87	2.37934E-07	SB125	8.83177E 00	PM148M	3.17844E-37	PU236	8.11777E-07
SR 89	9.59357E-31	SB126	2.79579E-04	SM147	3.25283E-07	PU237	5.39863E-40
SR 90	4.20208E-01[c]	SB126M	1.99699E-03	SM148	7.43413E-13	PU238	1.02486E-01
Y 90	4.20318E-01[c]	TE125M	1.07803E 01	SM149	2.30439E-13	PU239	1.04360E-03
Y 91	4.26160E-27	TE127	4.87605E-12	SM151	2.89275E 01	PU240	6.58980E-04
ZR 93	2.39288E-02	TE127M	4.97807E-12	EU152	2.93561E-02	PU241	7.74102E-02
ZR 95	[b]	TE129	1.81291E-45	EU154	[b]	PU242	8.78966E-07
NB 95	[b]	TE129M	2.85529E-45	EU155	1.53421E 00	AM241	2.80618E-01
NB 95M	2.71253E-23	I129	9.77092E-02	TB160	9.17126E-23	AM242	1.79681E-04
TC 99	7.70179E 01[c]	CS134	[b]	TL206	1.04528E-16	AM242M	1.80582E-04
RU103	2.56069E-35	CS135	7.96098E-05	TL207	1.27675E-07	AM243	7.58838E-05
RU106	2.04194E 01	CS137	2.12826E 01[c]	TL208	1.54948E-03	CM242	1.49034E-04
RH103M	2.56323E-35	BA137M	2.01333E 01[c]	TL209	1.34413E-11	CM243	5.73662E-05
RH106	2.04194E 01	CE141	7.52416E-46	U232	8.92189E-05	CM244	1.46315E-03
PC107	6.29927E-03	CE142	1.26123E-06	U233	1.30598E-08	CM245	8.74579E-08
AG110	[b]	CE144	[b]	U234	4.80362E-04	CM246	6.97646E-09
CD115M	1.40539E-34	PR144	[b]	U235	6.95911E-07	CM247	8.58880E-15
SN121M	3.76966E-03	PR144M	[b]	U236	1.51114E-05	CM248	8.96900E-15

a. The isotopic concentrations were computed by a computer model which simulates the flow of isotopes through the reference process. Unless otherwise noted, no credit was taken for decontamination by the ion exchange flowsheet except for cesium, plutonium, and strontium.

b. Based on chemical analyses (see footnote c) the total contribution from these isotopes is <0.5 n Ci/g.

c. These values were determined analytically after actual SRP waste supernate was clarified and treated by the reference ion exchange process (see "Reference Process for Disposal of SRP Waste Salt." Internal memorandum, B. W. Benjamin–P. L. Roggenkamp to S. Mirshak, November 16, 1979). Concentrations computed by the computer model are documented in appendix 13.7.

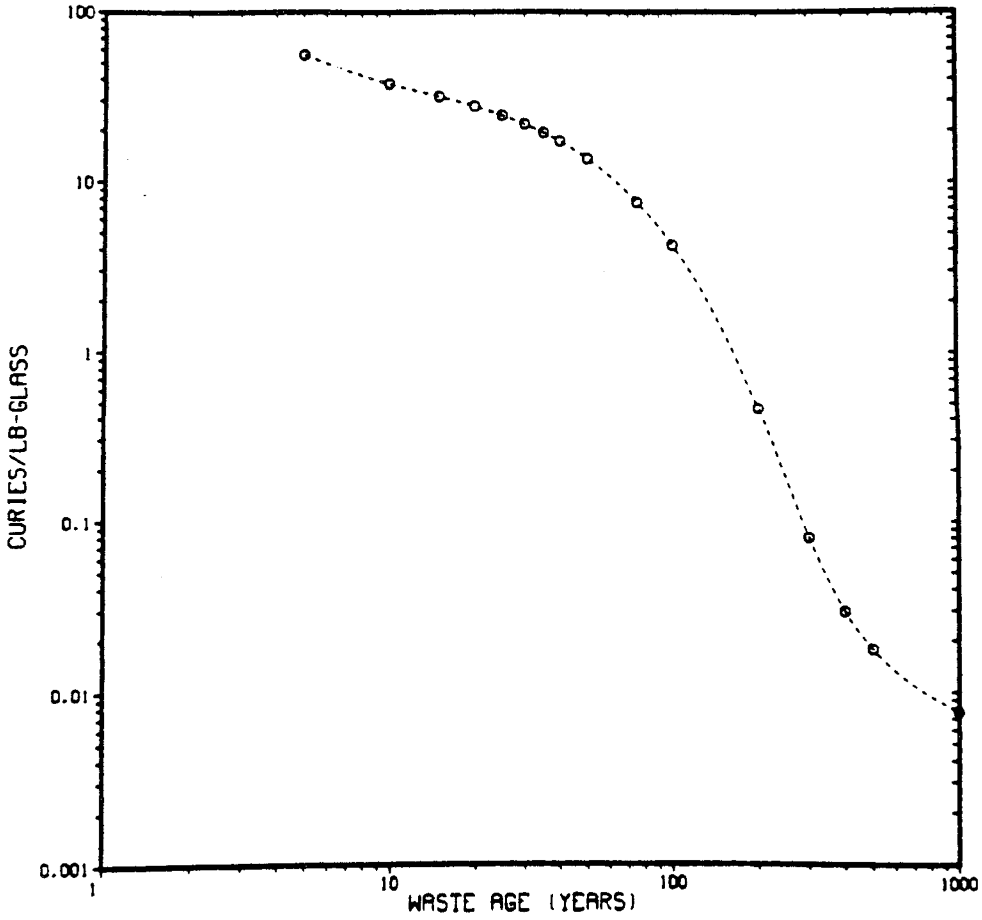


FIGURE 3.1 Activity in DWPF Glass

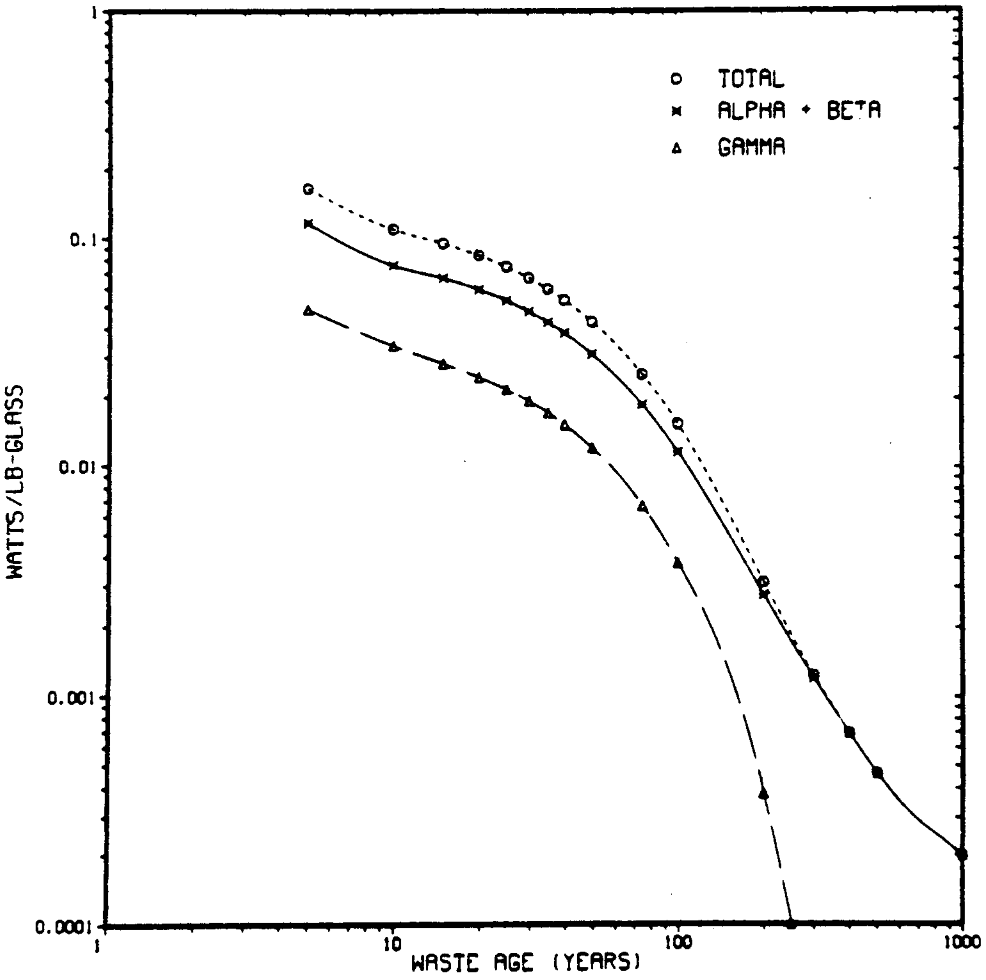


FIGURE 3.2 Decay Heat in DWPF Glass

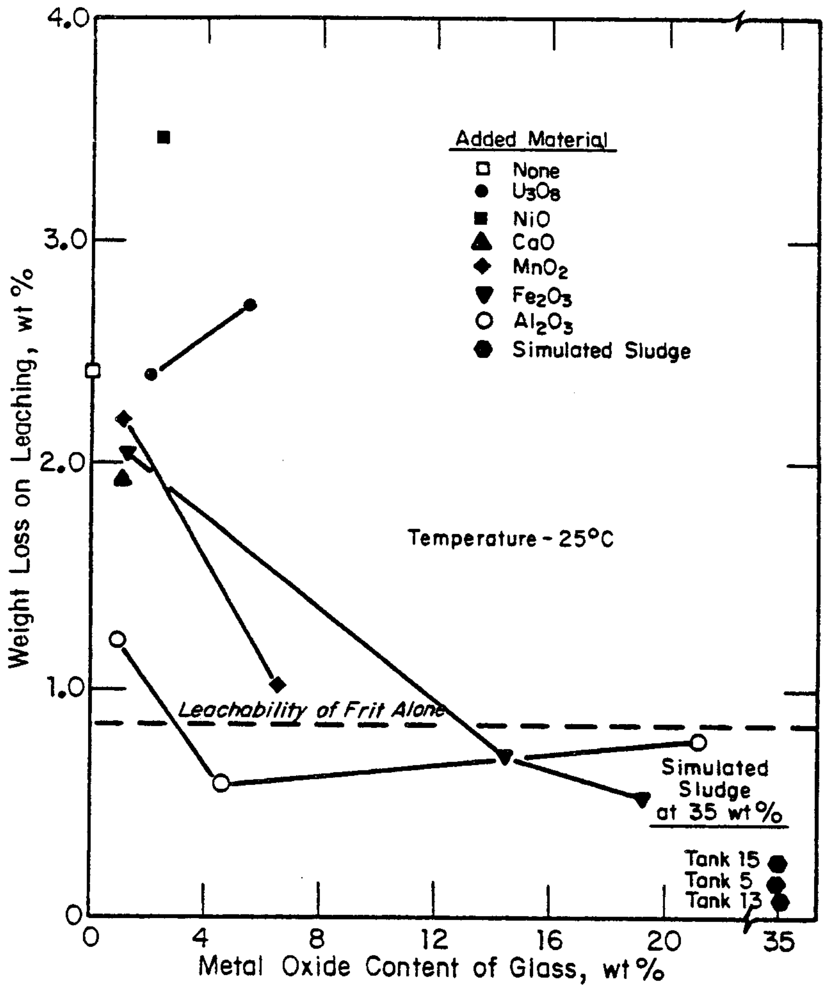


FIGURE 3.3. Leachability of Sludge Components in Frit 21

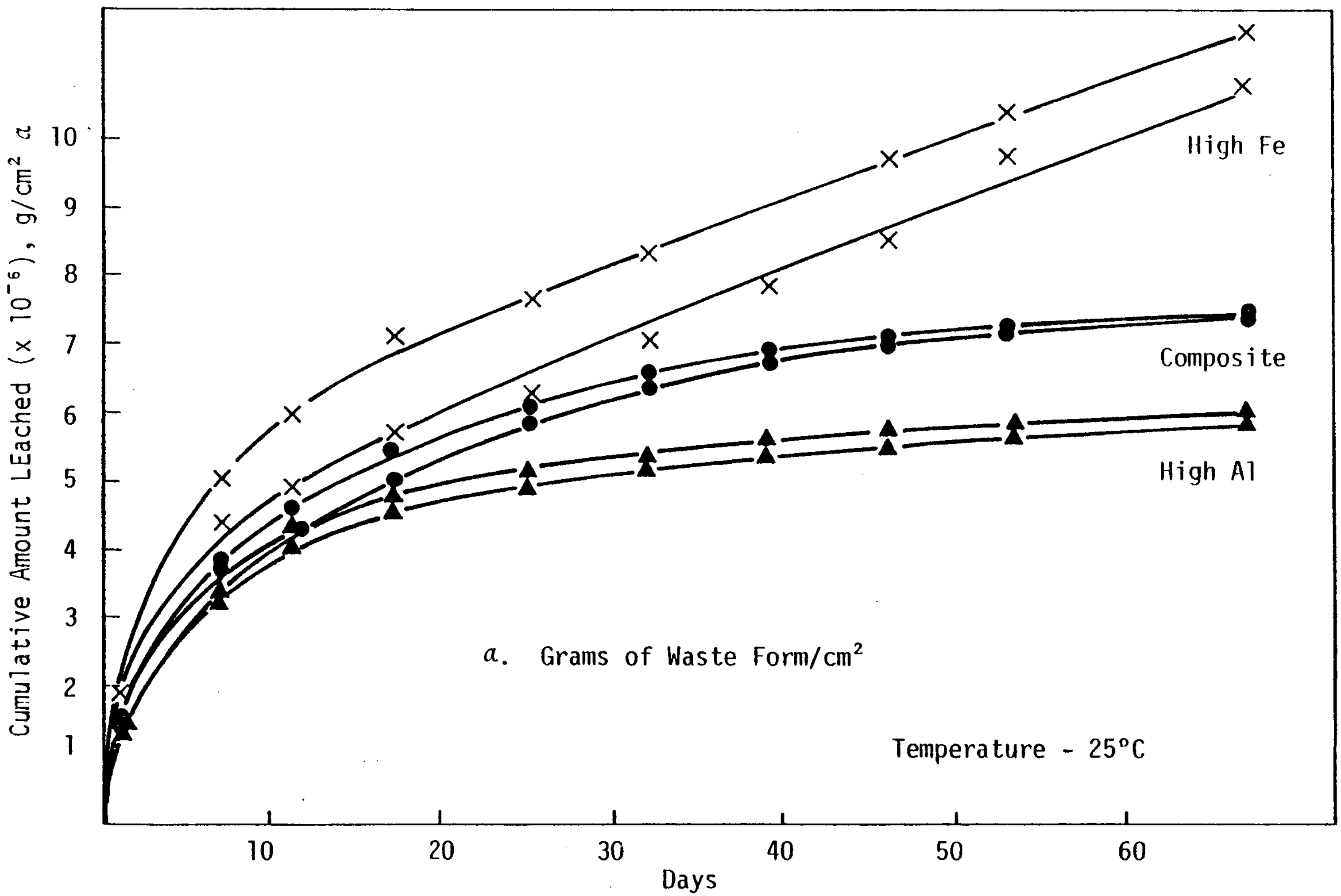


FIGURE 3.4. Cumulative Leaching of Frit 21-Simulated SRP Sludge Glasses in Brine Based on ^{137}Cs (Duplicate Sample Data Included)

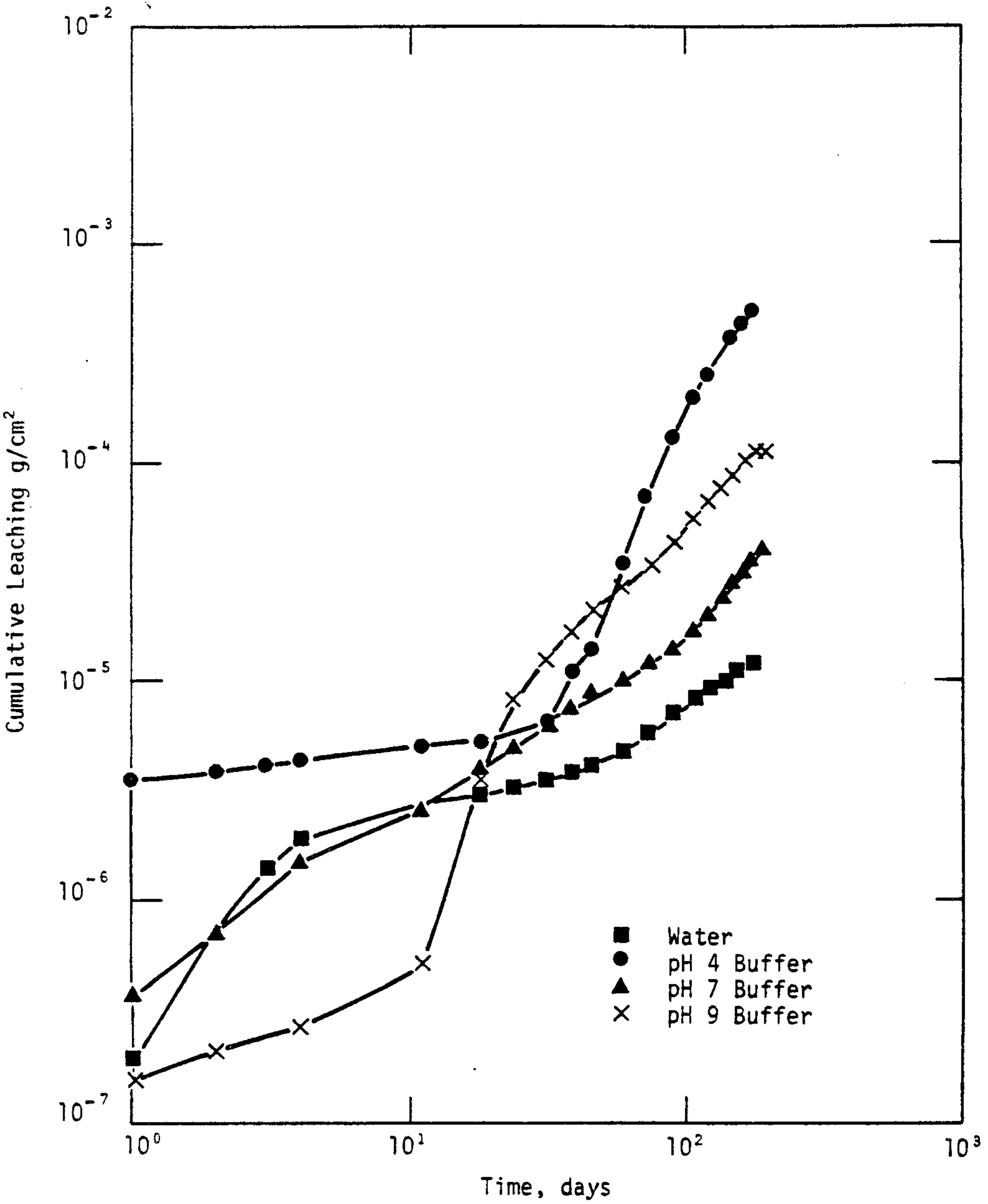


FIGURE 3.5. Cumulative Leaching of Frit 21-SRP Waste Tank No. 13 Glasses Based on ^{90}Sr

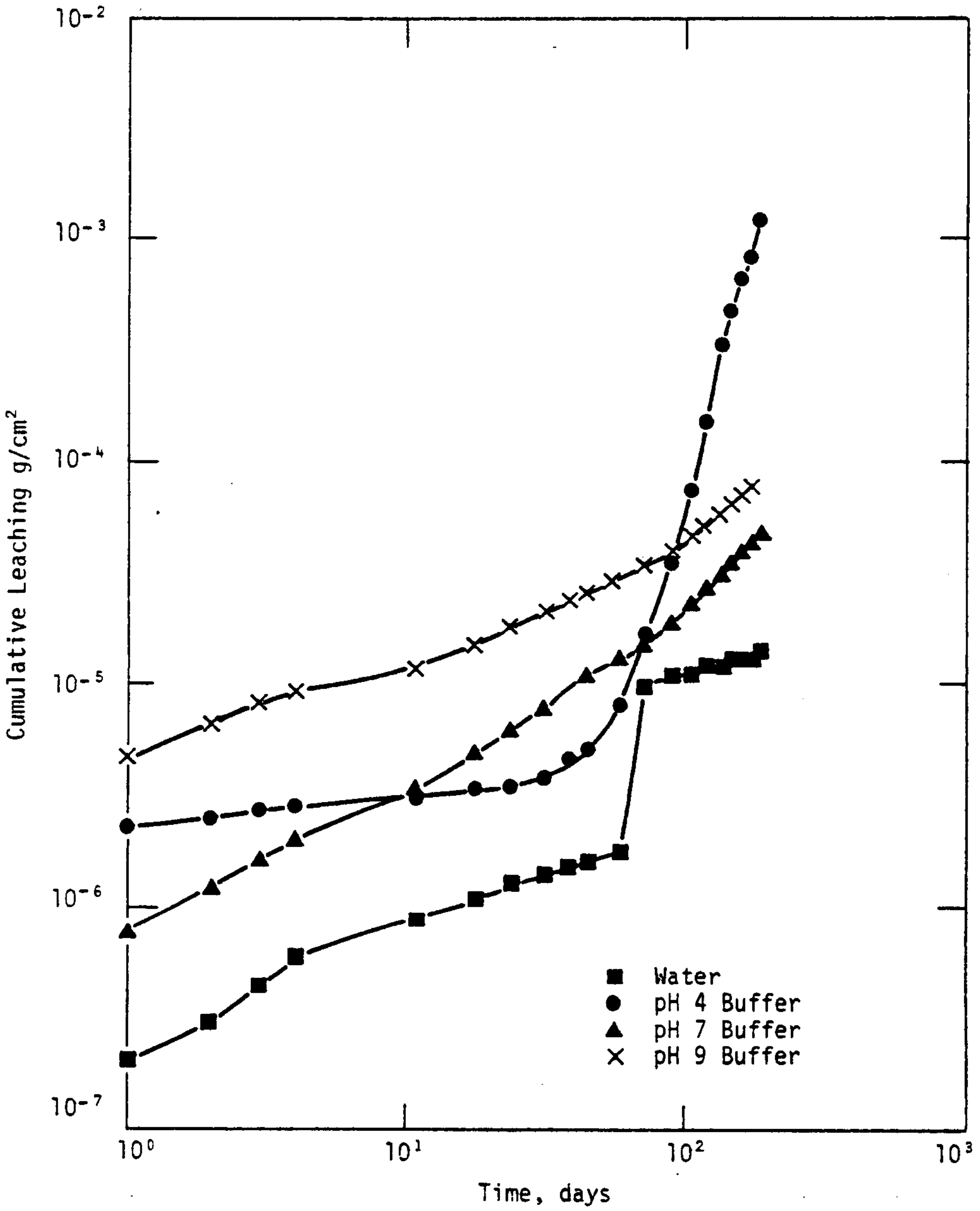


FIGURE 3.6. Cumulative Leaching of Frit 21-SRP Waste Tank No. 16 Glasses Based on ^{90}Sr

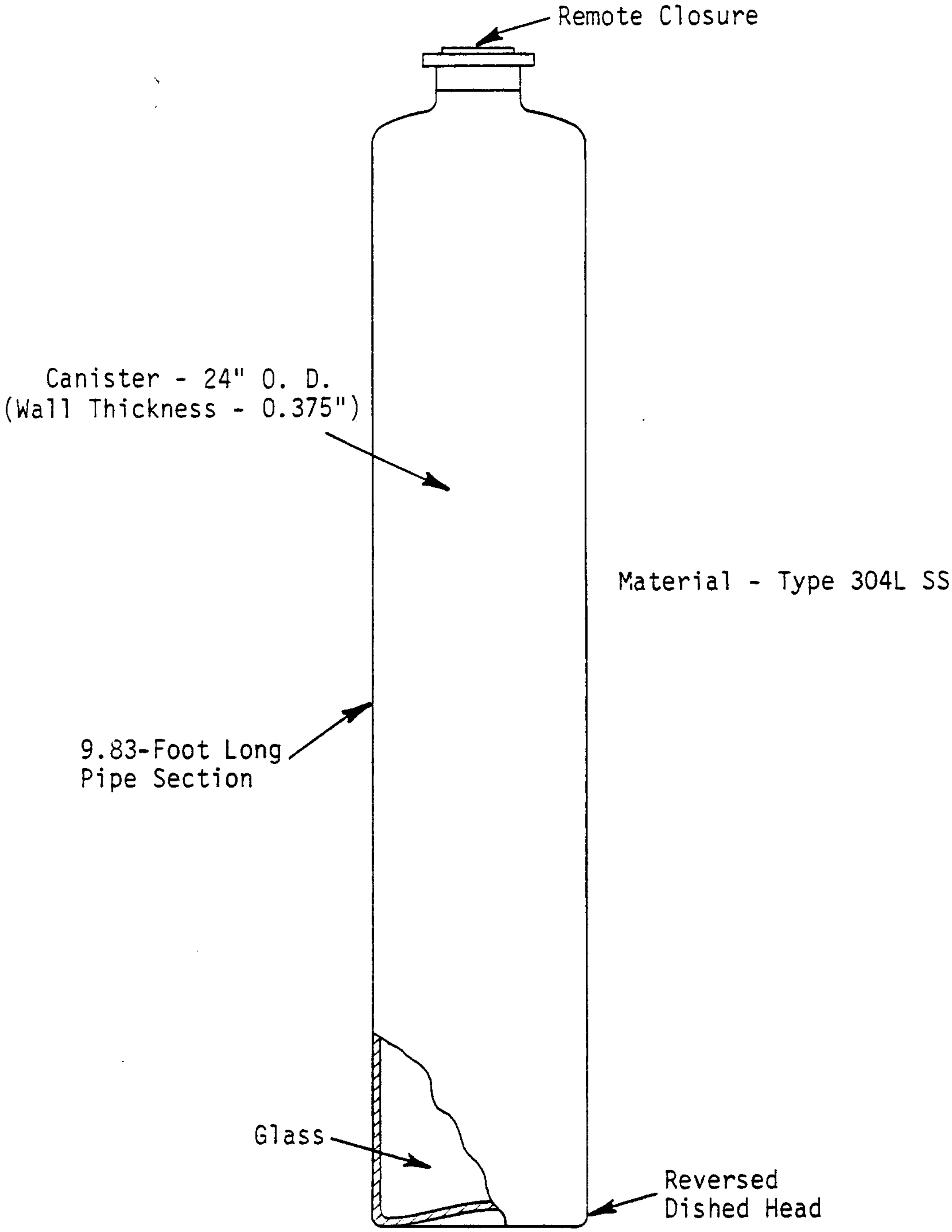


FIGURE 3.7. Reference Canister Design

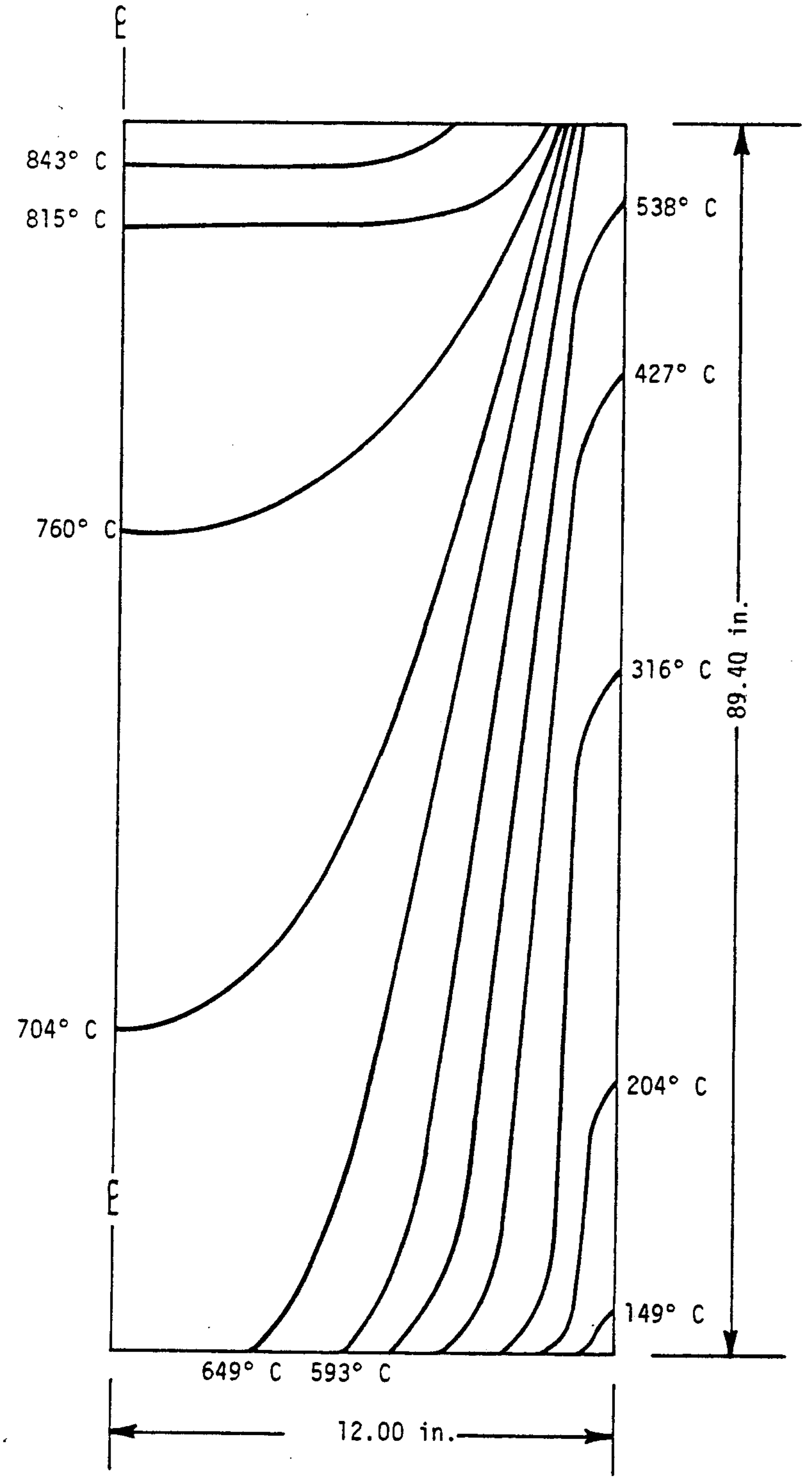


FIGURE 3.8. Isotherms at End of Canister Fill

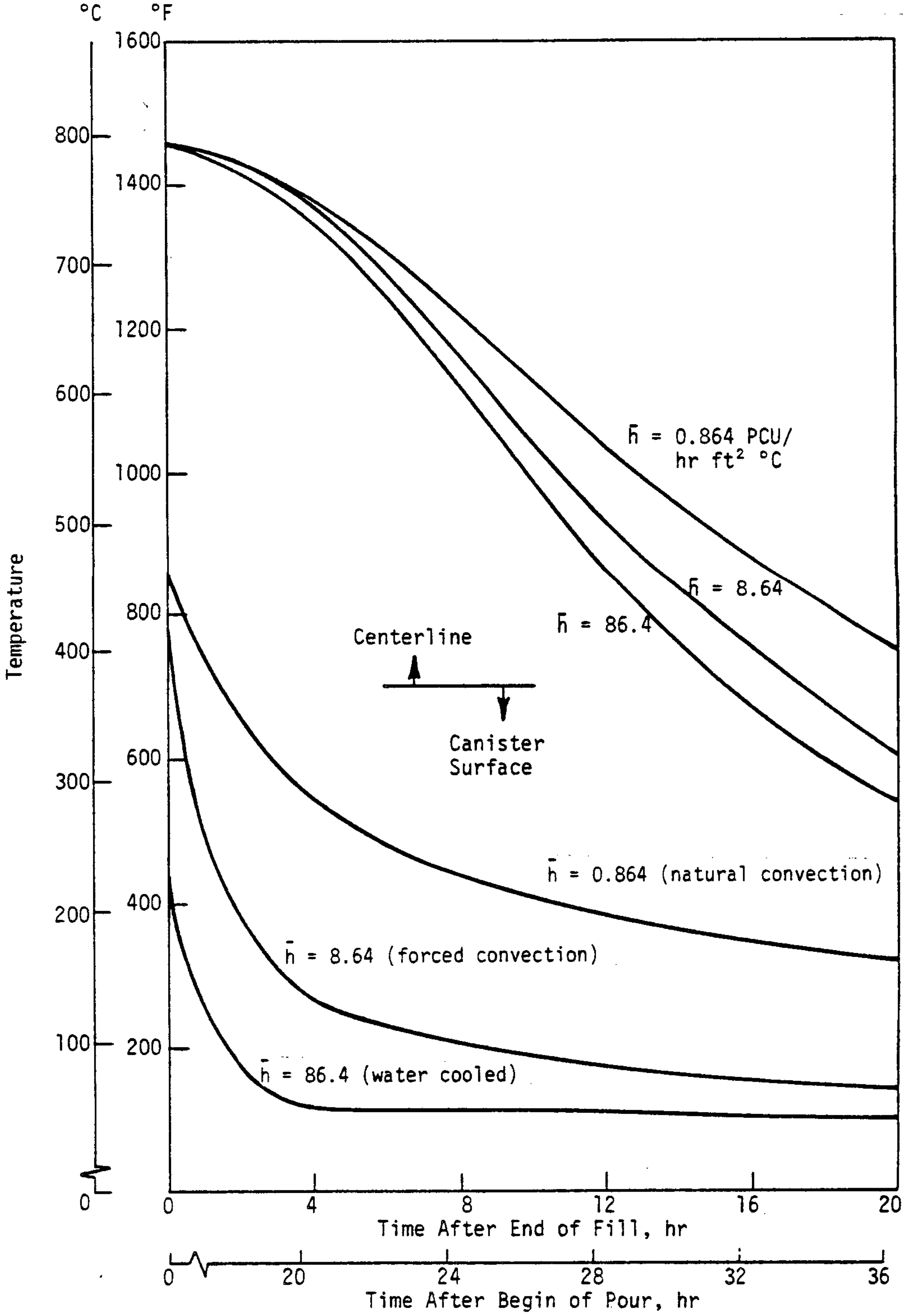


FIGURE 3.9 Temperature History for Canister

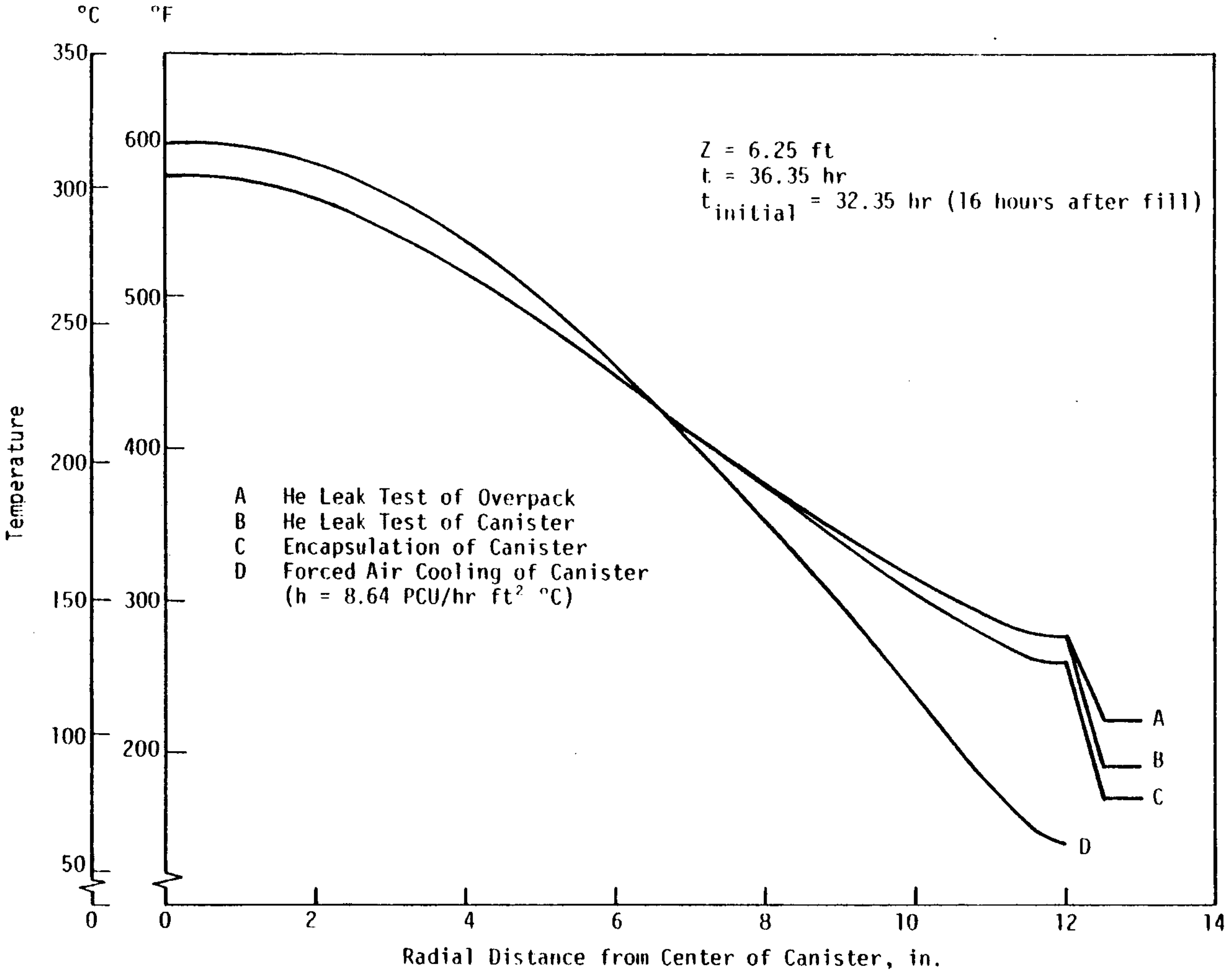


FIGURE 3.10. Short-Term Temperature Effects of Subsequent Canister/Container Processing (Process Duration = 4 hours)

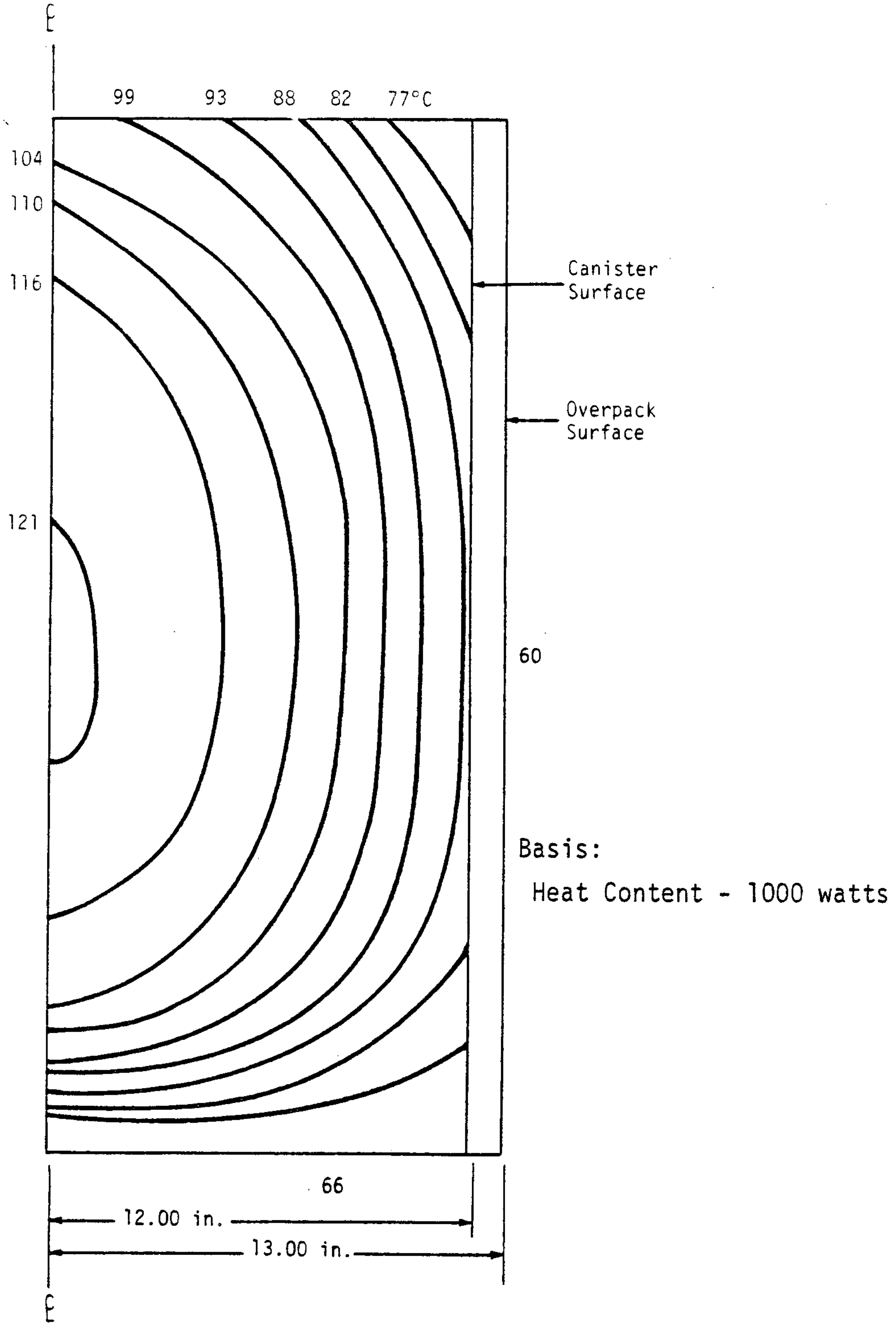


FIGURE 3.11. Canister Isotherms at Steady State
$\bar{h}$ = 0.864 PCU (hr-ft^2-°C)

FIGURE 3.12 (Deleted)

3.3 References

1. G. W. Morey. *The Properties of Glass*, Second Edition, Reinhold, New York (1952).

2. G. G. Wicks. *Phenomena and Processes of Interest in Making SRP Waste-Glass Forms*. Internal Report DPST-77-307, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (May 1977).

3. F. P. Hall. *J. Amer. Ceram. Soc.* *13*, 182 (1930).

4. J. A. Kelley. *Evaluation of Glass as a Matrix for Solidification of Savannah River Plant Waste - Nonradioactive and Tracer Studies*. USERDA Report DP-1382, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

5. R. P. Turcotte and F. P. Roberts. "Phase Behavior and Radiation Effects in High Level Waste Glass." In *Ceramic and Glass Radioactive Waste Forms*. CONF-770102 (1977).

6. J. A. Kelley and W. N. Rankin. *Correlation of Radionuclide Leachabilities with Microstructures of Glass Containing SRP Waste*. USERDA Report DP-1411, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

7. A. R. Hall, J. T. Dalton, B. Hudson, and J. A. C. Marples. "Development and Radiation Stability of Glasses for Highly Radioactive Wastes." In *International Symposium on the Management of Radioactive Wastes from the Nuclear Fuel Cycle*. IAEA-SM-207/24, International Atomic Energy Agency, Vienna, Austria (1976).

8. D. R. Uhlman. "The Stability of Glasses." In *Ceramic and Glass Radioactivce Waste Forms*. CONF-770102, p 121 (1977).

9. G. G. Wicks. *Phenomena and Processes of Interest in Making SRP Glass Waste Forms*. Internal Report DPST-77-307, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1977).

10. J. A. Kelley. *Evaluation of Glass as a Matrix for Solidification of SRP Waste*. USERDA Reports DP-1382 and DP-1397, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

11. W. Heimerl, H. Heine, L. Kahl, H. W. Levi, W. Letze, G. Malow, E. Schiewer, and P. Schubert. "Studies on the Behavior of Radioactive Glass." In *Management of Radioactive Wastes from Fuel Reprocessing*, Paris, France (1972).

12. T. H. Smith and W. A. Ross. Impact Testing of Vitreous Simulated High-Level Waste in Canisters. USERDA Report BNWL-1903, Battelle Northwest Laboratories, Richland, WA (1975).

13. "Thermal Effects." Report of a Committee. In Ceramic and Glass Radioactive Waste Forms. CONF-770102, pp 249-255 (1977).

14. Savannah River Laboratory Monthly Report, May 1977. USERDA Report DP-77-1-5, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1977) (Confidential).

15. J. E. Mendel, W. A. Ross, F. P. Roberts, R. P. Turcotte, Y. B. Katayama, and J. H. Westsik, Jr. "Thermal and Radiation Effects on Borosilicate Waste Glasses." In Management of Radioactive Wastes from the Nuclear Fuel Cycle. IAEA-SM-207/100, V. II, International Atomic Energy Agency, Vienna, Austria (1976).

16. W. M. Hampton. J. Soc. Glass Tech. 20, 461 (1936).

17. J. A. Kelley. Evaluation of Glass as a Matrix for Solidification of Savannah River Plant Waste: Nonradioactive and Tracer Studies. USERDA Report DP-1382, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

18. Savannah River Laboratory Quarterly Report: Waste Management January-March 1977. USERDA Report DPST-77-125-1, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1977).

19. J. A. Stone. Separation of SRP Waste Sludge and Supernate. USERDA Report DP-1441, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

20. Savannah River Laboratory Quarterly Report: Waste Management July-September 1976. USERDA Report DPST-76-125-3, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

21. J. A. Kelley. Evaluation of Glass as a Matrix for Solidification of Savannah River Plant Waste: Radioactive Studies. USERDA Report DP-1397, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

22. W. N. Rankin. Prediction of Canister Lifetime. Internal Report DPST-79-584, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (December 1979).

23. Deleted

24. Deleted

25. W. N. Rankin. "Compatibility Testing of Vitrified Waste Forms." Presented at Corrosion/78 NACE Meeting, Houston, Texas, March 6-10, 1978.

26. Deleted

27. W. N. Rankin. Attack of High-Strength, Oxidation-Resistant Alloys During In-Can Melting of Simulated Waste Glasses. SRL Manuscript DP-MS-79-39 (Rev.), proposed for presentation at Corrosion/80 NACE Meeting, Chicago, Illinois, March 6-10, 1980.

28. R. M. Wallace, H. L. Hull, and R. F. Bradley. Solid Forms for Savannah River Plant High-Level Waste. USAEC Report DP-1335, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1974).

29. R. S. Ondrejcin. Chemical Compositions of Supernate Stored in SRP High Level Waste Tanks. USAEC Report DP-1347, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1974).

30. M. H. Tennant to G. F. Merz. Thermal Analysis of DWPF Canister Processing. Internal Report DPST-78-380, E. I. Du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (June 20, 1978).

4. PROCESS DESCRIPTION

4.1 General (L. F. Landon)

High-level liquid wastes are separated into two fractions in the 241-F and the 241-H waste tank storage facilities prior to transfer to the DWPF. The first fraction, designated the supernate feed stream, is a blend of appropriately aged supernate and redissolved salt cake. The other fraction, designated as the sludge-slurry feed stream, is a blend of the in-tank settled insolubles.

The aluminum content of the sludge-slurry is reduced by caustic dissolution. Soluble salts are then separated from the sludge by washing and centrifugation.

The insoluble solids fraction of the supernate feed stream is separated by gravity settling and filtration. Cesium, plutonium, and strontium are removed from the clarified supernate using ion exchange resins. The clarified supernate is solidified in concrete and buried in soil trenches.

Cesium and plutonium eluted from the ion exchange resin are separated from the elutriant by fixation on zeolite. The zeolite slurry, concentrated strontium eluate, and washed sludge are dried and melted with additives to form a borosilicate glass. The glass is poured into stainless steel canisters where it hardens upon cooling. Lids are welded on the canisters. Each canister is inspected, leak checked, decontaminated and shipped to an on-site interim storage facility.

4.2 Facility Capacity (L. F. Landon)

The facility is to be capable of processing waste at an average attained rate of 9 gpm equivalent feed on a reconstituted basis. This rate is a good compromise between low cost and rapid waste inventory reduction. Smaller, slightly lower-cost plants would require excessively long processing periods and would be unresponsive to the need for prompt action on waste disposal. Larger plants, although processing waste faster, would be more expensive and would "catch up" with SRP waste generation after a few years of operation, thereafter requiring inefficient operation at a reduced rate and imposing an additional cost penalty. Additional information concerning the selection of the reference capacity is detailed in DPST-78-582.

4.3 Flow Diagram (L. F. Landon)

Figure 4.1 is a block flow diagram for the defense waste processing facility.

4.4 Flowsheets and Material Balances (G. W. Becker, J. R. Chandler, L. F. Landon)

This section describes in detail the bases used to develop flowsheets and material balances for each process module. Only main process lines are illustrated and parallel operations are combined into a single representative operation. Streams that are inconsistent in terms of chemical makeup and solids content (such as lab waste, stack condensate and sand filter condensate) were considered in terms of total flow only. The material balances were prepared using the Du Pont Engineering Department's Chemical Process Evaluation System (CPES) computer program. Unless otherwise specified, process streams are assumed to be at 38°C for material balance purposes.

Table 4.1 was prepared to assist in locating flowsheet/ material balance information quickly. Listed are (1) the various process modules which comprise the defense waste processing facility, (2) the flowsheet identification numbers, (3) the flowsheet figure number, (4) the material balance identification numbers, and (5) the material balance table number. The basis used to develop each module's material balance is presented below. More comprehensive discussions of each module are in Section 4.5.

4.4.1 Nonradioactive Constituents

4.4.1.1 Sludge and Supernate Feed Stream Preparation

The purpose of these operations is to feed the DWPF two feed streams — a supernate stream and a sludge-slurry stream. The flowsheet (FS-2) is shown in Figure 4.2. The material balance (MB-2) is tabulated in Table 4.2. The material balance bases assumed are:

- F- and H-Area sludges and supernates are blended.
- Sludge is slurried and removed from storage tanks with recycle water. The original compacted sludge volume is slurried with a volume of water such that the resultant volume is twice the original sludge volume. The sludge-slurry is then transferred to aluminum dissolving.
- Redissolved salt cake and aged decanted supernate are removed from storage tanks and sent to gravity settling. One gallon of salt cake makes four gallons of supernate.

- The detailed bases for the compositions and quantities used in preparing these feed streams are detailed in Appendix 13.2.

- The equivalent of 130 lb/hr recycle water is used to flush the sludge-slurry transfer line. This is equivalent to a 9360 lb water flush following a transfer made every three days.

4.4.1.2 Aluminum Dissolution

The purpose of these facilities is to remove aluminum from the sludge by boiling the sludge in a caustic solution. The flowsheet (FS-3) is shown in Figure 4.3. The material balance (MB-3) is tabulated in Table 4.3. The material balance bases are:

- Sludge is in a water-sludge slurry produced by slurrying the original settled volume of the sludge with a volume of water such that the resultant volume is twice that of the original sludge volume.

- Sodium hydroxide is added to the sludge as a 50 wt % solution so that there are 16 moles of added NaOH per mole of undissolved aluminum.

- The solution is adjusted to 5M NaOH at the beginning of the batch.

- Forty-five percent of the water fed is boiled at total reflux for at least 30 min. For material balance purposes, 75% of the aluminum is assumed to be dissolved according to the reaction:

$$Al_2O_3\cdot 3H_2O_{(s)} + 2NaOH_{(aq)} \;^{x}\; 2NaAlO_{2(aq)} + 4H_2O$$

$$x = 75\%$$

- Gravity settler bottoms and waste sand/coal are blended in the dissolver after aluminum dissolution is complete.

4.4.1.3 Sludge Washing

The purpose of this operation is to wash salts from the sludge in order to maintain spray dryer feed (Figure 4.5) with $\leq 5\%$ Na^+, $\leq 10\%$ NO_3^-, and $\leq 3\%$ SO_4^{2-} on a dry weight bases. The flowsheet (FS-4) is shown in Figure 4.4. The material balance (MB-4) is tabulated in Table 4.4. The material balance bases are:

- Washed sludge contains 2.0 wt % soluble salts on a dry weight basis.
- Sludge is batch washed by dilution with water.
- Three centrifuge passes per batch of feed. The first pass is a sludge dewatering step followed by two wash passes.
- Solids recovery - 98% in each centrifuge pass.
- Fill basket to 90% volume in first centrifuge pass.
- Skim to cake surface in each pass.
- Three (3.0) lbs H_2O/lb solids in cake.
- Addition of spray water following the third centrifuge pass to provide a washed sludge slurry containing 17 wt % total solids.
- Use an equal volume of spray water in each centrifuge pass.
- Use an equal volume of wash water plus spray water in each centrifuge pass.
- Centrifuge bowl volume - 120 gallons.

4.4.1.4 Spray Drying and Vitrification

The purpose of spray drying is to convert the sludge slurry feed into a powder for feed to the melter. The purpose of the continuous joule-heated melter is to melt borosilicate glass frit and dryer product into a homogeneous molten glass to be poured into canisters. The flowsheet (FS-5) is shown in Figure 4.5. The material balance (MB-5) is tabulated in Table 4.5. Bases used in developing the material balance are:

- The spray nozzles are operated with four pounds of atomizing air per gallon of dryer feed slurry.
- Total average filter blowback air is 85 SCFH.
- 65 lb of frit added/35 lb of solids and salt in spray dryer feed (dry basis).
- Air inleakage rate assumed at 20 lb/hr.

- Entrained frit air has the same volume as frit.
- 2% free H_2O in spray dryer product.
- Glass melt temperature - 1150°C.
- Off-gas temperature - 350°C (at sintered metal filters).
- For material balance purposes, the spray dryer/melter stoichiometry is as follows:

$Hg_{(s)} \rightarrow Hg_{(v)}$

$HgO_{(s)} \rightarrow Hg_{(v)} + 1/2\ O_{2(v)}$

$Hg(OH)_{2(s)} \rightarrow HgO_{(s)} + H_2O_{(v)}$

$Cl^- + Na^+ \rightarrow NaCl_{(s)}$

$F^- + Na^+ \rightarrow NaF_{(s)}$

$2NaF_{(s)} + H_2O_{(v)} \xrightarrow{x} 2HF_{(v)} + Na_2O_{(s)}$ $x = 3.8\%$

$2I^- + Hg_{(v)} \rightarrow HgI_{2(v)}$

$HgI_{2(v)} \xrightarrow{x} Hg_{(v)} + I_{2(v)}$ $x = 1\%$ (@ 350°C)

$2Al(OH)_3 \rightarrow Al_2O_{3(s)} + 3H_2O$

$2Fe(OH)_3 \rightarrow Fe_2O_{3(s)} + 3H_2O$

$Na_2CO_3 \rightarrow Na_2O_{(s)} + CO_{2(v)}$

$CaCO_3 \rightarrow CaO_{(s)} + CO_{2(v)}$

$2Na_4C_{10}H_{12}O_8N_2 + 22O_2 \rightarrow 20CO_{2(v)} + 4NO_{(v)} + 12H_2O_{(v)} + 4Na_2O_{(s)}$

$2Na^+ + SO_4^{2-} \rightarrow Na_2SO_{4(s)}$

$2NaNO_{3(s)} \rightarrow Na_2O_{(s)} + 2NO_{(v)} + 3/2\ O_{2(v)}$

$2NaOH_{(v)} \rightarrow Na_2O_{(s)} + H_2O_{(v)}$

$2NaNO_{2(s)} \rightarrow Na_2O_{(s)} + 2NO_{(v)} + 1/2\ O_{2(v)}$

$Ni(OH)_2 \rightarrow NiO_{(s)} + H_2O_{(v)}$

$2NaAlO_{2(s)} \rightarrow Na_2O_{(s)} + Al_2O_{3(s)}$

$3UO_2(OH)_{2(s)} \rightarrow U_3O_8 + 3H_2O_{(v)} + 1/2\ O_{2(v)}$

$C_6H_{10}O_{5(s)} + 6O_{2(v)} \rightarrow 5H_2O_{(v)} + 6CO_{2(v)}$

4.4.1.5 Off-Gas Treatment

The purpose of these facilities is to decontaminate gaseous effluents such that they meet state and federal regulations.

The flowsheet (FS-6) is shown in Figure 4.6. The material balance (MB-6) is shown in Table 4.6. Material balance bases are as follows:

4.4.1.5.1 Spray Dryer/Melter Off-Gas

- Temperature of vapor leaving spray dryer filters - 350°C.
- The ejector/venturi scrubber liquid cooled to 40°C vapor temperature.
- Off-gas temperature reduced to 50°C in ejector/venturi.
- Water and mercury vapor concentrations in the vapor effluent from the off-gas condensate tank and the secondary deep bed filter are the saturation concentrations at the vapor temperature.
- Mercury is separated as 100% mercury liquid.
- HF is totally soluble in the off-gas condensate.
- HgI_2 vapor and the volatile species of cesium, technetium, selenium, tellurium, rubidium, and molybdenum condense and coalesce in the ejector/venturi to form submicron particulates with a nominal diameter of 0.3 μm.
- Washed deep bed filter lower spray - 2 gpm; upper spray - 40 gpm.
- Atomizing air to deep bed filter lower spray nozzle - 5 scfm/gpm.
- Secondary deep bed scrubber liquid cooled to a temperature such that the vapor temperature is reduced to 10°C.
- Temperature of vapor feed to Ru adsorber - 10°C above its dew point.
- Temperature of vapor feed to I_2 guard bed - 150°C.
- Temperature of vapor feed to exhauster - 50°C.
- Assumed DF's are as follows:

	Vapors	Solids (particulates)
Spray Dryer Filters	1	10^3
E/V Scrubber	1	2.5
Deep Bed Filter (each)	20 on Ru 1 on others	50
Ru Adsorber (each)	100 on Ru 1 on others	2
I_2 Guard Bed	100 on I_2 1 on others	2

4.4.1.5.2 Process Vessel Vent Systems

- Purge Rate - 50 scfm (inlet)/vessel
- Inlet Conditions - 35°C DB, 25.6°C WB
- Outlet Conditions - 35°C DB, 29.4°C WB
- Process Vessel Vent Filter DF - Particulates - 10^3
  Volatiles - 1
- HEPA Filter DF - Particulates - 10^3
  Volatiles - 1
- Preheater Capacity - raise temperature 10°C above dew point.

4.4.1.5.3 Canyon Air

- DB - 35°C
  WB - 25.6°C
- Flow - 356,400 acfm

4.4.1.6 Mercury Recovery

Approximately 1.2 lb of metallic mercury will be condensed each hour from the off-gas vapor stream and accumulate in the off-gas condensate tank. The mercury will most likely be as a sludge and will require further cleaning before it is of a purity suitable for reuse in the separations process and/or storage. The flowsheet (FS-6A) is shown in Figure 4.6A.

The mercury that accumulates will be intermittently pumped to a mercury receipt tank and subsequently pumped through a backwashable filter to remove the majority of solids occluded to the mercury. Periodically, the filter cake will be dislodged from the filter and pumped to the off-gas condensate tank for recycle into the process.

The filtered mercury, on a batch basis, will be pumped to the top of a column containing 10% HNO_3. The formed droplets will fall by gravity through the acid and overflow a barometric leg to an oxidizing tank. Particulates, not removed by the initial filtration step, that are soluble will be removed from the mercury. Periodically, the nitric acid will be pumped to the backwash hold tank and replaced with fresh acid.

To remove contaminants such as iron and aluminum, the acid-washed mercury will be air sparged at room temperature to oxidize the contaminants. After sparging is complete, the mercury is filtered through another backwashable filter to remove the formed oxides. Final cleanup of the mercury is achieved by vacuum distilling the mercury and bottling the condensed overheads.

4.4.1.7 Recycle Evaporation

The purpose of this operation is to (1) remove excess water from dilute recycle streams to maintain the salt concentration in the gravity settler feed at 30 wt %, (2) to reduce supernate processing equipment size, and (3) provide the first stage of decontamination for process water. The flowsheet (FS-7) is shown in Figure 4.7. The material balance (MB-7) is tabulated in Table 4.7. Material balance bases are:

- Recycle concentrator bottoms are concentrated (to about 35 wt % salt) so that the gravity settler feed contains 30 wt % salt supernate.
- Recycle evaporator condensate is sent to the general purpose evaporator for another stage of evaporation.
- HF in off-gas condensate reacts with excess NaOH in the recycle evaporator feed tank to form soluble NaF.
- The ratio of the concentration of salt in the concentrate to the concentration of salt in the condensate is 10^6.

- A fraction of the HgI_2 collected in E/V and deep bed filter scrubber liquid reacts in the Recycle Evaporator Feed Tank as follows:

$$HgI_{2(s)} + NaOH_{(DS)} \quad \overset{x}{\quad} \quad 2NaI_{(DS)} + Hg(OH)_{2(s)} \qquad x = 8\%$$

4.4.1.8 Settling and Filtration

The purpose of this operation is to clarify the supernate feed to ion exchange. The flowsheet (FS-8) is shown in Figure 4.8. The material balance (MB-8) is tabulated by Table 4.8. Material balance bases are:

- Feed concentration - 30 wt % salt. Feed temperature - 40°C.
- 99% of the solids fed to the gravity settler (GS) are recovered for recycle to sludge washing. 93 vol % of the GS feed is sent to sand filtration and 7 vol % is recycled to sludge washing via the aluminum dissolver.
- 0.0005 gal of 8 wt % starch dispersion/gal GS feed. Starch follows the insoluble fraction.
- Decanted supernate is cooled to $\leq 25°C$ before feeding to sand filters.
- Sand filter No. 1 removes 90% of its feed solids. Sand filter feed consists of 1.15 gpm/ft^2 supernate and 0.05 gpm/ft^2 polyelectrolyte solution (1N NaOH and trace polyelectrolyte).
- Sand filter No. 2 removes 80% of its feed solids. This unit's feed also consists of 1.15 gpm/ft^2 of filtrate and 0.05 gpm/ft^2 of polyelectrolyte solution.
- Each filter is backwashed with clarified supernate at a rate of 15 gpm/ft^2 for 5 min each day.
- Used sand and coal are recycled via the aluminum dissolver. Beds are assumed to be dumped every three months. Beds are fluidized with 15 gpm/ft^2 of 1N NaOH for 10 min and are jetted out.
- For purposes of preparing a material balance, the following filter bed details are assumed.

	Density, lb/ft^3	No. 1 Filter Height, in.	No. 2 Filter Height, in.	Bed Diameter, ft
Coal	85	8	3	4
Sand	100	24	18	4

4.4.1.9 Cesium Ion Exchange

The purpose of this operation is to remove cesium and plutonium from clarified supernate. There are two ion exchange columns, in series, each containing 1525 gallons (50% voidage) of Duolite® (Diamond Shamrock) ARC-359 resin. Each column will have at least 75% freeboard above the resin for expansion during backwashing. The flowsheet (FS-9) is shown in Figure 4.9. The material balance is tabulated in Table 4.9. Material balance bases are:

- Assumed resin stoichiometry is:

		lb moles Na^+/gal of Resin
Load:	$RNa + Cs^+ \rightleftharpoons RCs + Na^+$	-
1st Rinse:	$NaOH_{(bound)} \longrightarrow NaOH_{(aq)}$	0.002
Elution:	$NaOH_{(bound)} \longrightarrow NaOH_{(aq)}$	0.008
	$RNa + NH_4OH \longrightarrow RNH_4 + NaOH$	0.01
	$RCs + NH_4OH \longrightarrow RNH_4 + CsOH$	-
Regeneration:	$NaOH_{(aq)} \longrightarrow NaOH_{(bound)}$	0.01
	$RNH_4 + NaOH \longrightarrow RNa + NH_4OH$	0.01

- Note that bound sodium is different from sodium in the interstitial liquid. Displacement of interstitial liquids is assumed to be by plug flow.

- Cesium and plutonium decontamination factors assumed for preparing the material balance are 10^4 and 165, respectively.

- Resin capacity - 20 gal liquid feed/gal resin.

- The steps for a complete cycle are:

	Time, hr	CV/hr*	CV	Direction	Stream
Load	12	1.67	20	Down	Supernate
1st Rinse	3	1.67	5	Down	Water
Elution	8.33	1.2	10	Up	2M NH_4OH, 2M$(NH_4)_2CO_3$
2nd Rinse	2.5	1.2	3	Up	Water
Regeneration	4.17	1.2	5	Up	2M NaOH
Standby	1				
Total	31				

---

* CV = column volume.

- Resin is replaced annually.
- Material balance rates are average rates based on the 31-hour cycle.
- Maximum temperature of feed streams to columns - 30°C.

4.4.1.10 Strontium Ion Exchange

The purpose of this operation is to remove strontium from clarified supernate. The Sr ion exchange column contains 762 gallons (with 50% voidage) of Amberlite® (Rohm and Haas) IRC-718 resin. This column is provided with a freeboard allowing at least a 75% expansion of the resin. The flowsheet (FS-10) is shown in Figure 4.10. The material balance (MB-10) is tabulated in Table 4.10. Material balance bases are:

- Elution and regeneration take place simultaneously. Simplified resin exchange reactions are,

Load: $R_2Na_2 + Sr^{2+} \longrightarrow R_2Sr + 2Na^+$

Elution/Regeneration:

$$R_2Sr + C_2H_4N_2(CH_2COO)_4Na_4 \longrightarrow R_2Na_2 + C_2H_4N_2(CH_2COO)_4Na_2Sr$$

- The decontamination factor for both soluble and insoluble strontium is 10^3.
- Resin capacity: 40 gal liquid feed/gal resin.
- The steps for a complete cycle are:

	Time, hr	CV/hr*	CV	Direction	Stream
Cs Column Effluent					
Supernate	12	3.33	40	Down	Supernate
1st Rinse	3	3.33	10	Down	Water
1st Rinse	0.45	3.33	1.5	Down	Water
Elution/Regeneration	6	1	6	Up	0.01M Alk. EDTA 0.001M NaOH
2nd Rinse	3	1	3	Up	Water
Standby	6.55				
Total	31				

---

* CV = column volume.

- The maximum temperature of feed streams to the column - 30°C.
- The eluate/regenerate effluent goes to the strontium concentrator. The strontium concentrator produces a 1.0M alkaline EDTA concentrate.
- Resin is replaced annually.
- The ratio of the concentration of salt in concentrate to the concentration of salt in condensate is 10^6.

4.4.1.11 Cesium Elutriant Recovery and Cesium Concentration

The purpose of these facilities is to remove ammonia and carbon dioxide from the eluate and to concentrate the cesium eluate to a 2.0M $Na_2CO_3 + Cs_2CO_3$ solution. The flowsheet (FS-11) is shown in Figure 4.11. The material balance (MB-11) is tabulated in Table 4.11. Material balance bases are:

- NH_4OH and $(NH_4)_2CO_3$ are decomposed and the NaOH/CsOH in the eluate is converted to Na_2CO_3/Cs_2CO_3 in the steam stripper.
- Cooled (38°C) concentrate is 2M ($Na_2CO_3 + Cs_2CO_3$). Purge condensate is sent to the recycle evaporator.
- Stripper condensate is at 6M NH_3.
- All the NH_3 in the spent regenerant along with some water (0.2 lb H_2O/lb of NH_3) is evolved to the cesium vent scrubber. Other vent scrubber feeds are based on:

	NH_3[a]	CO_2[a]
Tank vents	1	2
Stripper vent	1	7
Vent Scrubber Off-gas	0.1	Net of $(NH_4)_2CO_3$

a. As percent of feed.

- The vent scrubber bottoms contain 2M $(NH_4)_2CO_3$ and is recycled to the Cs concentration feed.
- Make-up CO_2 is introduced into the cesium elutriant makeup tank as a gas and ammonia as an 8M NH_4OH solution.
- DF for entrainment across the stripping section - 10^6.
- The ratio of the concentration of salt in concentrate to the concentration of salt in purge condenser condensate is $\geq 10^4$.
- 99.95% of the NH_3 entering in the feed to the cesium concentrator is stripped as overhead products.

- 0.05% of the NH_3 entering in the feed to the cesium concentrator is removed with the purge condensate. The purge condenser will be run hot to ensure that NH_3 flashes to the vent scrubber.

- Stripper is assumed to operate at 100% efficiency.

4.4.1.12 Cesium Fixation on Zeolite

The purpose of these facilities is to remove the Na_2CO_3 from the feed to spray drying and melting by fixation of Cs and Pu on zeolite (Linde® AW-500 or Ionsiv IE-95). The flowsheet (FS-12) is shown in Figure 4.12. The material balance (MB-12) is tabulated on Table 4.12. Material balance bases are:

- There is one zeolite bed which is changed out every 60 days. Other column size variables are zeolite bulk density (45.4 lb/ft^3) and design loading (50 gallons of Cs concentrate to one gallon of zeolite). The column is 20 ft high and contains a 1494-gallon zeolite bed (11 ft high). Column liquid holdup (1969 gallons) is made up of freeboard and 50% bed voidage.

- Column operation consists of accumulating concentrate for three days and processing downflow at 1.5 gpm/ft^2. The column is flushed (downflow at 1.5 gpm/ft^2) with 2 bed volumes of water (2988 gallons) of which 2648 gallons are retained and circulated for cooling purposes. The effluent from the column depleted in cesium by a factor averaging at least 100, is recycled to the sand filter feed tank.

- Loaded beds are removed in a water slurry with a total volume 6 times the bed volume. Four bed volumes of water are decanted and sent to recycle evaporation. The remaining 2-bed-volume zeolite-water slurry is sent to spray drying/melting.

- Fresh zeolite is introduced from cold feed in a 4-bed-volume slurry. Water in excess of 2648 gallons is sent to recycle evaporation.

- Between loading cycles, water is circulated through the bed to maintain the zeolite at 50°C or less.

4.4.1.13 General-Purpose Evaporation

The purpose of this operation is to provide a final stage of evaporation (decontamination) on miscellaneous evaporator condensate prior to purging to the environment. The flowsheet (FS-13) is shown in Figure 4.13. The material balance (MB-13) is tabulated in Table 4.13. Material balance base is:

- The weight ratio of cooled bottoms to feed is 1 to 10.

- The ratio of the concentration of salt in the concentrate to the concentration of salt in the condensate is 10^6.

4.4.1.14 Solidification of Product Salt Solution in Concrete

The purpose of these facilities is to solidify clarified supernate from ion exchange in concrete and bury the concrete in soil trenches. The flowsheet (FS-14) is shown in Figure 4.14. The material balance (MB-14) is tabulated in Table 4.14. Bases for developing the material balance are as follows:

- Descaling flow - 20% of evaporator vapor rate.
- Evaporator concentrate - 35 wt % salt.
- Rework return and flush constant at 240 lb/hr water and 40 lb/hr concrete.
- Concrete plant water flush constant at 14.8 lb/hr.
- Saltcrete composition - 29.2 wt % H_2O, 15.0 wt % salt, 55.8 wt % cement.
- Source of flush water is the Product Salt Evaporator condensate. The balance sent to the Recycle Water Tank.

4.4.1.15 Mechanical Cell A

Following sealing and leak checking of the canister, the canister undergoes the first of two, two-step surface decontamination processes (the second is carried out in Mechanical Cell B). The canister is initially etched in a 3.5M HNO_3 - 0.4M NaF solution. Following rinsing, the canister is cleaned in an oxalic acid solution (100 g $C_2H_2O_4$/L). These solutions are initially used in Mechanical Cell B. Spent oxalic acid is digested prior to blending with the spent etching solution. The flowsheet (FS-15) is shown in Figure 4.15. The material balance is tabulated in Table 4.15. Bases used to develop the material balance are as follows:

- Decontamination solutions are introduced as cold feeds in Mechanical Cell B and reused in Mechanical Cell A.
- Etching agent - 3.5M HNO_3 - 0.4M NaF at 350 gal/canister.
- Cleaning agent - 100 g/L $C_2H_2O_4$ at 350 gal/canister.
- Rinsing agent - H_2O at 100 gal/canister.
- Etch cycle - 1 hour.

- Cleaning cycle - 1 hour.
- Etching rate - 0.3 mil SS/hour (assumed to be Fe).

  $Fe_{(s)} + 4HNO_3 \rightarrow Fe(NO_3)_{3(DS)} + NO_{(v)} + 2H_2O$

- Canister surface area - 69 ft^2.
- Etching solutions maintained at <50°C.
- Spent cleaning solution is digested in 1.0M HNO_3 - 0.01M $Mn(NO_3)_2$ at ∿95°C for 2 hours. Digestion reaction:

  $3C_2H_2O_4 + 2HNO_3 \xrightarrow{x} 6CO_{2(v)} + 2NO_{(v)} + 4H_2O \qquad x = 95\%$

- Spent etching solution is blended with the digested cleaning solution and neutralized with 10% excess 50% NaOH. The following reactions are assumed for material balance purposes.

  $C_2H_2O_4 + 2NaOH \rightarrow Na_2C_2O_{4(DS)} + 2H_2O$

  $HNO_3 + NaOH \rightarrow NaNO_{3(DS)} + H_2O$

  $Mn(NO_3)_2 + 2NaOH + 1/4\ O_2 \rightarrow MnO \cdot OH_{(s)} + 1/2\ H_2O + 2NaNO_{3(DS)}$

  $Fe(NO_3)_3 + 3NaOH \rightarrow Fe(OH)_{3(s)} + 3NaNO_{3(DS)}$

- 98% of the fluoride upon neutralization forms the soluble salt of sodium and upon recycle to the Recycle Evaporator Feed Tank remains soluble, ultimately being carried through ion exchange. The remaining fluoride is associated with the insoluble fraction of the neutralized spent decontamination solutions and ultimately will be part of the feed to the spray dryer.

4.4.1.16 Mechanical Cell B

The function of this facility is to carry out the second of the two-step canister decontamination processes (See Section 4.4.1.15). The etching solution (3.5M HNO_3 - 0.4M NaF) and the cleaning solution (100 g/L $C_2H_2O_4$) are introduced into this cell as cold feeds. The canister surface is to be decontaminated to <220 d/min/dm^2 alpha and <2200 d/min/dm^2 beta-gamma before transfer to Mechanical Cell C. The flowsheet (FS-16) is shown in Figure 4.16. The material balance (MB-16) is tabulated in Table 4.16. Bases used to develop the material balance are as follows:

- Etching agent - 3.5M HNO_3 - 0.4M NaF at 350 gal/canister.
- Cleaning agent - 100 g/L $C_2H_2O_4$ at 350 gal/canister.
- Rinsing agent - H_2O at 100 gal/canister.
- Etch cycle - 1 hour.
- Cleaning cycle - 1 hour.
- Etching rate - 0.3 mil SS/hr (assumed to be Fe).

$$Fe_{(s)} + 4HNO_3 \rightarrow Fe(NO_3)_{3(DS)} + NO_{(v)} + 2H_2O$$

- Canister surface area - 69 ft^2.
- Etching solution maintained <50°C.

4.4.1.17 Mechanical Cell C

The function of this facility is to (1) perform a contamination survey of the exterior surface of the canister, (2) make temperature and radiation profile on the canister, and (3) perform spot electropolishing if the contamination survey dictates. The flowsheet (FS-17) is shown in Figure 4.17 and the material balance (MB-17) is tabulated in Table 4.17.

4.4.2 Radionuclide Constituents (J. R. Chandler)

4.4.2.1 General

A model has been written and placed on SRL's IBM-360 computer which calculates the concentration (and corresponding heat generation rates) in every process stream for >160 specific radionuclides. Isotopic content of the two reference feed streams, glass product, saltcrete product, and gaseous/aqueous effluents are tabulated in Tables 2.3-2.10, 3.3-3.4, 3.15-3.16, and 8.2-8.10, respectively. The concentration of a specific radionuclide in any process stream may be obtained from the microfiches in Appendix 13.7.

4.4.2.2 Feed Stream Composition

The radionuclide composition of the two reference feed streams to the DWPF (see Tables 2.3-2.10) were calculated from the 200 Area waste blend (see Section 7). This waste blend is computed from a knowledge of reactor operating parameters, 200 Area processing rates and waste generating factors (Section 7). Using the radionuclide composition of the waste blend, the radionuclide inventory is distributed between the supernate and sludge-slurry feed streams based on the insoluble fraction of each stream and the distribution of each radionuclide between the supernate fraction of the reference waste blend and the in-tank settled in-soluble fraction. The resulting percent distribution of these radionuclides between the reference feed streams, as well as between the soluble and insoluble fractions of each stream, are tabulated in Table 4.18.

4.4.2.3 Curie Balance Bases

4.4.2.3.1 Aqueous Process Streams

- Soluble fraction of each isotope (exclusive of tritium) follows the salt.
- Insoluble fraction of each isotope follows the insoluble solids.
- Tritium follows the water throughout the process.
- Behavior of isotopes during vitrification and off-gas treatment is detailed in Section 4.5.6.3.
- Eight (8) percent of the iodine recycled from the off-gas condensate tank as unsoluble HgI_2 is converted to soluble NaI.
- The radionuclides associated with the insoluble fraction in the sludge-slurry feed stream remain with the solid fraction across aluminum dissolving.

4.4.2.3.2 Gaseous Process Streams

- Calciner Off-Gas Treatment

  See Section 4.5.6.3.

- Process Vessel Vapor Space Purge

  Inlet Flow - 50 scfm (dry air) at 95°F dry bulb and 78°F wet bulb

  Outlet Flow - 95°F dry bulb, 85°F wet bulb

  Entrainment - 10^{-9} gal/ft^3

- Canyon Air

  Flow - 356,400 acfm (dry bulb - 95°F, wet bulb - 78°F)

  Radionuclide Content - 2.25 times that calculated in the filtered Process Vessel Vent System. This is based on measured contribution of the filtered process vessel vent system and canyon air (unfiltered) system non-volatile beta radioactivity in the 221-F and -H Area facilities over the period of 1/78 through 12/79.

4.5 Process Details

4.5.1 Sludge and Supernate Feed Preparation

4.5.1.1 General

The purpose of these operations is to prepare two feed streams - a supernate stream and a sludge-water slurry stream for transfer to the DWPF. The generalized flowsheet, material balance, and calculational bases were described in Section 4.4.1.1 and Appendix 13.2. The technical bases upon which waste removal equipment and blending procedures were developed are outside the scope of this document and will be presented in a separate basic data report.

4.5.2 Aluminum Dissolution (C. T. Randall)

4.5.2.1 General

The purpose of this section is to present the process details and technical data bases for reducing the aluminum content of the sludge. Advantages of this process step are:

- The amount of glass required to contain SRP waste is reduced by 20%.
- Glass melt viscosities are reduced for improved glass quality.
- Requirements for blending high-aluminum sludges with other sludges are relaxed.

4.5.2.2 Process Description

Batches of 1:1 sludge slurry are adjusted to an OH^-/Al^{3+} molar ratio* of 16 and an initial NaOH concentration of 5M. The slurry is boiled at total reflux for a minimum of 30 minutes. The aluminum-rich liquid phase and the aluminum depleted solid phase are subsequently transferred to the sludge washing module (FS-4) where solid phase separation and washing is performed. A flowsheet (FS-3) is shown in Figure 4.3 and the material balance (MB-3) in Table 4.3.

4.5.2.3 Technical Data

This section summarizes experience and technology in dissolving aluminum from SRP sludges. Initial investigation concluded that boiling 5M NaOH removed >75% of the aluminum

---

* Moles of NaOH added per mole of undissolved aluminum.

in washed, dried sludge from Tank 16. Subsequent studies that used as-received (raw) sludge from Tanks 11, 15, and 21 showed that 70-78% of the solid phase aluminum is removed from the high-alumina sludges from Tanks 11 and 15, and 45-50% from the low-alumina sludge from Tank 21.

The two crystalline forms of hydrated aluminum likely to be found in SRP sludges are the trihydrate, gibbsite ($Al(OH)_3$), and the monohydrate, boehmite (AlOOH). Freshly precipitated aluminum in SRP sludges is an amorphous material that crystallizes to gibbsite. Dissolution of the amorphous or gibbsite form is rapid. The aluminum industry typically obtains 99% solubility of gibbsite in 20-30 minutes using ∿3M caustic at 150°C.

In caustic mixtures, gibbsite begins converting to boehmite at significant rates at about 140°C, a temperature that has probably been reached in several SRP sludges. Boehmite is harder to dissolve than gibbsite - dissolution temperatures around 230°C are used industrially. Solubilities of gibbsite and boehmite in caustic solutions are shown in Figures 4.18 and 4.19 [3].

Also plotted in Figure 4.18 are the compositions of six aluminum-bearing supernate solutions that have been stable at 20°C for over 2 months. Synthetic gravity settler feed solutions were spiked with $Al(NO_3)_3$, seeded with $Al(OH)_3$ crystals, and observed over a period of 2 months. No precipitation of gibbsite occurred. Apparently, other ions in solution (Na^+, NO_3^-, NO_2^-, CO_3^{2-}, SO_4^{2-}) increase the solubility of aluminum in caustic solution and, in addition, dramatically reduce the effect of temperature on solubility. This conclusion is supported by the data of Barney.

SRL experience dissolving aluminum in actual SRP waste sludges is summarized in Table 4.19. These results show that a large fraction of the aluminum in SRP sludges can be removed by boiling NaOH solution in 30 minutes to 1 hour.

For dissolution in 5M NaOH the final Al/OH molar ratio in the supernate was typically 0.04 (OH/Al ratio = 25). This is well below the solubility line at T=100°C in Figure 4.18 and also below the T=100°C line in Figure 4.19. Therefore, it may be possible to decrease the initial OH/Al ratio significantly and still allow good aluminum removal.

Table 4.20 shows how Al dissolution changes the composition of Tank 15 sludge. The percent of each metal ion in the sludge after Al dissolution is still well within the overall variation of SRP sludges. Aluminum removal will therefore not create any new problems associated with sludge composition. Tank 15 sludge, before Al removal, has a relatively high Al/Fe ratio, but is otherwise typical of most SRP sludges.

For convenience of operation the laboratory tests used 5 g of dry sludge (or 5 mL of as-received sludge) and 100 mL of caustic, although data in Figures 4.18 and 4.19 show that lower caustic concentrations should be acceptable. Because they have been demonstrated to give good aluminum dissolution, reaction conditions chosen for preliminary process design are those that yielded 76% dissolution of Tank 16 sludge (see Table 4.19):

OH/Al molar ratio = 16 to 1

$[OH^-]$ = 5M

Temperature = boiling (∿105°C)

Time = 30 minutes to an hour

No major incompatibilities with other parts of the solidification process have been identified as resulting from the additional NaOH.

Boiling caustic should be used for best aluminum recovery. Higher temperatures would ensure removing essentially all aluminum from SRP sludge. Lower temperatures would greatly slow the dissolution rate and increase the chance that aluminum in the boehmite form would not be adequately removed. Residence times of 30 minutes to 1 hour in boiling caustic should be used.

Sludge bottoms from the gravity settlers and spent filter media (sand and coal) from the sand filters are blended with the dissolver bottoms (after aluminum dissolution is completed). The volumes of sludge recycle and spent filter media added are controlled to maintain a relatively uniform process feed composition for sludge washing.

4.5.3 Sludge Washing (D. W. Jones)

4.5.3.1 General

The objective of the sludge washing step is to remove most of the soluble salt from the sludge waste prior to vitrification. This is necessary in order to meet sulfate, sodium, and nitrate salt concentration criteria for waste vitrification and to reduce the volume of vitrified product. Without washing, the glass volume and therefore the cost of product handling and storage would be increased severalfold. Washing also removes caustic and dissolved aluminum added to the sludge during aluminum dissolution.

The sludge waste is received from the aluminum dissolver and batch washed with water in two parallel processing units. Each unit contains an agitated wash tank to mix the gelatinous sludge solids and wash water, a solid-wall basket centrifuge to separate the sludge and liquid phases after contacting, and a centrate tank to hold the centrifuge liquid effluent. The centrifuge has 48-inch-diameter by 30-inch-high bowl with a 120-gallon fill capacity and generates 1300 g's maximum separating force at 1400 rpm.

A simple three-step dilution washing process is employed consisting of an initial sludge dewatering step followed by two wash steps. These operations reduce sludge salt content from 88% to 2% on a dry weight basis. The 2% concentration is nearly optimum for the process and is more than sufficient to meet individual product specifications for sulfate, sodium, and nitrate salts in the washed sludge. These specifications are $\leq 3\%$, SO_4^{2-}, $\leq 5\%$ Na^+, and $\leq 10\%$ NO_3^- dry weight basis.[a] The final washed sludge is slurried with water to produce a slurry containing 17 wt % total solids. The design processing rate for the two sludge washing units is 85 lb/hr of insoluble solids, and about 40 pounds of wash water are used per pound of solids washed.

4.5.3.2 Process Description

A process flow diagram is shown in Figure 4.4, material balance data are listed in Table 4.4, and an estimated operating cycle for the process is described below and in Table 4.21.

---

[a] Bases for these limits are as follows:

SO_4^{2-} - See Section 3.1.4

Na^+ - Glass leachability

NO_3^- - Ruthenium volatility.

Sludge feed for the washing process is received batchwise in the sludge feed tank from the aluminum dissolver at the end of each dissolving cycle. This feed includes sludge bottoms from the supernate gravity settlers and spent sand and coal from the sand filters which are combined with the digested sludge in the dissolver in fixed proportions in order to maintain a uniform feed composition for the washing process. This composition is monitored by periodic sampling and analysis of sludge feed tank contents for volume % solids and weight % solids, salt, and water.

Fixed volume batches of feed are pumped from the sludge feed tank to the two wash tanks at the start of each batch washing cycle. Batch volume is controlled so that the centrifuge bowl is filled to 90% of capacity with sludge (108 gallons) during the dewatering step. If this volume is exceeded, heavy overflow of solids in the centrifuge effluent will result. Both the batch volume and wash water addition are adjusted to compensate for changes in feed composition.

The undiluted sludge feed is initially centrifuged in the dewatering step to remove as much of the salt-rich liquid as possible before washing. Use of the dewatering step before washing minimizes water usage and is the most efficient processing scheme. The centrifuge bowl is accelerated to full speed and the bowl filled at a 30 gpm rate. A centrifuge feed rate of 5.0 gpm is used during dewatering to meet the design basis of 98% solids recovery for each centrifuge pass. The feed rate for the wash steps is 12.0 gpm. A lower centrifuge throughput is necessary in the dewatering step to compensate for lower solids separation due to the smaller density difference between the sludge and liquid phases.

The centrifuge effluent containing salt removed from the sludge and the unrecovered sludge fines drains by gravity into the centrate tank. At the end of each centrifuge cycle the centrate is pumped to the centrate hold tank where centrate from both washing units is combined. The centrate is then transferred to the recycle evaporation system for concentration by evaporation. The evaporator bottoms containing the concentrated salt and sludge fines are added to the plant supernate feed stream and fed to the gravity settlers where the fines are agglomerated and removed from the salt solution by gravity settling. The bottoms from the settling units are then recycled to the aluminum dissolver.

A constant centrifuge feed rate is maintained during dewatering until the wash tank is empty. The centrifuge is then operated at full speed (1400 rpm) for five minutes to further compact the sludge cake. This step reduces cake volume by about 10%. A 1-gpm water feed must be maintained during the compaction spin to prevent standing waves from forming on the pool surface in the bowl which can cause bowl imbalance. The excess liquid left on the cake surface after compaction is skimmed off, and the bowl is braked by the drive motor to a speed of 50 rpm for sludge unloading. A vertical knife-edged plow is then activated to scrape the sludge from the bowl wall. The cake falls through the open bottom of the centrifuge and through a chute into the wash tank below. Discharge is assisted by high pressure water sprays which are directed on the cake to help disperse the cake and clean the bowl. An estimated operating cycle for the centrifuge is given in Table 4.22.

During sludge compaction and discharge, wash water for the first wash is added to the wash tank, and the sludge and water are well mixed. During mixing, the salt ions diffuse rapidly from the interstitial liquid in the sludge particles to the bulk liquid phase. Concentration equilibrium is achieved within a matter of minutes. After discharge is completed, the centrifuge bowl is accelerated to full speed and the bowl is filled with the diluted sludge from the wash tank at a 30 gpm rate. This rate is controlled so that the bowl is filled to capacity (120 gallons) between a speed of 400 rpm, the minimum speed needed to support liquid in the bowl, and 1400 rpm. At full speed, the feed is reduced to a 12 gpm rate, and this rate is maintained throughout the feed step. When the wash tank is emptied, feed is stopped and centrifuge spin, skim, deceleration, and discharge operations are repeated to complete the first wash cycle.

Operating steps and timing for the second wash are very similar to those in the first wash. However, an on-line measurement of centrate conductivity is made during the second wash to determine whether the washed sludge batch meets the product specification of ≤ 2 dry wt % salt. If the conductivity reading indicates less than 0.68 wt % salt in the centrate liquid on a solids free basis, product specifications have been met and sludge washing is complete. Otherwise, additional washing will be necessary. The washed sludge is discharged from the centrifuge into the wash tank and slurried using only the discharge spray water. The amount of spray water is controlled to obtain 17 wt % total solids (insoluble plus dissolved solids) which is the maximum solids content for satisfactory slurry transfer and storage. The same amount of spray water is used in the dewatering and first wash steps. The washed sludge is then transferred from the wash tank to the washed sludge run tank where it is combined with slurry from the other washing unit. The washed sludge in the run tank is sampled and analyzed for wt % total solids, dry wt % salt, and dry wt % SO_4^{2-}, Na^+, and NO_3^-, and then transferred batchwise to the slurry mix tank prior to spray drying and vitrification.

4.5.3.3 Dilution Model

Sludge washing studies show that washing follows a simple dilution model described by the equation:

$$S_n = \frac{S_f}{\left(\frac{W_f + RI}{RI}\right)_d \left(\frac{W + RI}{RI}\right)_1 \left(\frac{W + RI}{RI}\right)_2 \cdots \left(\frac{W + RI}{RI}\right)_n} \qquad (1)$$

where

d = dewatering step

I = mass of insoluble solids in centrifuged sludge

n = number of washes

R = mass ratio of water to insoluble solids in centrifuged sludge

S_f = mass of salt in unwashed sludge feed

S_n = mass of salt in washed sludge

W = mass of wash water and spray water added to centrifuged sludge

W_f = mass of water in unwashed sludge feed.

The values of I and R are essentially constant for each step of the DWPF washing process, and an equal amount of wash water is added in each wash. Thus, Equation 1 can be simplified to give

$$S_n = \frac{S_f}{\left(\frac{W_f + RI}{RI}\right)\left(\frac{W + RI}{RI}\right)^n} \quad (2)$$

where average values of I and R are used. These equations describe the relationship between salt removal and major process parameters of solids throughput, wash water addition, sludge cake water content, and number of wash steps.

4.5.3.4 Large-Scale TNX Test Results

Large scale tests of the washing process and equipment are being conducted at TNX using a nonradioactive, synthetic sludge waste. The test equipment is shown in Figure 4.23 and includes a 1200-gallon agitated wash tank, 48-inch batch basket centrifuge, a 250-gallon sludge slurrying tank, and a large centrate tank (not shown).

The sludge washing centrifuge is one of the more complex pieces of mechanical equipment to be operated in the DWPF canyon, and therefore considerable attention is being given to its development and design. Figure 4.24 is a cutaway drawing of the large scale centrifuge now being tested at TNX. This unit was procured from DeLaval Separator Company of Poughkeepsie, New York, and is a vertical, solid-wall, batch basket centrifuge which generates 1300 g's force at the basket wall and 900 g's at the liquid pool surface when operating at maximum operating speed of 1380 rpm. The bowl is unbaffled. The centrifuge is made of 304L stainless steel and weighs 7300 pounds with the bowl empty. The static load on the spindle bearings with an empty bowl is 3400 lb, and the machine is rated for a maximum sludge loading of 1500 lb based on a sludge bulk density of 94 lb/ft^3. Bowl dimensions are 48 inches in diameter by 30 inches high by 7-1/4 inches deep and fill capacity is 120 gallons. Bowl wall thickness is 1.04 inches.

The motor and drive, bowl, and curb housing are all rigidly connected and the entire assembly is suspended by three stands on steel rods or links. The links have ball and socket end joints, and any load imbalance in the machine is accommodated for by displacement of the entire assembly on these links. The bowl is supported from the curb cover and is driven by a top-mounted, variable-speed, 75-hp hydraulic motor. The drive delivers 300-ft-lb torque and can provide full drive torque during plowing. The hydraulic drive also provides regenerative braking for bowl deceleration. The centrifuge is fed through a bottom rotating feed accelerator which brings the feed up to the angular velocity of the bowl before it enters the liquid pool or settling zone. This minimizes turbulence due to feed entry and thereby substantially improves solids separation. The separated sludge is discharged from the basket at approximately 50 rpm by single, air-driven, scraper-type plow which advances to the bowl wall during discharge and then is retracted from the wall during the remainder of the centrifuge operating cycle. A single, air-driven, linear skimming device is also provided to remove excess liquid from the cake surface prior to discharge. The centrifuge can be operated in either a fully automatic or manual mode.

The synthetic sludge waste used in the large scale test program simulates the slurry feed entering the washing process as characterized in Table 4.23. The sludge waste contains only the Fe, Al, Mr, Ca, and Ni cations; other major metal constituents, Hg and U, were omitted for health and environmental control reasons. Based on a comparison of the sludge properties and small scale test results obtained so far, the synthetic sludge waste appears to be less dense, more gelatinous, and have a higher water content than actual wastes. Consequently, test results with synthetic waste should provide a conservative basis for plant design.

Figure 4.25 shows sludge recovery in the 48-inch centrifuge as a function of feed rate and liquid density, the two major parameters affecting sludge separation. As expected from sedimentation theory, recovery declines with increasing throughput and liquid density. Sludge separation is directly proportional to the density difference between the sludge and liquid phases and therefore varies inversely with liquid density at constant throughput. Feed rate affects separation by altering the residence time for sludge settling in the centrifuge bowl. Based on preliminary recovery data in Figure 4.25, the design basis of 98% sludge recovery can be achieved with a throughput of up to 5 gpm in the dewatering step and at least 12 gpm in the first and second wash steps where the estimated liquid densities are 1.21, 1.00, and 0.993 g/mL, respectively.

A typical plot of sludge recovery versus time is shown in Figure 4.26. Recovery remains nearly constant until the bowl is filled with sludge and then drops abruptly as solids overflow in the effluent begins. Figure 4.27 shows the bowl fully loaded with a uniform, standup cake. The photograph was taken after the machine was shut down after solids overflow had started but without the normal five minute cake compaction spin. Other tests have shown that cake volume is reduced by about 10% in the compaction step. Analysis of the cake reveals that the dense, dry solids settle at the bowl bottom and outer wall while the light, more gelatinous solids collect in the inner, upper portion of the bowl. Cake density in the dewatering step ranges from 1.3 to 1.7 g/mL.

The effect of feed acceleration on separating performance was also studied in the large TNX centrifuge. Complete acceleration of the feed before entry into the liquid pool is normally provided by the rotating feed pump and distributor located at the bottom of the centrifuge (see Figure 4.24). The centrifuge is also fitted with a 1-inch-diameter, top-entering, stationary feed pipe which discharges the feed directly onto the pool surface near the bowl floor and provides essentially no acceleration. Figure 4.28 compares centrifuge separation with and without feed acceleration and indicates that complete or nearly complete feed acceleration is necessary to achieve 98% sludge recovery at the desired feed rates. Based on this data, the simpler stationary feed pipe does not appear suitable for the DWPF centrifuge.

An alternate means of skim liquid removal has been successfully tested in the small and large TNX centrifuges in which the liquid on the cake surface is allowed to drain into the wash or slurry tank below as the centrifuge bowl is decelerated for sludge discharge. The liquid is then pumped from the tank before plowing. This method of liquid removal would simplify centrifuge design by eliminating the skimming device but would require an additional pump or transfer jet in the wash tank.

The TNX small-scale washing tests indicated that slurrying of the centrifuge cake with water in the wash tank might be difficult. Lumps of sludge tended to adhere to the tank wall and floor and often plugged the centrifuge feed line. However, tests with the large-scale TNX slurry tank have shown that satisfactory cake dispersion can be obtained with a cylindrical tank using a conventional turbine agitator, and that a specialized, high-shear mixing device is not required. The slurry tank is shown in Figure 4.29 and is equipped with a dual-impeller, 45° pitched-turbine agitator driven by a 5-hp, SCR-controlled, variable-speed DC motor. The impeller to tank diameter ratio is 0.6 and maximum impeller speed is 125 rpm. The lower portion of the tank is unbaffled and usually only the bottom impeller is submerged during operation. In a typical slurring test, 50 gallons of sludge cake are discharged from the centrifuge into 30 gallons of water in the slurry tank with the agitator operating at maximum speed. Under these conditons, the sludge is fully dispersed within eight minutes of the start of discharge which takes five minutes. Agitation conditions can best be described as strong with surface splashing, a deep center vortex, and good batch circulation. No problem has been experienced with sludge holdup or buildup in the discharge chute which enters the slurry tank at a 60° angle and converges in area by about 60%. Undiluted sludge cake has been mixed in the slurry tank, although the batch circulation rate is low and a stagnant zone 4 to 5 inches wide exists along the tank wall. To avoid the possibility of agitator stallout which has occurred with undiluted sludge, the agitator should be operated during discharge and some water present in the tank prior to discharge.

4.5.3.5 Small-Scale TNX Test Results

Washing tests at roughly 1/100 of plant scale have been performed at TNX using synthetic sludge waste. The test equipment is shown in Figure 4.30 and consists of an agitated wash tank, bench model basket centrifuge, and a centrate collector. The centrifuge contains a 12-inch-diameter by 5.5-inch-high imperforate bowl and was procured from DeLaval Separator Company of Poughkeepsie, New York. Bowl cap height is 2 inches and fill capacity 1.5 gallons. Unless otherwise noted, all tests were conducted at 1300 g's force (2775 rpm) measured at the bowl wall (900 g's at the pool surface). Feed is introduced near the center of the solid bottom of the baffled bowl and is accelerated to bowl speed before it enters the liquid pool.

Table 4.24 summarizes centrifuge separating performance, sludge capacity, and cake water content as a function of feed throughput for undiluted sludge slurry. This data shows that throughput has a substantial effect on sludge recovery and capacity but appears to have little effect on cake water content. The process design criteria of a 90% basket fill and 3.0 lb cake water/lb solids were selected primarily on the basis of this data. Additional results not included in this report demonstrate that the cake water to solids ratio remains essentially constant throughout the washing process. Figure 4.31 is a typical plot of centrifuge sludge recovery versus time showing that recovery is nearly constant up to basket capacity and then drops abruptly as in for the large TNX centrifuge.

Centrifuge scaleup was also investigated. The Σ method described by Ambler[1] was found to be an effective means of scale up of centrifuge throughput from small scale test results. Using this method, a feed flow scaleup factor of 23 was estimated for the TNX small and large scale centrifuges, where

$$\text{Feed Flow Factor} = \frac{\text{gpm Feed in Large Centrifuge}}{\text{gpm Feed in Small Centrifuge}}$$

As shown in Table 4.25, the measured factor for the TNX centrifuges is in close agreement with the predicted value. The scaleup factor for sludge loading capacity is simply the ratio of basket fill volume in the large centrifuge to that of the small centrifuge. This factor equals 80 for the TNX centrifuges. After being tested at TNX with synthetic waste, the sigma technique will be used to scale up results of HLC small scale centrifuge tests with actual wastes.

Numerous small scale tests have been performed with synthetic waste which demonstrate the basic feasibility of the dilution washing process. Figure 4.32 shows salt removal in a typical test in which 8 liters of sludge slurry were washed three times with 29 liters of water using the test equipment shown in Figure 4.30. This data shows that removal of the soluble SO_4^{2-}, Na^+, and NO_3^- salts closely follows the dilution model. Most of the salt remaining in the washed sludge appears to be effectively insoluble. However, even with this residual insoluble material, product quality criteria for the washed sludge were easily met as shown in Table 4.26.

The rheology of washed sludge slurry was evaluated to determine the maximum solids content for satisfactory slurry handling and transport. Washed sludge cake from the small centrifuge was mixed with different amounts of water and slurry rheology analyzed using a Haake Model RV-3 rotational viscometer (Haake, Inc., Saddlebrook, New Jersey). Figure 4.33 is a typical slurry rheogram or shear stress-shear rate diagram obtained with the Haake instrument. The slurries were found to be Bingham plastic fluids displaying definite yield stress and consistency properties. The rheology of a Bingham plastic is described by the equation

$$T = T_y + n\dot{Y}$$

where T and T_y are the fluid shear stress and yield stress, respectively, in dynes/cm^2, n is the fluid consistency in centipoise, and $\dot{Y}$ is the shear rate in reciprocal seconds. Slurry yield stress and consistency properties were calculated from the rheograms and are plotted as a function of slurry total solids content (insoluble plus dissolved solids) in Figures 4.34 and 4.35. A qualitative description of slurry fluidity is also given on these plots. Based on this data, a conservative design basis of 17 wt % total solids was selected for the washed sludge slurry. Large-scale slurry transport tests are now being performed and may show that a higher solids loading is feasible. The rheology of the washed sludge slurry did not show any significant time-dependency.

4.5.4 Spray Drying (M. H. Tennant)

4.5.4.1 General

The purpose of this section is to present a description and available technical data bases of the process to convert the feed slurry from the sludge washing and ion-exchange modules into a dry powder suitable for feed to a melter.

Spray drying of simulated SRP waste has been demonstrated at Battelle-Pacific Northwest Laboratories (PNL). Simulated SRP waste was initially dryed in a 21-inch-ID developmental spray dryer at PNL. Feed rates ranged from 15 to 55 L/hr and no problems were encountered [6].

More-recent runs were made in PNL's 36-inch-ID spray dryer to determine dryer capacity and to evaluate off-gas sintered metal filter performance. The dryer was successfully operated at feed rates up to 300 L/hr.

4.5.4.2 Process Description

The flowsheet (FS-5) and material balance (MB-5) for the spray drying system is shown in Figure 4.5 and Table 4.5, respectively. In the reference process, the washed sludge cake from the washed sludge run tank is slurried with the cesium-zeolite slurry and the Sr concentrate to produce a feed containing 17 to 18 wt % total solids. The slurry is sampled for sludge content, conveyed to a hold tank, and subsequently transferred to the spray dryer feed tank. This slurry is then fed at a controlled rate to the dryer at a pressure of 1 to 4 atm. The slurry is pneumatically atomized in an internal mix nozzle and sprayed into top center of a cylindrical spray dryer chamber. The ratio of atomizing air and slurry feed is controlled at approximately 4.00 lb/gal. The atomized slurry in the form of fine droplets is sequentially evaporated, dried, and partially calcined as it falls through the spray dryer chamber.

The dryer walls are heated to a temperature between 800 and 950°C. Inside the chamber heat is transferred to the droplets by a combination of radiation and convection to produce a powder containing less than 2 wt % moisture. Fouling of the drying chamber heat transfer surface is minimized by the periodic operation of wall-mounted vibrators. The dryer off-gases, which consist primarily of superheated steam and air, may entrain as much as 50% of the particles. The entrained particles are removed by passing the off-gas through sintered metal filters. Less than 0.1% of the particulates are expected to penetrate the filters. The off-gas exits the filters and is routed to an off-gas system for radionuclide abatement and mercury recovery. For the purpose of designing the sintered metal filters and off-gas treatment system, the off-gases are assumed to be at 350°C. The powder collected on the filters is periodically removed by a pulse of blowback air. The total average quantity of blowback air is estimated to be 85 acfm. The dry sludge powder from the filters drops into the cone below the dryer along with that which falls directly from the chamber and is combined with glass-forming frit. Frit is fed into the cone to provide a 35:65 ratio by weight of centrifuged sludge (on a dry basis) and glass frit. The frit addition rate is set based on a determination of the sludge content of the waste slurry and the dryer feed rate. No special care is provided to mechanically ensure good mixing of the calcine and frit. However, the size of the frit particles should be as near to that of the dryer product, consistent with reliable transport to the dryer cone. The dried sludge and frit mixture are then discharged to the continuous ceramic melter by gravity flow.

4.5.4.3 Technical Data

4.5.4.3.1 Spray Dryer Stoichiometry

The primary reaction that occurs in the spray dryer is the loss of water. Additional reactions assumed for material balance purposes were detailed in Section 4.4.1.4.

A thermodynamics study of the spray dryer/melter off-gas has raised several unresolved questions. These are briefly highlighted below.

- Chlorine and fluorine which vaporize from the melt surface may reflux between the melter and spray dryer filters as sodium, cesium, and lithium halides. These elements form gaseous products at melter temperatures and form solids at the filter.

- Sodium hydroxide, which melts at 318°C, will form if Na_2CO_3 is left on the filters when sludge feed to the spray dryer is stopped.

- LiCl and CsCl may accumulate on the sintered metal filters. A LiCl-CsCl eutectic (60% LiCl) melts at 306°C and could possibly blind the filters if allowed to accumulate.

Until appropriate experimental programs are carried out to resolve the previously outlined questions, the bases in Section 4.4.1.4 should serve as a design bases.

4.5.4.3.2 Characteristics of Spray Dryer Product

Physical

Tables 4.27 through 4.29 summarize measured physical characteristics of the powder produced in the PNL 36-inch spray dryer with simulated SRP waste feed for constant chamber wall temperature. Experience with the powder shows that it dusts readily and is hydroscopic. Bin storing, conveying, or transporting of the powder is therefore not recommended.

Chemical

Table 4.30 summarizes the concentration of the major components in the powder produced during the 3rd run in the 36-inch PNL spray dryer as a function of feed rate. Also included is weight loss data at 200°C and 800°C. These data were provided by PNL.

Additional chemical characterization of the powder is under way at the Savannah River Laboratory. The following paragraphs summarize the observations and findings to date. The powder in these analyses was produced during operation of the PNL 21-inch spray dryer.

- Scanning electron microprobe analyses indicate (1) higher concentrations of sodium than anticipated, (2) sodium exists primarily on the surface of the particle and (3) iron, manganese, nickel, calcium, and residual sodium and aluminum were generally uniformly distributed throughout the powder (some areas indicated less abundant manganese - these areas were more abundant in iron and nickel).

- X-Ray Diffraction Analysis (XRD) showed both amporphous and crystalline material. The crystalline phase was identified as a spinel-type oxide with a cubic structure similar to $NiFe_2O_4$. XRD analysis of the water soluble fraction of the powder (after crystallization by evaporation) showed $Al(OH)_3$ and $Na_3H(CO_3)_2$.

- Elemental and ionic analyses of the powder following dissolution in HCl are summarized in Table 4.31. These data indicate that approximately 95% of the sodium, 90% of the nitrate, and 60% of the aluminum are present as a water-soluble form. Solubility data for sodium and aluminum indicate $NaAlO_2$. The remainder of the aluminum and essentially all the iron, manganese, nickel, and calcium are present in water-insoluble forms. The insoluble aluminum species is probably aluminum oxide, possibly hydrated carbonate and nitrate exist primarily in a water-soluble form.

- Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) data are summarized in Table 4.32. These data indicate that the powder may contain as much as 13% water, probably in hydrous oxides. Transitions above 500°C are likely thermal decompositions yielding CO_2 or oxygen.

- Mossbauer spectrometry of the powder leads to the following initial observations:

  1. All iron is in the ferric state (FeOOH or as Fe_2O_3 with particle size <10 µm).

  2. None of the following iron species are present (in detectable quantities) - Fe_2O_3 (particle size >10 µm), Fe_2O_4, FeOOH, FeOOH, or FeOOH.

4.5.4.3.3 PNL Experience

As noted earlier in this section, several spray dryer runs have been performed at PNL using simulated SRP waste. Table 4.33 summarizes the first four runs. The first two runs were made in PNL's 21-inch I.D. spray dryer and the latter two in their 36-inch I.D. spray dryer.

4.5.5 Vitrification (T. A. Willis, M. J. Plodinec)

4.5.5.1 General

Vitrification in a Joule-heated continuous melter is the current reference process for incorporating SRP high-level liquid waste into a solid matrix. Experience has been limited to large-scale tests at Battelle-Pacific Northwest Laboratories and small-scale tests at the Savannah River Laboratory using simulated SRP waste.

4.5.5.2 Process Description

The reference process is comprised of four basic steps. First, the product from the spray dryer is combined with glass-forming additives (frit) and delivered onto the melt surface. Secondly, the spray dryer product and frit are incorporated into the molten glass at 1150°C. Thirdly, the melt undergoes homogenization and finally, the glass melt is poured into steel canisters. The reference flowsheet (FS-5) and material balance (MB-5) are found on Figure 4.5 and Table 4.5, respectively.

4.5.5.3 Technical Data

4.5.5.3.1 Basic Theory

Molten glass is an electrolytic conductor at high temperatures due to its low resistivity (about 10 ohm-cm). Thus, an electric current can pass through the glass and heat it by the Joule effect. The heat generated, q, as the current passes through a glass will be

$$q = I^2rk$$

where I is the current, r is the resistivity, and k is a constant which depends on the geometry of the melter.

4.5.5.3.2 Rheology

The rheological (fluid) behavior of molten glass is the most important single property in the pouring phase [7]. The maximum viscosity of the molten glass in the melter and tank riser should be limited to 50 poise or less. This assures an acceptable rate of dissolution of calcine and frit. However, to minimize refractory corrosion and assure sufficient power is dissipated in the glass, the viscosity should not be less than 10 poise. For smooth pouring from the pour spout and adequate flow of melt in the canister, the viscosity of the glass leaving the pour spout should not exceed about 200 poise.

The reference glass melt is considered a Newtonian fluid. Viscosities of simulated SRP waste glassforms have been measured as functions of temperature, composition, and shear rate. The viscosities of Newtonian melts were modeled as a function of temperature by least-squares fit of the data to Fulcher's equation [8]. Results for the reference glass waste form are tabulated in Table 3.9, Section 3.

If the glass melt contains $\geq$ 35 wt % sludge, the melt will contain an increasing percentage of crystals. Consequently, the melt behaves as a non-Newtonian fluid and does not have a constant viscosity. However, a reasonably good agreement with experimental results was obtained by fitting the data to [9]:

$$T = mS^n$$

(T = shear stress in dyne cm, S = rate of shear in sec^{-1}). Values of m and n were determined at several temperatures for the non-Newtonian melts by the method of least squares. The values listed in Table 4.34 are probably accurate to 20%.

4.5.5.3.3 Resistivity

In the melter, the amount of energy produced for melting is controlled by the resistivity of the melt, which is dependent on the composition, the viscosity, and the temperature [10].

The resistivity of the molten glass has been discussed in detail elsewhere [11]. The resistivity of composite sludge with Frit 21 is shown in Figure 4.36. As the percent of sludge in glass increases, the resistivity increases. This can be thought of as simply a dilution of the alkali content, which should increase the resistivity. The resistivities have been fitted to the empirical equation:

$$\log \rho = a_0 + a_1/T + a_2/T^2$$

where ρ = resistivity, ohm cm; a_i are regression coefficients; and T is the temperature, °K. Each of the regression coefficients (a_i) was assumed to be a linear function of the wt % of each principal sludge and frit component in a melt.

$$a_i = b_0\ (Si) + b_2\ (Na) + b_3\ (Li) + b_4\ (Fe) + b_5\ (Al)$$

where the terms in parentheses are the concentrations of the element in the glass, as wt %. The values of the b_i's are listed in Table 4.35.

For stable melter operation, the temperature dependence of the resistivity, $d\rho/dT$, is just as important as the resistivity itself. In an actual melter, there will not be perfect thermal equilibrium. Hot areas will have lower resistivities, hence pass more current, than cooler regions. Thus, the hotter areas will tend to become even hotter, and the cooler ones even cooler. This "self-deregulating" effect is governed by $d\rho/dT$ at whatever melting temperature is chosen [10,12,13].

Borel [13] and others have pointed out that the ideal condition for controlling electric melting is $d\rho/dT \leq 7 \times 10^{-3}$ ohm cm/K, but that control was still possible up to about twice this value. Using the calculated regression coefficients (see Table 4.35) and implicitly solving the empirical resistivity equation for $d\rho/T$, one can calculate the approximate minimum operating temperatures.

4.5.5.3.4 Process Details

Feed Blending

Glassforming additives (frit) are introduced into the bottom of the spray dryer and combined with the calcine. Care must be taken not to exceed the softening temperature of the frit (about 400°C) before the frit enters the melter to preclude plugging the dryer/melter transition piece. Frit feed rate is proportional to the sludge feed rate to the spray dryer.

The present dryer/melter concept assumes the natural mixing that will take place in the bottom of the dryer is adequate. Laboratory studies with a small-scale melter indicate that the degree of mixing has a significant effect on the waste dissolution rate, foam persistence, and slag formation. Results of these tests are summarized in Tables 4.36 and 4.37.

The data demonstrates that waste can be vitrified up to 60 times faster if the frit and waste are well mixed (this assumes that no segregation of frit and waste occurs during processing - see subsequent section). In addition, premixing virtually eliminates formation of persistent foam and slags.

Spray Dryer Product/Frit Particle Size

Laboratory studies indicate that if the particle size of the frit and the dried waste differ markedly, the benefits attained by premixing are somewhat negated due to frit and waste segregation in the melter. Table 4.38 summarizes these data.

Feeds containing the largest frit size (1.7 mm) separated on the melt surface, forming islands of calcine nearly free of glass-former. Analysis of these islands showed that they contained ferrite-spinel crystals. As the frit particle size decreased, the number and size of the islands decreased until none was observed in tests that used the smallest frit size (0.15 mm). This trend was reversed when frit particles of less than 0.15 mm diameter were used. This is attributed to the greater amount of water absorbed by the finer particle during handling. These data suggest that the waste dissolution rate, the depression of slag formation, and foam persistence can be optimized by feeding a dry frit the same size as the median particle diameter of the spray dryer product.

Melting

The melter is assumed to operate at 1150°C. The composition of the melt corresponds to 65 wt % Frit 131 and 35 wt % dried waste solids. After the waste is dried, the melt composition is 71.1 wt % frit, 28.9 waste oxides, for composite sludge. The resistivity is about 2 ohm-cm, the viscosity is about 12 poise, and 1150°C is well above the minimum operating temperature. Thus, on the basis of the physical criteria, good-quality glass can be produced as long as concentration fluctuations are not too severe.

Homogenization

After the melting process, the glass is homogenized [14]. In the glass industry, a glass is considered homogeneous when no difference in the properties of the glass can be measured. The degree of homogeneity will be determined by the thermal history of the glass, its composition, the degree of mixing of the glass components, and the presence of convection current in the melt. At a given temperature, the glass will increase its homogeneity quickly in the first few hours, then more slowing thereafter [15,16].

The single most important way to ensure homogeneity is to mix the batch well. This means that the particles should be as small as possible and their distribution of sizes as narrow as possible [17]. The time required for mixing will then be short, separation of the batch constituents minimal, and homogeneity ensured [18,19].

Material flow through the melter is to be balanced so that a constant level is maintained in the melter (amount added from the calciner equals the amount poured into the canister). A mean residence time for the melt of about 25 hours will assure the molten glass will be as homogeneous as possible. The minimum residence time required to homogenize the glass depends on the composition and degree of uniformity of the feed (size and composition) and the temperature of the melt.

Pouring

After melting and homogenization, the molten glass flows through the throat and is allowed to cool slightly. A heater in the pouring section maintains the glass at about 1000°C. The glass overflows into steel canisters. Based on a heat transfer model developed to predict glass temperatures during canister fill and subsequent cooling (see Section 3.1.7.3), approximately 11 to 15 hours will be required for the glass to cool below 500°C. Consequently, some devitrification may be expected to occur.

4.5.5.4 Summary of Vitrification Experience with SRP Waste

Based on large-scale tests at Battelle-Pacific Northwest Laboratories (PNL) and small-scale tests at SRL, using simulated SRP waste, four potential problems have been identified.

- Formation of a slag at the bottom of the melter.
- Formation of a persistent foam at the melt/batch interface.
- Formation of a foam when the melter is heated after extended low-temperature idling (Reboil).
- Electrode destruction by molten glass.

4.5.5.4.1 Slag Formation

Slag formation has been discussed in detail elsewhere [20]. The slag observed in both the small-scale and the PNL melter has been identified as ferrite-spinel crystals in a glassy matrix. The data indicate that slag forms as a result of exceeding the solubility of this crystalline phase in molten glass. Slag formation is enhanced by sludges high in iron, low melter temperature, and lack of uniformity (particle size and composition) of the feed. For a given composition there is a residence time which minimizes slag accumulation on the melter bottom. This residence time is determined by throughput, settling of the slag through the melt, and dissolution of the slag.

4.5.5.4.2 Formation of Persistent Foam

Tests in both the PNL and SRL melters have demonstrated that the batch may produce a persistent foam as it melts [21]. This results in a reduced melting rate. The foam persistence is apparently determined by the effective viscosity of the molten material. Thus, sludges high in aluminum or which form large amounts of ferrite-spinels will produce persistent foam. In both cases, good mixing of frit and calcine, higher melt temperatures, and decreased TiO_2 content of the frit, will reduce foam persistence.

4.5.5.4.3 Reboil

When the melter is cooled from 1150°C to a lower temperature (such as 900°C) for extended periods, the glass in the melter reaches a new equilibrium state, where gases (especially O_2) are absorbed. Transition metal ions, such as iron or manganese, shift to higher oxidation states (i.e., Fe^{2+} to Fe^{3+}, Mn^{2+} to Mn^{3+}, etc.). Ferrite-spinels collect on the relatively cool floor of the melter. When the glass is reheated, oxygen solubility decreases. The slag on the melter bottom starts to dissolve. In the region of the dissolving slag, the iron equilibrium shifts more toward the lower oxidation state, reducing the amount of oxygen required to maintain electroneutrality, and thus further increasing the supersaturation of oxygen in the glass. The dissolving slag rapidly nucleates bubbles which can form a stable foam. If there is insufficient distance between the molten surface and the top of the melter, this foam can clog feed lines and stop melter operation.

There are three ways to prevent this from occurring.

(1) Design the melter so that any reboil foam will not cause melter failure.

(2) Operate the melter in such a manner that slag cannot form, either by reducing the proportion of waste in the glass, or by flushing the melter with pure frit before reducing the temperature.

(3) Never reduce the melter temperature.[a]

Items (1) and (2) will not prevent reboil, but they will prevent it from being a significant operational problem.

---

[a] The melt temperature may be raised 75°C (max) without experiencing a serious foaming problem when not feeding. If raised >100°C, foaming is a problem whether the melter is being fed or not.

4.5.5.4.4 Electrode Destruction

During small-scale tests at SRL, three electrodes have been destroyed during the glass melting process. In all three cases, the current density on the electrode destroyed was greater than 7 A/in.^{2}, and the electrode was hotter than its partner. In each case, gas evolution was observed from the electrode that was eventually lost. In each case, the electrode was partially recovered as spheres of metal, indicating that at least part of the electrode had melted.

The mechanism for this destruction is not understood, but the cause is probably excessive current density on the electrode. The gas evolved (probably O_2) could be due to electrolysis of the glass at the electrode, which is symptomatic of excessive current density [22]. Obviously, this points out the need to design the electrodes so that high current densities are unnecessary to generate sufficient power to melt glass.

4.5.6 Off-Gas Treatment (E. L. Wilhite, G. B. Woolsey)

4.5.6.1 General

There are three primary sources of airborne radioactive releases to the environment from the DWPF: 1) off-gas generated during spray drying and vitrification, 2) vapor space purge of process vessels, and 3) the canyon atmosphere.

During spray drying and vitrification, a vapor stream is evolved that contains both nonradioactive and radioactive pollutants. The vapor stream is composed mostly of steam and the inerts used to atomize the feed slurry into the spray dryer chamber. Several radioactive volatile species will be generated during melting such as ruthenium and cesium. To a lesser degree, varying amounts of iodine, technetium, selenium, tellurium, rubidium, and molybdenum will be evolved. Corrosive species such as the alkali borates and halides will also be present. The principal nonradioactive constituents will be mercury vapor and mercury iodide. Various abatement systems are employed to reduce the radioactive emissions to within existing SRP guidelines.

Each canyon process vessel will be purged with 50 scfm of canyon air to maintain the vapor space slightly negative with respect to the canyon atmosphere pressure. These purges are combined and drawn through a process vessel vent filter prior to release to the sand filter. The vents from the product salt hold tanks, cesium vent scrubber and the general purpose evaporation module vessels are combined, super heated and vented to the atmosphere through HEPA filters. The vents from the saltcrete facility are handled similarly.

The canyon air atmosphere is combined with the treated spray dryer off-gas and the filtered vessel vent air and filtered through a deep-bed sand filter before being discharged to the atmosphere via a stack. Appropriate online instrumentation and stack air sampling facilities must be provided to monitor and audit the airborne radionuclide discharges to the environment.

4.5.6.2 Process Description

The off-gas treatment flowsheet (FS-6) and the material balance (MB-6) are shown in Figure 4.6 and Table 4.6, respectively.

4.5.6.2.1 Spray Drying/Vitrification

The temperature of the vapor stream leaving the spray dryer sintered metal filters is expected to be in the range of 300-350°C. The material balance flowsheet is based on 350°C. A DF of 1000 for particulates is assumed to be attained across the sintered metal filters (recent tests with the type of sintered metal filter element to be used on the spray dryer that will be installed at TNX indicates that a coated filter may provide DF's as high as 5000).

The off-gas stream, composed principally of steam and inerts, enters an ejector/venturi where it is cooled to 50°C by contacting cooled, circulating off-gas condensate (40°C). The vapor and condensate discharge into a collecting tank.

Exiting the collection tank, the vapor stream is drawn successively through two, washable, deep-bed filters to reduce the particulate loading by at least 99.96%. An overall DF for volatile ruthenium of 400 is assumed for material balance purposes. No DF is taken for I_2. The first deep-bed filter is operated at 50°C. The latter is operated at 10°C to reduce mercury vapor emissions to about 50 g/day. Mercury that is condensed at the ejector/venturi and the second deep-bed filter is accumulated and periodically drawn off for purification and recovery (see Section 4.5.7). Contents of the off-gas condensate tank are purged at a rate equal to the rate at which steam is condensed from the off-gas stream leaving the spray dryer. This purge is accumulated in a hold tank (recycle collection tank) and periodically transferred for subsequent evaporation in the recycle evaporator and recovery of insolubles in the settling and filtration module.

Exiting the latter deep-bed filter, the vapor stream is heated to 10°C above its dew point and then drawn through two silica gel beds in series to adsorb the volatile species of ruthenium. A DF of 100/bed is assumed for material balance purposes.

The vapor effluent from the second silica gel bed is heated to 150°C and drawn through a silver mordenite (Ag^oZ) bed to reduce the iodine concentration in the vapor stream. A DF of 100 is assumed for material balance purposes.

The vapor effluent from the iodine adsorber bed is cooled to <50°C prior to being combined with canyon air and filtered vessel vent air. Effluent from the sand filter is discharged to the atmosphere via a 200-ft stack.

4.5.6.2.2 Vessel Vent System

The vapor space in each canyon process vessel is maintained slightly negative with respect to the canyon atmosphere by drawing approximately 50 scfm (dry basis) of canyon air through the vessel overflow pipe. The purge from each vessel is combined and drawn through a deep-bed canyon filter. A DF of 1000 is assumed for entrained activity across the process vessel vent filter.

4.5.6.2.3 Canyon Air

The atmosphere in the process building canyon is maintained negative with respect to less-contaminated areas of the building by continuously purging the canyon air to the sand filter. Canyon air is combined with filtered vessel vent air and off-gas from the spray dryer/vitrification module prior to the sand filter. After being drawn through the sand filter, the filtered air is discharged to the atmosphere through a 200 ft stack. A DF for particulates of 1000 is assumed across the sand filter.

4.5.6.3 Technical Data

4.5.6.3.1 Spray Dryer/Melter

The composition of the vapor stream leaving the sintered metal filters has not been fully defined. Thermodynamic studies performed by the Engineering Services Division demonstrate that the composition of the off-gas is very sensitive to spray dryer feed composition and the temperature of the off-gas at the point of equilibria (currently assumed to be at the sintered metal filters). Results of these studies are summarized below [23].

- Iodine is present mostly as I or I_2 at equilibria temperatures >627°C and as an increasing percentage of $HgI_2(v)$ as the equilibria temperature falls below 627°C (at 327°C, the iodine exists essentially all as HgI_2). Since the fate of iodine is so temperature sensitive and dependent upon the presence of mercury, the off-gas system must be able to handle all predictable species of iodine. High temperature excursions and/or the absence of mercury will greatly increase the rate of silver mordenite depletion. Material balance calculations are based on 1.0% HgI_2 disassociation (350°C).

- Mercury in excess of the iodine will be present as Hg(v) and trace amounts of HgO.

- Boron is present as $H_3BO_3(v)$ at 627°C and cooler. At about 175°C, it will condense.

The following DF's are assumed for preparation of the material balance and the curie balance across the spray dryer off-gas treatment systems.

Sintered Metal Filters	
Particulates	- 10^3
Volatiles	- 1

Ejector/Venturi	
Particulates	- 2.5
Iodine	- 1
Volatile Ruthenium	- 1

Deep-Bed Filter	
Particulates	- 50
Volatile Ruthenium	- 20
Iodine	- 1

Silica Gel Bed	
Particulate	- 2
Volatile Ruthenium	- 10^2
Iodine	- 1

Silver Mordenite Bed	
Particulates	- 2
Volatile Ruthenium	- 1
Iodine	- 10^2

With the exception of HF, I_2, and the volatile specie of ruthenium (RuO_4), all volatiles condense as particulates across the wet scrubbing portion of the off-gas system. Consequently the stated DF's for particulates are applicable.

4.5.6.3.2 Process Vessel Vent

For purposes of material balance calculations, the vapor space of each canyon process vessel is purged with 50 scfm of canyon air. The canyon air enters the vessel at a dry bulb temperature of 35°C and a wet bulb temperature of 25.6°C. The exit purge is assumed to have a dry bulb temperature of 35°C and a wet bulb temperature of 29.4°C.

To compute the degree of entrainment in a vessel vent, an entrainment of 10^{-9} gal/ft^3 was used. This factor was based on observed entrainment in the vapor sweep exiting a fresh alkaline waste receiver (Waste Tank No. 35) in the 241-H tank farm. Observed entrainment was increased 200 fold to account for agitated vessels. Where the amount of entrainment is known to be significantly higher, as with the centrifuges, it is assumed that adequate de-entrainment systems will be provided to reduce entrainment to design bases or less.

The combined vessel vents are to be heated to assure the vapor temperature is at least 10°C above the dew point to prevent condensation in the process vessel vent filter. A DF of 10^3 is assumed for particulates across the filter.

4.5.6.3.3 Volatile Components in Spray Dryer Off-Gas

Ruthenium

Volatilization of ruthenium is not expected to be a problem in the spray dryer. However, it is anticipated that ruthenium volatility will be significant at the expected temperature (about 1150°C) in the melter. Based on experiments completed at SRL, it is assumed that 10% of the ruthenium in the waste feed will volatilize.

Cesium

The cesium entering the melter is expected to volatilize as Cs_2O and CsCl (the degree of volatilization is based on the reference surface area of the glass melt). Although a thermodynamics study indicates the Cs_2O and CsCl will exist as particulates at the sintered metal filter temperature (350°C) and experience a DF of 10^3 across the filters, the curie balance assumes no DF. Design volatilization - .05% of the cesium entering the melter.

Mercury

Mercury occurs in SRP waste from the use of Hg^{2+} catalyst during dissolution of aluminum-clad fuel in H Area. It is assumed that the mercury exists as HgO in the neutralized wastes. Some mercury is soluble and exists as Na[HgO(OH)]. All the mercury that enters the spray dryer/melter is volatilized as Hg. A fraction of the mercury will react with iodine depending upon the equilibria temperature (Design bases - 99.0% of the iodine reacts with Hg to form $HgI_2(v)$).

Mercury halides condense as particulates in the ejector/venturi and are recycled back to the recycle evaporator.

Fluorides and Chlorides

Chloride and fluoride volatilize from glass melts as HCl and HF in the presence of water vapor. Laboratory studies (with the melter decoupled from the spray dryer) indicate that 50% of the fluoride and less than 10% of the chloride volatilize. However, as indicated by thermodynamic studies, no HCl and only 3.8% of the fluoride (as HF) will leave in the spray dryer off-gas. The chloride and majority of the fluoride react preferentially with sodium and are solids at the sintered metal filter temperature (350°C).

Sodium and Boron

Sodium and boron volatilize from sodium borosilicate glass melts as sodium metaborate. The sodium metaborate subsequently hydolyzes to form $H_3BO_{3(v)}$ and $Na_2O_{(s)}$ at the reference sintered metal filter temperature (350°C). The reference process assumes a $NaBO_2$ vaporization rate of 2.4×10^{-2} lb/hr.

Iodine

The reference flowsheet shows an insoluble iodine feed rate to the DWPF of about 0.23 lb/hr. Of this amount, only about 10% is attributed to fission product iodine (I-127, I-129). Greater than 90% of the iodine inventory is attributed to the I-127 used by plutonium reduction processes from 1953 to 1963. Once the process works off the current waste inventory, the iodine content in the feed will be that of fission product iodine only.

Iodine may exist in the spray dryer/melter off-gas as a mixture of HgI_2, I_2, or I depending upon the spray dryer temperature and the amount of mercury. At the reference waste composition to the spray dryer and an equilibria temperature of 350°C, 1% of the iodine will exist as I_2 or I.

Other Radionuclides

Other radionuclides that may volatilize include rubidium, molybdenum, tellurium, technetium, and selenium. Of these, Tc-99 and Se-79 are of particular interest because of their long half-lives (2.1 x 10^5 yr and 6.5 x 10^4 yr, respectively). Essentially no data exists on the volatility of these radionuclides during the vitrification of SRP defense waste. It is assumed for material and curie balance purposes that 5% of each volatilize from the glass melter and enter the off-gas system. It is further assumed that these volatile species will condense as submicron particulates in the ejector/venturi.

4.5.6.3.4 Particulate Characterization of Off-Gas Stream

Preliminary results from efficiency tests of the sintered metal filter to be used in the SRP spray dryer indicate a removal efficiency (based on 0.7-micrometer-diameter particles) of 99.98%. This collection efficiency is based on the filter element being loaded as would be the case immediately prior to filter blowback. Based on PNL observations, a significant increase in total particle loading downstream of the filters occurs immediately following blowback of the filter elements. For material balance purposes, the filters are assumed to remove 99.9% of the particulates generated during spray drying of the reference waste.

During the first run of simulated SRP waste at PNL, particle size analyses were completed on the spray dryer off-gas. The analysis was done on the vapor stream immediately downsteam of the sintered stainless steel filters. Table 4.39 summarizes the total particle and mass loading per actual cubic foot of off-gas vapor for four particle size ranges. The PNL spray dryer filters have a nominal (98%) particle removal rating of 65 micrometers.

The tests indicate that a large portion of the particles passed the filter immediately following the blowback and vibrator operation. A sample taken during no blowback or vibrator operation indicated that only one-third of the particles observed during normal operation passed the filters. In addition, it was found that essentially no particles greater than 0.5 micrometer in diameter passed the filters when there were no filter blowback vibrator operations.

4.5.7 Mercury Recovery Facility (L. F. Landon)

4.5.7.1 General

Approximately 1.2 lb of metallic mercury will be condensed each hour from the off-gas vapor stream and accumulate in the off-gas condensate collection tank. The mercury will most likely be as a sludge and will require further cleaning before it is of a purity suitable for reuse in the separations process and/or storage.

4.5.7.2 Process Description

Figure 4.6A is a schematic drawing of a conceptual mercury recovery process. The mercury that accumulates in the off-gas condensate tank will be intermittently pumped to a mercury hold tank through a backwashable filter to remove the majority of solids occluded to the mercury. Periodically, the filter cake will be dislodged from the filter and pumped back to the recycle evaporator via the off-gas condensate tank for recycle to the process.

The filtered mercury, on a batch basis, will be pumped to the top of a column containing 10% HNO_3. The formed droplets will fall by gravity through the acid and overflow a barometric leg to a sparge tank. Particulates, not removed by the initial filtration step, that are soluble will be removed from the mercury. Periodically, the nitric acid will be pumped from the column, neutralized, and recycled back to the off-gas condensate collection tank.

In order to remove contaminants such as iron and aluminum, the acid-washed mercury will be sparged gently at room temperature to oxidize the contaminants. After sparging is complete, the mercury is filtered through another backwashable filter to remove the formed oxides. Final cleanup of the mercury is achieved by vacuum distilling the mercury and bottling the condensed overheads.

4.5.7.3 Physical Properties of Mercury

Density	- 13.59 g/cm^3
Boiling Point	- 356.66°C at 760 torr
Viscosity	- 1.407 cp at 50°C
Vapor Pressure	- See Figure 4.37

4.5.7.4 SRL Experience

Mercury that is used in laboratories throughout the SRP that is no longer of suitable purity is sent to the Apparatus and Glassblowing Shop in 773-A for reclaiming. The mercury reclaiming facility is housed in a ventilated glass hood approximately 2 ft deep x 4 ft wide x 5 ft high. Recovery rate averages about 6 lb Hg/hr.

The mercury is first filtered through filter paper shaped into a cone with several 0.5-mm holes punched in the bottom. The filtered mercury is then poured into a separatory funnel which disperses the mercury into an acid wash column containing 10% HNO_3.

After acid washing, the mercury is transferred to an oxifier in which air is bubbled through the mercury for 1 hour. After oxification, the filtration step is repeated. The solids removed during this filtration step are subsequently treated with HNO_3 for mercury recovery.

The filtered mercury is then introduced into a vacuum distillation apparatus (see Figure 4.38). The still operates at a pressure of about 5×10^{-2} torr (Hg b.p. - 192° ± 2°C). The recovered mercury is stored in 1-liter bottles (about 10 lb of Hg/bottle).

4.5.8 Recycle Concentration

4.5.8.1 General

An evaporation step is included in the reference flowsheet to (1) remove excess water from dilute recycle streams to maintain the salt concentration in the gravity settler feed at about 30 wt %, (2) to reduce the size of supernate processing equipment, and (3) provide the first stage of decontamination of process water. The flowsheet (FS-7) and material balance (MB-7) are shown in Figure 4.7 and Table 4.7, respectively.

4.5.8.2 Process Description

Process streams that are presently candidates for evaporation are combined in the evaporator feed tank. These streams include:

- Condensate purge from the cesium concentrator
- Centrate from the sludge-washing centrifuges
- Off-gas condensate

- Aluminum dissolver condensate
- Ion exchange transfer water
- Canyon sump contents
- Sand filter and stack condensate
- Laboratory waste
- Contents of the cesium regenerant catch tank (spent cesium ion exchange regenerant after NH_3 removal)
- Excess water from the cesium fixation module
- Bottoms from the general-purpose evaporator
- Deionizer purge
- Spent canister decontamination solutions and water rinses from Mechanical Cell A

The feed will be concentrated to about 35 wt % salt. Evaporator concentrate is transferred to the gravity settler feed tank for recovery of the solids. Overheads are transferred to the general-purpose evaporator feed tank for additional decontamination. A DF of 10^6 is assumed across the evaporator/de-entrainer (concentration in the evaporator concentrate/the concentration in the evaporator condensate).

4.5.9 Settling and Filtration (E. J. Weber)

4.5.9.1 General

The purpose of this section is to present the process details and technical data bases for reducing the suspended matter in feed to ion exchange to 1 ppm or less. It is estimated that feed to this module will nominally contain 6000 to 7000 ppm of sludge. Essentially complete sludge removal is desired to provide:

- Operation of the ion exchange columns for cesium, plutonium, and strontium removal without pluggage or fouling.
- Removal of the highly insoluble Sr-90 to produce an acceptable clarified supernate for subsequent incorporation into concrete.

4.5.9.2 Process Description

The supernate stream from the waste tanks is blended with recycled evaporator concentrate and sand-filter backwash to form the feed to gravity settlers. The decanted supernate is blended with zeolite raffinate and fed successively through a primary, No. 1, sand filter, and (3) a polish, or No. 2, sand filter to reduce the concentration of sludge to 1 ppm or less. A flow diagram (FS-8) is shown in Figure 4.8, and a material balance (MB-8) is shown in Table 4.8.

Blended feed is heated, then transferred to one of two gravity settler (GS) tanks. A small quantity of coagulant is added to agglomerate the colloidal particles into larger, faster-setting masses. After periods of high speed, moderate, then gentle mixing, agitation is stopped and the agglomerates allowed to settle. The clear top layer, representing most of the feed volume, is then decanted. The bottom sludge layer is left for resettling with the next feed batch. After several batches of feed slurry are received, settled, and decanted, the accumulated sludge is agitated and transferred to the gravity settler bottoms tank.

Decanted supernate from the GS is cooled to less than 25°C. Zeolite raffinate is blended with the decanted supernate. Polyelectrolyte solution at 0.05 gpm/ft^2 is added to the cooled supernate via a mixing tee just before the supernate reaches the No. 1 sand filter. Total flow to the filter is 1.2 gpm/ft^2. Filtrate is collected in the first filtrate tank.

When the No. 1 sand filter loads up with suspended matter (3 psi ΔP max), the sand filter is backflushed with filtrate from the filtrate hold tank. The backwash is transferred to the gravity settler feed tank via the filter backwash tank for treatment in the gravity settler.

Polyelectrolyte is added to the No. 1 sand filter filtrate as above, just before it reaches the No. 2 sand filter. Filtrate from sand filter No. 2 is collected in the second filtrate tank and sampled for vol % suspended matter. If it is 1 ppm or less, the filtrate is transferred to the filtrate hold tank for ion-exchange feed. Out-of-spec filtrate is recycled to the sand filter feed tank. When required, the No. 2 filter is backflushed the same as No. 1 filter.

4.5.9.3 Technical Data

4.5.9.3.1 Gravity Settling

The objective of gravity settling is to serve as a pretreatment for sand filtration to reduce the load of sludge that must be removed in the sand filters. Without gravity settling, the filters would be abruptly clogged, terminating the filter run. In addition, prohibitive quantities of backwash requiring recycle would be produced. The gravity settling treatment must remove suspended matter in supernate to 50 ppm or less to obtain an acceptable sand filter operating cycle ($\geq$24 hrs) without prohibitive backwashing requirements and thus produce acceptable recycle quantities in the sand filter backwashes. This is seen in the 4-inch diameter sand filter results of Figure 4.39. With 40 ppm of sludge in the gravity settler product, the filter can produce acceptable filtrate product for almost 48 hr before a rapid rise in filter pressure drop concludes the run. With 150 ppm of sludge in the GS product, only about 12 hrs of filtrate production is obtained before excessive pressure drop dictates backwashing. The same quantity of filter backwash is required in both cases, so that the better quality GS product results in about one-fourth the recycle volume. 50 ppm of sludge has therefore been selected as the desired upper limit in GS product.

Glassware Studies

Destabilization of the colloidal hydrous oxides suspended in settled or centrifuged supernate is essential to accomplish the settling in reasonably-sized vessels. According to Kolthoff and Sandell [26], coagulation of suspensions of colloidal hydrous ferric oxide and especially the agglomeration of primary particles, is greatly accelerated by raising the temperature of the solution. This was confirmed in glassware studies. Agglomeration is accomplished by heating the centrate to temperatures of 60 to 100°C using very gentle agitation. When the centrate reaches 60 to 65°C, particles large enough to observe with the unaided eye (80 to 100 micrometers) become visible. Agglomeration reaches its maximum after 20 to 30 minutes without mechanical agitation, but with the required gentle agitation supplied by thermal convection generated at the higher temperatures. At this point, cooling to temperatures below 45°C reduces thermal currents and allows more rapid settling of the agglomerates.

Figure 4.40 shows that heat alone agglomerates suspended matter to produce a faster settling rate. Both Samples "A" and "B" were taken from the same centrate batch which contained 0.70 vol %, or 7000 ppm, of suspended matter. The agglomerates that mostly settled out, and relatively clear supernate is seen in the heated sample after 16 to 25 minutes. It took the unheated control 12 times as long to settle to the same quantity of suspended matter in supernate [27].

Using Flojel® 60 (National Starch and Chemical Corp.) cornstarch derivative as a coagulant proved to be a second method of destabilizing the colloidal suspension. Starch was tested after SRL learned of its use in the chemically similar Bayer process for destabilizing colloidal red mud, with subsequent removal of these impurities from caustic sodium aluminate solution. The red mud consists of hydrous oxides of iron, silicon, and titanium which must be separated for recovery of pure alumina from bauxite. Similar to defense waste supernate, the impurities are suspended in a highly conductive solution containing several percent free sodium hydroxide and several molar sodium ion. A number of polyelectrolytes, normally effective in agglomerating impurities from raw water, were tried without success on the supernate.

With both heat and the starch coagulant, larger and tougher agglomerates are produced than with heat alone. Figure 4.41 illustrates the destabilization of suspended matter in composite centrate using heat and coagulant. The two samples shown were from the same centrate batch which contained 2000 ppm (0.20 vol %) suspended matter. 50 ppm of Flojel® 60 was added to the treated sample prior to heating it for 1 hr to 80°C with gentle agitation. It was removed from the heat and allowed to settle for about one minute when the photo was made. The unheated control sample was agitated and had been settling for 1 hr at the time.

Figure 4.42 shows quantitative effects of heat and coagulant addition on supernate quality. Using composite centrate containing 2000 ppm suspended matter in 4-liter containers, samples were taken 4 in. beneath the liquid surface at designated times and treatment conditions. With neither heat nor starch, there is little settling in 1 hr, as the samples show no change from the feed concentration. With heat alone, visual agglomeration is confirmed by the decrease to less than 300 ppm suspended matter in 1 hr. With addition of as little as 5 ppm of starch, suspended matter in the samples was reduced to about 100 ppm in 10 minutes. Concentrations of starch up to 200 ppm did not change the settling rate significantly.

Mini-scale glassware tests showed that the GS operations are best performed batchwise in a single vessel to minimize pumping and flows that fracture the agglomerates. Continuous gravity settling produces smaller and slower settling agglomerates, results in poorer quality supernate, and introduces a sludge layer control problem in the continuous settler. Detection and control of the sludge layer would be very difficult in the remotely operated canyon. On the other hand, all batch tank operations of agglomeration, settling, decanting, and sludge removal have been performed for years in routine F and H canyon operations.

700-Gallon Semiworks Studies

Following these glassware studies, seven 700-gallon test runs were made using salt compositions specified in the PTDS No. 1 flowsheet. This earlier flowsheet did not include aluminum dissolution and consequently contained less free caustic (see Table 4.40 for salt concentrations). Semiworks Tank A-6, 5-ft diameter x 6-ft high was used in this study of GS variables. The A-6 tank is about 1/15 the size of the anticipated GS plant vessel.

Feed batch volumes were 715 to 740 gallons of "average" or "composite" centrate containing 4000 to 8500 ppm of suspended matter. Test procedure was to add the starch in a pre-mixed 8% aqueous dispersion to the agitated tank contents. The slurry was heated with steam to the tank coils during the mixing period. After mixing periods of up to one hour, the agglomerating particles were allowed to settle over the next 3 to 8 hours with cooling water to the tank coils. The clear supernate was then decanted via a 3/4-inch suction pipe and exterior pump to stainless drums. Decanting was completed when the liquid level was reduced to the height of the upturned weir of the suction pipe. At this time, the settled sludge on the tank bottom was covered with an undecanted layer of clear supernate some 4 to 8 inches high. The agitation was turned on and the resulting slurry, with 10 to 15% of the starting feed volume and 98% of its sludge, was pumped to waste. The decanted supernate product was subsequently treated in the 4-inch diamter sand filter studies as described later.

The test data are shown in Table 4.41. Runs 1 to 3 were made by first adding starch to the cold centrate, then heating. Because of the desire to avoid heating in a cooled and jacketed plant settler (whereby heat would be added in an upstream tank), Runs 4, 5, and 7 were made by first heating with agitation, then shutting off steam and adding starch with 1 hr of agitation. The agglomerating particles were then settled and the run continued in normal fashion. Run 6 was made as above, except without any heat addition.

Further 700-gallon test Runs, 8 and 9, were made using a high-caustic flowsheet as a consequence of changing the reference process to include aluminum dissolution of waste tank sludge. Glassware studies indicated higher temperatures were essential for acceptable settling in the high-caustic supernate. Consequently, the large-scale followup tests made in Tank A-6 were conducted at maximum temperatures between 90 and 100°C, as shown in Table 4.42.

Figure 4.43 relates supernate quality and settling time for all the 700-gallon runs. Results indicate the desired maximum of 50 ppm or less of sludge in supernate feed to sand filters is attained at a settling time equivalent to a 10 in./hr rate. The latter appears to be optimum because allowing longer settling times, or shorter equivalent settling rates, produces smaller quality improvement. No difference is noted in product quality attained in the higher caustic supernate.

Figure 4.44 is a photograph of samples obtained from the initial 700-gallon GS run. The sample at the left is the decanted supernate which contains about 150 ppm, or 0.015 vol % suspended matter. The middle sample is the feed centrate containing 4000 ppm suspended matter. The sludge sample at the right contains 2.5 vol % suspended matter. All suspended matter determinations were made by centrifuging at 10,000 g for 3 minutes.

Large-Scale Studies

Large-scale GS studies were continued in Semiworks Tank W-2, a nominal 6000-gallon capacity flat-bottomed unit, 10-ft OD by 11-ft high flat bottom. The tank is equipped with a variable-speed agitator, baffles, and coils. A 2-in.-diameter standpipe, 10 in. high is mounted on the tank bottom for decanting the clear supernatant liquid with the W-2 pump to the filter feed tank. The semiworks W-2 vessel is approximately one-half the size of the anticipated plant GS tank. Length-to-diameter ratios of the filled test and plant units are both about equal to unity. Figure 4.45 is a scaled drawing of the W-2 GS tank.

Ten large scale GS runs were made. The procedure was similar to the 700 gallon study except:

- Product decant rate with the W-2 pump was 125-130 gpm or some 12 times greater than the 700-gallon scale.
- High caustic (see Table 4.40) and intermediate caustic flowsheets were used. Intermediate flowsheet concentrations of caustic (0.99 M), sodium aluminate, (0.48 M) and total sodium ion (5.3 M) represent minimal addition of caustic in the Al-dissolving process.

- Variable mixing speeds using flat paddles were employed, as compared with single-speed, high shear agitation using a propeller-type mixer in the 700-gallon work. An effective combination of mixing speeds in the baffled W-2 tank was 20 minutes of high-intensity agitation (50 rpm), during which 8% starch was added to the preheated slurry, followed by 10 minutes at 30 rpm, and 60 minutes at 6 rpm. The agitator was then turned off to allow agglomerates to settle.

- Several of the runs were made using the technique of leaving the undecanted sludge for reslurrying and resettling with the next feed batch. In the 700-gallon runs, the sludge layer was removed before the next feed batch was introduced. When reslurring, starch was added for the new sludge only, since the reslurried sludge had already received starch.

Objective of the latter tests was to demonstrate a decrease in GS bottoms volume recycled to sludge washing. By thickening the undecanted layer with sludge from additional feed batches, volume recycled to the washers should be reduced below the nominal 10% obtainable when recycling a single sludge batch. It is assumed that the height of clear supernate in the undecanted layer is the same as for a single sludge batch and that the decant pump orifice is raised to accommodate multiple sludge batches. A second feature is that salt is displaced by sludge in the thickened recycle. Both features improve feed characteristics to sludge washing where salt removal is the objective.

Results of these large-scale tests, Table 4.43, show cleaner decanted product is obtained at faster settling and with less bottoms recycle than earlier small-scale results. Use of reduced temperatures evidently reduces sludge in decanted product, probably because of water evaporation, supersaturation, then post precipitation occurring at higher temperatures. At 35-45°C, less than 25 ppm sludge is found in decanted supernate. Corresponding settling times are equivalent to 20-25 in./hr settling rates. Demonstrated recycle volume with the sludge reslurrying and resettling technique (Runs 1-3) is 7.9%. Use of this technique has no apparent ill effects on product quality or settling rate. In fact, results indicate the increased sludge quantity present may produce a scavenging effect on the particles most difficult to settle.

4.5.9.3.2 Sand Filtration

The objective of sand filtration is to remove the small quantity of suspended matter (50 ppm or less) remaining in supernate after GS treatment via deep-bed filtering. Sand filtration is a part of the conceptual process because of the successful results obtained in small-scale studies performed at the semiworks and in the high-level caves. In the latter tests already referred to, actual plant waste supernates and sludges were blended, then separated in a series of two centrifuge runs, followed by sand filter clarification. Centrate feeds containing 500 to 2000 ppm of suspended matter were clarified to less than 100 ppm of suspended matter [24]. The sand-filtered supernate was subsequently processed in ion exchange columns, producing a final clarified supernate with about two nanocuries or less of Sr-90 per gram of damp salt cake [25].

4-Inch-Diameter Filter Studies

The sand filters are fed downflow and backwashed upflow in a dual-media (anthracite/sand) bed. In depth filtration, larger particles are arrested first, followed by removal of the smaller particles in the deeper portions of the filter media. As the filter loads with suspended matter, filtration resistance increases, and the filter must eventually be backwashed to remove the particulates and recycle them for treatment in GS. Figure 4.47 shows photographs taken during the various operations. At left, the GS supernate product (50 ppm suspended matter) can be seen flowing downward through the layers of anthracite/sand at a rate of 1.2 gpm/ft^2, equivalent to a superficial velocity of 2 in./min. Fluidization of the filter media during backwash is shown in the middle picture. An air-water mix of about 2 cfm-5 gpm per ft^2, respectively, is being used to free the arrested particulate from the filter media and float it out the top of the column. The picture at right in Figure 4.47 was taken about 5 minutes after backwashing was completed. The sharpness of the anthracite/sand interface that occurs on resettling can be observed in this picture.

The reference process is to filter GS supernate product through a primary (or No. 1) bed of anthracite (700-micrometer average diameter) and 25- to 40-mesh sand (490 micrometer average diameter), and then refilter the primary filtrate through a polishing bed of anthracite (400-micrometer average diameter) and 40- to 60-mesh sand (270-micrometer average diameter). By comparison, high-level cave sand filtration was performed directly on secondary centrate (no GS treatment) in a series of two 4-in.-diameter columns, each containing 24 in. of 25- to 40-mesh sand and 8 in. of 20- to 30-mesh, 700-micrometer average diameter, anthracite [24].

Table 4.44 summarizes performance at the semiworks with the 4-in.-diameter (roughly 1/200-plant scale) filter, using composite GS product from the initial low-caustic flowsheet. The data presented in Table 4.44 is an average for the feed cycle over several backwash cycles. Conditions for feeding and backwashing include addition of (1) high-molecular weight anionic polyelectrolyte in feed to the filters and, (2) air in the backwash cycle used to clean the filters. The GS supernate was reduced from 50 to 5 ppm of suspended matter across 24 in. of sand and 8 in. of anthracite in the primary filter. In the polishing unit, refiltration across 18 in. and 3 in., respectively, of the finer sand and anthracite produced filtrate containing 1 ppm of suspended matter. Thus, design basis for filtrate quality is met in the polish sand filter product when processing the synthetic supernate from "composite" slurry.

The GS composite supernate from the high caustic flowsheet runs were also tested in the 4-in.-diameter primary sand filter. No filtration problems were indicated. Performance was essentially the same as that obtained with the lower caustic flowsheet. Figure 4.48 shows (1) the increase in ΔP, and (2) color migration down the 24 in. of sand, both with increasing volumes of feed slurry containing 40 ppm of sludge. The brownish-red color front, caused by the arrested sludge particles, was visually observed through the glass column walls, and this movement was plotted in Figure 4.48. In all cases, volume % sludge in filtrate was less than 3 ppm. Presumably, sludge breakthrough would occur when the color had migrated the entire 24-in. sand depth. It appears under the conditions tested that excessive ΔP would conclude the filter run before such a depth of color migration was reached.

Based on results shown in Table 4.44 and Figure 4.48, ΔP increase across the primary sand filter will approximate 1 psi for 24 hours of filtrate production with feed of 50 ppm sludge or less for GS. An upper limit for the ΔP rise of 1 to 3 psi is consistent with industrial water purification practice where a maximum ΔP rise of 3.5 psi is used to avoid penetration of arrested matter through the filter media and into the effluent [28].

Filtrate production of 24 hours through the primary bed results in a backwash volume of about 5% of the feed volume. This recycle rate has been arbitrarily selected as a satisfactory goal that is within indicated capabilities of GS processing. Because the polishing filter removes a fraction of the sludge removed by the primary unit, the ΔP rise, backwash frequency, and recycle volume should be even smaller through the polishing unit. For flowsheet calculations, the 5% recycle rate was used for each of the two filters.

Large-Scale Sand Filter Studies

A one-eighth-scale sand filtration facility, Figure 4.49, featuring 17.25-in. I.D. columns was built to process large-scale GS products. Filtration through coarse, then fine media (same bed depths and particle sizes as before) was started after receipt of the initially decanted GS batch in the sand filter feed tank. Filtration was continued until all GS product was depleted.

Four GS-sand filter runs were made. Sand filter feed cycle results, presented in Table 4.45, confirm earlier small-scale work in that acceptable filtrate quality and pressure drops were demonstrated. Solids in final filtrate averaged about 1 ppm or less according to analysis of hourly samples from the four runs by the Coulter Counter. Spot checks for centrifugable sludge (10,000 g/s for 3 min) revealed 1 ppm when the two filters were operated in series and each received the Versa TL® 700 polymer (Runs 3 and 4). Under these conditions, turbidities of 0.07 JTU also showed good duplication of small-scale work.

In Run 4, filtrate quality was maintained during an interruption that will routinely occur in plant operation. After 31.7 hours of continuous feed, the primary column was backwashed. Following this backwash, feed addition was resumed and polishing column product continued well below 1 ppm, despite upset of the primary column caused by the backwashing. An important design function of the second bed is to maintain product quality during such temporary upsets of the first bed.

Pressure drop in the primary bed while feeding during Run 4 is shown in Figure 4.50. The filtration of an average 35 ppm sludge required about 32 hr at 1.38 gpm/ft^2 to reach a ΔP rise of 1.2 psi (vs 3.0 psi plant max). At a design feedrate of 1.2 gpm/ft^2, a feed cycle of 36.4 hours is calculated, a satisfactory margin over design basis feed cycle of 24 hours. ΔP rise across the polishing bed was less than 0.5 psi during the 32-hour feed period.

Three sand filter backwash runs were made following the corresponding GS-sand filter feed runs. In this initial large-scale test work, objective of backwashing was to determine relative quantities of sludge arrested in the two beds. The results from Table 4.46, Run 1 (which was made with parallel feeds to the two columns), show a 74/26 split in primary/polishing filters. This is about as expected because the respective ratio of clean bed ΔP's is 0.8/2.2, and most flow should go through the primary bed with smaller ΔP. Average for Runs 2 and 3, fed in series to primary then polish filters, shows 90% of the sludge was arrested in the primary column. This is also about as expected from small-scale experience.

To demonstrate efficient large-scale backwashing and minimize recycle, three full-sized Roto-Scour® (Grover Water Conditioning Co., Union, N. J.) air distributors have been installed on each of the two columns. Testing is under way. The reference backwashing cycle consists of these steps:

1.	Drain excess supernate	5 minutes
2.	Air sparge at 4 scfm/ft^2	10 minutes
3.	Resettle filter bed	5 minutes
4.	Backwash with polishing bed filtrate at 15 gpm/ft^2	5 minutes
5.	Resettle filter bed	5 minutes
6.	Restart filter feed	---

Filter Media Service Life

The eventual disposal of the filter media will be required because of (a) the gradual dissolution of the media and resultant loss of particulate removal efficiency, (b) irreversible radionuclide or other particulate adsorption, or (c) failure for any reason to backwash to initial clean ΔP or adsorption efficiency. Facilities will be provided for jetting the media to sludge washing after a final backwash to GS, then 1M NaOH fluidization to enable the jet transfer to take place. Facilities to acid wash the media will also be provided for decontamination of excessive radioactivity, mudball dissolution, or clean ΔP restoration as necessary.

At temperatures below 25°C, use of the same primary sand filter media in the 4-in.-diameter column over a period of 6 months' submergence (about 15% operating time) has shown no detectable loss in particulate removal efficiency. Recovery of the initial clean-bed ΔP has been complete after each backwash (this assumes that air is used for backwashing and polyelectrolyte has been added with the feed). In studies to determine solubility of sand in both the low-caustic and high- caustic supernates, no detectable Si (<1 ppm) was found in the filtrate at operating temperatures below 30°C. In low-caustic supernate at 60°C, 26 parts SiO_2 per million parts supernate dissolved in 15 minutes, the average bed contact time. Tests with high-caustic supernate showed no detectable SiO_2 dissolution at temperatures below 30 to 40°C. Facilities should therefore be provided to maintain sand filter feed temperatures below 25°C.

Stock Solution Viscosities

Viscosities of the polymer stock solutions for GS as well as sand filter treatment are included in Table 4.47. Viscosities were measured at several spindle speeds with a Brookfield Model RVT viscometer at temperatures of the stock solutions as indicated. The 8% starch solution was dispersed in 1M NaOH, and the 0.1% Versa TL® 700 was made up in distilled water.

4.5.10 Supernate Decontamination

4.5.10.1 Cesium and Plutonioum (P. K. Baumgarten, R. M. Wallace, J. R. Wiley, D. A. Whitehurst)

4.5.10.1.1 General

Cesium and plutonium will be removed from clarified supernate by ion exchange by Duolite® (Trademark of Diamond Shamrock Corporation, Redwood City, CA) ARC-359 resin, using countercurrent elution and regeneration. The resin is a strong-acid cation exchanger, of the phenol-formaldehyde type with sulfonic and phenolic functionality. It is selective to cesium at high pH. The Savannah River Laboratory has demonstrated cesium removal from SRP plant wastes obtaining decontamination factors up to 100,000. Plutonium was removed at DF's = 30 to 300.

4.5.10.1.2 Process Description

As shown in flowsheet FS-9 (Figure 4.9) filtrate from the sand filters (FS-8-20) is pumped through two ion exchange columns in series containing Duolite® ARC-359 resin. After the loading step, the columns are rinsed with water. Both the loading and first rinse steps are downflow. The effluents continue on to strontium ion exchange (FS-10). Cesium and plutonium decontamination factors assumed for material balance purposes are 10^4 and 165, respectively.

The cesium and plutonium are eluted countercurrently from the columns using 2M NH_4OH - 2M $(NH_4)_2CO_3$ followed by a water rinse. Eluate and water rinse effluent pass on to elutriant recovery and cesium concentration (FS-11). The columns are then countercurrently regenerated with 2M NaOH; the effluent goes to a heated catch tank to separate residual ammonia.

4.5.10.1.3 Cycle Schedule

The proposed ion exchange cycle schedule is shown in Table 4.48.

The ion exchange equipment will consist of two columns in series. (Note that 1 column volume as used in the table above is based on the volume of a single column.) Ge(Li) gamma detectors will continuously monitor Cs-137 in the effluent of the first columns where DF's as low as 3 to 30 may be acceptable. The second column will remove the remaining cesium. The second column effluent will also be monitored. The usual second column effluent concentrations may be too low to be detectable against background radiation.

To compensate for varying feed composition, the feed volume and cycle length can be increased or decreased to maintain the desired overall DF. Periodically, probably every 2 months, the resin is backwashed in upflow to remove fines and accumulated miscellaneous solids, correct possible channeling, and regrade the particles. Ultimately, the resin is removed by slurrying and transferring the slurry. Fresh resin is similarly transferred into the columns. If residual radioactivity content is low enough, the resin is checked for residual activity. Spent resin can be buried. Otherwise, the resin will be dewatered, dried, and incinerated in a dedicated incinerator tied into the melter off-gas system.

The proposed cycle schedule is based on countercurrent elution and regeneration. Countercurrent operation is far more efficient than cocurrent [32]. Table 4.49 is a listing of recommended operating techniques for successful countercurrent operation. Between steps the liquid in the freeboard above the resin will be lowered to a level just above the resin to permit proper displacement in the subsequent step.

To achieve maximum advantage with countercurent ion exchange, a few rules must be observed. Most of these relate to the need to maintain a piston-like zone movement of ion exchange in the resin column. To draw the analogy with a distillation column, the "theoretical plate height" must be kept to a minimum.

4.5.10.1.4 Resin Description and Physical Properties

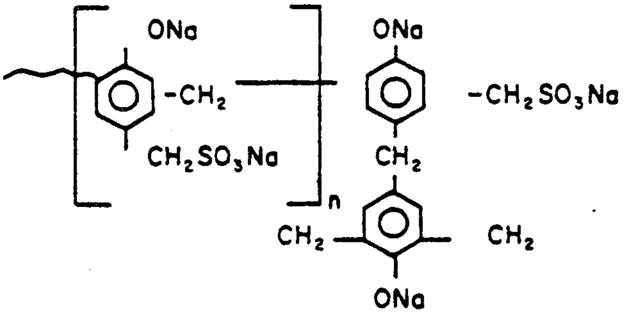
The ion exchange follows the following simplified equations:

Load: $RNa + Cs^+ \leftrightarrows RCs + Na^+$ (1)

Eluate: $RCs + NH_4^+ \leftrightarrows RNH_4 + Cs^+$ (2)

Regenerate: $RNH_4 + Na^+ \leftrightarrows RNa + NH_4^+$ (3)

where R represents the resin. A simplified structural formula of Na^+ form "Duolite" ARC-359 resin, with both sulfonic and phenolic groups sodium-equilibrated is:



At near-neutral pH only the sulfonic acid groups convert to the Na form. As pH increases, more and more of the phenolic groups exchange and convert to the Na^+ or Cs^+ form.

Diamond-Shamrock produces the resin by sulfite-treating crushed, cross-linked phenol-formaldehyde polymer [33]. The standard resin is called "C-3," and is refined and fully regenerated to make "ARC-359." The NH_4^+ form is obtained by treating the Na^+ form with an $(NH_4)_2CO_3$ solution to which NH_4OH has been added to improve solution stability. This is the elution step. The resin is regenerated with 2M NaOH.

Physical properties are tabulated in Table 4.50. Particle size of the commercial resin is mainly in the 16 to 40-mesh range, but specifications may be set in the future calling for a more closely graded, finer size distribution. The bed expansion data shows that 8 to 12 gpm/ft^2 water flow is required for the recommended backwash expansion of 50%. Table 4.51 gives swelling data, weight and volume increase when the resin is immersed in different strength Na and NH_4 solutions [34]. The resin swells the least in $(NH_4)_2CO_3$ solution, more in $NaNO_3$ (or another sodium salt), and most in NaOH. Both particle and bulk density increase in the same order since in each case the weight increase is more than the volume increase, and void fraction remains approximately constant. As observed in a glass column, resin swelling is greater in the supernate than in 2M NaOH in upflow, but less when the flow directions are those of the reference process (supernate downflow, 2M NaOH upflow).

The pressure drop through the bed in downflow will depend on the resin size distribution. A calculated figure is 0.1 to 0.2 psi/ft at 1.12 gpm/ft^2. In upflow, a pressure drop of 0.54 psi/ft is calculated based on an average resin and liquid density of 1.24 This should increase only slightly as velocity increases.

4.5.10.1.5 Resin Capacity

Ion exchange capacity for sodium was determined from static experiments and is given in Table 4.52. The capacity increases considerably with NaOH concentration (i.e., pH) as already discussed. Since the supernate is expected to be 0.5M in OH^-, a Na capacity of about 2.49 + 3.77 = 6.26 eq/kg dry resin is expected. This is approximately equal to 2.28 g-eq/L or 0.019 lb-eq/gal wet resin.

Cesium capacity can be correlated in terms of the distribution coefficient $K_d = [\overline{Cs}]/[Cs^+]$. Here $[\overline{Cs}]$ is the equilibrium concentration of cesium on the resin, with units of g-eq/Kg Na^+-form resin, and $[Cs^+]$ is the equilibrium concentration of Cs^+ in the liquid, with units of g-eq/L of liquid. The value of this coefficient for a range of Na^+ and OH^- concentrations in batch equilibrium measurements is shown in Table 4.53 and Figure 4.51. These data were obtained before many of the problems associated with such measurements were fully appreciated; the results must therefore be considered only approximately. They do, however, show qualitatively the general behavior of the resin in which the K_d increases with increasing OH^- concentration and decreases with increasing Na^+ concentration.

More recent data have shown that the K_d is a very sensitive function of the cesium concentration. Table 4.54 shows the variation of K_d with Cs^+ concentration for Duolite® ARC-359 in equilibrium with solutions containing 4.75M $NaNO_3$-1.0M NaOH.

If only a single equilibrium were involved, the ion exchange reaction could be written:

$$\overline{Na} + Cs^+ \quad \overline{Cs} + Na^+ \tag{4}$$

$$K_s = \frac{[\overline{Cs}]\ [Na]}{[\overline{Na}]\ [\overline{Cs}]} = K_d \frac{[Na^+]}{[\overline{Na}]} = K_d\left(\frac{[Na^+]}{Ex - [\overline{Cs}]}\right) \tag{5}$$

where $[\overline{Cs}]$ and $[\overline{Na}]$ are the respective concentrations of Cs and Na in the resin, $[Cs^+]$ and $[Na^+]$ are their respective concentrations in solution, Ex is the total exchange capacity of the resin and Ks is the equilibrium constant for reaction (4) also known as the selectivity coefficient.

Equation (5) can be rearranged as follows:

$$K_d = \frac{Ks}{[Na^+]} \; (Ex - [\overline{Cs}])$$

or

$$K_d = \frac{Ex\ (Ks/[Na^+])}{1 + [Cs^+]\ (K_s/[Na^+])} \qquad (7)$$

These equations did not give a satisfactory representation of the data in Table 4.54 or other similar data for solutions of different compositions. If, however, the resin is assumed to contain two different types of sites that act independently of each other so that the resin behaves as a mixture of two different resins each with its own capacity (Ex_1 and Ex_2) and its own selectivity coefficient (K_{s_1} and K_{s_2}) the following equation is obtained.

$$K_d = \frac{Ex_1\ (K_{s_1}/[Na^+])}{1 + [Cs^+]\ (K_s/[Na^+])} + \frac{Ex_2\ (K_{s_2}/[Na^+])}{1 + [Cs^+]\ (K_{s_2}/[Na^+])} \qquad (8)$$

Equation (8) is able to fit the data on Table 4.54 reasonably well as shown by the comparison of observed values of K_d with those calculated from parameters (shown at the bottom of the table) obtained by a least squares fit of the data.

The values of K_d shown in the table are only valid for the particular batch of resin for which the measurements were made. Preliminary studies with other batches of resin show that the K_d curves may vary significantly from one batch of resin to the next.

4.5.10.1.6 Ion Exchange Kinetics

The ion exchange kinetics over Duolite® ARC 359 are extremely complicated because the distribution coefficient K_d varies with cesium concentration and because both resin and fluid phase resistances affect mass transfer rates. A computer code for the loading cycle has been developed (by R. M. Wallace) assuming diffusion through spherical particles. Liquid film resistance and preloaded (i.e., not completely eluted) resin will be included in further development. The computer program divides both particles and the column itself into discrete space elements. It has now been modified for variable K_d.

Diffusion coefficients have been measured for various resin types supplied by Diamond Shamrock. A fairly strong negative correlation (-0.804) was obtained between diffusion coefficients and cesium capacity.* Measured resin phase diffusivities were in the range of 0.5 to 3 x 10^{-8} cm^2/sec, considerably less than for other ion exchange resins. One would therefore expect resin phase diffusion to control. On the other hand, some column data indicate that increased column height at constant volumetric throughput improves performance. This may be due to either liquid film influence or more surface area exposure at higher superficial velocity.

Two simplified approaches to predicting ion exchange performance may be used. Breakthrough C/C_0 may be plotted against throughput in column volumes on log-probability paper. This gives a straight line above $C/C_0 > 1\%$. The steepness of the line is proportional to the kinetic rate, while the left-to-right position measures the equilibrium.

A somewhat more complicated approach is to use the J-function** chart, Figure 16-20 in the Chemical Engineer's Handbook. Here C/C_0 is plotted against NT with N as parameter where

N = number of mass transfer units

$$\sim \Psi_p K_d \frac{60 D_p}{d_p^{\,2}} \cdot \frac{1}{(CV/hr)}$$

4.5.10.1.7 Savannah River Laboratory Demonstrations

Removal of Cs-137 from simulated and actual plant wastes was demonstrated in a series of laboratory tests using Duolite® ARC-359 [35, 36, 37]. Figure 4.52 shows the general scheme used in the final tests [36]. Two 22-in.-long by 3-in.-dia stainless steel columns in series contained the Duolite®. They were followed by a third similar column using "Chelex"-100† iminodiacetic

---

* DPST-80-257

** A two-argument function originally derived for recuperative heat transfer.

† Product of Bio-Rad Laboratories.

acid resin for strontium removal. The supernate feed was prepared to simulate closely the reference salt composition and contain the expected radioactive components. Supernate at least 10 years old from H- and F-Area waste tanks was adjusted to the reference composition (2.2M $NaNO_3$, 1.1M $NaNO_2$, 0.75M NaOH, 0.5M $NaAlO_2$, 0.3M Na_2SO_4), slurried with waste sludge to regain equilibrium in waste components, and separated from the sludge by centrifugation and filtration. In the tests, about 775 liters of waste were decontaminated in 9 trials during a 3-month campaign.

Results are shown in Figure 4.53 and Table 4.55. For 40 column volumes throughput, DF's averaged 4×10^5 for Cs-137. For Test 5, first-column effluent showed Cs DF's from 60 (at 25 CV's) to 5 (at 40 CV's). This indicated that the critical cleanup occurred in the second column. Flow rate was 0.67 gal/min-ft^2 in this test which is 2/5 of the gpm/ft^2 expected in the reference process. Plutonium removal was also adequate. DF's averaged 35 for 40 CV's throughput and reached 60 to 20 CV's. In a similar test, but with the supernate saturated with Pu-238 (6.8 Ci/mL vs about 0.014 Ci/mL in most other tests) the DF was 300.

Preliminary tests in 25-mL, 1.3-in.-dia columns showed the effect of process variables [41]. In tracer tests at constant CV/hr and constant diameter, DF improved with longer columns and higher linear flow rate [38] in the range of 0.077 to 0.26 gpm/ft^2. This was probably due to reduced end effects (distributor, dead zones) and better liquid-solid mass transfer at higher linear flow rate. At constant CV/hr and constant linear flow rate (i.e., constant bed height) limited data showed that DF improved with larger diameter [39] probably due to reduced wall effects.

Small-scale tests with actual plant waste (Fig. 4.54) showed that a DF = 10^4 could be obtained at 15 column volumes or higher for Na^+ concentrations of 4 and 9M. The blended DWPF liquid waste will be about 6M in Na^+. Tank 24 supernate which had the lowest Na^+ concentration gave the highest DF. This result agrees with predicted feed concentration effects.

4.5.10.1.8 TNX Semiworks Studies

An experimental study is under way at TNX semiworks to demonstrate the proposed process and investigate process variables. Two 3-in.-diameter by 40-in.-tall glass ion exchange columns, each with its own 3-in.-diameter backwash column, are installed in a temperature-controlled cabinet. Separate metering pumps feed the upflow and downflow streams from appropriate tankage. The supernate feed is obtained from the centrifuging and filtration steps carried out at TNX, and is dosed with "cold" Cs-133. Product samples are obtained in a clean glovebox and analyzed by isotope dilution mass spectrometry. This method can determine Cs concentrations as low as 1×10^{-8}M. Two 8-ft tall columns are currently in operation at the same volumetric (CV/hr) and linear feed rates as the plant columns. A 1/13 scale column, 4 ft high x 2 ft diameter, is expected to become operational in 1981.

Results from the TNX studies show:

1) Sodium capacity of the resin at the high pH of the feed is much larger than that indicated by the manufacturer, namely 0.020 vs 0.010 lb mol/gal. The sodium cannot be effectively removed by water even up to 6 CV's of first rinse, and would overload the glass melter if not removed otherwise. A step to fix cesium on zeolite was therefore inserted in the process after eluate concentration/cesium recovery.

2) Electrical conductivity is an effective indication of the regeneration end point, as shown in Figure 4.55. It is at least as good as pH for this purpose. If the feed is started before the resin is fully regenerated, aluminum hydroxide will precipitate in the bed, plug it up, and ruin its performance.

3) Some $Al(OH)_3$ precipitant has been observed in eluate following 3 CV rinses indicating a longer water first rinse is required. A 5-CV first rinse has been recommended to completely remove the sodium aluminate from the column. An experiment was conducted in which equal volumes of first rinse effluent (3, 4, and 5 CV's) and elutriant were mixed and the resulting solution analyzed for suspended solids by centrifugation. The solutions had 150, 30, and 15 ppm of solids for the 3, 4, and 5-CV effluent-mixtures, respectively. The 3 and 4-CV samples had white and brown solids while the 5-CV sample had only brown solids. The white solids are representative of the $Al(OH)_3$ precipitant while the brown solids were probably introduced by somewhat dirty glassware. A typical set of $Al(OH)_4^-$ analyses during a rinse step are presented in Figure 4.56 from which it can be seen that 5 CV of first rinse removes essentially all of the $Al(OH)_4^-$ from the column.

4) The volume of a given weight of resin depends on the chemical state, the previous resin history, and on whether flow is up or down (see Section 4.5.10.1.4). The columns should therefore be loaded in the ammonia form (which has the smallest volume) to permit the most resin to be loaded. As the bed cycles it tends to shrink, and more resin should be loaded after two or three weeks of operation. Ability to gage the resin level is essential to avoid excessive dead space between the resin and upper distributor.

5) During elution the resin shrinks and the particles tend to fluidize near the top of the column. Some actual gaps in the bed have been noted in the 3-in. columns during this step. This problem may not affect overall performance, but should be kept in mind during further development efforts.

6) The eluate analyses show that the cesium peak occurs @ 4 CV (Figure 4.57) with 97% of the cesium having been removed from the column after 8 CV's. Note that the feed cycle for this run was 60 CV's instead of 20 CV's. The sodium is removed somewhat earlier than the cesium, and the Na concentration decreases more rapidly.

7) Elutriant spiked with cesium to a level corresponding to a decontamination factor of 4,000 (based on concentrator feed) in the elutriant recovery process appears to have no detectable detrimental effects on the cesium column performance. However, the TNX process is limited to a detection limit of 1 ngCs/mL corresponding to a DF = 3×10^4 for 2.4×10^{-4}M Cs feed. The effect of elutriant below this level may be significant but cannot be observed at TNX. Therefore a reduction in the decontamination factor of 10^6 for the elutriant recovery equipment cannot be recommended at this time if the possible higher DF's obtained in the high level caves studies DF = $10^5 - 10^6$ are to be taken advantage of and less than 10 nCi Cs/mL salt product produced.

8) Large variations in column performance have been observed with different resin batches. Three resin batches have been used at TNX:

   a. Duolite® ARC-359, Lot #512-17E, a resin manufactured in 1977.

   b. Duolite® ARC-359, Lot #512-43K, a resin manufactured in 1973 and used in the high level caves tests (HLC).

   c. Duolite® ARC-359N, Lot #512-28G, Lab #1463-113, a resin manufactured in 1978.

   Figure 4.58 shows that the cesium capacity of the 1977 and 1973 resin were quite similar (19-20 CV to C/Co = 0.5) and considerably lower than that for the 1978 resin. It should be noted that the 1973 resin 'lost' more than 50% of its original capacity when used in the HLC tests. This suggests that for design purposes, the TNX data on 1977 and 1973 resin are to be regarded as degraded resin prior to removal. Programs at SRL are under development to ensure the delivery of a resin with a capacity equal to or greater than that of the 1978 resin Lot 512-28G.

9) The effect of feed composition is also presented in Figure 4.58. The capacity of the 1973 resin increased by about 70% with the increased hydroxide concentration (due to aluminum dissolution). Thus the number of CV to reach 50-55% breakthrough (C/C_o x 100) for the first column effluent increased from about 19.6 CV to about 28 CV (extrapolated) with the addition of the aluminum dissolution process. Thus the performance of ion exchange is primarily dependent on feed ($[Na^+]$ and $[OH^-]$) and resin batch. The effect of feed composition will be determined for a particular resin batch in order to set the acceptable limits of feed composition.

10) Figure 4.59 shows that DF $\geq 10^4$ were obtained from both columns for at least 60 CV. The effluent from between the two columns began to "break through" at 20-40 increasing to 50% breakthrough at 60-65 CV. It should be noted that for a feed with $[C_s^+] = 2 \times 10^{-4}$M, a DF = 2.6×10^4 is the most that can be shown using the present method of analysis. The column may be performing considerably better than the 7.5×10^{-9}M product suggested from Figure 4.58. The differences between 1 and 3 CV/hr feed rate should be considered only qualitative, since relatively large variations occurred with the same flow rates and because the differences observed may have been due to variation in $[OH^-]$ or an effect due to time (resin history).

11) Figure 4.60 presents the effect of feed concentration on the "degraded" 1973 resin. It may be seen that for feeds 3-4 times higher than the expected 2.4×10^{-4}M cesium concentration acceptable breakthrough from the second column is still obtained. Note that the DF $\approx 10^5$ for $C_o = 7.7 \times 10^{-4}$M corresponds to the same effluent as DF $\approx 3 \times 10^4$ for $C_o = 2 \times 10^{-4}$M. The canyon process will probably not run the first column to near the 50% breakthrough required to achieve DF = 10^4 after 20 CV in order to prevent the possible contamination of the product salt.

12) The relatively minor effect of flow rate is presented in Figure 4.61 for the "degraded" resin. Again both of these flow rates achieved the desired goal of DF = 10^4 but only just barely. The effect of flow rate is most pronounced at low concentrations where the breakthrough curves begin to deviate from linearity (log-probability coordinates).

13) Correlation between the C/Co's of the two columns will be depended upon to help control plant operation. The correlation may vary with feed composition and resin condition. Further data will be obtained during the course of this program.

4.5.10.1.9 Hanford Experience

Duolite® ARC-359 resin has been used extensively in Atlantic-Richfield-Hanford's B Plant* to remove about 95% of radiocesium from alkaline Purex and Redox supernates. Original experience was with synthetic zeolite, "Linde" AW-500 [40], [41], which, however, was not stable when exposed to high alkalinity for a long time. It was therefore replaced by Duolite® ARC-359 [42], [43].

Atlantic-Richfield used the refined-grade ARC-359 instead of the standard C-3 grade, since they wanted to be sure the resin would work and it was simpler to have the supplier rather than Atlantic-Richfield pretreat the resin.

The Hanford techniques are somewhat different from ours since their purpose is different. They use a single 6-ft-diameter x 13-ft-tall column (with 10 to 12-ft-deep bed) and operate it in downflow except for the regenerate step. The column is drained between steps. The Hanford cycle includes a sodium elute step after the load, using a 0.2M $(NH_4)_2CO_3$-0.1M NH_4OH scrub solution to separate most of the sodium from the cesium prior to cesium elution. This also removes potassium and rubidium ions from the resin. This step was considered for the present DWPF process to remove excess sodium from the eluate, but did not appear as attractive as cesium fixation on zeolite. The scrub effluent is butted with caustic and returned to the column as regenerant to recover leaked cesium. Hanford practices backwashing only in the form of a biweekly upflow water "fluff" within the ion exchange column. They use an extra elute/regenerate cycle to correct poor column performance.

Periodically concentrated eluate is reworked to reduce the Na/Cs ratio further. After NH_3 and CO_2 are stripped off in elutriant recovery, the eluate contains chiefly cesium and sodium carbonate and Fe and Al contaminants. It is reloaded onto the column. Subsequent steps - Na scrub, elution, rinse, and regeneration - are similar to the primary processing.

The Duolite® resin is used for about one year before being replaced [44]. The last batch was in use for 3 years (1975-78), but had deteriorated significantly when it was replaced. Atlantic-Richland-Hanford standard operating procedures are on file, including SOP 11.28 "Cesium Ion Exchange PSS Processing," SOP 11.22 "Cesium Ion Exchange Product Rework Procedure," and Flowsheet ARH-F-106 (1977). Analytical procedures, "Cesium Absorption Cs-1," "Determination of Particle Size - Wet Sieve Method - Zy-24a," and "Determination of Moisture Retention Capacity - 0.7," are also available.

---

* Currently operated by Rockwell International.

4.5.10.1.9.1 Resin Aging and Decay

Duolite® ARC-359 degradation under the influence of high pH and high radiation flux is slow. The Hanford experience has been favorable. One batch of 435 ft^3 processed 1.8 million gallons of Purex waste (17 Ci/gal) between March 1973 and May 1975. When a fresh batch of 442 ft^3 was substituted, bed capacity increased 33%. The second batch processed 1.5 million gallons between May 1975 and February 1976, at which time load sizes had decreased 10%. Some of the reduced resin performance may have been due to channeling, which would have been corrected by backwashing.

Hanford monitors resin capacity by taking a sample from the bed measuring moisture retention and cesium capacity. For instance, the first batch of resin described above increased from 50 to 78% moisture retention between March 1973 and October 1974. Radioactive cesium capacity is measured by shaking 0.5 g resin with 5-ml cesim-spiked liquid for an hour, decanting the supernate, and measuring gamma-activity of the separated resin. The liquid Na^+, OH^-, and Cs^- concentrations should be at specified levels for the test.

Hanford also monitors bed height, and found a column decrease (7.6%) in the first campaign cited and a very slight increase (4%) in the second. The conclusion, therefore, is that fines are only occasionally produced, and that the main result of degradation is increased porosity. SRP waste did not chemically degrade Duolite® ARC-359 resin by prolonged contact, and the radiation stability was also good [42].

Diamond Shamrock recommends a maximum resin service temperature of 40°C in caustic service. Above this temperature, the resin degrades by de-crosslinking. Hanford maintains its feed streams at 20-25°C.

4.5.10.1.10 Heat Effects

Heat development via radioactive decay should not be a problem except in the extreme case of 20 CV's of supernate containing Cs-137/Ba-137 being sorbed on the resin, and no flowthrough of liquid. Even in that case a temperature rise of only 0.087°C/hr is calcualted for the case of liquid remaining in the column, and 0.25°C/hr for the case of a drained column. Heat load was calculated to be 929 Btu/hr for 20 column volumes of 15-year aged waste supernate sorbed on the resin.

4.5.10.1.11 Detailed Description of Unit Operation

Resin Preparation and Column Loading

The Duolite® resin is prepared on the cold side of the canyon by slurrying it with water. The resin slurry is then gravity-fed or pumped into the ion exchange columns. Excess water is collected in the spent resin catch tank. The columns are then backwashed and settled 3 times to remove fines and grade the resin. According to Diamond Shamrock, 95% of resin fines can be removed in this step. Following backwashing, the resin is subjected to two elution-regeneration cycles. Each column is checked to make sure it is full. A velocity of 3 to 5 ft/sec in the connecting piping is recommended for hydraulic conveying. Compressed air may be used to assist the conveying and break plugs.

Load (Feed) Cycle

Filtered supernate will be fed downflow through each set of series columns. A flow rate of 1.67 CV/hr, or 1.67 gpm/ft^2 is planned. Temperature of the feed is not to exceed 30°C. A feed density of 1.24 g/cc can be used for design purposes. 20 to 30 column volumes of feed can be processed with 20 CV's being used as design basis.

The make-effluent is routed to intermediate tankage ("bounce tanks") for feed to the strontium ion-exchange columns.

First Rinse Cycle

Water for the first rinse cycle is obtained from recycle water. The rinse has two purposes. It will keep elutriant from mixing with feed retained in the column voids which would cause $Al(OH)_3$, Al_2O_3, and/or aluminum basic carbonate to precipitate and plug the columns. After pushing the supernate out of the column voids it will also remove sodium from the resin, thereby minimizing the amount reaching the cesium concentrator. The rinse follows the feed to the strontium ion exchange column.

The bounce tanks should be kept relatively empty to take advantage of the increasing feed purity as the rinse passes through the cesium columns. Water purity is important to prevent elution of cesium. Its pH should be in the range 7 to 9, and total cation concentration (including NH_4^+) should be less than 0.02M. The flow rate is to be the same as for the feed. The design-basis first rinse volume is 5 column volumes. Temperature is not to exceed 30°C.

Elution Cycle

The elutriant will be 2M NH_4OH - 2M $(NH_4)_2CO_3$ and is obtained from the elutriant recovery area. Make-up CO_2 and NH_3 are obtained from the cold side. Elutriant composition may be allowed to vary ±10% and radioisotope concentration should not exceed the desired load-effluent concentration (i.e., 10^{-8}M). Flow will be upflow at a rate of 1.2 CV/hr, with a total volume of 10 column volumes. Temperature is not to exceed 30°C. Effluent will be routed to a catch tank, for subsequent concentration and stripping in the elutriant recovery area.

Second Rinse Cycle

The second water rinse, upflow, follows the eluate into the eluate catch tank. This rinse prevents buildup in the recycle water system. Flow rate will be 1.2 CV/hr, with a total volume of 3 column volumes (may be adjusted downward). Temperature and water quality are the same as for the first water rinse except for any limitation on NH_3 concentration.

Regeneration Cycle

The resin, now in the NH_4^+ form, will be regenerated with 2M NaOH in upflow. Regenerant composition may be allowed to vary ±10% and radioisotope concentration should not exceed 10^{-2} times the desired load-effluent concentration. Flow rate will be 1 CV/hr, with a total volume of 5 column volumes. The regeneration endpoint will be determined by electrical conductivity >100,000 μmho/cm. Temperature is not to exceed 30°C. Effluent will be routed to a regenerant catch tank, which is heated and stirred in such a manner as to drive off eluted NH_3 to the cesium vent scrubber.

Backwash

About every two months the resin may require backwashing. This is done with water in upflow to remove fines and miscellaneous deposits, correct channeling, and regrade the bed hydraulically. Need for backwashing is signaled by reduced decontamination factors and increased bed pressure drop. An expansion of 50 to 75% is desired in the backwash, so the required flow rate can vary, according to Table 4.50, from 4 to 10 gpm/ft^2 depending on the ionic form, water temperature and particle size. During each 4-hr backwash period, recycle water is recirculated through the ion exchange column to expand the bed into the available freeboard space. Degraded resin flushed into the fines are sent resin catch tank, where it remains for disposal. After backwashing, the resin settles back into the ion exchange column. Two or three separate backwash periods, with settling in between, are suggested. The introduction of air should be meticulously avoided. The ion exchange column is then level-gaged and fresh resin added, if necessary.

Since the backwash procedure mixes the resin bed, the bed is then eluted and regenerated at least twice to make sure the bottom zone is clean enough to produce low-contaminant make-effluent. Elution time could be extended to double the usual period if it is suspected that excessive Cs or Pu remains on the resin.

Spent Resin Removal

The time for resin removal is signaled by reduced DF's even after backwash, and by increased resin moisture absorption and reduced Cs capacity in thieved samples. The resin is removed from the columns by slurrying it with water fed in through the bottom distributor. Additional water may be introduced from the top of the column. A water velocity of 3 to 5 ft/sec will be required in the up-legs of the transfer lines. The use of compressed air to break plugs and facilitate conveying is recommended.

Resin Disposal

Spent resin is checked for residual alpha, beta, and gamma activity, interstitual water is drained, and the resin is packaged in 10-50 lb batches. Packaging the resin puts it in a form suitable for burial or incineration. If total activity is less than 10 nCi/g, burial as a low-level waste should be considered. In the high-level cave tests, residual radioactivity did not build up after 320 column volumes of actual plant waste had been processed. Hanford presently buries its spent Duolite® resin.

If activity is greater than 10 nCi/g incineration in equipment with proper smoke and fly-ash control is preferred. A small (50-100 lb/hr) incinerator could be installed in the S canyon ion exchange area. The incinerator off-gas would be routed to the melter off-gas system.

4.5.10.2 Strontium Ion Exchange

4.5.10.2.1 General

Strontium is removed from clarified supernate by ion exchange on "Amberlite" IRC-718* resin. This resin contains a chelating functionality which results in a strong selectivity for transition metals. The Savannah River Laboratory has shown that strontium is selectively sorbed onto the resin from simulated waste supernates. Small-scale column tests led to the conclusion that plant scale columns should perform well with the "Amberlite" resin [45]. Decontamination factors approaching 1000 were obtained with a single column. Based on this DF, the reference flowsheet forecasts the Sr-90 activity in the saltcrete will be less than 2 nCi Sr/g [46].

4.5.10.2.2 Process Description

The effluent from the Cs columns is pumped downflow through the ion exchange column containing "Amberlite" IRC-718 resin. After the loading step, the column is first rinsed downflow with the effluent from the cesium first rinse and then rinsed downflow with water. The strontium is eluted upflow using a 0.01M solution of ethylene diamine tetrasodium acetate (EDTNaA at pH = 11). The column is finally rinsed upflow with water to remove residual EDTNa. The cycle schedule is summarized in Table 4.56.

Because the cesium ion exchange process will be monitored to maintain acceptable DF's, the actual feed times may vary for the strontium cycle. The ion exchange operation will be countercurrent to ensure that high DF's are obtained.

A flow diagram (FS-10) is shown in Figure 4.10 and a material balance (MB-10) in Table 4.10.

4.5.10.2.3 Resin Properties

"Amberlite" IRC-718 is a crosslinked macroreticular cation exchange resin. It has a styrene divinyl benzene matrix with a chelating functionality like ethylene diamine tetra-acetic acid (EDTA). This functionality consists of cation active sites which coordinate with the transition metal ion and therefore have a high selectivity toward them [47].

---

* Trademark of Rohm and Haas.

Sorption experiments with various resins indicated that "Amberlite" IRC-718 has one of the most favorable equilibria for strontium sorption. The distribution coefficients (Sr on resin)/(Sr in supernate) for the resins tested are presented in Table 4.57.

"Amberlite" IRC-718, while having a favorable distribution coefficient for strontium (k_d = 1040 to 3250), is also selective to other metal ions such as Hg, Ca, and the lanthanides. A selectivity series for IRC-718 is presented in Table 4.58 for an idealized supernate solution. The competing ions are present in concentrations much higher than that of strontium. Column tests using strontium tracers are to begin shortly to determine the effect of competing ions under dynamic conditions.

The highly crosslinked macroeticular structure of "Amberlite" IRC-718 prevents the excessive swelling and contracting which fragments and degrades gelular chelating resins [47] such as "Chelex" 100. Since IRC-718 particles are considerably larger than "Chelex" 100 particles, column pressure drop is less and the possibility of losing fines through screen distributors is reduced. "Amberlite" is a spherical resin which typically has a 20-50 mesh particle size range. The maximum swelling is 40% when converting from H^+ to Na^+ form [48]. The swelling expected in the strontium columns is less than 10% since elution will be with alkaline EDTA instead of acid.

Pressure drop data for downflow operation is presented in Figure 4.62 [49].

4.5.10.2.4 Detailed Description of Unit Operations

Resin Preparation and Column Loading

Each new shipment of resin is washed initially to remove any fines that have accumulated during handling and shipment. After characterizing each batch as to particle size range and preliminary strontium absorption capacity, the "Amberlite" resin is slurried with dilute caustic and gravity fed into the ion exchange column. Gravity feeding is used to prevent destruction of the fragile spherical particles. The resin is then backwashed at least 3 times to remove any additional fines which may have accumulated during handling and to classify the resin according to particle diameter. Finally, the column is eluted and regenerated twice to prepare the resin for actual use.

Feed

The effluent from cesium ion exchange will be fed downflow into the column prepared for loading. The flow rate presently proposed is 1.67 gpm/ft^2. The feed temperature is not to exceed 30°C. Because the strontium feed comes directly from cesium ion exchange, the proposed 12-hour feed time is subject to the variations in cesium feed time which might occur because of changes in supernate composition. Thus the strontium column is to be sufficiently overdesigned so that any increased feed times for cesium ion exchange do not cause strontium DF's to fall below an acceptable level.

Although the volumetric flow rate to the strontium column will remain the same as for cesium (2542 gph while being fed), the flow rate on a column volume basis will be twice as high (3.33 CV/hr), since the strontium column resin capacity is one-half that of the cesium column(s). Also since there is only one Sr column, but two Cs columns, the relative throughput (volume solution/volume resin) will be 4 times larger for Sr than Cs. The column will be loaded for 40 CV's (20 hrs) with cesium column effluent, where a column volume is based on the Sr resin bed volume (762 gal). The effluent from strontium ion exchange will be transferred to the product salt hold tank.

Breakthrough behavior for strontium ion exchange using "Amberlite" resin is shown in Figure 4.63 [45].

Cs Rinse

The first rinse from the cesium column will be passed downflow through the strontium column. This rinse should be kept separate from the Cs make (feed) effluent to properly rinse the Sr columns. Most of the strontium remaining in the holdup volume of the cesium column will be flushed out by this rinse step and sorbed onto the "Amberlite" resin. The flow rate is to be the same as the feed (1.67 gpm/ft^2, 3.33 CV/hr for 3 hrs), and the temperature is not to exceed 30°C.

Sr First Rinse

The Sr first rinse will be used primarily to push the remaining sodium and nitrates out of the column voids to reduce the load on the spray dryer and melter. Water purity should be such that leakage of strontium is held to an acceptable level. Experimentation will be done to determine the maximum allowable levels of EDTA in the water. The flow rate is to be the same as for the feed (1.67 gpm/ft^2, 3.33 CV/hr for 0.45 hr), and temperature is not to exceed 30°C.

Elution

The elutriant will be EDTA and caustic. The concentrations proposed are 0.01 M EDTA and 0.001 M NaOH. The pH should be 11 or greater to keep the EDTA in the tetra sodium form. Elution with 0.01 M EDTA will keep the resin in the sodium form, which will eliminate large volume changes and reduce the osmotic shock. Laboratory tests were run using 0.01 M EDTA as an elutriant for both "Amberlite" and "Chelex" resins. Figure 4.64 shows that elution with EDTA is very effective in removing strontium from the resin.

The elutriant will be made in the Sr elutriant make-up tank, sampled and tested for EDTA and pH. The eluate from Sr ion exchange will be sent to an evaporator where it will be concentrated to a 1.0M alkaline EDTA concentration in order to reduce the water load on calcination.

The proposed flow rate for the elutriant is 0.5 gpm/ft^2 (1 CV/hr) for a total volume of 6 CV (4572 gal). The temperature is not to exceed 30°C. The maximum permissible level of Sr in the elutriant is being studied.

Sr Second Rinse

The purpose of the second rinse is to wash the EDTA remaining in the voids out of the column. This will prevent the strontium in the next feed step from possibly being chelated by remaining EDTA. The effluent will be mixed with the eluate before entering the Sr concentrator.

The proposed flow rate is the same as for the elutriant (0.5 gpm/ft^{2}d, 1 CV/hr). A total volume of 3.0 CV (2286 gal) of rinse water shall be used. Temperature is not to exceed 30°C.

Backwash

About every two months the resin may require backwashing. This is done with water in upflow to remove fines and deposits, correct channeling, and regrade the bed hydraulically. Need for backwashing is signaled by reduced decontamination factors or increased pressure drop. An expansion of 50 to 75% is desired in the backwash, so the required flow rate can vary, from 3 to 6 gpm/ft^2 depending on the particle diameter and water temperature. Figure 4.65 presents expansion data for backwash operation [49]. During the 2-hr backwash period, recycle water is recirculated through the ion exchange column to expand the bed. Degraded resin fines are flushed into the spent resin tank for disposal. Two or three separate backwashes with settling in between are suggested. The ion exchange column is then level-gaged and fresh resin added if necessary. In that case, a second backwash is required to regrade the whole bed.

Since the backwash procedure mixes the resin bed, the bed is then eluted/regenerated with 0.01M EDTA at pH=11 at least twice to make sure the bottom zone is clean enough to produce low-contaminant make-effluent.

Spent Resin Removal and Disposal

Spent resin is checked for residual alpha, beta, and gamma activity, interstitial water is drained, and the resin is packaged in 10-50 lb batches. Packaging the resin puts it in a form suitable for burial or incineration. If total activity is less than 10 nCi/g, burial as a low-level waste should be considered. In the HLC tests residual radioactivity did not build up after 320 column volumes of actual plant waste had been processed. Hanford presently buries its spent Duolite® resin.

If activity is greater than 10 nCi/g, incineration in equipment with proper smoke and fly-ash control is preferred. A small (50-100 lb/hr) incinerator could be installed in the S Canyon ion exchange area. The incinerator off-gas would be routed to the melter off-gas system.

4.5.10.2.5 Resin Aging

"Amberlite" IRC-718 resin degrades mainly because of osmotic shock. The radiation level from cesium-free supernate ($<5 \times 10^{-3}$ watt-hr/g) is not expected to significantly degrade the resin [50]. The structural properties of "Amberlite" IRC-718 are considerably better from a resin aging standpoint than the resin formerly suggest ("Chelex" 100). A service life of at least one year is to be expected for the "Amberlite" resin.

Aging effects will be noticed by a reduction in the decontamination factors obtained. Since continuous monitoring of Sr-90 is not practical, samples of the column effluent are to be taken each cycle. As the performance of the resin degrades, the amount of supernate fed to the cesium column will have to be adjusted accordingly in order to obtain a salt cake with acceptable levels of Sr-90.

4.5.10.2.6 Process Control

Strontium Feed Bounce Tank

Function

Feed cesium ion exchange column effluent to the strontium column at 1.67 gpm/ft^2 ±10%.

Control

(1) Monitor flow to ion exchange columns.

(2) Monitor discharge pressure of pump.

Sr Ion Exchange Column

Function

Provide a DF of greater than 1000 for strontium.

Control

(1) Hold the temperature of the feed to <30°C.

(2) Monitor ΔP across the columns.

(3) Resin level indicator.

(4) Monitor flow during loading, rinse, elution, and regeneration.

(5) Resin level indicator for the backwashing process.

4.5.11 Cesium Elutriant Recovery/Eluate Concentration

(B. E. Murphree)

4.5.11.1 General

The cesium ion exchange column eluate is processed through this module to concentrate the eluate to 2.0M (Na_2CO_3 + Cs_2CO_3) and recover NH_3-CO_2. Greater than 99.99% of the NH_3 and CO_2 is driven from the cesium eluate during this process. The flowsheet (FS-11) is shown in Figure 4.11 and the material balance (MB-11) in Table 4.11.

4.5.11.2 Process Description

Cesium eluate collects in the cesium concentrator feed tank and is fed continuously to the top of the steam stripper. The steam stripper is a packed bed which contacts cesium eluate countercurrently with steam from the cesium concentrator. $(NH_4)_2CO_3$ and NH_4OH break down in the steam by the reactions:

$$2NH_4^+ + CO_3^{2-} \xrightarrow[heat]{} 2NH_3 + CO_2 + H_2O \tag{1}$$

and

$$NH_4^+ + OH^- \xrightarrow[heat]{} NH_3 \quad H_2O \tag{2}$$

Removing NH_3 and CO_2 in the steam stripper prevents foaming in the cesium concentrator. The NH_3-CO_2-water vapor overheads pass through a de-entrainment section which removes entrained non-volatile radioactivity with a DF of $\geq 10^6$. The vapor stream is condensed to produce an $(NH_4)_2CO_3$-NH_4OH solution by the reverse reactions of (1) and (2):

$$2NH_3(g) + CO_2(g) \xrightarrow[cooling]{} 2NH_4^+ + CO_3^{2-} \tag{3}$$

and

$$NH_3(g) + H_2O \xrightarrow[cooling]{} NH_4^+ + OH^- \tag{4}$$

The solution flows to the cesium elutriant makeup tank via the stripper condensate tank. The concentration of the elutriant is adjusted to 2M $(NH_4)_2CO_3$-2M NH_4OH ±10% by sparging appropriate amounts of CO_2 and by adding aqueous ammonia and process water. The elutriant is then ready for reuse in elution of cesium from the Duolite® resin.

NH_3 and CO_2, which escape from the various process vessels, are combined and drawn through a packed bed absorber (cesium vent scrubber). Chilled water countercurrently contacts the NH_3-CO_2 containing gas stream. NH_3 and CO_2 are absorbed by the liquid phase and returned to the cesium concentrator feed tank. The depleted gas stream is vented to the regulated facility vessel vent system.

The concentrated Na_2CO_3-Cs_2CO_3 (2.0M) solution is pumped from the cesium concentrator to the Cs concentrator bottoms tank for subsequent processing through a zeolite column.

A purge condenser condenses a steam sidestream from the cesium concentrator. This removes water introduced by ion exchange rinse steps, jet dilution, and vent scrubber bottoms. The purge condensate is transferred to the recycle evaporator feed tank for subsequent decontamination.

4.5.11.3 Hanford Pilot Plant Study

Hanford runs an elutriant recovery/eluate concentration system which performs exactly the same function as that proposed for the DWPF process. Two major problems have appeared occasionally: (1) foaming in the evaporator and (2) $(NH_4)_2CO_3$ pluggage in the condenser. Reference 70 describes a pilot plant study performed to solve these problems at Battelle-Northwest Laboratories. The feed composition used (about 7M NH_4^+ and about 3M CO_3^{2-}) was similar to the DWPF cesium-loaded elutriant (about 6M NH_4^+ and 2M CO_3^{2-}).

Steam stripping the feed in a packed bed effectively prevented foaming in the evaporator. The stripping operation removed >99% of the NH_3 and CO_2 from the liquid entering the evaporator. Heats of vaporization for $(NH_4)_2CO_3$ and NH_4OH at 25°C are 51.2 and 18.8 kcal/mole, respectively. Overall heat transfer coefficient in the steam-heated tube bundle reboiler leg was about 500 Btu/ft^2-hr °F. A mist eliminator pad effectively disengaged entrained feed from the vapor stream exiting the stripper. Decontamination factors as high as 2×10^4 were demonstrated.

Downdraft condensation prevented pluggage in the condenser. Overall heat transfer coefficients of about 100 Btu/ft^2-hr-°C were calculated for the condenser. 98% recovery of NH_3 and CO_2 were demonstrated by the downdraft condenser. Significant losses of NH_3 and CO_2 occurred at condensate temperatures above 60 and 20°C, respectively.

4.5.12 Cesium Fixation on Zeolite

4.5.12.1 General

Concentrated eluate from the cesium concentrator/steam stripper is processed through this module to separate the cesium from the Na_2CO_3 solution by adsorption of the cesium on zeolite. The cesium-loaded zeolite is hydraulically slurried and transferred to the slurry hold tank for subsequent processing through the spray dryer with washed sludge and strontium eluate concentrate. The flowsheet (FS-12) is shown in Figure 4.12 and the material balance (MB-12) in Table 4.12.

4.5.12.2 Process Description

Feed to this step is the 2.0M (Na_2CO_3 + Cs_2CO_3) cesium concentrator bottoms solution. The cesium content is about 0.001M Cs_2CO_3. Feed is pumped downflow through a 5 ft diameter x 11 ft bed of sodium-form Ionsiv® IE-95 (formerly Linde® AW-500)*. Effluent from the column depleted in cesium by a factor averaging at least 100 is recycled to the sand filter feed tank. The column is run intermittently for about 2.5 hours every 3 days during the loading step in order to maintain a superficial velocity of 0.2 ft/min in the bed. A 2-bed-volume water wash flushes the bed to remove interstitial salt each time the feed is terminated. Residual rinse water circulates through the bed for cooling while it is idle. Cesium breakthrough occurs at $\geq$50 bed volumes of feed and is signaled by an online gamma detector. The column is sized such that breakthrough occurs at a minimum of every 60 days.

Following breakthrough, the bed is rinsed with 7 CV's of water to remove sodium. The bed is then backflow-expanded to 150-175% of its settled height. A steam jet empties the expanded bed into a separate tank where it is dewatered to a 1:1 water slurry using a profile wire screen separator. Cesium content of the slurry is determined analytically. The slurry is sent in controlled batches to be mixed with the sludge slurry to the spray dryer/melter for incorporation in glass.

The empty column is refilled with a slurry of fresh sodium-form zeolite from cold feed.** The bed is back-flow expanded to 150-175% of its settled height and backwashed for about 1 hour. It is then allowed to settle for about 30 minutes. This step is repeated twice more and thus classifies the bed according to size and rounds the corners of the granular zeolite particles. This promotes even distribution to the bed.

4.5.12.3 Zeolite Properties

Zeolite was chosen as the ion exchanger on the basis of radiation and chemical stability and cesium capacity. Zeolites (natural and synthetic) are a class of hydrated crystalline alkali metal aluminosilicate minerals which exhibit cation exchange properties. Their crystal structure is composed of AlO_4^- and SiO_4

---

* The zeolite now manufactured as Linde AW-500 does not have the desirable cesium selectivity properties, and Linde IE-95 must be specified.

** The fresh zeolite must be pretreated in cold feed with $4MNaNO_3$ to prevent Ca_2CO_3 formation.

tetrahedra sharing common oxygen atoms. The bond lengths and strengths are such that the crystal lattice is both open and rigid. This produces a structure with a fixed negative charge at each Al site. Mobile cations present within the voids of the crystal balance this charge. The fixed negative charges therefore serve as cation exchange sites [51].

"Ionsiv" IE-95 (formerly Linde AW-500) was chosen as the zeolite best suited for cesium fixation. It has been used successfully in similar service at Hanford [53]. It is a naturally occurring chabazite which is mined, sized, and refined by Union Carbide. It is mixed with clay binder, fired, and crushed prior to marketing [52], as a 20-50 mesh solid, and has a formula of $(Na^+, Ca^{++}), M^{++}) (Si_2AlO_6)_2 \cdot H_2O$. Bulk densities are given in Table 4.59. Water content is 1-10% as shipped and 12-17% hydrated [54]. Figure 4.66 shows experimental pressure drop data with water. Figure 4.67 gives experimental backwash expansion data [55].

Total ion exchange capacity of "Linde Ionsiv" IE-95 is 2.2-2.5 meq/gm (anyhydrous) [54]. Figure 4.68 shows the effect of sodium ion on cesium loading for "Linde" AW-500 [57]. Reference 58 gives detailed information on the thermodynamics and kinetics of cesium-sodium ion exchange on chabazite.

4.5.12.4 Savannah River Laboratory Studies

SRL ion exchange studies with both tracer level synthetic eluate and adjusted composition plant waste demonstrated the feasibility of fixing cesium on zeolite from concentrated ion exchange eluate [59], [60].

Tracer level column tests were run as follows. To ensure conversion to Na^+ form, 25 ml (19.5 g) of "Linde" AW-500, 20-50 mesh zeolite was washed with 3M $NaNO_3$. The resin was rinsed with water and transferred to a 1.3-cm-ID column. 2M Na_2CO_3-0.007M $CsNO_3$ (with 1.7×10^5 dis/min-ml Cs-137) was pumped downflow through the column at 1 CV/hr at ambient temperature. 2% breakthrough (Cs in column effluent = 2% Cs in feed) occurred after 70 CV; 20% breakthrough occurred after 76 CV.

These results show that it will be possible to sorb at least 70 CV of concentrated "Duolite" column eluate on one zeolite column. After an initial water wash, further contact with water will not leach Cs-137 appreciably from zeolite [59].

The eluate of "Duolite" ion exchange from actual plant waste was concentrated by boiling to remove NH_3, CO_2, and H_2O. This concentrated eluate was used to test Cs-137 sorption onto columns containing four solid sorbents. Effluents from the sorbent columns was monitored by on-line gamma counting [59]. Plutonium and Sr-90 could not be counted with the on-line system. Their sorption onto "Linde" AW-500 was shown previously [61].

As shown in Table 4.60 "Linde" AW-500 and "Zeolon" 900 (trademark of Norton Chemical Company) zeolites sorbed Cs-137 equally well. Each column held 100 ml of zeolite. Including concentration of Cs-137 by the "Duolite" columns and by eluate evaporation, each zeolite bed sorbed Cs-137 from about 150 liters of SRP supernate. The Cs-137 concentration factor was about 1500. (Sorption of Cs-137 from supernate directly onto zeolite gives a concentration factor of only 37 [59]. After being loaded with Cs-137, the "Linde" AW-500 and the "Zeolon" 900 columns each emitted gamma radiation >4000 rad/hr at 3 in. "Zeolon" 500 and "Vermiculite" (trademark of Zonolite Company, Travelers Rest, SC) were not acceptable sorbents for 137-Cs in these tests [60].

4.5.12.5 Hanford Experience

In 1967, Hanford started its fission product separation operation in B-plant. The Cs-137 separation step consisted of removing this isotope from alkaline liquid waste solution by ion exchange on "Linde" AW-500. The loaded resin was eluted with $(NH_4)_2CO_3$ - NH_4OH solution. The eluate was boiled down to a concentrated Na_2CO_3 solution containing the Cs-137 [62]. This solution was later loaded on zeolite to reduce the Na/Cs ratio. This rework step is very similar to the Cs fixation step proposed for the DWPF [63, 64]. Reference 62 describes intended operation prior to startup and contains a concise summary of development data.

4.5.13 General Purpose Evaporation

4.5.13.1 General

A second evaporation step is included to perform a final decontamination step on excess water that must be purged to the environment. The flowsheet (FS-13) and material balance (MB-13) are shown in Figure 4.13 and Table 4.13, respectively.

4.5.13.2 Process Description

Process streams that comprise the feed to the GPE include:

- Recycle evaporator condensate
- Strontium concentrator condensate
- Product salt solution evaporator condensate

A boildown ratio of 10:1 was assumed for material balance purposes. Overheads, after accounting for the radionuclide inventory, are discharged if within limits to a plant surface stream. Evaporator bottoms are sent to the recycle evaporator feed tank. Concentration of salt in concentrate/concentration of salt in condensate = 10^6.

4.5.14 Solidification of Product Supernate in Concrete

(H. W. Bledsoe)

4.5.14.1 General

Clarified supernate, following treatment through ion exchange, is evaporated to 35 wt % salt and subsequently incorporated into concrete. The concrete mix is pumped into excavated trenches located at least 10 ft above the maximum recorded water table level and surrounded by 5 ft of highly impermeable soil. The concrete monolith is backfilled with 5 ft of highly impermeable soil followed by at least 28 ft of backfill. The flowsheet (FS-14) and material balance (MB-14) are shown in Figure 4.14 and Table 4.14, respectively.

4.5.14.2 Process Description

The effluent from the strontium ion exchange module, following storage in Product Salt Hold Tanks in S Area, is transferred to a product salt solution storage tank located in an area adjacent to the to-be-selected concrete disposal site (selected to meet both NRC and EPA requirements). From this tank, the decontaminated supernate will be dewatered to a salt content of 50-55 wt %. Concentration of salt in the concentrate/concentration of salt in the condensate = 10^6.

The concentrated salt solution will be mixed with cement at a central batch plant. The concrete mixture will contain 55.8 wt % cement, 15.0 wt % salt and 29.2 wt % water. The concrete/salt slurry is then pumped from the batch concrete plant to the disposal site for placement. The concrete/salt mixture will be placed in trenches approximately 20' wide x 25' deep to a depth of ∿20 feet and then backfilled with a minimum of 5 ft of 10^{-7} cm/s permeability material. As trenches are filled, they will have a minimum of 33 ft of soil overlying the top of the concrete monoliths.

4.5.15 Glass Packaging, Leak Testing, Canister Decontamination, and Interim Storage (J. P. Howell and W. N. Rankin)

4.5.15.1 General

The purpose of this section is to present the process details and technical data bases for the processes designed to prepare quality-assured packages of waste glass for shipment to the on-site interim storage facility. These processes will be performed in three cells. Overall function of each cell is outlined below:

Mechanical Cell A

(1) Weld a plug on the canister

(2) Helium leak check the canister plug

(3) Decontaminate the canister surface

(4) Perform contamination survey of canister surface

Mechanical Cell B

(1) Decontaminate the canister surface

(2) Perform contamination survey of canister surface

Mechanical Cell C

(1) Perform a contamination survey of the exterior surface of the canister

(2) Perform spot electropolishing if the contamination survey dictates

(3) Perform a temperature and radiation profile of the canister

The flowsheets (FS-15, 16, and 17) are shown in Figures 4.15, 4.16, and 4.17. Material balances (MB-15, 16, and 17) are tabulated in Tables 4.16, 4.17, and 4.18. Each canister will contain about 3260 lbs of waste glass.

The flowsheets, described below, were developed to supply a single, quality-assured, storage container using minimum production operations, particularly in the glass melt cell [68]. Canisters are filled with molten glass, and after solidification and cooling to an equilibrium temperature, a plug is welded in place. After helium leak checking to ensure leaktight integrity, the primary canister is decontaminated, surveyed, and transferred to a cleaner cell where further decontamination can be done as necessary. After decontamination in Cell A and Cell B, the canister is transferred to the final Cell C where radiation and temperature profiles are recorded for the individual canister. The canister under goes a final smear test for contamination and can be further spot decontaminated as required before shipment to the interim storage facility.

The estimated probable transferable contamination levels, in dis/min/dm^2, assumed possible to be maintained in the production facility, will be about 10^7 in the spray dryer/melter area, 10^5 in "A" cell, 10^2 in "B" cell, and <10 in "C" cell.

The SRP Equipment Engineering Department (EED) is developing the required resistance welding methods, repair welding techniques, helium leak test techniques, and ultrasonic inspection techniques which may, but is not at this time, an absolute requirement. These requirements are all related to primary canister closure and integerity. This development program is leading toward full-scale demonstration of these processes at the TNX-Container Development Facility. This facility has been approved and construction should begin in early 1980.

4.5.15.2 Process Description

4.5.15.2.1 Mechanical Cell "A"

General

NDT examination of the glassform structure after cooling may be required on canisters to verify glass analysis and structure. As an aid to process control, canister surface temperatures will be measured before canister welding.

Canister Closure

The reference closure process for the canister is electrical resistance-upset welding. Joint preparation is required prior to welding. These techniques, along with the resistance plug welding techniques are being developed on a laboratory scale welder capable of welding up to 5-in.-diameter plugs into the canister fill opening. A full scale demonstration welder capable of welding up to 8-in.-diameter stainless steel plugs is being designed and fabricated by Newcor, Inc. It is expected to be available in the latter part of 1980.

Process parameter optimization continues on the laboratory welder with stainless steel, low carbon steel, and other oxidation and corrosion resistant alloys. For the 5-in. diameter plug weld, 70,000 lbs of force, at 230,000 amps for 2 seconds are required to make the weld.

Leak Testing

A technique (using helium) is being developed to leak check the remote resistance weld prior to canister decontamination. The maximum allowable leak at the weld is 10^{-7} atm cm^3/sec helium as defined by ANSI Standard N14.5, "Proposed American National Standard Leakage Tests on Packages for Shipment of Radioactive Materials." Tasks are in progress to determine the surface condition, outgassing effect, helium concentration requirements, and helium injection techniques for remote canyon-type leak test facilities.

The 10^{-7} atm-cm^3/sec leak rate criteria is conservative for establishing watertight integrity and for containment of solid particulate radioactive nuclides as they are immobilized by the glass matrix. This has been set as the maximum criteria but will be reduced to a level of 10^{-4} to 10^{-7} atm-cm^3/sec if the higher permissible leak rate can be shown not to release radioactive contamination to the interim storage facility. The same test equipment and techniques will be required for the whole range of sensitivity levels.

A fusible plug concept has been selected as the reference concept for helium injection into the seal canister. In this concept a pressurized helium reservoir is sealed with a low melting point alloy. The reservoir is attached to the closure plug which is subsequently welded into the canister fill opening. At the desired time a resistance heater is applied to the top of the closure plug and the heat is transferred to the reservoir fusible plug. When the fusible plug reaches its melting point, (which can range from 360°F to 600°F depending on the alloy) melting takes place and the plug is blown out by the pressurized helium. Vibration as well as acoustical monitors can be used to verify helium injection.

Canister Decontamination

The exterior surfaces of canisters will be decontaminated to minimize transfer of particulate contamination from cell "A" to cell "B" by producing a DF of $>10^3$ of the transferable surface contamination (alpha, beta, or gamma). The contamination level in "A" cell is assumed to be maintained at about 10^5 dis/min/dm^2 alpha and 10^6 d/m/dm^2 beta-gamma. During filling and cooling, canister exterior surfaces will reach a maximum temperature of approximately 600°C. A #2B surface finish (ASTM-A-480-75) is specified for the outside surface of the as-fabricated canister to ensure that a uniform oxide film will form when the canister is being filled with glass. This specification is necessary to ensure consistency in decontaminating the finished waste form. The oxide films pro duced will be removed, along with included particulate contamination, in a HNO_3-NaF etch solution with a temperature-controlled recirculating solution system. After canisters are rinsed, they will be cleaned in an oxalic acid solution, also with a temperature-controlled recirculating solution system, to remove additional surface contamination. After the final rinse, canisters will air-dry by self-heat and surveyed before transfer to Mechanical Cell "B." Process solutions for decontamination in Mechanical Cell "A" will come from Mechanical Cell "B," a cleaner cell, where they were used previously.

Oxalic Acid Digestion

Spent oxalic acid must be digested prior to neutralization to avoid accumulation of $Na_2C_2O_4$ between the washing and the settling/filtration modules. The spent oxalic acid is digested in 1M HNO_3-0.01M Mn^+ solution. Digestion liquor is combined with the spent etching solution and neutralized with 10% excess 50 wt % NaOH. The neutralized spent cleaning solutions are transferred to the recycle collection tank along with canister water rinses.

4.5.15.2.2 Mechanical Cell "B"

General

The second of the two-step canister decontamination proesses are carried out in Mechanical Cell "B". The decontamination equipment in this cell will be identical to that in Cell "A," but the overall contamination level will be lower in Cell "B" which should permit a lower level of canister decontamination prior to shipment to Cell "C."

Final Canister Decontamination

The exterior surfaces of canisters will be decontaminated of transferable radioactive particulates to a level acceptable for transfer to cell "C" and final product qualification. The system will be similar to that described for Mechanica Cell "A" and produce a similar DF of 10^3. Process solutions from final canister decontamination in Mechanical Cell "B" will be transferred to Mechanical Cell "A" where they will be used again. The transferrable contamination level in "C" cell is assumed to be maintained at less than 10 d/min/dm^2 alpha and 10^2 dis/min/dm^2 beta-gamma.

4.5.15.2.3 Mechanical Cell "C"

Smear, Radiation, and Temperature Measurements

The exterior surfaces of the canister will be dry smeared, and temperature and radiation profiles of the waste form will be measured in "C" cell to qualify the product canister and contents prior to interim storage on plant. Contamination levels on equipment surfaces in "C" cell should be maintained a at less than 10 dis/min/dm^2 alpha and less than 100 dis/min/dm^2 beta-gamma.

Limits for surface contamination of the canister are <220 d/min/dm^2 alpha and <2200 d/min/dm^2 beta-gamma. These maximum limits are based on U.S. Department of Transportation specifications for maximum smearable contamination for air, rails, highway, and water shipment [71]. This specification is the same that is presently required for off plant shipment of material from SRP [72]. This was established as the maximum limits for SRP interim storage criteria because if this could be met, there was an excellent chance that the contamination level of the interim storage facility would not become a problem in future years of storage. Any greater levels of surface contamination could lead to interim storage contamination with the large numbers of canisters involved and require more expensive interim storage ventilation and filtration systems.

Interim Storage

Reference design storage canisters, filled with waste glass, will be placed in retrievable surface storage at SRP. Outside air will flow by natural convection through the building to remove decay heat. In the event surveillance systems (airborne radioactivity detectors) indicate airborne radioactivity, a forced ventilation system must come online to route the ventilation through a bank of HEPA filters.

4.6 REFERENCES

1a. Letter, L. F. Landon to W. J. Mottel. Defense Waste Processing Facility - Spray Dryer/Melter/Off-Gas System - Revised Basic Data (May 8, 1979).

1b. Letter, R. W. Sylvester to A. M. Eisenberg. Defense Waste Processing Facilities - Calciner and Melter Gas Compositions (April 10, 1979).

1c. Letter, R. W. Sylvester to A. M. Eisenberg. Defense Waste Processing Facilities and Melter Gas Compositions - Supplement 1 (April 18, 1979).

1d. Deleted

2. Deleted

3. A. S. Russell, J. D. Edwards, and C. S. Taylor. Solubility and Density of Hydrated Aluminas in NAOH Solutions. J. Metals, 1123 (1955).

4. Deleted

5. A. J. Hill, et al. Description of Aged Savannah River Plant Waste. Internal Report DPST-77-425, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (August 1977).

6. H. L. Hull. Trip Report - Battelle-Pacific Northwest Laboratories - Spray Calciner Feasibility Test. Internal Report DPST-77-402, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (July 27, 1977).

7. M. J. Plodinec. Viscosity of Glass Melts. Internal Report DPST-77-409, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (July 27, 1977).

8. G. S. Fulcher. "Analysis of Recent Measurements of Glass Viscosity - I, II." J. Am. Ceram. Soc. 8, 339, 789 (1925).

9. R. B. Bird, W. E. Stewart, and E. N. Lightfoot. Transport Phenomena. J. Wiley and Sons, New York, 1960, p. 3-15.

10. J. Stonek, J. Sasek, and H. Merssnerova. Proceedings of the 8th Conference on the Silicate Industry, 1965, 554-578.

11. J. R. Wiley. Electrical Resistivity of Glass Melts. Internal Report DPST-77-239, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (May 23, 1977).

12. I. Peyches. "The Principles Underlying the Electric Melting of Glass." J. Soc. Glass Tech. 32, 399 (1948).

13. E. V. Borel. "Practical Aspects to the Electric Melting of Glass." J. Soc. Glass Tech. 34, 248 (1950).

14. J. Horowitz. "Electrical Glass Melting." Glass Industry 34, 65-9, 98, 132-7, 160, 203-8, 226 (1953).

15. F. V. Tooley and R. L. Tiede. "Factors Affecting the Degree of Homogeneity of Glass." J. Am. Ceram. Soc. 27, 42 (1944).

16. F. V. Tooley and R. L. Tiede. "Effect of Temperature on Homogenizing Rate of Soda-Lime-Silica Glass." J. Am. Ceram. Soc. 28, 42 (1945).

17. F. V. Tooley and R. L. Tiede. "Influence of Batch-Mixing Time and Grain Size on Homogeneity of a Soda-Lime-Silica Glass." J. Am. Ceram. Soc. 29, 197 (1946).

18. R. F. Bradley, T. A. Willis, M. J. Plodinec, J. K. Brown, and H. K. Bethmann. Trip Report - Corning Glass Works, January 19, 1976. Internal Report DPST-77-228, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (January 27, 1977).

19. T. A. Willis, H. L. Hull, R. F. Bradley, M. J. Plodinec, and G. G. Wicks. Trip Report - Owens Corning Technical Center, May 25, 1977. Internal Report DPST-77-362, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (July 5, 1977).

20. M. J. Plodinec. Small-Scale Electric Melter, II-Slag Formation. Internal Report DPST-78-453, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (August 3, 1978).

21. M. J. Plodinec. Small-Scale Electric, I-Foaming of Glass Melts. Internal Report DPST-78-384, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (June 12, 1978).

22. P. A. M. Gell. "Electric Melting for Large Tonnage Furnaces." The Glass Industry (March-April 1973).

23. Deleted.

24. J. A. Stone. Separation of SRP Waste Sludge and Supernate. USERDA Report DP-1441, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

25. J. R. Wiley. Decontamination of Savannah River Plant Waste Supernate. USERDA Report DP-1436, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

26. I. M. Kolthoff and E. B. Sandell. Textbook of Quantitative Inorganic Analysis. 3rd Ed., McMillan, New York (1952).

27. Savannah River Laboratory Quarterly Report, Waste Management, April-June 1977. USERDA Report DPST-77-125-2, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1977).

28. Kirk-Othmer. Encyclopedia of Chemical Technology. 2nd Ed., Vol. 22, Interscience Publisher, NY (1970).

29. P. Loganathan and W. J. Maier. "Some Surface Chemical Aspects in Turbidity Removal by Sand Filtration." J. Am. Water Works Assoc. 67, 336 (1975).

30. G. D. Jones, R. E. Friedrich, and D. C. MacWilliams. Factors in Flocculation Mechanism. Paper B6683B presented at Meeting of American Institute of Chemical Engineers, New Orleans, LA (February 1961).

31. J. W. Langhaar and H. W. Bellas. Water Purification in Feed Storage Basin. Internal Report DPSPU-70-30-2, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (February 1971).

32. I. M. Abrams. "Countercurrent Ion Exchange with Fixed Beds." Industrial Water Engineering 10, 18-26 (1973).

33. I. M. Abrams and L. Benezra. "Ion Exchange Polymers." In Encyclopedia of Polymer Science and Technology, Vol. 7, p. 704, Wiley, 1967.

34. J. R. Wiley. Supernate Decontamination. Internal Report DPST-77-423, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (August 19, 1977).

35. J. R. Wiley and R. M. Wallace. Removal of Cesium from Savannah River Plant Waste Supernate. USERDA Report DP-1388, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

36. J. R. Wiley. Decontamination of Savannah River Plant Waste Supernate. USERDA Report DP-1436, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

37. J. R. Wiley. A Study of Methods for Removing Strontium, Plutonium, and Ruthenium from Savannah River Plant Waste Supernate. USERDA Report DP-1408, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

38. Savannah River Laboratory Quarterly Report: Waste Management, July-September 1975. USERDA Report DPST-75-125-3, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

39. Savannah River Laboratory Quarterly Report: Waste Management, January-March 1976. USERDA Report DPST-76-125-1, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

40. B Plant Recovery of Cesium from Purex Supernatant. USAEC Report ARH-1639, Atlantic Richfield Hanford Co., Richland, WA (1970).

41. Waste Management Technical Manual ISO-100. Atlantic Richfield Hanford Co., Richland, WA.

42. *Savannah River Laboratory Quarterly Report: Waste Management, April-June 1975.* USERDA Report DPST-75-125-2, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

43. Technical Bulletin for *Dowex* A-1. Dow Chemical Company, Midland, MI.

44. W. W. Schulz and J. S. Buckingham, Atlantic Richfield Hanford Co. Unpublished progress reports and personal communications.

45. J. R. Wiley. *Removal of ^{90}Sr from Defense Waste Supernate: Alternate Sorbent and Elution Methods.* Internal Report DPST-78-318, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1978).

46. J. R. Wiley. *A Study of Methods for Removing Strontium, Plutonium, and Ruthenium from Savannah River Plant Waste Supernate.* USERDA Report DP-1408, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

47. *Amberlite Ion Exchange Resins - Amberlite XE-318.* Rohm & Haas Company Leaklet #IE-217-76, Rohm & Haas Company, Philadelphia, PA (1975).

48. *Amberlite XE-318 - Preliminary Technical Information. Rohm & Haas Company, Philadelphia, PA (1975).*

49. G. C. Rodrigues (data to be published).

50. *Savannah River Laboratory Quarterly Report: Waste Management, April-June 1975.* USERDA Report DPST-75-125-2, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

51. F. Helfferich. *Ion Exchange.* McGraw-Hill Book Company, Inc., p 11, New York (1962).

52. R. Dobson. Sales Engineer, Linde Molecular Sieve Products, Union Carbide Corporation (personal communication).

53. J. C. Buckingham. *Laboratory Evaluation of Zeolite Material for Removing Radioactive Cesium from Alkaline Waste Solutions.* USAEC Report ARH-SA 49, Atlantic Richfield Hanford Co., Richland, WA (1970).

54. *Linde Ionsiv* IE-95 Ion Exchanger. *Linde Molecular Sieves Ion Exchange Bulletin*, Union Carbide Corporation.

55. G. C. Rodrigues (data to be published).

56. J. D. Sherman. *Ion Exchange Separations with Molecular Sieves; Linde Molecular Sieves Ion Exchange Bulletin*, Union Carbide Corporation (1977).

57. L. L. Ames and K. C. Knoll. *Loading and Elution Characteristics of Some Natural and Synthetic Zeolites*. USAEC Report HW-74609, p 18, Figure 4. General Electric Company, Hanford Atomic Products, Richland, WA (August 1962).

58. D. W. Breck. *Ion Exchange Reactions in Zeolite, Linde Molecular Sieves Ion Exchange Bulletin*, Union Carbide Corp.

59. J. R. Wiley and R. M. Wallace. *Removal of Cesium from Savannah River Plant Waste Supernate*. USERDA Report DP-1388, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1975).

60. J. R. Wiley. *Decontamination of Savannah River Plant Waste Supernate*. USERDA Report DP-1436, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

61. J. R. Wiley. *A Study of Methods for Removing Strontium, Plutonium, and Ruthenium from Savannah River Plant Waste Supernate*. USERDA Report DP-1408, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1976).

62. J. S. Buckingham. *Waste Management Technical Manual*. USAEC Report ISO-100, Isochem, Inc., Richland, WA (1967).

63. J. S. Buckingham. Personal communication. Rockwell Hanford Operations (January 1979).

64. R. F. Carlstrom. *Ion Exchange Flowsheet for Recovery of Cesium from Purex Sludge Supernate at B Plant*. USERDA Report ARH-F-106, Atlantic Richfield Hanford Co., Richland, WA (April 29, 1977).

65. C. B. Goodlett. *Concentration of Radioactive Wastes*. USAEC Report DP-1135, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1968).

66. C. B. Goodlett. *Transfer of Radioactive Slurries*. USAEC Report DP-1136, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (1968).

67. Tank Farm Evaporator Experience. Internal Memorandum, B. S. Johnson to H. K. Bethmann, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (March 8, 1977).

68. Canister Processing Flowsheet, Defense Waste Solidification Program. Internal Memorandum, J. P. Faraci to R. T. Huntoon, Internal Report DPST-77-405, E. I. du Pont de Nemours & Co. (Inc.), Savannah River Laboratory, Aiken, SC (August 1, 1977).

69. Defense Waste Solidification Program, Conceptual Designs of Mechanical Cell Equipment. Memorandum, SRP-EED to R. T. Huntoon (October 24, 1977).

70. G. L. Richardson. Evaporation of Cesium Ion Exchange Eluate and Recovery of Ammonium Carbonate; Pilot Plant Studies. USAEC Report BNWL-CC-2084, Battelle-Northwest, Richland, WA (May 15, 1969).

71. R. M. Grazrano's Tariff No. 32, Supplement 2, "Hazardous Materials Regulations of the Department of Transportation." Section 173.397(a), p 203 (June 1, 1979).

72. Deleted

TABLE 4.1

Defense Waste Processing Facility Material Balance and Flowsheet Identification

	Flowsheet		Material Balance	
	Ident.	Figure No.	Ident.	Table No.
Sludge and Supernate Feed Preparation	FS-2	4.2	MB-2	4.2
Aluminum Dissolution	FS-3	4.3	MB-3	4.3
Sludge Washing	FS-4	4.4	MB-4	4.4
Spray Drying/Vitrification	FS-5	4.5	MB-5	4.5
Off-Gas Treatment	FS-6	4.6	MB-6	4.6
Mercury Recovery	FS-6A	4.6A	MB-6A*	4.6A*
Recycle Evaporation	FS-7	4.7	MB-7	4.7
Settling and Filtration	FS-8	4.8	MB-8	4.8
Cesium Ion Exchange	FS-9	4.9	MB-9	4.9
Strontium Ion Exchange	FS-10	4.10	MB-10	4.10
Cesium Elutriant Recovery and Cesium Concentration	FS-11	4.11	MB-11	4.11
Cesium Fixation on Zeolite	FS-12	4.12	MB-12	4.12
General Purpose Evaporation	FS-13	4.13	MB-13	4.13
Product Salt Solution Concentration and Solidification in Concrete	FS-14	4.14	MB-14	4.14
Mechanical Cell "A"	FS-15	4.15	MB-15	4.15
Mechanical Cell "B"	FS-16	4.16	MB-16	4.16
Mechanical Cell "C"	FS-17	4.17	MB-17	4.17

---

* To be issued.

TABLE 4.2
SLUDGE AND SUPERNATE PREPARATION (MB-2)

		1	2	3	4	5	6	7	8
	PROCESS MATERIAL	H2O FLUSH	SLUDGE SLURRY	LINE FLUSH	SLUDGE FEED	WATER	DECON SOLN	DISS SALT	SALT FEED
A *	FLOW, LBS./HOUR - AVE.	433	1036	130	1166.	4126		6858	6858.
B *	FLOW, LBS./HOUR - MAX.								
C *	FLOW, GPM - AVE.	0.864		0.259	2.02	8.23		11.1	11.1
D *	FLOW, GPM - MAX.								
E *	FLOW, CFM - AVE.								
F *	FLOW, CFM - MAX.								
G *	OPERATING TEMPERATURE, DEGREES C				38.0				38.0
H *	OPERATING PRESSURE, PSIG. OR HG AB				4.99				4.99
*	AVERAGE STREAM PHYSICAL PROPERTIES								
J *	SPECIFIC GRAVITY				1.14				1.22
K *	DENSITY, LBS./CU. FT., OPER. COND.				71.6				76.6
L *	VISCOSITY, CENTIPOISE, OPER. COND.								
M *	SPEC. HT., PCU/LB-C, OPER. COND.				.638				.784
N *	NORMAL BOILING POINT, DEGREES C				100.				102.
O *	FREEZING POINT, DEGREES C								
P *	FLASH POINT, DEGREES C								
Q *	LATENT HEAT, PCU/LB OPER. COND.				475.				443.
R *	AVE. MOLECULAR WEIGHT				21.6				23.1
*	COMPOSITION, LB./HR. - AVE. FLOW								
1*	H2O	433	789	130	918.	4126	206	4882	4882.
2*	NANO3				65.7				926.
3*	NANO2				26.6				355.
4*	NAALO2				14.4				191.
5*	NAOH				10.5				143.
6*	NA2CO3				11.1				148.
7*	NA2SO4				14.9				199.
8*	OSALT				.570[a]				10.0[c]
9*	EDTNAA								
	TOTAL SALTS		144		144		19.7	1975	1975
10*	FEOH3				39.6				.500
11*	ALOH3				35.4				.450
12*	MNO2				8.15				.100
13*	UO2OH2				2.99				.0490
14*	NIOH2				4.54				.0680
15*	CACO3				3.92				.0499
16*	HGOH2				1.24				.0200
17*	HGI2				.390				
18*	OSOLID				6.70[b]				.0800[d]
19*	ZEOLTE								
20*	SIO2								
	TOTAL SOLIDS		103		103			1.3	1.3

a. NaCl - 0.45
NaF - 0.029
Na[HgO(OH)] - 0.090

b. Na_2O - 1.87
$NaNO_3$ - 1.10
Na_2SO_4 - 0.595
NaCl - 1.19
NaF - 0.125
C - 1.27
SiO_2 - 0.544

c. $Na_2C_2O_4$ - 2.42
NaCl - 6.00
NaF - 0.392
Na[HgO(OH)] - 1.20

d. Na_2O - 0.0213
$NaNO_3$ - 0.0126
Na_2SO_4 - 0.0068
NaCl - 0.0136
NaF - 0.00142
C - 0.0145
SiO_2 - 0.00622
HgI_2 - 0.00346

TABLE 4.3
ALUMINUM DISSOLUTION (MB-3)

	PROCESS MATERIAL	1 SLUDGE FEED	2 DSLVER FEED	3 50% CAUSTC	4 MAKEUP WATER	5 DSLVER VAPOR	6 GRVSET BOTTMS	7 WASTE SAND	8 BOTTMS TRNSFR	9 SLG RE TK VNT	10 DSLVER CNDSTE	11 CNDNSR VENT	12 CNDSTE TK VNT
A *	FLOW, LBS./HOUR - AVE.	1166.	1166.	582.	111.	594.	719.	19.7	2599.	247.2[a]		247.2	247.2
B *	FLOW, LBS./HOUR - MAX.												
C *	FLOW, GPM - AVE.	2.02	2.02	.800	.225		1.14	.0364	4.24				
D *	FLOW, GPM - MAX.												
E *	FLOW, CFM - AVE.					269.				58.5		58.5	58.5
F *	FLOW, CFM - MAX.												
G *	OPERATING TEMPERATURE, DEGREES C	38.0	38.0	39.0	39.5	100.	38.0	38.0	38.0	35.0			35.0
H *	OPERATING PRESSURE, PSIG, OR HG AB	4.99	4.99	4.99	4.99	.00000	4.99	4.99	4.99				
*	AVERAGE STREAM PHYSICAL PROPERTIES												
J *	SPECIFIC GRAVITY	1.14	1.14	1.45	.988	.456	1.25	1.07	1.22				
K *	DENSITY, LBS./CU. FT., OPER. COND.	71.6	71.6	90.6	61.7	.0368	78.0	67.4	76.3				
L *	VISCOSITY, CENTIPOISE, OPER. COND.												
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.836	.839	.656	.998	.481	.770	.876	.789				
N *	NORMAL BOILING POINT, DEGREES C	110.	110.	117.	100.	100.	102.	100.	103.				
O *	FREEZING POINT, DEGREES C												
P *	FLASH POINT, DEGREES C												
Q *	LATENT HEAT, PCU/LB OPER. COND.	475.	475.	413.	570.	539.	436.	508.	455.				
R *	AVE. MOLECULAR WEIGHT	21.6	21.6	24.8	18.0	18.0	23.5	20.1	22.5				
*	COMPOSITION, LB./HR. - AVE. FLOW												
1*	H2O	918.	918.	291.	111.	594.	495.	16.6	1846.				
2*	NANO3	65.7	65.7				88.3		154.				
3*	NANO2	26.6	26.6				31.5		59.2				
4*	NAALO2	14.4	14.4				19.3		61.7				
5*	NAOH	10.5	10.5	291.			40.4	.654	329.				
6*	NA2CO3	11.1	11.1				13.9		25.1				
7*	NA2SO4	14.9	14.9				17.7		32.6				
8*	OSALT	.570	.570				1.03		1.60				
9*	EDTNAA				TRACE[b]		.00002		.00002				
10*	FEOH3	39.6	39.6				3.28		42.9				
11*	ALOH3	35.4	35.4				1.03		9.89				
12*	MNO2	8.15	8.15				1.05		9.20				
13*	UO2OH2	2.99	2.99				.229		3.21				
14*	NIOH2	4.54	4.54				.347		4.89				
15*	CACO3	3.92	3.92				.297		4.21				
16*	HGOH2	1.24	1.24				.284		1.52				
17*	HGI2	.390	.390				3.88		4.27				
18*	OSOLID	6.70	6.70				1.05	.447	8.20				
19*	ZEOLTE												
20*	SIO2						.125	2.00	2.13				

[a] 73.74 wt % N_2, 22.61 wt % O_2, 1.26 wt % A, 0.0489 wt % CO_2, 2.34 wt % H_2O (This distribution holds for all process vessel vents except those on MB-9 and MB-11 that vent to the cesium vent scrubber).

[b] $< 10^{-5}$ lb/hr.

TABLE 4.4
SLUDGE WASHING (MB-4)

	PROCESS MATERIAL	1 BOTTMS TRNSFR	2 SLURRY TOWASH	3 CNTFGE FEED	4 CNTRTE	5 FIRST SKIM	6 FIRST SPRAY	7 CAKE + SPRAY	8 FIRST WASH	9 FIRST WASH	10 CNTFGE FEED	11 CNTRTE
A *	FLOW, LBS./HOUR - AVE.	2599.	2599.	2599.	2104.	43.9	168.	619.	1481.	1481.	2100.	1672.
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	4.24	4.24	4.24	3.50	.0732	.340	1.00	2.99	2.99	3.99	3.26
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.											
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	38.0	38.0	38.0	38.0	38.0	38.0	38.0	39.5	39.5	38.0	38.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99	4.99	4.99	.00000	.00000	500.	.00000	4.99	4.99	4.99	.00000
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	1.22	1.22	1.22	1.19	1.19	.989	1.22	.989	.988	1.04	1.02
K *	DENSITY, LBS./CU. FT., OPER. COND.	76.3	75.3	76.3	74.8	74.8	61.7	76.5	61.7	61.7	65.5	63.8
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.789	.789	.799	.809	.810	.998	.777	.998	.998	.933	.964
N *	NORMAL BOILING POINT, DEGREES C	103.	103.	103.	103.	103.	100.	101.	100.	100.	100.	100.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	455.	455.	455.	458.	469.	544.	444.	570.	570.	533.	552.
R *	AVE. MOLECULAR WEIGHT	22.5	22.5	22.5	21.9	21.8	18.0	23.1	18.0	18.0	19.2	18.6
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	1846.	1846.	1846.	1547.	32.3	168.	435.	1481.	1481.	1916.	1591.
2*	NANO3	154.	154.	154.	129.	2.70		22.2			22.2	18.4
3*	NANO2	58.2	58.2	58.2	48.9	1.02		8.39			8.39	6.97
4*	NAALO2	61.7	61.7	61.7	51.7	1.08		8.89			9.89	7.38
5*	NAOH	329.	329.	329.	275.	5.76		47.4			47.4	39.3
6*	NA2CO3	25.1	25.1	25.1	21.0	.440		3.61			3.61	3.00
7*	NA2SO4	32.6	32.6	32.6	27.4	.573		4.71			4.71	3.91
8*	OSALT	1.60	1.60	1.60	1.34	.0291		.231			.231	.192
9*	EDTNAA	.00002	.00002	.00002	.00002	TRACE		TRACE	.00005	.00005	.00005	.00004
10*	FEOH3	42.9	42.9	42.9	.859			42.1			42.1	.842
11*	ALOH3	9.89	9.89	9.89	.197			9.70			9.70	.194
12*	MNO2	9.20	9.20	9.20	.184			9.01			9.01	.180
13*	UO2OH2	3.21	3.21	3.21	.0643			3.15			3.15	.0630
14*	NIOH2	4.88	4.88	4.88	.0977			4.78			4.78	.0957
15*	CACO3	4.21	4.21	4.21	.0843			4.13			4.13	.0826
16*	HGOH2	1.52	1.52	1.52	.0304			1.49			1.49	.0298
17*	HGI2	4.27	4.27	4.27	.0855			4.19			4.19	.0838
18*	OSOLID	8.20	8.20	8.20	.164			8.04			8.04	.160
19*	ZEOLITE											
20*	SIO2	2.13	2.13	2.13	.0426			2.09			2.09	.0418

TABLE 4.4 CONT'D

	SLUDGE WASHING (MB-4)	12	13	14	15	16	17	18	19	20	21	22	23	24
	PROCESS MATERIAL	SECOND SKIM	SECOND SPRAY	CAKE + SPRAY	SECOND WASH	SECOND WASH	CNTFGE FEED	CNTRTE	THIRD SKIM	THIRD SPRAY	CAKE + SPRAY	WASHED SLUDGE	SLURRY TRNSFR	CNTRTE TRNSFR
A	FLOW, LB/HR - AVE	67.4	168.	529.	1481.	1481.	2011.	1591.	77.4	169.	511.	511.	511.	5557.
B	FLOW, LB/HR - MAX													
C	FLOW, GPM - AVE	.131	.340	.939	2.99	2.99	3.92	3.19	.155	.340	.920	.920	.920	10.3
D	FLOW, GPM - MAX													
E	FLOW, CFM - AVE													
F	FLOW, CFM - MAX													
G	OPER TEMP, DEGREE C	38.0	38.0	38.0	39.5	39.5	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
H	OPER PRES, PSIG,HGAB	.00000	500.	.00000	4.99	4.99	4.99	.00000	.00000	500.	.00000	4.99	4.99	4.99
	PHYSICAL PROPERTIES													
J	SPECIFIC GRAVITY	1.02	.989	1.12	.988	.986	1.02	.994	.994	.989	1.10	1.10	1.10	1.07
K	DENSITY, LB/CU FT	63.7	61.7	70.2	61.7	61.7	63.8	62.0	62.0	61.7	69.2	69.2	69.2	67.0
L	VISC. CP													
M	SPEC. HT, PCU/LB-C	.964	.998	.854	.998	.996	.960	.993	.993	.998	.867	.867	.867	.913
N	BOIL PT, DEGREE C	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	101.
O	FREEZE PT, DEGREE C													
P	FLASH PT, DEGREE C													
Q	LAT. HT. PCU/LB	553.	544.	484.	570.	570.	548.	569.	568.	544.	491.	491.	491.	524.
R	AVE. MOLE. WT.	18.6	18.0	21.2	18.0	18.0	18.7	18.1	18.0	16.0	20.9	20.9	20.9	19.5
	COMP, LB/HR-AVE FLOW													
1	H2O	64.2	168.	429.	1481.	1481.	1911.	1578.	76.9	168.	424.	424.	424.	4891.
2	NANO3	.744		3.02			3.02	2.49	.121		.404	.404	.404	153.
3	NANO2	.281		1.14			1.14	.944	.0467		.152	.152	.152	58.0
4	NAALO2	.298		1.21			1.21	1.00	.0467		.162	.162	.162	61.5
5	NAOH	1.59		6.45			6.45	5.33	.259		.863	.863	.863	328.
6	NA2CO3	.121		.492			.492	.406	.0198		.0659	.0659	.0659	25.0
7	NA2SO4	.158		.641			.641	.530	.0258		.0858	.0858	.0858	32.6
8	OSALT	.00777		.0315			.0315	.0260	.00127		.00422	.00422	.00422	1.60
9	EDTNAA	TRACE		TRACE	.00005	.00005	.00006	.00005	TRACE		TRACE	TRACE	TRACE	.00012
10	FEOH3			41.2			41.2	.825			40.4	40.4	40.4	2.52
11	ALOH3			9.50			9.50	.190			9.31	9.31	9.31	.582
12	MNO2			8.83			8.87	.176			8.65	8.65	8.65	.541
13	UO2OH2			3.09			3.09	.0618			3.02	3.02	3.02	.189
14	NIOH2			4.69			4.69	.0938			4.59	4.59	4.59	.287
15	CACO3			4.05			4.05	.0810			3.96	3.96	3.96	.248
16	HGOH2			1.46			1.46	.0292			1.43	1.43	1.43	.0896
17	HGI2			4.10			4.10	.0821			4.02	4.02	4.02	.251
18	OSOLID			7.88			7.88	.157			7.72	7.72	7.72	.482
19	ZEOLTE													
20	SIO2			2.04			2.04	.0409			2.00	2.00	2.00	.125

TABLE 4.4 CONT'D

	SLUDGE WASHING (MB-4) =	25	26	27	28	29	30	31
	PROCESS MATERIAL =	CNTRTE TO RF	SLG FD TK VNT	WSH TK VENT	CNTRFG VENT	SLG RN TK VNT	CTK TK VENT	CNT HD TK VNT
A	FLOW, LB/HR - AVE =	5557.	247.2	594.4[a]	594.4[b]	247.2	247.2	247.2
B	FLOW, LB/HR - MAX =							
C	FLOW, GPM - AVE =	10.3						
D	FLOW, GPM - MAX =							
E	FLOW, CFM - AVE =		58.5	117[b]	117[b]	58.5	58.5	58.5
F	FLOW, CFM - MAX =							
G	OPER TEMP, DEGREE C =	38.0	35.0	35.0	35.0	35.0	35.0	35.0
H	OPER PRES, PSIG,HGAB=	4.99						
	PHYSICAL PROPERTIES							
J	SPECIFIC GRAVITY =	1.07						
K	DENSITY, LB/CU FT =	67.0						
L	VISC. CP =							
M	SPEC. HT, PCU/LB-C =	.913						
N	BOIL PT, DEGREE C=	101.						
O	FREEZE PT, DEGREE C=							
P	FLASH PT, DEGREE C=							
Q	LAT. HT. PCU/LB =	524.						
R	AVE. MOLE. WT. =	19.5						
	COMP, LB/HR-AVE FLOW							
1	H2O =	4891.						
2	NANO3 =	153.						
3	NANO2 =	58.0						
4	NAALO2 =	61.5						
5	NAOH =	328.						
6	NA2CO3 =	25.0						
7	NA2SO4 =	32.6						
8	OSALT =	1.60						
9	EDTNAA =	.00012						
10	FEOH3 =	2.52						
11	ALOH3 =	.582						
12	MNO2 =	.541						
13	UO2OH2 =	.189						
14	NIOH2 =	.287						
15	CACO3 =	.248						
16	HGOH2 =	.0896						
17	HGI2 =	.251						
18	OSOLID =	.482						
19	ZEOLTE =							
20	SIO2 =	.125						

---

[a] Two wash tanks

[b] Two centrifuges.

TABLE 4.5
CALCINATION AND VITRIFICATION (MB-5)

	PROCESS MATERIAL	1 SRCCNC BOTTMS	2 WASTE ZEOLTE	3 SLURRY TRNSFR	4 SLURRY TO HLD	5 CAL TK FEED	6 CAL FD TK DIS	7 CAL FD TK RY	8 CALCIN ER FED
A *	FLOW, LBS./HOUR - AVE.	24.3	20.4	511.	556.	556.	22974.	22417.	556.
B *	FLOW, LBS./HOUR - MAX.								
C *	FLOW, GPM - AVE.	.0414	.0309	.928	.992	.992	40.9	40.0	.992
D *	FLOW, GPM - MAX.								
E *	FLOW, CFM - AVE.								
F *	FLOW, CFM - MAX.								
G *	OPERATING TEMPERATURE, DEGREES C	76.0	39.0	38.0	38.0	38.0	38.0	38.0	38.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99
-*	AVERAGE STREAM PHYSICAL PROPERTIES								
J *	SPECIFIC GRAVITY	1.17	1.32	1.10	1.11	1.11	1.11	1.11	1.11
K *	DENSITY, LBS./CU. FT., OPER. COND.	73.2	82.6	69.2	69.8	69.8	69.8	69.8	69.8
L *	VISCOSITY, CENTIPOISE, OPER. COND.								
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.697	.837	.867	.867	.867	.867	.867	.867
N *	NORMAL BOILING POINT, DEGREES C	100.	100.	100.	100.	100.	100.	100.	100.
O *	FREEZING POINT, DEGREES C								
P *	FLASH POINT, DEGREES C								
Q *	LATENT HEAT, PCU/LB OPER. COND.	459.	389.	491.	486.	486.	486.	486.	486.
R *	AVE. MOLECULAR WEIGHT	22.2	26.2	20.9	21.1	21.1	21.1	21.1	21.1
*	COMPOSITION, LB./HR. - AVE. FLOW								
1*	H2O	19.4	13.8	424.	457.	457.	18906.	18448.	457.
2*	NANO3			.404	.404	.404	16.7	16.3	.404
3*	NANO2			.152	.152	.152	6.31	6.16	.152
4*	NAALO2			.162	.162	.162	6.69	6.52	.162
5*	NAOH	.0492		.863	.913	.913	37.7	36.7	.913
6*	NA2CO3			.0659	.0659	.0659	2.72	2.65	.0659
7*	NA2SO4			.0858	.0858	.0858	3.54	3.45	.0858
8*	OSALT			.00422	.00422	.00422	.174	.170	.00422
9*	EDTNAA	4.87		TRACE	4.87	4.87	201.	196.	4.87
10*	FEOH3			40.4	40.4	40.4	1670.	1629.	40.4
11*	ALOH3			9.31	9.31	9.31	384.	375.	9.31
12*	MNO2			8.65	8.65	8.65	357.	348.	8.65
13*	UO2OH2			3.02	3.02	3.02	125.	122.	3.02
14*	NIOH2			4.59	4.59	4.59	189.	185.	4.59
15*	CACO3			3.96	3.96	3.96	163.	159.	3.96
16*	HGOH2			1.43	1.43	1.43	59.2	57.7	1.43
17*	HGI2			4.02	4.02	4.02	166.	162.	4.02
18*	OSOLID			7.72	7.72	7.72	318.	311.	7.72
19*	ZEOLTE		6.63		6.63	6.63	273.	267.	6.63
20*	SIO2			2.00	2.00	2.00	82.9	80.9	2.00

TABLE 4.5 CONT'D
CALCINATION AND VITRIFICATION (MB-5)

	PROCESS MATERIAL	9	10	11	12	13	14	15	16	17	18
		ATOMIZING AIR	BLOWBACK AIR	FRIT	AIR IN LEAK	E-V GAS FEED	WASTE GLASS	CANIS-TERS	SL MIX TK VNT	SL HLD TK VNT	CAL FD TK VNT
A *	FLOW, LBS./HOUR - AVE.	238.	6.85	183.	20.0	748.	255.	1.877[a]	247.2	247.2	594.4[b]
B *	FLOW, LBS./HOUR - MAX.										
C *	FLOW, GPM - AVE.										
D *	FLOW, GPM - MAX.										
E *	FLOW, CFM - AVE.	12.8	.739		4.52	518.			58.5	58.5	117
F *	FLOW, CFM - MAX.										
G *	OPERATING TEMPERATURE, DEGREES C	40.0	300.	35.0	25.0	344.	1050.		35.0	35.0	35.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	50.2	47.0	.00000	.00000	HG703.	.00000				
*	AVERAGE STREAM PHYSICAL PROPERTIES										
J *	SPECIFIC GRAVITY	3.84	1.99		.912	.297					
K *	DENSITY, LBS./CU. FT., OPER. COND.	.309	.160		.0736	.0240					
L *	VISCOSITY, CENTIPOISE, OPER. COND.	.0184	.0296		.0177	.0251					
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.243	.256	.254	.242	.449	39.6				
N *	NORMAL BOILING POINT, DEGREES C	-195.	-195.		-195.	-183.					
O *	FREEZING POINT, DEGREES C										
P *	FLASH POINT, DEGREES C										
Q *	LATENT HEAT, PCU/LB OPER. COND.	-3.24	-58.2		.0812	231.					
R *	AVE. MOLECULAR WEIGHT	28.8	28.8	59.9	28.8	21.0	70.0				
*	COMPOSITION, LB./HR. - AVE. FLOW										
1*	H2O					473.					
2*	FE2O3					.0302	30.1				
3*	AL2O3					.00608	6.08				
4*	U3O8					.00279	2.79				
5*	NIO					.00370	3.70				
6*	CAO					.00222	2.15				
7*	CO2					7.19					
8*	HG					1.24					
9*	O2	55.1	1.58	.0996	4.64	57.6					
10*	NA2O			32.3		.00249	34.8				
11*	I2					.0224					
12*	NO					.948					
13*	SIO2			105.7		.00200	107.7				
14*	NRSLDS					.0230	23.0				
15*	NRSALT					.00025	.251				
16*	N2	183.	5.26	.329	15.3	203.					
17*	HGI2					3.98					
18*	B2O3			20.8			26.8				
19*	TIO2			1.83			1.83				
20*	LI2O			10.4			10.4				
21*	MgO			3.65			3.65				
22*	ZrO_2			0.913			0.913				
23*	La_2O_3			0.913			0.913				

---

a. Canister per day.
b. Two-feed tank.

TABLE 4.6
OFF-GAS TREATMENT (MB-6)

	PROCESS MATERIAL	1 E-V GAS FEED	2 E-V CLF FD	3 E-V CLD FD	4 OP BED 1 FD	5 OP BED 1 LSP	6 ATMZNG AIR 1	7 OP BED 1 USP	8 OP BED 1 LOD	9 OP BED 2 FDD	10 OP BED 2 LSP	11 ATMZNG AIR 2
A *	FLOW, LBS./HOUR - AVE.	748.	68035.	88035.	288.	994.	48.2	19891.	20886.	335.	1008.	48.9
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.		177.	176.		2.00		40.0	41.9		2.00	
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.	518.			76.6		7.74			90.0		7.84
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	344.	43.9	43.2	43.9	43.9	25.0	43.9	43.9	41.2	10.0	25.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	HG703.	4.99	4.99	HG703.	4.99	6.02	4.99	HG703.	HG692.	5.00	6.02
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	.297	.993	.995	.776	.993	1.28	.993	.993	.769	1.00	1.28
K *	DENSITY, LBS./CU. FT., OPER. COND.	.0240	61.9	62.1	.0626	61.9	.103	61.9	62.0	.0621	62.4	.103
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.449	1.00	1.00	.263	1.00	.242	1.00	1.00	.255	.997	.242
N *	NORMAL BOILING POINT, DEGREES C	-183.	50.3	50.3	-194.	50.3	-194.	50.3	51.2	-194.	20.5	-194.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	231.	562.	564.	32.5	562.	.0772	562.	563.	28.5	593.	.0772
R *	AVE. MOLECULAR WEIGHT	21.0	18.1	18.1	28.1	18.1	28.8	18.1	18.1	28.1	19.0	28.8
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	473.	87191.	87191.	17.6	985.		19700.	20685.	17.9	1004.	
2*	FE2O3	.0302	5.60	5.60	.0120	.0633		1.26	1.34	.00024	.0156	
3*	AL2O3	.00608	1.12	1.12	.00243	.0127		.255	.270	.00034	.00316	
4*	U3O8	.00279	.518	.518	.00111	.00585		.117	.124	.00002	.00145	
5*	NIO	.00370	.686	.686	.00148	.00776		.155	.164	.00002	.00192	
6*	CAO	.00222	.412	.412	.00398	.00465		.0931	.0987	.00001	.00115	
7*	CO2	7.19	31.5	31.5	6.97	.356		7.12	7.41	7.03	.693	
8*	HC	1.24			TRACE				TRACE	TRACE	TRACE	
9*	O2	57.5	25.8	25.6	57.3	.291	11.2	5.83	6.04	68.6	.440	11.3
10*	NA2O	.00246	.461	.461	.00099	.00521		.104	.110	.00031	.00128	
11*	I2	.0224	TRACE	TRACE	.0224	TRACE		TRACE	TRACE	.0224	TRACE	
12*	NO	.949	.0350	.0350	.948	.00039		.00792	.00819	.948	.00071	
13*	SIO2	.00290	.372	.372	.00080	.00420		.0840	.0890	.00001	.00103	
14*	NRSLDS	.0230	4.26	4.26	.00920	.0482		.964	1.02	.00018	.0119	
15*	NRSALT	.00025	.0467	.0467	.00019	.00052		.0105	.0111	TRACE	.00013	
16*	N2	203.	35.7	35.7	293.	.404	37.0	8.08	8.36	240.	.586	37.5
17*	HGI2	3.98	737.	737.	1.59	8.33		166.	176.	.0318	2.05	
18*	B2O3											
19*	TIO2											
20*	LI2O											

TABLE 4.6 CONT'D

OFF-GAS TREATMENT (MB-6) =		12	13	14	15	16	17	18	19	20	21	22	23	24
	PROCESS MATERIAL =	DP BED 2 USP	DP BED 2 LQD	CIRC TK OVRF	MSTAR2 VAPOR	RU BED FEED	RU BED FEED	I2 HTR FEED	I2 BED FEED	I2 CLR FEED	BLOWER FEED	BLOWER EXHAST	CANYON AIR	UNFTRD PVV
A	FLOW, LB/HR - AVE =	20165.	21189.	15.0	320.	369.	359.	369.	369.	369.	369.	369.	1,505,917	14,835
B	FLOW, LB/HR - MAX =													
C	FLOW, GPM - AVE =	40.0	42.0	.0298										
D	FLOW, GPM - MAX =													
E	FLOW, CFM - AVE =				76.8	92.9	92.9	112.	164.	204.	159.	159.	356,400	3,510
F	FLOW, CFM - MAX =													
G	OPER TEMP, DEGREE C =	10.0	10.5	10.0	10.5	20.0	20.0	20.0	150.	149.	50.0	120.	35.0	35.0
H	OPER PRES, PSIG,HGAB=	5.00	HG692.	HG692.	HG681.	HG671.	HG671.	HG556.	HG546.	HG439.	HG430.	.176		
	PHYSICAL PROPERTIES													
J	SPECIFIC GRAVITY =	1.00	1.00	1.00	.860	.820	.820	.679	.462	.372	.477	.699		
K	DENSITY, LB/CU FT =	62.8	62.8	62.8	.0694	.0662	.0662	.0548	.0373	.0300	.0385	.0564		
L	VISC. CP =													
M	SPEC. HT, PCU/LB-C =	.997	.997	.997	.243	.243	.243	.243	.250	.250	.245	.249		
N	BOIL PT, DEGREE C=	20.5	20.5	20.5	-194.	-194.	-194.	-194.	-194.	-194.	-194.	-194.		
O	FREEZE PT, DEGREE C=													
P	FLASH PT, DEGREE C=													
Q	LAT. HT. PCU/LB =	583.	584.	584.	10.1	7.13	7.13	7.14	-23.2	-23.2	.269	-16.3		
R	AVE. MOLE. WT. =	18.0	18.0	18.0	28.9	28.9	28.9	28.8	28.8	28.9	28.8	28.8		
	COMP, LB/HR-AVE FLOW													
1	H2O =	20089.	21108.	15.0	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94		
2	FE2O3 =	.313	.329	.00023		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
3	AL2O3 =	.0632	.0664	.00004		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
4	U3O8 =	.0290	.0305	.00002		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
5	NIO =	.0384	.0404	.00002		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
6	CAO =	.0230	.0242	.00001		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
7	CO2 =	13.8	14.5	.0193	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02		
8	HG =	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
9	O2 =	8.80	9.25	.00657	68.6	80.0	80.0	80.0	80.0	80.0	80.0	80.0		
10	NA2O =	.0257	.0271	.00001		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
11	I2 =	TRACE	TRACE	TRACE		.0224	.0224	.0224	.0224	.00022	.00022	.00022		
12	NO =	.0143	.0151	.00001	.948	.948	.948	.948	.948	.948	.948	.948		
13	SIO2 =	.0207	.0219	.00001		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
14	NRSLDS =	.238	.250	.00017		TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
15	NRSALT =	.00261	.00274	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE		
16	N2 =	11.7	12.3	.00875	240.	278.	278.	278.	278.	278.	278.	278.		
17	HGI2 =	41.0	43.1	.0306		.00063	.00063	.00047	.00047	.00023	.00023	.00023		
18	B2O3 =													
19	TIO2 =													
20	LI2O =													

TABLE 4.6 CONT'D

OFF-GAS TREATMENT (MB-6) =	25	26	27	28	29	30
PROCESS MATERIAL =	FILTRD PVV	STACK AIR	SOLID WASTE	SOLID WASTE	RECVRD HG	OGC TK OVFL
A FLOW, LB/HR - AVE =	14,835	1,521,071	.0059	0.2218	1.24	474.
B FLOW, LB/HR - MAX =						
C FLOW, GPM - AVE =					.00018	.954
D FLOW, GPM - MAX =						
E FLOW, CFM - AVE =	3,510	360,000	1.998-06	7.512-05		
F FLOW, CFM - MAX =						
G OPER TEMP, DEGREE C =	35.0	35.0			43.9	43.9
H OPER PRES, PSIG,HGAB=					4.99	4.99
PHYSICAL PROPERTIES						
J SPECIFIC GRAVITY =					13.3	.993
K DENSITY, LB/CU FT =					834.	61.9
L VISC. CP =						
M SPEC. HT, PCU/LB-C =					.0329	1.00
N BOIL PT, DEGREE C=					360.	50.3
O FREEZE PT, DEGREE C=						
P FLASH PT, DEGREE C=						
Q LAT. HT. PCU/LB =					72.1	562.
R AVE. MOLE. WT. =					200.	18.1
COMP, LB/HR-AVE FLOW						
1 H2O =						473.
2 FE2O3 =						.0302
3 AL2O3 =						.00609
4 U3O8 =						.00279
5 NIO =						.00370
6 CAO =						.00222
7 CO2 =						.169
8 HG =					1.24	
9 O2 =						.139
10 NA2O =						.00248
11 I2 =						TRACE
12 NO =						.00018
13 SIO2 =						.00200
14 NRSLDS =						.0230
15 NRSALT =						.00025
16 N2 =						.193
17 HGI2 =						3.97
18 B2O3 =						
19 TIO2 =						
20 LI2O =						

TABLE 4.6 CONT'D
OFF-GAS TREATMENT (MB-6)

	PROCESS MATERIAL	31 MECH A DEINZR	32 EAST SUMPS	33 LAB WASTE	34 STK+SN COND	35 CNSTER DECON	36 IE TRN WATER	36 IE TRN WATER	38 FM COL TK VNT	39 PE COL TK VNT
A *	FLOW, LBS./HOUR - AVE.	50.0		276.	27.6	844.			1672.	247.2
B *	FLOW, LBS./HOUR - MAX.									
C *	FLOW, GPM - AVE.	.100		.557	.0557	1.59			3.25	
D *	FLOW, GPM - MAX.									
E *	FLOW, CFM - AVE.									
F *	FLOW, CFM - MAX.									58.5
G *	OPERATING TEMPERATURE, DEGREES C	38.0		38.0	38.0	38.0			38.0	35.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99		4.99	4.99	5.00			4.99	
*	AVERAGE STREAM PHYSICAL PROPERTIES									
J *	SPECIFIC GRAVITY	.989		.989	.989	1.05			1.02	
K *	DENSITY, LBS./CU. FT., OPER. COND.	61.7		61.7	61.7	66.0			63.9	
L *	VISCOSITY, CENTIPOISE, OPER. COND.	.706		.706	.706	.721			.719	
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.998		.998	.998	.924			.963	
N *	NORMAL BOILING POINT, DEGREES C	100.		100.	100.	100.			100.	
O *	FREEZING POINT, DEGREES C									
P *	FLASH POINT, DEGREES C									
C *	LATENT HEAT, PCU/LB OPER. COND.	571.		571.	571.	562.			547.	
R *	AVE. MOLECULAR WEIGHT	18.0		19.0	18.0	19.5			19.7	
*	COMPOSITION, LB./HR. - AVE. FLOW									
1*	H2O	50.0		276.	27.6	761.			1585.	
2*	NANO3					77.0			77.0	
3*	NANO2									
4*	NAALO2									
5*	NAOH					3.73			3.73	
6*	NA2CO3									
7*	NA2SO4									
8*	OSALT					1.77			1.77	
9*	EDTNAA									
10*	FEOH3					.257			.257	
11*	ALOH3									
12*	MNO2					.409			.409	
13*	UO2OH2									
14*	NIOH2									
15*	CACO3									
16*	HGOH2									
17*	HGI2								3.97	
18*	OSOLID					.0775			.137	
19*	ZEOLTE									
20*	SIO2									

TABLE 4.7
RECYCLE EVAPORATION (MB-7)

	PROCESS MATERIAL	1 CNTRTE TO RE	2 AL DIS COND	3 SPENT CAUSTC	4 GPE BOTTMS	5 FM MLT CND TK	6 ZEOLTE FLUSH	7 ZEOLTE TRNSFR	8 WEST SUMPS	9 RCEVAP FEED	10 RCEVAP BOTTMS	11 REVAP BOTTMS
A *	FLOW, LBS./HOUR - AVE.	5557.		2115.	1069.	1672.	36.9	31.2		12579.	2281.	2281.
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	10.3		4.32	2.15	3.25	.0745	.0630		24.3	3.86	3.53
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.											
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	38.0		85.0	38.0	38.0	38.0	38.0		38.0	105.	38.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99		4.99	4.99	4.99	4.99	4.99		4.99	.00000	4.99
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	1.07		.977	.989	1.02	.989	.989		1.03	1.17	1.29
K *	DENSITY, LBS./CU. FT., OPER. COND.	67.0		60.9	61.7	63.9	61.7	61.7		64.5	73.5	80.5
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.913		.981	.998	.960	.998	.998		.952	.746	.745
N *	NORMAL BOILING POINT, DEGREES C	101.		100.	99.9	100.	100.	100.		100.	104.	104.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	524.		539.	571.	547.	571.	571.		545.	411.	433.
R *	AVE. MOLECULAR WEIGHT	19.5		18.2	18.0	18.7	18.0	18.0		18.8	23.6	23.6
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	4891.		2063.	1069.	1585.	36.9	31.2		11772.	1475.	1475.
2*	NANO3	153.				77.0				230.	230.	230.
3*	NANO2	58.0								58.0	58.0	58.0
4*	NAALO2	61.5								61.5	61.5	61.5
5*	NAOH	328.		52.5		3.73				384.	384.	384.
6*	NA2CO3	25.0								25.0	25.0	25.0
7*	NA2SO4	32.6								32.6	32.6	32.6
8*	OSALT	1.60				1.77				3.60	3.60	3.60
9*	EDTNAA	.00010			.00028					.00038	.00038	.00038
10*	FEOH3	2.52				.257				2.78	2.78	2.78
11*	ALOH3	.582								.582	.582	.582
12*	MNO2	.541				.409				.950	.950	.950
13*	UO2OH2	.189								.189	.189	.189
14*	NIOH2	.287								.287	.287	.287
15*	CACO3	.248								.248	.248	.248
16*	HGOH2	.0896								.264	.264	.264
17*	HGI2	.251				3.97				3.89	3.89	3.89
18*	OSOLID	.483				.150				.633	.633	.633
19*	ZEOLTE											
20*	SIO2	.125								.125	.125	.125

TABLE 4.7
RECYCLE EVAPORATION (MB-7) (Contd)

	PROCESS MATERIAL	12 RCEVAP CNDSTE	13 CNDSTE TRNSFR	14 CSCONC PURGE	15 EVP FD TK VNT	16 EVP PM TK VNT	17 EVP CN TK VNT	18 CNDNSR TK VNT
A	FLOW, LB/HR - AVE =	10297.	10297.	2096.	247.2	247.2	247.2	247.2
B	FLOW, LB/HR - MAX =							
C	FLOW, GPM - AVE =	20.7	20.7	4.23				
D	FLOW, GPM - MAX =							
E	FLOW, CFM - AVE =				58.5	58.5	58.5	58.5
F	FLOW, CFM - MAX =							
G	OPER TEMP, DEGREE C =	38.0	38.0	38.0	35.0	35.0	35.0	35.0
H	OPER PRES, PSIG,HGAB=	.00000	4.99	4.99				
	PHYSICAL PROPERTIES							
J	SPECIFIC GRAVITY =	.989	.989	.989				
K	DENSITY, LB/CU FT =	61.7	61.7	61.7				
L	VISC. CP =							
M	SPEC. HT, PCU/LB-C =	.998	.998	.998				
N	BOIL PT, DEGREE C=	100.	100.	100.				
O	FREEZE PT, DEGREE C=							
P	FLASH PT, DEGREE C=							
Q	LAT. HT. PCU/LB =	571.	571.	571.				
R	AVE. MOLE. WT. =	18.0	18.0	18.0				
	COMP, LB/HR-AVE FLOW							
1	H2O =	10297.	10297.	2096.				
2	NANO3 =							
3	NANO2 =							
4	NAALO2 =							
5	NAOH =							
6	NA2CO3 =							
7	NA2SO4 =							
8	OSALT =							
9	EDTNAA =	TRACE	TRACE					
10	FEOH3 =							
11	ALOH3 =							
12	MNO2 =							
13	UO2OH2 =							
14	NIOH2 =							
15	CACO3 =							
16	HGOH2 =							
17	HGI2 =							
18	OSOLID =							
19	ZEOLTE =							
20	SIO2 =							

TABLE 4.8
SETTLING AND FILTRATION (MB-8)

PROCESS MATERIAL	1 SALT FEED	2 SALT TRNSFR	3 REVAP BOTTMS	4 GRVSET FEED	5 STARCH SOLN	6 GRVSET BOTTMS	7 GRVSET BOTTMS	8 GRVSET SPNATE	9 SPNATE TRNSFR	10 SFILTR FEED	11 PELECT SOLN
A * FLOW, LBS./HOUR - AVE.	6858.	6858.	2281.	10122.	4.48	719.	719.	9407.	9407.	10293.	365.
B * FLOW, LBS./HOUR - MAX.											
C * FLOW, GPM - AVE.	11.1	11.1	3.53	17.4	.00858	1.14	1.14	15.1	15.1	16.6	.719
D * FLOW, GPM - MAX.											
E * FLOW, CFM - AVE.											
F * FLOW, CFM - MAX.											
G * OPERATING TEMPERATURE, DEGREES C	38.0	38.0	38.0	95.0	38.0	38.0	38.0	38.0	38.0	25.0	38.0
H * OPERATING PRESSURE, PSIG. OR HG AB	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99
* AVERAGE STREAM PHYSICAL PROPERTIES											
J * SPECIFIC GRAVITY	1.22	1.22	1.29	1.15	1.04	1.25	1.25	1.23	1.23	1.23	1.01
K * DENSITY, LBS./CU. FT., OPER. COND.	76.6	76.6	80.5	72.3	65.0	78.0	78.0	77.2	77.2	77.1	63.3
L * VISCOSITY, CENTIPOISE, OPER. COND.											
M * SPEC. HT., PCU/LB-C, OPER. COND.	.784	.784	.745	.778	.906	.770	.770	.778	.778	.790	.971
N * NORMAL BOILING POINT, DEGREES C	102.	102.	104.	102.	100.	102.	102.	102.	102.	102.	100.
O * FREEZING POINT, DEGREES C											
P * FLASH POINT, DEGREES C											
Q * LATENT HEAT, PCU/LB OPER. COND.	443.	443.	433.	422.	522.	436.	436.	442.	442.	454.	558.
R * AVE. MOLECULAR WEIGHT	23.1	23.1	23.6	23.2	19.6	23.5	23.5	23.1	23.1	22.8	18.4
* COMPOSITION, LB./HR. - AVE. FLOW											
1* H2O	4882.	4882.	1475.	7078.	3.96	495.	495.	6586.	6586.	7377.	351.
2* NANO3	925.	926.	233.	1262.		88.3	88.3	1173.	1173.	1173.	
3* NANO2	355.	355.	58.0	450.		31.5	31.5	419.	419.	419.	
4* NAALO2	191.	191.	61.5	276.		19.3	19.3	256.	256.	256.	
5* NAOH	143.	143.	384.	577.	.161	40.4	40.4	537.	537.	537.	19.3
6* NA2CO3	148.	148.	25.0	198.		13.9	13.9	184.	184.	278.	
7* NA2SO4	199.	199.	32.6	252.		17.7	17.7	235.	235.	235.	
8* OSALT	10.0	10.0	3.60	14.9		1.03	1.03	13.7	13.7	13.7	
9* EDTNAA			.00032	.00035		.00002	.00002	.00032	.00032	.00032	
10* FEOH3	.500	.500	2.78	3.31		3.28	3.28	.0331	.0331	.0331	
11* ALOH3	.450	.450	.592	1.04		1.03	1.03	.0104	.0104	.0104	
12* MNO2	.100	.100	.950	1.06		1.05	1.05	.0106	.0106	.0106	
13* UO2OH2	.0400	.0400	.189	.231		.229	.229	.00231	.00231	.00231	
14* NIOH2	.0600	.0600	.297	.350		.347	.347	.00350	.00350	.00350	
15* CACO3	.0499	.0499	.248	.301		.297	.297	.00301	.00301	.00301	
16* HGOH2	.0200	.0200	.264	.286		.284	.284	.00286	.00286	.00286	
17* HGI2			3.98	3.92		3.88	3.88	.0392	.0392	.0392	
18* OSOLID	.0800	.0800	.620	.710	.358	1.05	1.05	.0106	.0106	.0106	
19* ZEOLTE											
20* SIO2			.125	.126		.125	.125	.00126	.00126	.00126	

TABLE 4.8 CONT'D
SETTLING AND FILTRATION (MB-8)

		PROCESS MATERIAL	12	13	14	15	16	17	18	19	20	21	22	23	24
			FEED + PE	#1 FLR FLTRTE	SFILTR 2FEED	PELECT SOLN	FEED + PE	#2 FLR FLTRTE	FLTRTE TRNSFR	I/E FEED	#1 FLR RWASH	#2 FLR RWASH	#1 FLR BWASH	#2 FLR BWASH	BACK WASH
A		FLOW, LB/HR - AVE =	13658.	13658.	13658.	361.	10293.	11079.	10055.	10056.	482.	499.	482.	499.	982.
B		FLOW, LB/HR - MAX =													
C		FLOW, GPM - AVE =	17.3	17.3	17.3	.749	16.8	18.3	16.4	16.4	.790	.818	.793	.819	1.62
D		FLOW, GPM - MAX =													
E		FLOW, CFM - AVE =													
F		FLOW, CFM - MAX =													
G		OPER TEMP, DEGREE C =	25.5	25.0	25.0	38.0	37.9	25.0	25.0	25.0	25.0	25.0	25.0	25.0	38.0
H		OPER PRES, PSIG,HGAB=	4.99	.00000	4.99	4.99	4.99	.00000	4.99	4.99	4.99	4.99	.00000	.00000	4.99
		PHYSICAL PROPERTIES													
J		SPECIFIC GRAVITY =	1.22	1.22	1.22	1.01	1.22	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.20
K		DENSITY, LB/CU FT =	76.6	76.6	76.6	63.3	76.2	76.1	76.1	76.1	76.1	76.1	76.1	76.1	75.2
L		VISC. CP =													
M		SPEC. HT, PCU/LB-C =	.796	.796	.796	.971	.796	.802	.802	.802	.802	.802	.802	.802	.803
N		BOIL PT, DEGREE C=	102.	102.	102.	100.	102.	102.	102.	102.	102.	102.	102.	102.	102.
O		FREEZE PT, DEGREE C=													
P		FLASH PT, DEGREE C=													
Q		LAT. HT. PCU/LB =	457.	458.	457.	556.	449.	462.	461.	461.	461.	461.	461.	452.	456.
R		AVE. MOLE. WT. =	22.6	22.6	22.6	18.4	22.8	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4
		COMP, LB/HR-AVE FLOW													
1	H2O	=	7728.	7728.	7728.	366.	7377.	8094.	7374.	7374.	353.	366.	353.	366.	720.
2	NANO3	=	1173.	1173.	1173.		1173.	1173.	1069.	1069.	51.3	53.1	51.3	53.1	104.
3	NANO2	=	419.	419.	419.		419.	419.	381.	381.	18.3	18.9	18.3	18.9	37.3
4	NAALO2	=	256.	256.	256.		256.	256.	234.	234.	11.2	11.6	11.2	11.6	22.8
5	NAOH	=	551.	551.	551.	14.9	537.	566.	516.	516.	24.7	25.6	24.7	25.6	50.4
6	NA2CO3	=	278.	278.	278.		278.	278.	254.	254.	12.1	12.6	12.1	12.6	24.8
7	NA2SO4	=	235.	235.	235.		235.	235.	214.	214.	10.2	10.6	10.2	10.6	20.9
8	OSALT	=	13.7	13.7	13.7		13.7	13.7	12.5	12.5	.603	.624	.603	.624	1.22
9	EDTNAA	=	.00032	.00032	.00032		.00032	.00032	.00030	.00030	.00001	.00001	.00001	.00001	.00002
10	FEOH3	=	.0331	.00331	.00331		.0331	.00066	.00060	.00060	.00002	.00003	.0298	.00268	.0325
11	ALOH3	=	.0104	.00104	.00104		.0104	.00022	.00018	.00019	TRACE	TRACE	.00939	.00084	.0102
12	MNO2	=	.0106	.00106	.00106		.0106	.00021	.00019	.00019	TRACE	TRACE	.00955	.00085	.0104
13	UO2OH2	=	.00231	.00023	.00023		.00231	.00004	.00004	.00004	TRACE	TRACE	.00208	.00018	.00227
14	NIOH2	=	.00350	.00035	.00035		.00350	.00007	.00006	.00006	TRACE	TRACE	.00316	.00028	.00344
15	CACO3	=	.00301	.00030	.00030		.00301	.00006	.00005	.00005	TRACE	TRACE	.00271	.00024	.00295
16	MGOH2	=	.00286	.00028	.00028		.00286	.00005	.00005	.00005	TRACE	TRACE	.00258	.00023	.00281
17	MGI2	=	.0392	.00392	.00392		.0392	.00078	.00071	.00071	.00003	.00003	.0353	.00317	.0385
18	OSOLID	=	.0106	.00106	.00106		.0106	.00021	.00019	.00019	TRACE	TRACE	.00953	.00086	.0104
19	ZEOLTE	=													
20	SIO2	=	.00126	.00012	.00012		.00126	.00002	.00002	.00002	TRACE	TRACE	.00114	.00010	.00124

TABLE 4.8 CONT'D

SETTLING AND FILTRATION (MB-8)

		25	26	27	28	29	30	31	32	33	34	35	36	37
	PROCESS MATERIAL =	SAND FLUSH	MOTIVE STEAM	EAST SUMPS	SAND FLUSH	MOTIVE STEAM	SAND TRNSFR	WASTE SAND	SAND + COAL	#1 FLR FLUSH	HNO3 FLUSH	#2 FLR FLUSH	SAND + COAL	HNO3 FLUSH
A	FLOW, LB/HR - AVE =	9.81	.294		9.32	.279	9.60	19.7	4.36	8.34		8.34	2.88	
B	FLOW, LB/HR - MAX =													
C	FLOW, GPM - AVE =	.0179			.0173		.0191	.0364	.00719	.0164		.0164	.00470	
D	FLOW, GPM - MAX =													
E	FLOW, CFM - AVE =		.0142			.0135								
F	FLOW, CFM - MAX =													
G	OPER TEMP, DEGREE C =	38.0	185.		38.0	185.	108.	38.0	38.0	38.0		38.0	38.0	
H	OPER PRES, PSIG,HGAB=	.00000	150.		.00000	150.	4.99	4.99	.00000	4.99		4.99	.00000	
	PHYSICAL PROPERTIES													
J	SPECIFIC GRAVITY =	1.09	4.26		1.07	4.26	1.00	1.07	1.21	1.01		1.01	1.22	
K	DENSITY, LB/CU FT =	68.2	.344		66.8	.344	62.6	67.4	75.6	63.3		63.3	76.3	
L	VISC. CP =													
M	SPEC. HT, PCU/LB-C =	.855	.487		.850	.487	.894	.876	.710	.971		.971	.709	
N	BOIL PT, DEGREE C=	100.	100.		100.	100.	100.	100.	100.	100.		100.	100.	
O	FREEZE PT, DEGREE C=													
P	FLASH PT, DEGREE C=													
Q	LAT. HT. PCU/LB =	498.	482.		517.	482.	487.	508.	422.	558.		558.	423.	
R	AVE. MOLE. WT. =	20.6	18.0		19.8	18.0	19.9	20.1	24.3	18.4		18.4	24.2	
	COMP, LB/HR-AVE FLOW													
1	H2O =	8.01	.294		8.01	.279	8.29	16.6	2.78	8.01		8.01	1.82	
2	NANO3 =													
3	NANO2 =													
4	NAALO2 =													
5	NAOH =	.327			.327		.327	.654	.113	.327		.327	.0744	
6	NA2CO3 =													
7	NA2SO4 =													
8	OSALT =													
9	EDTNAA =													
10	FEOH3 =													
11	ALOH3 =													
12	MNO2 =													
13	UO2OH2 =													
14	NIOH2 =													
15	CACO3 =													
16	HGOH2 =													
17	HGI2 =													
18	OSOLID =	.325			.121		.121	.447	.325				.121	
19	ZEOLTE =													
20	SIO2 =	1.14			.860		.863	2.00	1.14				.860	

TABLE 4.8 CONT'D
SETTLING AND FILTRATION (MB-8)

PROCESS MATERIAL =	38 NA2CO3 RCYCLE	39 SSR TK VENT	40 GSF TK VENT	41 GS TNK VENT	42 GSS TK VENT	43 SFF TK VENT	44 GSR TK VENT	45 SF1 TK VENT	46 1FT TK VENT	47 SF2 TK VENT	48 FBW TK VENT	49 WS TNK VENT	50 2FT TK VENT	51 FN TNK VENT
A FLOW, LB/HR - AVE =	895.	247.2	247.2	494.4[a]	247.2	247.2	247.2	247.2	247.2	247.2	247.2	247.2	247.2	247.2
B FLOW, LB/HR - MAX =														
C FLOW, GPM - AVE =	1.65													
D FLOW, GPM - MAX =														
E FLOW, CFM - AVE =		58.5	58.5	117.0[a]	58.5	58.5	58.5	58.5	58.5	58.5	58.6	58.5	58.5	58.5
F FLOW, CFM - MAX =														
G OPER TEMP, DEGREE C =	38.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
H OPER PRES, PSIG,HGAB=	4.99													
PHYSICAL PROPERTIES														
J SPECIFIC GRAVITY =	1.06													
K DENSITY, LB/CU FT =	66.6													
L VISC. CP =														
M SPEC. HT, PCU/LB-C =	.921													
N BOIL PT, DEGREE C=	100.													
O FREEZE PT, DEGREE C=														
P FLASH PT, DEGREE C=														
Q LAT. HT. PCU/LB =	520.													
R AVE. MOLE. WT. =	19.7													
COMP, LB/HR-AVE FLOW														
1 H2O =	791.													
2 NANO3 =														
3 NANO2 =														
4 NAALO2 =														
5 NAOH =														
6 NA2CO3 =	94.0													
7 NA2SO4 =														
8 OSALT =														
9 EDTNAA =														
10 FEOH3 =														
11 ALOH3 =														
12 MNO2 =														
13 UO2OH2 =														
14 NIOH2 =														
15 CACO3 =														
16 HGOH2 =														
17 HGI2 =														
18 OSOLID =														
19 ZEOLTE =														
20 SIO2 =														

---

[a] Two gravity settlers.

TABLE 4.9
CESIUM ION EXCHANGE (MB-9)

	PROCESS MATERIAL	1 I/S FEED	2 CS COL FEED	3 CS COL EXIT	4 RNS TO CS COL	5 RNS FR CS COL	6 CS COL ELTRNT	7 ELT TO CS COL	8 ELT FR CS COL	9 TO ELT CTM TK	10 RNS TO CS COL	11 RNS FR CS COL
A *	FLOW, LBS./HOUR - AVE.	10056.	10056.	9203.	2054.	2299.	4469.	4458.	5108.	5098.	1230.	1266.
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	16.4	16.4	15.1	4.11	4.12	8.43	8.41	9.69	9.67	2.46	2.48
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.											
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99	24.9	4.99	24.9	4.99	4.99	24.9	4.99	4.99	24.9	4.99
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	1.21	1.21	1.20	.996	1.11	1.05	1.05	1.05	1.05	.996	1.01
K *	DENSITY, LBS./CU. FT., OPER. COND.	76.1	76.1	75.5	62.2	69.5	66.0	66.0	65.7	65.6	62.2	63.5
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.802	.802	.809	.998	.685	.851	.853	.877	.879	.998	.947
N *	NORMAL BOILING POINT, DEGREES C	102.	102.	102.	100.	101.	102.	102.	101.	101.	100.	100.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	461.	460.	466.	575.	511.	475.	474.	495.	496.	575.	542.
R *	AVE. MOLECULAR WEIGHT	22.4	22.4	22.2	18.0	20.3	21.8	21.7	20.9	20.9	18.0	19.1
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	7374.	7374.	6834.	2054.	1945.	3392.	3393.	4113.	4114.	1230.	1159.
2*	NANO3	1069.	1069.	931.		137.						
3*	NANO2	361.	361.	332.		49.2						
4*	NAALO2	234.	234.	203.		30.1						
5*	NAOH	516.	516.	482.		74.4			70.9	70.9		
6*	NA2CO3	254.	254.	221.		32.7						
7*	NA2SO4	214.	214.	186.		27.6						
8*	OSALT	12.5	12.5	10.9		1.61						
9*	NH4OH						287.	290.	227.	229.		29.0
10*	NH4CO3						789.	773.	696.	687.		77.3
11*	NH3											
12*	CO2											
13*	ELTNAA	.00030	.00030	.00026		.00003						
14*	ZEOLTE											
15*	HNO3											
16*	N2											
17*	O2											

TABLE 4.9 CONT'D

	CESIUM ION EXCHANGE (MB-9) =	12	13	14	15	16	17	18	19	20	21	22	23	24
	PROCESS MATERIAL =	PNS TO CTH TK	SPENT ELTRNT	CS COL RGNRNT	RGN FR CS COL	SPENT RGNRNT	CAUSTC TO PE	IX FD TK VNT	CS FD BTKVNT	CS ELT BTKVNT	CS RGT CTH TK	CS ELT CTH TK	FRESH RESIN	FRESH RESIN
A	FLOW, LB/HR - AVE =	1266.	6353.	2213.	2135.	2135.	2115.	247.2	219.	221.	229.	220.		
B	FLOW, LB/HR - MAX =													
C	FLOW, GPM - AVE =	2.48	12.3	4.22	4.20	4.20	4.32						1,525[a]	1,525[a]
D	FLOW, GPM - MAX =													
E	FLOW, CFM - AVE =							58.5	39.4	39.7	67.2	53.1		
F	FLOW, CFM - MAX =													
G	OPER TEMP, DEGREE C =	25.0	38.0	25.0	25.0	25.0	65.0	35.0	38.0	38.0	85.0	38.0		
H	OPER PRES, PSIG,HGAB=	4.99	4.99	4.99	4.99	4.99	4.99		4.99	4.99	.00000	.00000		
	PHYSICAL PROPERTIES													
J	SPECIFIC GRAVITY =	1.01	1.03	1.04	1.01	1.01	.977		1.14	1.14	.705	.857		
K	DENSITY, LB/CU FT =	63.5	64.3	65.3	63.4	63.4	60.9		.0927	.0927	.0569	.0691		
L	VISC. CP =													
M	SPEC. HT, PCU/LB-C =	.947	.904	.947	.976	.976	.981		.254	.255	.276	.255		
N	BOIL PT, DEGREE C=	100.	101.	100.	100.	100.	100.		-194.	-194.	-193.	-194.		
O	FREEZE PT, DEGREE C=													
P	FLASH PT, DEGREE C=													
Q	LAT. HT. PCU/LB =	542.	500.	553.	564.	564.	539.		22.0	22.9	31.5	22.6		
R	AVE. MOLE. WT. =	19.1	20.5	18.7	18.4	18.4	18.2		28.2	28.2	26.7	28.2		
	COMP, LB/HR-AVE FLOW													
1	H2O =	1159.	5276.	2049.	2048.	2048.	2063.		7.08	7.08	10.4	7.79		
2	NANO3 =													
3	NANO2 =													
4	NAALO2 =													
5	NAOH =		70.9	164.	52.5	52.5	52.5							
6	NA2CO3 =													
7	NA2SO4 =													
8	OSALT =													
9	NH4OH =	29.0	261.		34.5	34.5								
10	NH4CO3 =	77.3	744.											
11	NH3 =								3.57	4.19	16.7	3.95		
12	CO2 =								6.37	7.23		6.95		
13	EDTNAA =													
14	ZEOLTE =													
15	HNO3 =													
16	N2 =								155.	155.	155.	155.		
17	O2 =								46.8	46.8	46.8	46.8		

---

[a] Gallons per year.

TABLE 4.9 CONT'D
CESIUM ION EXCHANGE (MB-9)

	PROCESS MATERIAL	25 RESIN BCKWSH	26 CS SPT RESIN	27 SR SPT RESIN	28 SPENT RESIN	29 DECANT RESIN	30 SPR TK VENT
A	FLOW, LB/HR - AVE						247.2
B	FLOW, LB/HR - MAX						
C	FLOW, GPM - AVE		3,050[a]	760[a]	3,810[a]		
D	FLOW, GPM - MAX						
E	FLOW, CFM - AVE						58.5
F	FLOW, CFM - MAX						
G	OPER TEMP, DEGREE C						35.0
H	OPER PRES, PSIG,HGAB						
	PHYSICAL PROPERTIES						
J	SPECIFIC GRAVITY						
K	DENSITY, LB/CU FT						
L	VISC, CP						
M	SPEC. HT, PCU/LB-C						
N	BOIL PT, DEGREE C						
O	FREEZE PT, DEGREE C						
P	FLASH PT, DEGREE C						
Q	LAT. HT. PCU/LB						
R	AVE. MOLE. WT.						
	COMP, LB/HR-AVE FLOW						
1	H2O						
2	NANO3						
3	NANO2						
4	NAALO2						
5	NAOH						
6	NA2CO3						
7	NA2SO4						
8	OSALT						
9	NH4OH						
10	NH4CO3						
11	NH3						
12	CO2						
13	EDTNAA						
14	ZEOLTE						
15	HNO3						
16	N2						
17	O2						

---

a. Gallons per year.

TABLE 4.10
SR ION EXCHANGE + CONCENTRATION (MB-10)

	PROCESS MATERIAL	1	2	3	4	5	6	7	8	9	10	11
		TO SR FD TK	SR COL EXIT	RNS FR CS COL	RNS FR SR COL	RNS TO SR COL	RNS FR SR COL	PRSALT TRNSFR	SR COL ELTRNT	ELT FR SR COL	RNS TO SR COL	RNS FR SR COL
A *	FLOW, LBS./HOUR - AVE.	9283.	8996.	2299.	2506.	307.	204.	11707.	1232.	1334.	615.	615.
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	15.1	14.8	4.12	4.42	.615	.410	19.9	2.46	2.66	1.23	1.23
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.											
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	25.0	25.0	25.0	25.0	25.0	25.0	38.0	25.0	25.0	25.0	25.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99	4.99	4.99	4.99	15.0	4.99	4.99	4.99	4.99	15.0	4.99
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	1.20	1.20	1.11	1.13	.996	.996	1.17	.999	.999	.996	.997
K *	DENSITY, LBS./CU. FT., OPER. COND.	75.5	75.3	69.5	70.6	62.2	62.2	73.1	62.4	62.3	62.2	62.2
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.609	.812	.885	.871	.998	.998	.628	.995	.996	.998	.998
N *	NORMAL BOILING POINT, DEGREES C	102.	102.	101.	101.	100.	100.	102.	100.	100.	100.	100.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	466.	467.	511.	502.	576.	577.	471.	575.	575.	576.	577.
R *	AVE. MOLECULAR WEIGHT	22.2	22.2	20.3	20.6	18.0	18.0	21.7	18.0	18.0	18.0	18.0
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	6834.	6709.	1945.	2070.	307.	204.	8984.	1227.	1330.	615.	614.
2*	NANO3	931.	898.	137.	170.			1069.				
3*	NANO2	332.	320.	49.2	61.5			381.				
4*	NAALO2	203.	196.	30.1	37.7			234.				
5*	NAOH	482.	467.	74.4	89.2			557.	.0492	.0451		.00410
6*	NA2CO3	221.	213.	32.7	40.8			254.				
7*	NA2SO4	166.	179.	27.6	34.5			214.				
8*	OSALT	10.9	10.5	1.61	2.02			12.5				
9*	NH4OH											
10*	NH4CO3											
11*	NH3											
12*	CO2											
13*	EDTNAA	.00026	.00024	.00003	.00005			.00030	4.87	4.47		.406
14*	ZEOLTE											
15*	HNO3											
16*	N2											
17*	O2											

TABLE 4.10 CONT'D
SR ION EXCHANGE + CONCENTRATION (MB-10)

	PROCESS MATERIAL	12 SRCONC FEED	13 SRCONC BOTTMS	14 BOTTMS TRNSFR	15 SRCONC CNDSTE	16 CNDSTE TRNSFR	17 FRESH RESIN	18 RESIN BCKWSH	19 SPENT RESIN	20 SRFB TK VNT	21 SREP TK VNT	22 PSH TK VENT	23 SRE TK VENT	24 SRCB TK VNT
A	FLOW, LB/HR - AVE	1950.	24.3	24.3	1925.	1925.				247.2	247.2	741.6[b]	247.2	247.2
B	FLOW, LB/HR - MAX													
C	FLOW, GPM - AVE	3.92	.0437	.0414	3.88	3.88	760[a]		760[a]					
D	FLOW, GPM - MAX													
E	FLOW, CFM - AVE									58.5	58.5	175.5[b]	58.5	58.5
F	FLOW, CFM - MAX													
G	OPER TEMP, DEGREE C	38.0	102.	38.0	38.0	38.0				35.0	35.0	35.0	35.0	35.0
H	OPER PRES, PSIG,HGAB	4.99	.00000	4.99	.00000	4.99								
	PHYSICAL PROPERTIES													
J	SPECIFIC GRAVITY	.991	1.11	1.17	.989	.989								
K	DENSITY, LB/CU FT	61.8	69.4	73.2	61.7	61.7								
L	VISC, CP													
M	SPEC. HT, PCU/LB-C	.996	.843	.843	.998	.996								
N	BOIL PT, DEGREE C	100.	100.	100.	99.9	99.9								
O	FREEZE PT, DEGREE C													
P	FLASH PT, DEGREE C													
Q	LAT. HT. PCU/LB	569.	436.	461.	571.	571.								
R	AVE. MOLE. WT.	18.0	22.2	22.2	18.0	18.0								
	COMP, LB/HR-AVE FLOW													
1	H2O	1945.	19.4	19.4	1925.	1925.								
2	NANO3													
3	NANO2													
4	NAALO2													
5	NAOH	.0492	.0492	.0492										
6	NA2CO3													
7	NA2SO4													
8	OSALT													
9	NH4OH													
10	NH4CO3													
11	NH3													
12	CO2													
13	EDTNAA	4.87	4.87	4.87	.00048	.00046								
14	ZEOLTE													
15	HNO3													
16	N2													
17	O2													

---

a. Gallons per year.

b. Three product salt hold tanks.

TABLE 4.10 CONT'D
SR ION EXCHANGE + CONCENTRATION (MB-10)

```
                                              25
-------------------------------------------------------------------------------------------------------------------
  PROCESS MATERIAL        = SRCC
                            TK VNT
-------------------------------------------------------------------------------------------------------------------
 A  FLOW, LB/HR    - AVE =  247.2
 B  FLOW, LB/HR    - MAX =
-------------------------------  ------
 C  FLOW, GPM      - AVE =
 D  FLOW, GPM      - MAX =
 E  FLOW, CFM      - AVE =   58.5
 F  FLOW, CFM      - MAX =
-------------------------------  ------
 G  OPER TEMP, DEGREE C =    35.0
 H  OPER PRES, PSIG,HGAB=
    PHYSICAL PROPERTIES    ------
 J   SPECIFIC GRAVITY   =
 K   DENSITY, LB/CU FT  =
 L   VISC. CP           =
 M   SPEC. HT, PCU/LB-C =
-------------------------------  ------
 N   BOIL   PT, DEGREE C=
 O   FREEZE PT, DEGREE C=
 P   FLASH  PT, DEGREE C=
 Q   LAT. HT. PCU/LB    =
 R   AVE. MOLE. WT.     =
    COMP, LB/HR-AVE FLOW   ------
 1    H2O               =
 2    NANO3             =
 3    NANO2             =
 4    NAALO2            =
 5    NAOH              =
-------------------------------------------------------------------------------------------------------------------
 6    NA2CO3            =
 7    NA2SO4            =
 8    OSALT             =
 9    NH4OH             =
10    NH4CO3            =
-------------------------------------------------------------------------------------------------------------------
11    NH3               =
12    CO2               =
13    EDTNAA            =
14    ZEOLTE            =
15    HNO3              =
-------------------------------------------------------------------------------------------------------------------
16    N2                =
17    O2                =
```

TABLE 4.11
CS ELUTRIANT RECOVERY + CONCENTRATION (MB-11)

	PROCESS MATERIAL	1 SPENT ELTRNT	2 CSCONC FEED	3 CSCONC BOTTMS	4 CSCONC PURGE	5 CSCONC CNDSTE	6 RCVRD ELTRNT	7 MAKEUP NH4OH	8 MAKEUP CO2	9 ELTRNT TRNSFR	10 ELTRNT TO I/E	11 CHILLD WATER
A *	FLOW, LBS./HOUR - AVE.	6353.	7107.	528.	2096.	4453.	4442.	.915	49.6	4481.	4469.	588.
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	12.3	13.7	.989		8.55	8.54	.00182		8.59	8.43	1.16
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.				948.				5.70			
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	38.0	38.0	102.	100.	38.0	38.0	38.0	38.0	38.0	25.0	5.00
H *	OPERATING PRESSURE, PSIG. OR HG AR	4.99	4.99	.00000	.00000	.00000	4.99	4.99	4.99	4.99	4.99	4.99
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	1.03	1.03	1.06	.456	1.03	1.03	1.00	1.80	1.04	1.05	1.00
K *	DENSITY, LBS./CU. FT., OPER. COND.	64.3	64.3	66.5	.0369	64.9	64.8	62.5	.145	65.0	66.0	62.9
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.904	.902	.869	.481	.872	.874	.972	.223	.865	.851	.998
N *	NORMAL BOILING POINT, DEGREES C	101.	101.	100.	100.	102.	102.	101.	-88.5	102.	102.	100.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	510.	497.	459.	539.	471.	472.	-529.	47.9	468.	475.	588.
R *	AVE. MOLECULAR WEIGHT	20.5	20.5	21.1	19.0	21.7	21.7	19.0	44.0	21.8	21.8	18.0
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	5276.	5903.	434.	2096.	3366.	3368.	.812		3391.	3392.	588.
2*	NANO3											
3*	NANO2											
4*	NAALO2											
5*	NAOH	70.9	77.9									
6*	NA2CO3			94.0								
7*	NA2SO4											
8*	OSALT											
9*	NH4OH	261.	265.			358.	360.	.103		284.	287.	
10*	NH4CO3	744.	866.			727.	713.			925.	799.	
11*	NH3											
12*	CO2								49.6			
13*	EDTNAA											
14*	ZEOLTE											
15*	HNO3											
16*	N2											
17*	O2											

TABLE 4.11 CONT'D
CS ELUTRIANT RECOVERY + CONCENTRATION (MB-11)

	PROCESS MATERIAL	12 PURGE CNDSTE	13 SCRBBR PURGE	14 BOTTMS TRNSFR	15 FEEDTK VENT	16 CSCB TK VNT	17 CND TK VENT	18 MU TK VENT	19 CSEF TK VNT	20 PC TNK VENT	21 CSCONC VENT	22 CS RGT CTH TK	23 CS ELT CTH TK	24 CS FD BTKVNT
A	FLOW, LB/HR - AVE =	2596.	766.	528.	222.	247.2	220.	221.	221.	209.4	239.	229.	220.	219.
B	FLOW, LB/HR - MAX =													
C	FLOW, GPM - AVE =	4.23	1.43	.934										
D	FLOW, GPM - MAX =													
E	FLOW, CFM - AVE =				53.4	58.5	53.2	53.3	53.3	50.4	56.0	67.2	53.1	39.4
F	FLOW, CFM - MAX =													
G	OPER TEMP, DEGREE C =	38.0	5.00	38.0	38.0	35.0	38.0	38.0	38.0	38.0	38.0	85.0	38.0	38.0
H	OPER PRES, PSIG,HGAB=	4.99	4.99	4.99	.00000		.00000	.00000	.00000		.00000	.00000	.00000	4.99
	PHYSICAL PROPERTIES													
J	SPECIFIC GRAVITY =	.989	1.07	1.12	.857		.855	.857	.857		.880	.775	.857	1.14
K	DENSITY, LB/CU FT =	61.7	66.8	70.4	.0692		.0690	.0691	.0691		.0710	.0569	.0691	.0927
L	VISC. CP =													
M	SPEC. HT, PCU/LB-C =	.998	.859	.869	.255		.255	.255	.255		.253	.276	.255	.254
N	BOIL PT, DEGREE C=	99.9	101.	100.	-194.		-194.	-194.	-194.		-193.	-193.	-194.	-194.
O	FREEZE PT, DEGREE C=													
P	FLASH PT, DEGREE C=													
Q	LAT. HT. PCU/LB =	571.	499.	486.	23.3		23.0	23.1	23.0		25.5	31.5	22.6	22.0
R	AVE. MOLE. WT. =	18.0	21.1	21.1	28.2		28.2	28.2	28.2		29.0	26.7	28.2	28.2
	COMP, LB/HR-AVE FLOW													
1	H2O =	2596.	625.	434.	7.09		7.08	7.08	7.08		7.07	10.4	7.09	7.08
2	NANO3 =													
3	NANO2 =													
4	NAALO2 =													
5	NAOH =													
6	NA2CO3 =			94.0										
7	NA2SO4 =													
8	OSALT =													
9	NH4OH =													
10	NH4CO3 =		141.											
11	NH3 =				4.41		4.37	4.28	4.23		4.36	16.7	3.95	3.57
12	CO2 =				8.11		6.66	7.52	7.37		25.0		6.95	6.37
13	EDTNAA =													
14	ZEOLTE =													
15	HNO3 =													
16	N2 =				155.		155.	155.	155.		155.	155.	155.	155.
17	O2 =				46.8		46.8	46.8	46.8		46.8	46.8	46.8	46.8

TABLE 4.11 CONT'D
CS ELUTRIANT RECOVERY + CONCENTRATION (MB-11)

```
                                   25      26

------------------------------------------------------------------------------------------------
  PROCESS MATERIAL         = CS ELT CSVS
                             STKVNT VENT
------------------------------------------------------------------------------------------------
 A  FLOW, LB/HR    - AVE =   221.  2046.
 B  FLOW, LB/HR    - MAX =
-------------------------  ------ ------
 C  FLOW, GPM      - AVE =
 D  FLOW, GPM      - MAX =
 E  FLOW, CFM      - AVE =   39.7   432.
 F  FLOW, CFM      - MAX =
-------------------------  ------ ------
 G  OPER TEMP, DEGREE C =   38.0   5.00
 H  OPER PRES, PSIG,HGAB=   4.99 .00009
    PHYSICAL PROPERTIES    ------ ------
 J   SPECIFIC GRAVITY    =   1.19   .976
 K   DENSITY, LB/CU FT   =  .0927  .0788
 L   VISC. CP            =
 M   SPEC. HT, PCU/LB-C  =   .245   .242
-------------------------  ------ ------
 N   BOIL   PT, DEGREE C=  -194.  -194.
 O   FREEZE PT, DEGREE C=
 P   FLASH  PT, DEGREE C=
 Q   LAT. HT. PCU/LB     =   22.9   7.92
 R   AVE. MOLE. WT.      =   28.2   28.8
    COMP, LB/HR-AVE FLOW   ------ ------
 1    H2O                =   7.08   10.9
 2    NANO3              =
 3    NANO2              =
 4    NAALO2             =
 5    NAOH               =
------------------------------------------------------------------------------------------------
 6    NA2CO3             =
 7    NA2SO4             =
 8    OSALT              =
 9    NH4OH              =
10    NH4CO3             =
------------------------------------------------------------------------------------------------
11    NH3                =   4.19  .0501
12    CO2                =   7.23   10.6
13    EDTNAA             =
14    ZEOLTE             =
15    HNO3               =
------------------------------------------------------------------------------------------------
16    N2                 =   155.  1556.
17    O2                 =   46.8   468.
```

TABLE 4.12
CS FIXATION ON ZEOLITE (MB-12)

	PROCESS MATERIAL	1	2	3	4	5	6	7	8	9	10	11
		BOTTMS TRNSFR	ZL COL FEED	ZL COL EXIT	TO RCY HLD TK	RINSE WATER	RNS TO ZL COL	RNS FR ZL COL	TO RCY HLD TK	NA2CO3 RCYCLE	FLUSH WATER	ZEOLTE FLUSH
A *	FLOW, LBS./HOUR - AVE.	528.	529.	560.	560.	357.	357.	324.	324.	885.	49.0	55.7
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	.934	.934	1.06	1.06	.725	.720	.587	.587	1.65	.0997	.101
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.											
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	38.0	38.0	38.0	38.0	50.0	38.0	38.0	38.0	38.0	50.0	37.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99	15.0	15.0	4.99	4.99	15.0	15.0	4.99	4.99	4.99	.00000
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	1.12	1.12	1.04	1.04	.982	.989	1.10	1.10	1.06	.982	1.09
K *	DENSITY, LBS./CU. FT., OPER. COND.	70.4	70.4	65.4	65.4	61.3	61.7	68.9	68.9	66.6	61.3	68.1
L *	VISCOSITY, CENTIPOISE, OPER. COND.	.734	.734	.718	.718	.577	.706	.729	.729	.722	.577	.725
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.869	.869	.939	.939	.998	.998	.889	.889	.921	.998	.939
N *	NORMAL BOILING POINT, DEGREES C	100.	100.	100.	100.	100.	99.9	100.	100.	100.	100.	100.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	486.	485.	531.	532.	564.	570.	498.	499.	520.	564.	505.
R *	AVE. MOLECULAR WEIGHT	21.1	21.1	19.3	19.3	18.0	18.0	20.5	20.5	19.7	18.0	20.3
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	434.	434.	515.	515.	357.	357.	275.	275.	791.	49.0	49.0
2*	NANO3											
3*	NANO2											
4*	NAALO2											
5*	NAOH											
6*	NA2CO3	94.0	94.0	45.3	45.3			48.6	48.6	94.0		
7*	NA2SO4											
8*	OSALT											
9*	NH4OH											
10*	NH4CO3											
11*	NH3											
12*	CO2											
13*	EDTNAA											
14*	ZEOLTE											6.63
15*	HNO3											
16*	N2											
17*	O2											

TABLE 4.12 CONT'D
CS FIXATION ON ZEOLITE (MB-12)

	PROCESS MATERIAL		12	13	14	15	16	17	18	19	20	21
		=	MOTIVE STEAM	ZEOLTE TRNSFR	WASTE ZEOLTE	DECANT WATER	MAKEUP ZEOLTE	TRNSFR WATER	ZFB TK VENT	ZRB TK VENT	ZRH TK VENT	ZS TNK VENT
A	FLOW, LB/HR - AVE	=	1.67	57.4	20.4	36.9	37.8	31.2	247.2	247.2	247.2	247.2
B	FLOW, LB/HR - MAX	=										
C	FLOW, GPM - AVE	=		.110	.0309	.0745	.0653	.0630				
D	FLOW, GPM - MAX	=										
E	FLOW, CFM - AVE	=	.0809						58.5	58.5	58.5	58.5
F	FLOW, CFM - MAX	=										
G	OPER TEMP, DEGREE C	=	185.	108.	38.0	38.0	22.5	38.0	35.0	35.0	35.0	35.0
H	OPER PRES, PSIG,HGAB	=	150.	4.99	4.99	4.99	.00000	4.99				
	PHYSICAL PROPERTIES											
J	SPECIFIC GRAVITY	=	4.26	1.03	1.32	.989	1.15	.989				
K	DENSITY, LB/CU FT	=	.344	64.5	82.6	61.7	72.3	61.7				
L	VISC. CP	=	.0159	.259	.729	.706	.949	.706				
M	SPEC. HT, PCU/LB-C	=	.487	.941	.837	.998	.911	.998				
N	BOIL PT, DEGREE C	=	100.	100.	99.9	99.9	100.	99.9				
O	FREEZE PT, DEGREE C	=										
P	FLASH PT, DEGREE C	=										
Q	LAT. HT. PCU/LB	=	482.	472.	389.	571.	480.	571.				
R	AVE. MOLE. WT.	=	18.0	20.2	26.2	18.0	21.6	18.0				
	COMP, LB/HR-AVE FLOW											
1	H2O	=	1.67	50.7	13.8	36.9	31.2	31.2				
2	NANO3	=										
3	NANO2	=										
4	NAALO2	=										
5	NAOH	=										
6	NA2CO3	=										
7	NA2SO4	=										
8	OSALT	=										
9	NH4OH	=										
10	NH4CO3	=										
11	NH3	=										
12	CO2	=										
13	EDTNAA	=										
14	ZEOLTE	=		6.63	6.63		6.63					
15	HNO3	=										
16	N2	=										
17	O2	=										

TABLE 4.13
GPE EVAPORATION (MB-13)

	PROCESS MATERIAL	1 RCEVAP CNDSTE	2 GPEF TK VNT	3 SRCONC CNDSTE	4 RECYL H2O TK	5 GPEVAP FEED	6 GPEVAP BOTTMS	7 BOTTMS TO RE	8 GPEVAP CNDSTE	9 CND TO DITCH	10 PREVAP CONSTE	11 TO TNK FARM
A *	FLOW, LBS./HOUR - AVE.	10297.	247.2	1925.	6398.	10692.	1069.	1069.	9623.	9623.	11011.	4854.
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	20.7		3.88	13.0	21.6	2.23	2.15	19.4	19.4	22.5	9.84
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.		58.5									
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	38.0	35.0	38.0	62.1	46.3	100.	38.0	38.0	38.0	62.1	46.3
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99		4.99	.00000	.00000	.00000	4.99	.00000	4.99	.00000	.00000
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	.989		.989	.976	.984	.955	.989	.989	.989	.976	.984
K *	DENSITY, LBS./CU. FT., OPER. COND.	61.7		61.7	60.9	61.4	59.6	61.7	61.7	61.7	60.9	61.4
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.998		.998	.998	.998	.998	.998	.998	.998	.998	.998
N *	NORMAL BOILING POINT, DEGREES C	99.9		99.9	100.	100.	100.	99.9	99.9	99.9	100.	100.
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	571.		571.	558.	567.	539.	571.	571.	571.	558.	567.
R *	AVE. MOLECULAR WEIGHT	18.0		18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	10297.		1925.	6398.	10692.	1069.	1069.	9623.	9623.	11011.	4854.
2*	NANO3											
3*	NANO2											
4*	NAALO2											
5*	NAOH											
6*	NA2CO3											
7*	NA2SO4											
8*	OSALT											
9*	NH4OH											
10*	NH4CO3											
11*	NH3											
12*	CO2											
13*	EDTNAA	TRACE		.00048		.00028	.00028	.00028				.00012
14*	ZEOLTE											
15*	HNO3											
16*	N2											
17*	O2											

TABLE 4.13 CONT'D
GPE EVAPORATION (MB-13)

GPE EVAPORATION (MB-13) =	12	13	14	15	16	17	18	19	20	21	22	23	24
PROCESS MATERIAL =	TO AL DSLVR	FIRST WASH	SECOND WASH	MAKEUP H2O	CS COC BCKWSH	SR COC BCKWSH	RINSE WATER	FLUSH WATER	RINSE WATER	RINSE WATER	RINSE WATER	RINSE WATER	PW TNK VENT
A FLOW, LB/HR - AVE =	111.	1481.	1481.				357.	49.0	2054.	1230.	307.	615.	247.2
B FLOW, LB/HR - MAX =													
C FLOW, GPM - AVE =	.226	3.00	3.00				.730	.100	4.20	2.51	.628	1.25	
D FLOW, GPM - MAX =													
E FLOW, CFM - AVE =													58.5
F FLOW, CFM - MAX =													
G OPER TEMP, DEGREE C =	46.3	46.3	46.3				62.1	62.1	62.1	62.1	62.1	62.1	35.0
H OPER PRES, PSIG,HGAB=	.00000	.00000	.00000				.00000	.00000	.00000	.00000	.00000	.00000	
PHYSICAL PROPERTIES													
J SPECIFIC GRAVITY =	.984	.984	.984				.976	.976	.976	.976	.976	.976	
K DENSITY, LB/CU FT =	61.4	61.4	61.4				60.9	60.9	60.9	60.9	60.9	60.9	
L VISC. CP =													
M SPEC. HT, PCU/LB-C =	.998	.998	.998				.998	.998	.998	.998	.998	.998	
N BOIL PT, DEGREE C=	100.	100.	100.				100.	100.	100.	100.	100.	100.	
O FREEZE PT, DEGREE C=													
P FLASH PT, DEGREE C=													
Q LAT. HT. PCU/LB =	567.	567.	567.				558.	558.	558.	558.	558.	558.	
R AVE. MOLE. WT. =	18.0	18.0	16.0				18.0	18.0	18.0	18.0	18.0	18.0	
COMP, LB/HR-AVE FLOW													
1 H2O =	111.	1481.	1481.				357.	49.0	2054.	1230.	307.	615.	
2 NANO3 =													
3 NANO2 =													
4 NAALO2 =													
5 NAOH =													
6 NA2CO3 =													
7 NA2SO4 =													
8 OSALT =													
9 NH4OH =													
10 NH4CO3 =													
11 NH3 =													
12 CO2 =													
13 EDTNAA =	TRACE	.00003	.00003										
14 ZEOLTE =													
15 HNO3 =													
16 N2 =													
17 O2 =													

TABLE 4.13 CONT'D
GPE EVAPORATION (MB-13)

	PROCESS MATERIAL	25 GPEC TK VNT	26 PSSST VENT	27 PSSST VENT	28 GPEC VENT	29 VNT TO ATM
A	FLOW, LB/HR - AVE	247.2	247.2	247.2	247.2	3,919
B	FLOW, LB/HR - MAX					
C	FLOW, GPM - AVE					
D	FLOW, GPM - MAX					
E	FLOW, CFM - AVE	58.5	58.5	58.5	58.5	920.6
F	FLOW, CFM - MAX					
G	OPER TEMP, DEGREE C	35	35	35	35	35
H	OPER PRES, PSIG,HGAB					
	PHYSICAL PROPERTIES					
J	SPECIFIC GRAVITY					
K	DENSITY, LB/CU FT					
L	VISC. CP					
M	SPEC. HT, PCU/LB-C					
N	BOIL PT, DEGREE C					
O	FREEZE PT, DEGREE C					
P	FLASH PT, DEGREE C					
Q	LAT. HT. PCU/LB					
R	AVE. MOLE. WT.					
	COMP, LB/HR-AVE FLOW					
1	H2O					
2	NANO3					
3	NANO2					
4	NAALO2					
5	NAOH					
6	NA2CO3					
7	NA2SO4					
8	OSALT					
9	NH4OH					
10	NH4CO3					
11	NH3					
12	CO2					
13	EDTNAA					
14	ZEOLTE					
15	HNO3					
16	N2					
17	O2					

TABLE 4.14
SALTCRETE PREPARATION (MB-14)

	PROCESS MATERIAL	1 PROCT SALT	2 PEVAP FEED	3 PSE VAPOR	4 PEVAP DSCALE	5 TOPEYL H2O TK	6 PEVAP BOTTOM	7 JET S STEAM	8 PSCT FEED	9 PSCT FLUSH	10 PSALT TO SCP	11 CEMENT TOSCP
A *	FLOW, LBS./HOUR - AVE.	11706.	11706.	4910.	982.	11011.	7779.	233.	8012.		8012.	10115.
B *	FLOW, LBS./HOUR - MAX.											
C *	FLOW, GPM - AVE.	19.9	19.9		1.99	22.5	13.3	.497	13.8		13.8	
D *	FLOW, GPM - MAX.											
E *	FLOW, CFM - AVE.			2221.								
F *	FLOW, CFM - MAX.											
G *	OPERATING TEMPERATURE, DEGREES C	38.0	38.0	100.	48.0	62.1	115.	132.	115.		115.	50.0
H *	OPERATING PRESSURE, PSIG. OR HG AB	4.99	4.99	.00000	.00000	.00000	.00000	24.9	.00000		.00000	5.00
*	AVERAGE STREAM PHYSICAL PROPERTIES											
J *	SPECIFIC GRAVITY	1.17	1.17	.456	.984	.976	1.16	.937	1.15		1.15	
K *	DENSITY, LBS./CU. FT., OPER. COND.	73.1	73.1	.0368	61.4	60.9	72.4	58.5	71.9		71.9	
L *	VISCOSITY, CENTIPOISE, OPER. COND.											
M *	SPEC. HT., PCU/LB-C, OPER. COND.	.828	.828	.481	.998	.996	.743	.998	.751		.751	.163
N *	NORMAL BOILING POINT, DEGREES C	102.	102.	100.	100.	100.	103.	100.	103.		103.	
O *	FREEZING POINT, DEGREES C											
P *	FLASH POINT, DEGREES C											
Q *	LATENT HEAT, PCU/LB OPER. COND.	471.	471.	539.	566.	558.	396.	520.	400.		400.	
R *	AVE. MOLECULAR WEIGHT	21.7	21.7	18.0	18.0	18.0	24.3	18.0	24.0		24.0	100.
*	COMPOSITION, LB./HR. - AVE. FLOW											
1*	H2O	8984.	8984.	4910.	982.	11011.	5056.	233.	5289.		5289.	
2*	NANO3	1069.	1069.				1069.		1069.		1069.	
3*	NANO2	381.	381.				381.		381.		381.	
4*	NAALO2	234.	234.				234.		234.		234.	
5*	NAOH	557.	557.				557.		557.		557.	
6*	NA2CO3	254.	254.				254.		254.		254.	
7*	NA2SO4	214.	214.				214.		214.		214.	
8*	OSALT	12.5	12.5				12.5		12.5		12.5	
9*	EDTNAA											
10*	FEOH3											
11*	ALOH3											
12*	MNO2											
13*	UO2OH2											
14*	NIOH2											
15*	CACO3											
16*	HGOH2											
17*	HGI2											
18*	OSOLID											10115.
19*	ZEOLTE											
20*	SIO2											

TABLE 4.14 CONT'D
SALTCRETE PREPARATION (MB-14)

PROCESS MATERIAL	12 SLTCTE FLUSH	13 REWORK RETURN	14 REWORK FLUSH	15 SALT CRETE	16 PSSST VENT	17 PSECT VENT	18 PSCT VENT	19 CFHT VENT	20 SCP VENT	21 150PSI STEAM	22 150PSI CONDST	23 PSEC VENT	24 VENT TO ATM
A FLOW, LB/HR - AVE =	14.8	240.	240.	18142.	247.2	247.2	247.2	247.2	247.2	7097.	7097.	247.2	1,487
B FLOW, LB/HR - MAX =													
C FLOW, GPM - AVE =	.0303	.462	.462								14.5		
D FLOW, GPM - MAX =													
E FLOW, CFM - AVE =					58.5	58.5	58.5	58.5	58.5	342.		58.5	351
F FLOW, CFM - MAX =													
G OPER TEMP, DEGREE C =	62.1	50.0	50.0	290.	35.0	35.0	35.0	35.0	35.0	184.	70.0	35.0	35.0
H OPER PRES, PSIG,HGAB=	.00000	5.00	5.00	.00000						149.	149.		
PHYSICAL PROPERTIES													
J SPECIFIC GRAVITY =	.976	1.03	1.03							4.27	.971		
K DENSITY, LB/CU FT =	60.9	64.7	64.7							.344	60.6		
L VISC. CP =													
M SPEC. HT, PCU/LB-C =	.998	.858	.858	.196						.487	.998		
N BOIL PT, DEGREE C=	100.	100.	100.							100.	99.9		
O FREEZE PT, DEGREE C=													
P FLASH PT, DEGREE C=													
Q LAT. HT. PCU/LB =	558.	531.	531.							483.	542.		
R AVE. MOLE. WT. =	18.0	20.8	20.8	41.7						18.0	18.0		
COMP, LB/HR-AVE FLOW													
1 H2O =	14.8	200.	200.	5304.						7097.	7097.		
2 NANO3 =				1069.									
3 NANO2 =				381.									
4 NAALO2 =				234.									
5 NAOH =				557.									
6 NA2CO3 =				254.									
7 NA2SO4 =				214.									
8 OSALT =				12.5									
9 EDTNAA =													
10 FEOH3 =													
11 ALOH3 =													
12 MNO2 =													
13 UO2OH2 =													
14 NIOH2 =													
15 CACO3 =													
16 HGOH2 =													
17 HGI2 =													
18 OSOLID =		40.0	40.0	19115.									
19 ZEOLTE =													
20 SIO2 =													

TABLE 4.15

Mechanical Cell A (MB-15)

	1	2	3	4	5	6	7	8
Flow, lb/hr								
Flow, gph								
SpG								
Temp. °C								
Comp. lb/hr								
H_2O								
HNO_3								
$C_2H_2O_4$								
$Fe(NO_3)_3$								
NO								
$Mn(NO_3)_2$								
NaOH								
$Na_2C_2O_4$								
$NaNO_3$								
MnO·OH								
NaF								
CO_2								
$Fe(OH)_3$								
Cans/Day	1.877			1.877	1.877	1.877	1.877	1.877

TABLE 4.15 (Contd)

	9	10	11	12	13	14	15	16
Flow, lb/hr				256.42	256.35	0.036*	238.07	238.07
Flow, gph				27.58	27.58		27.59	27.59
SpG				1.115	1.115		1.035	1.035
Temp. °C				38	50	50	38	38
Comp. lb/hr								
H_2O				201.84	201.79		215.07	215.07
HNO_3				50.43	50.12			
$C_2H_2O_4$							23.00	23.00
$Fe(NO_3)_3$				0.291	0.582			
NO						0.036		
$Mn(NO_3)_2$								
NaOH								
$Na_2C_2O_4$								
$NaNO_3$								
MnO•OH								
NaF				3.86	3.86			
CO_2								
$Fe(OH)_3$								
Cans/Day	1.877	1.877	1.877					

---

* Does not include the tank vapor space purge (25 scfm air).

TABLE 4.15 (Contd)

	17	18	19	20	21	22	23	24
Flow, lb/hr	244.35	32.05	0.455	26.23*	81.86	583.00	64.76	64.76
Flow, gph	27.81	2.94			6.44	64.16	7.82	7.82
SpG	1.054	1.310			1.525	1.090	0.993	0.993
Temp. °C	38	38			38	38	38	38
Comp. lb/hr								
H_2O	236.91	16.03			40.93	496.13	64.76	64.76
HNO_3	5.83	16.03						
$C_2H_2O_4$	1.15							
$Fe(NO_3)_3$								
NO				4.76				
$Mn(NO_3)_2$	0.455		0.455					
NaOH					40.93	3.72		
$Na_2C_2O_4$						1.715		
$NaNO_3$						76.91		
MnO·OH						0.415		
NaF						3.86		
CO_2				21.37				
$Fe(OH)_3$						0.256		
Cans/Day								

---

* Does not include the tank vapor space purge (25 scfm air).

TABLE 4.15 (Contd)

	25	26	27	28	29	30	31	32
Flow, lb/hr	64.76	64.76	129.52	100.0	100.0	2.08	129.52	842.04
Flow, gph	7.82	7.82	15.64	12.07	12.07	0.25	15.64	95.28
SpG	0.993	0.993	0.993	0.993	0.993	0.993	0.993	1.060
Temp. °C	38	38	38	38	38	38	38	38
Comp. lb/hr								
H_2O	64.76	64.76	129.52	100.0	100.0	2.08	129.52	55.17
HNO_3								
$C_2H_2O_4$								
$Fe(NO_3)_3$								
NO								
$Mn(NO_3)_2$								
NaOH								3.72
$Na_2C_2O_4$								1.715
$NaNO_3$								76.91
MnO·OH								0.415
NaF								3.86
CO_2								
$Fe(OH)_3$								0.256
Cans/Day								

TABLE 4.16

Mechanical Cell B (MB-16)

	1	2	3	4	5	6	7	8
Flow, lb/hr						0.036*	256.47	256.42
Flow, gph							27.59	27.59
SpG							1.115	1.115
Temp. °C							38	50
Comp. lb/hr								
H_2O							201.88	201.84
HNO_3							50.73	50.43
$C_2H_2O_4$								
$Fe(NO_3)_3$								0.291
NO						0.036		
$Mn(NO_3)_2$								
NaOH								
$Na_2C_2O_4$								
$NaNO_3$								
MnO·OH								
NaF							3.86	3.86
CO_2								
$Fe(OH)_3$								
Cans/Day	1.877	1.877	1.877	1.877	1.877			

---

* Does not include the tank vapor space purge (25 scfm air).

TABLE 4.16 (Contd)

	9	10	11	12	13	14	15
Flow, lb/hr	238.07	238.07	64.76	64.76	64.76	64.76	129.52
Flow, gph	27.59	27.59	7.82	7.82	7.82	7.82	15.64
SpG	1.035	1.035	0.993	0.993	0.993	0.993	0.993
Temp. °C	38	38	38	38	38	38	38
Comp. lb/hr							
H_2O	215.07	215.07	64.76	64.76	64.76	64.76	129.52
HNO_3							
$C_2H_2O_4$	23.00	23.00					
$Fe(NO_3)_3$							
NO							
$Mn(NO_3)_2$							
NaOH							
$Na_2C_2O_4$							
$NaNO_3$							
MnO·OH							
NaF							
CO_2							
$Fe(OH)_3$							
Cans/Day							

TABLE 4.17

Mechanical Cell C (MB-17)

Process Stream	Units/Day
1	1.877 canisters
2	1.877 canisters
3	1.877 canisters
4	1.877 canisters
5	1.877 canisters
6	
7	
8	40 Clean Smears
9	40 Smears (Individually wrapped)
10	
11	

TABLE 4.18

Percent Distribution of Radionuclide Groups Between the Soluble and Insoluble Fractions of the DWPF Feed Streams[a]

Radionuclide Group[b]	Percent in In-Tank Gravity Settled Sludge	Feed to DWPF-Percent Distribution			
		Supernate (FS-2-8)		Sludge/Slurry (FS-2-4)	
		Soluble	Insoluble	Soluble	Insoluble
I	6.8	93.20	0	6.80	0
II	52.8	46.60	0.63	3.40	49.37
III	94.2	4.66	1.19	0.34	93.81
IV	97.8	0.93	1.24	0.07	97.76
V	98.6	0.19	1.25	0.01	98.55
VI	98.7	0.09	1.25	0.01	98.65

The tritium composition of the feed streams to the DWPF are detailed below.

Sludge-Slurry Stream (FS-2-4)

Insoluble - 0, Ci/hr

Soluble - 48.97 (Ci/gal T in Ref. Waste Blend) +
67.37 (Ci/gal T in FS-13-11)

Supernate Stream (FS-2-8)

Insoluble - 0, Ci/hr

Soluble - 75.52 (Ci/gal T in Ref. Waste Blend) +
515.27 (Ci/gal T in FS-13-11)

---

a. See Appendix 13.9.

b. See Table 2.11.

TABLE 4.19

Summary of Aluminum Dissolving Tests

Sludge Type (Tank #)	Sludge Type Wt % Al[a]	Treatment	% Al Removed
16	17.8	30 min in 1M NaOH at 50°C	30
		30 min in 5M NaOH at 50°C	36
		30 min in 1M NaOH, boiling	54
		30 min in 5M NaOH, boiling	76
11	44	30 min in 5M NaOH, boiling	70
		1 hr in 5M NaOH, boiling	78
15	29	30 min in 5M NaOH,boiling	77
		1 hr in 5M NaOH, boiling	72
21	8.4	30 min in 5M NaOH, boiling	49
		1 hr in 5M NaOH, boiling	45

---

a. Based on washed, dried sludge.

TABLE 4.20

Effect of Aluminum Dissolving on Sludge Composition

Metal Ion	Tank 15H Composition, Wt %		Overall Range in SRP Sludges, wt %[c]
	Before Al Dissolving[a]	After Al Dissolving[b]	
Al	29.0	7.3	2-44
Fe	3.1	10.5	3-33
Mn	2.3	7.8	2-11
Na	1.2	4.1	-
Hg	0.9	3.1	-
U	0.9	3.1	0-15
Ni	0.5	1.7	0-6
Ca	0.2	0.7	0-3

---

a. Measured in actual washed, dried sludge, Ref. 4.

b. Calculated assuming removal of 75% of the initial aluminum.

c. From Ref. 5. Note that Al dissolution will greatly decrease in this range of Al concentrations.

TABLE 4.21

Batch Washing Cycle

Operation	Volume, gallons	Rate, gpm	Time, minutes
Transfer unwashed sludge feed to wash tank	693.9	75	9.3
Dewater sludge feed by centrifugation	693.9	5	129.5
Add water for first wash	489.3	75	6.5
Centrifuge first wash slurry	653.0	12	59.2
Add water for second wash	489.3	75	6.5
Centrifuge second wash slurry	641.5	12	58.2
Slurry washed sludge cake	150.6	0	5.0
Transfer washed sludge slurry to washed sludge run tank	150.6	75	2.0
Total cycle time			276.2

TABLE 4.22

Centrifuge Cycle

		Dewatering Step		First Wash		Second Wash	
Operation	Speed, rpm	Feed Rate, gpm	Time Required, minutes	Feed Rate, gpm	Time, minutes	Feed Rate, gpm	Time, minutes
Acceleration	50-400	0	0.8	0	0.8	0	0.8
Fill basket	400-1400	30	4.0	30	4.0	30	4.0
Feed	1400	5	114.7	12	44.4	12	43.4
Cake compaction	1400	1	5.0	1	5.0	1	5.0
Skim and decelerate	1400-50	0	3.0	0	3.0	0	3.0
Unload cake	50	0	2.0	0	2.0	0	2.0
Total Time			129.5		59.2		58.2

TABLE 4.23

Description of Synthetic Sludge Waste*

Composition Waste Slurry	Washed, Dried Sludge	Liquid
3.8 wt % solids	35.2 wt % Fe^{3+}	5.9 M Na^+
25.3 wt % salt	1.5 wt % Al^{3+}	3.7 M OH^-
70.9 wt % water	10.6 wt % Mn^{3+}	0.44 M AlO_4^-
	2.9 wt % Ca^{2+}	1.1 M NO_3^-
	5.3 wt % Ni^{2+}	0.46 M NO_2^-
	0.8 wt % Na^+	0.13 M SO_4^{2-}
	43.7 wt % other	0.12 M CO_3^{2-}

---

* Suspended solids - 12 vol % as measured by centrifugation at 5000 g's for 3 minutes

Density - 1.27 g/mL at 20°C

Particle Size - Near logarithmically declining fractional population/particle diameter distribution; bimodal fractional volume/particle diameter distribution with mean diameters of 2.5 μm and 10 μm and 1σ values of 1.2 μm and 2.3 μm, respectively.

Rheology - Newtonian fluid with 6 cp viscosity at 20°C

TABLE 4.24

Small Scale TNX Centrifuge Performance With Undiluted Slurry Feed

GPM Feed	% Sludge Recovery	Sludge Capacity, % Basket Fill at Solids Overflow*	Cake Water Content, lb water/lb solids
0.1	99.6	104	2.8
0.25	97.1	93	2.8
0.5	92.1	88	2.9

---

* Based on average cake thickness as measured after the five-minute cake compaction spin.

TABLE 4.25

Centrifuge Scaleup

	Feed Rate in gpm		
% Sludge Recovery	12-Inch TNX Centrifuge	48-Inch TNX Centrifuge	Feed Flow Factor
88.9	1.1	23	21
96.4	0.75	16	21
97.2	0.72	16	22
98.9	0.46	10	22
99.6	0.46	11	24
99.7	0.44	11	25
		Average	23

TABLE 4.26

Na^+, NO_3^-, and SO_4^{2-} Concentrations in Washed Sludge

	Dry wt %	
	Measured	Specification
Na^+	1.1	≤ 5
NO_3^-	1.4	≤ 10
SO_4^{2-}	0.5	≤ 3

TABLE 4.27

Spray Dryer Product Bulk Density[a]

Feedrate, L/hr	Pour Density, g/mL	Vibrated Density, g/mL
175	0.52	0.77
250	0.64	0.83
300	0.66	0.79

---

[a] A skeletal density of 3.18 g/cc was determined at the Du Pont Engineering Test Center on product produced during a 21" spray dryer run at PNL.

TABLE 4.28

Particle Size Distribution of Powder Produced with Simulated SRP Feed in the PNL 36-Inch Spray Dryer

Particle Size	Cumulative Amount Smaller Than Stated Size, Vol %			
Microns	175 L/hr	250 L/hr	280 L/hr	300 L/hr
2	0.20	0.00	0.00	0.00
6	8.20	0.50	0.00	0.00
10	17.6	1.50	0.10	0.10
20	48.4	6.50	1.00	0.80
30	58.0	13.0	4.90	3.00
40	69.4	41.0	14.4	6.70
50	100[a]	67.6	31.1	15.2
60		80.2	46.3	28.6
70		100.0	62.0	48.2
80			75.6	67.9
90			91.3	91.7
100			100.0	100.0

---

[a] 100% less than 44 microns.

TABLE 4.29

Median Particle Diameter of Spray Dryer Product

	Median Particle Diameter, μm			
	175 L/hr	250 L/hr	280 L/hr	300 L/hr
Volume %	25.8	45.7	63.1	70.1
Number %	3.67	9.05	32.6	31.9

TABLE 4.30

Spray Dryer Product Composition, wt %

	Feedrate, L/hr		
Component	175	250	300
Na	12.0	10.5	13.0
Fe	16.1	14.5	17.8
Al	17.8	21.6	14.2
Mn	7.1	6.3	7.6
Ca	1.2	1.9	1.6
CO_3^{2-}	2.6	3.5	6.5
Wt. loss @ 200°C	0.07	0.22	1.0
Wt. loss @ 800°C	3.8	5.5	7.6

TABLE 4.31

Elemental and Ionic Analyses of Spray Dryer Product

Element or Ion	Wt % in Calcine[a]	Wt % Insoluble
Fe	23.5	>95.0
Na	13.9	5.7
Al	8.4	40.0
Mn	5.5	~100.0
Ni	3.2	>96.0
Ca	1.9	>97.0
Carbonate	5.2	b
Nitrate	1.2	12.5

---

a. Percentages do not total 100% because oxide, water, and sulfate contents are not available.

b. Carbonate was calculated from total carbon analysis.

TABLE 4.32

TGA Analysis and DTA Analyses of Spray Dryer Product

Region	Type Reaction	Weight Loss, %	Comments
20 - 90°C	Endothermic	7	Loss of adsorbed species
90 - 500°C	Endothermic	6	Loss of adsorbed water
500 - 620°C	Exothermic	4	Decomposition
620 - 1150°C	(Small exotherm at 770°)	1	Decomposition and/or vaporization
	Total	18	

TABLE 4.33

Summary of PNL Spray Dryer Tests Using Simulated SRP Waste Feed

Test No.	Spray Chamber	Feed Type	Wall Temp, °C	Feed Rate, L/hr
First[a]	21-in	Avg. Comp. TNX Prepared	∿700-725	15-50[b]
Second[a]	21-in	Avg. Comp. TNX Prepared PNL Washed	700-725	30-55[b]
Third[c]	36-in	50/50 Mixture Avg. & Composite TNX Prepared	∿800	175-300[d]
Fourth[e]	36-in	Composite PNL Prepared Vendor Chemicals	∿800	200

---

a. The principal objectives of this test was to (1) demonstrate feasibility of drying an SRP-type waste, (2) determine dryer capacity, (3) evaluate sintered metal filter performance and (4) evaluate dryer wall scaling.

b. Feed rate was limited by furnace output.

c. The primary objective of this run was to obtain capacity data for use in sizing the SRP prototype spray dryer.

d. Feed pump limited.

e. The primary objective of this test was to evaluate the effect of long-term operation on sintered-metal filter performance and dryer wall scaling.

TABLE 4.34

Rheology of Non-Newtonian Melts

Sludge	Amount, wt, %	T, °C	m	n
Average	35	1200	877	0.69
		1150	1550	0.60
		1100	2320	0.52
		1050	3090	0.53
		1000	4460	0.52
Average	45	1200	3140	0.56
		1100	7720	0.46

TABLE 4.35

Composition Dependence of Coefficients

$a_i = b_o + b_1\,(Si) + b_2\,(Na) + b_3\,(Li) + b_4\,(Fe) + b_5\,(Al)$

a_i	b_o	b_1	b_2	b_3	b_4	b_5
a_o	−28.357	+1.865	−27.235	+109.851	+0.5047	+0.2884
a_1	+81029	−5008	+71821	−289822	−1440	−864.65
a_2	-5.57×10^7	$+3.24 \times 10^7$	-4.57×10^7	$+1.85 \times 10^8$	$+1.02 \times 10^6$	$+6.4 \times 10^5$

TABLE 4.36

Effect of Mixing Frit and Waste on Dissolution Rate

Frit	Waste	Mixed	Rate (g/in.^{2} hr)
21	Composite	No	4.47
		Yes	51.3
	High Aluminum	No	0.57
		Yes	34.0

TABLE 4.37

Mixing and Homogenization of Glass Melts

Melt*	Minimum Residence Time**
21-Al-35/Mixed	6-8 hours
21-Al-35/Unmixed	>2 days
21-Fe-35/Mixed	4-6 hours
21-Fe-35/Unmixed	>2 days (slag)
411-Fe-35/Mixed	1 hour
411-Fe-35/Unmixed	>2 days (slag)

---

* Melt composition is frit number (21 or 411) - sludge type - amount of sludge (wt %).

** Time required to produce a homogeneous melt. Tests lasted up to 48 hours. There was no discernible difference among samples heated longer than 10 hours.

TABLE 4.38

Effect of Frit Particle Size on Melting Behavior of Sludge Feed

Frit	Particle Size (mm)	Waste Dissolving Rate (g/in.^{2}-hr)	Foam Factor[a]
22[b]	0.30-1.7	29.0	0.40
	<1.7	32.0	0.35
	0.15-0.30	48.8	0.15
	<0.15	21.4	0.40
411[c]	0.30-1.7	19.4	0.40
	0.15-0.30	37.8	0.10
	<0.15	26.0	0.30
21[d]	<1.7	22.8	0.20
	<0.3	51.2	0.05

---

a. Measure of foam stability. Surface clearing time normalized to unit weight of the batch added to the melter.

b. Feed contained 75 wt % Frit 22, 22.5 wt % composite sludge, 2.5 wt % AW-500 zeolite. Melt temperature 1150°C.

c. Feed contained 75 wt % Frit 411, 25 wt % composite sludge. Melt temperature 1050°C.

d. Feed contained 75 wt % Frit 21, 25 wt % composite sludge. Melt temperature 1150°C.

TABLE 4.39

Total Particle and Mass Loading in Spray Dryer Off-Gas Stream

	Particle Size Range, micrometer			
	0.32-0.755	0.50-2.75	1.10-12.25	2.0-20.0
Total Particle Loading, particles/acf	7.74+07	4.44+05	6.4+04	5.9+03
Mass Laoding, g/acf[a]	6.08-06	8.18-07	4.3-07	4.0-07

---

a. Assumes a particle density of 4 g/cc.

TABLE 4.40

Composition of Supernate Used in 700-Gallon GS Tests

		High-Caustic Flowsheet (PTDS No. 2)	Initial Flowsheet (PTDS No. 1)
Molarity of:	NaOH	1.8	0.71
	$NaNO_3$	1.8	2.2
	$NaNO_2$	0.83	0.93
	Na_2CO_3	0.23	0.25
	Na_2SO_4	0.23	0.25
	$NaAlO_2$	0.43	0.42

TABLE 4.41

700-Gallon GS Results (PTDS No. 1 Flowsheet)

		Run No.						
		1	2	3	4	5	6	7
Type Centrate		Avg	Comp	Comp	Comp	Comp	Comp	Comp
Feed:	Liquid level, in.	61	62	63	62	62.5	63	63
	Volume, gal	715	725	735	725	730	735	740
	Sludge content, ppm	4000	8500	5000	7300	4000	8000	7000
Starch Added, lb/T suspended matter		25	12	20	14	12	8	9
Maximum Temperature, °C		65	71	70	70	65	32	60
Average Settling Rate, in./hr		16.0	12.9	10.2	10.0	7.8	10.5	14.0
Product;	Volume, % of feed	83.2	83.4	87.8	86.2	89.0	88.4	88.4
	Sludge content, ppm	150	80	50	30	25	30	16

TABLE 4.42

700-Gallon GS Results - (PTDS No. 2 Flowsheet)

	Run No.	
	8	9
Type Centrate	Comp	Comp
Feed: Liquid level, in.	63	64
Volume, gal	740	745
Sludge content, ppm	3500	4000
Starch Added, lb/T suspended matter	13.0	11.6
Maximum Temperature, °C	94	98
Average Settling Rate, in./hr	10.8	11.2
Product; Volume, % of feed	88.5	90.6
Sludge content, ppm	40	50

TABLE 4.43

Large-Scale GS Results

	Run No.									
	1	2	3	4	5	6	7	8	9	10
Flowsheet, M NaOH	1.8	1.8	1.8	1.8	1.8	1.8	1.0	1.0	1.0	1.0
Feed: liquid level, in.	52.5	56.7	56.7	114	110	108	95	95	88	89
volume, gal	2550	2750	2750	5500	5350	5250	4600	4600	4250	4300
sludge content, ppm*	5750	13500	19300	6000	8500	9000	4500	9500	5300	13300
Starch Added, lb/T sludge**	8.7	8.6	9.0	11.5	12.9	16.6	12.8	12.4	15.5	15.0
Temperature, °C	65	65	65	65	65	35	65	45	40	40
Average Settling Rate, in./hr	11.7	11.9	11.9	12.2	12.5	21.6	27.1	25.6	25.1	22.0
Decanted Product, gal	1975†	2200†	2200†	4925†	700	990	1000	1030	1010	1010
Sludge content, ppm††	80	40	30	45	40	10	50	10	15	10

---

* Undecanted layer with settled sludge reslurried and resettled following Runs 1, 2, 4, 5, 7, and 9.

** Total starch added to old and new feed sludge.

† Decanted product fed to sand filters via 1150-gal-capacity sand filter feed tank.

†† Analyses of samples in sand filter feed tank from first decant at indicated settling rate.

TABLE 4.44

4-In.-Diameter Sand Filter Performance

	Filter No. 1 Primary	 No. 2 Polishing
Sand Average Particle Size, μm	490	270
Sand Height, in.	24	18
Anthracite Average Particle Size, μm	700	400
Anthracite Height, in.	8	3
Sludge Content in Feed, ppm	50	5
Clean-Bed ΔP at 1.2 gpm/ft^2, psi	0.8	2.5
ΔP Rise, psi/100 Bed Volumes	<1	<0.5
Sludge Content in Product, ppm	5	1

TABLE 4.45

Large-Scale Sand Filter Feed Results

	GS and Sand Filter Run No.			
	1*	2**	3***	4***
Supernate Feed Rate, gal/min-ft^2	1.0	0.98	0.96	1.34
Polymer† Add Rate, gal/min-ft^2	0.015	0.015	0.07	0.04
Time of Feed, hr	20.3	8.0, 14.3††	23.8	31.7, 6.4¶
Avg Feed Sludge Content, ppm	54	31	25	35
Filtrate Quality				
Avg Hourly Coulter Solids, ppm	0.33	1.12¶¶	0.22	0.15
Spot Checks: Centrifugable Sludge, ppm	2	2.5	1	1
Spot Checks: Turbidity, JTU	0.10	0.16	0.07	0.07
Primary Column ΔP Rise, psi/100 bed volumes	<0.5	0.3	0.3	0.4

---

* Feed, polymer going to both columns in parallel for 18 hours before switch to series operation.

** Feed in series to primary, then polish filter. Polymer to primary filter only.

*** Feed in series to primary, then polish filter. Polymer to both filters.

† Versa TL® 700. (Trademark, National Starch and Chemical Corp., Bridgewater, N. J.)

†† Debris in feed pump caused failure in 8 hr. Shutdown 6 hr before restarting. Pump dismantled and cleaned before Run No. 3.

¶ Run interrupted 5 hr to backwash primary column.

¶¶ Hourly samples during last 14 hr only.

TABLE 4.46

Large-Scale Sand Filter Backwash Results

(Backwash Liquid - 2M NaOH)

		GS and Sand Filter Run No.		
		1	2	3
Total Sludge Feed, lb		1.06	0.673	0.545
Lb Sludge Removed, 75 gal/ft^2 per wash				
Primary Filter:	Wash #1	0.710	0.469	0.350
	Wash #2	0.054	0.048	0.139
	Wash #3	-----	-----	0.051
Polishing Filter:	Wash #1	0.216	0.056	0.023
	Wash #2	0.058	0.029	0.014
% of Sludge Removed		98	89	106

TABLE 4.47

Viscosities of Stock Solutions for Settling/Filtration

Brookfield RVT Spindle Speed, rpm	Viscosity of 0.1% Versa TL® 700 at Temperature of 20.2°C, cp.	Viscosity of 8% Flojel 60® at Temperature of 18.8°C, cp.
100	38	88
50	35	73
20	29	65
10	30	65
5	-	70

TABLE 4.48

Proposed Cesium Ion Exchange Cycle Schedule

	Stream Volume		Flow Rate		Time, Hours	Flow Direction
	CV*	Gallons	CV/hr	gpm/ft^2		
Load (Feed)	20	30,500	1.67	1.67	12	Down
First Rinse**	5	7,625	1.67	1.67	3	Down
Elute†	10	15,250	1.2	1.2	8.33	Up
Second Rinse**	3	4,575	1.2	1.2	2.5	Up
Regenerate††	5	7,625	1.2	1.2	4.16	Up
Standby	-	-	-	-	1	-
Total	-	-	-	-	31	-

---

* 1 CV = 1 column volume = 1525 gal = 204 ft^3. Height = 8 ft. Diameter - 68 in.

** H_2O.

† 2M NH_4OH - 2M $(NH_4)_2CO_3$.

†† 2M NaOH.

TABLE 4.49

Requirements for Optimum Results in Countercurrent Ion Exchange [32]

1. During upflow service or regeneration, movement of resin particles must be held to a minimum. The bed should remain packed. Even slight bed fluidization tends to destroy the flat ionic interface and can result in increased leakage or premature breakthrough.
2. If and when the bed is backwashed and resin expansion is allowed, the amount of regenerant should be at least twice the amount used in previous cycles. Since fluidization upsets the regular arrangement of ions in the column, the effluent end must be thoroughly regenerated to restore the full advantage of the countercurrent effect.
3. Uniform distribution is essential in both upflow and downflow to minimize channeling. Conventional laterals may not be adequate, especially for the bottom distributor. European equipment designers have exerted considerable effort to assure good distribution on upflow. One such concept involves the use of a double-layer porous disc made from fused quartz sand and pebbles in the upper and lower layers, respectively.
4. Care must be exercised to exclude air in both downflow and upflow operations. Any bubble formation in the resin bed will disturb the piston-like effect required.
5. The service run must be stopped at very nearly the same effluent level each time to achieve consistency. Preferably the cutoff point should be somewhat lower than the specified or required effluent level (be it sodium, silica, conductivity, or other parameter).
6. Decationized (or acidified) water should be used for rinsing cation exchangers and deionized water for rinsing anion exchangers. If raw water is used, the first part of the service run may be discarded to avoid contamination of the product water. Such practice is necessary only when very high-purity effluents are required.

TABLE 4.50

Physical Properties of *Duolite* ARC-359 Ion Exchange Resin[a]

Physical Characteristics

16-50 mesh, black granular, macroporous, received as water-saturated Na^+ form, 45-55% moisture

Bulk Density, Wet Resin

Na^+ form	0.70 g/cc
$NH_4{}^+$ form	0.72 g/cc

Specific Gravity

H^+ form	1.37 g/mL - dry
$Na_2{}^+$ form	1.60 g/mL - dry, 1.17 g/mL water - wet
→ Na^+ form	1.53 g/mL - dry
$NH_4{}^+$ form	1.56 g/mL - dry, 1.17 g/mL water - wet

Typical Wet Screen Analyses - Hydrogen Form

	Percent Retained		
Screen Numbers	1	2	3
10-16	6.7	17.0	22.8[b]
16-20	52.3	33.5	40.4
20-30	28.3	27.3	28.8
30-40	11.0	16.3	3.0
40-50	1.5	4.1	3.9
Pan	0.2	1.8	1.2

Maximum Service Temperature

40°C

Swelling

See Table 4.51

Bed Expansion in Upflow

(*Duolite* Bulletin TS-7719, June 21, 1977)
Wet Screen Analysis = Batch 1, Section 4 above

Flow Rate		*Bed Expansion, %* *NH_4 Ionic Form*		
ft/sec	*gpm/ft²*	*13°C*	*24°C*	*38°C*
0.0091	4.1	26	15	12
0.0137	6.1	47	34	28
0.0182	8.2	68	54	43
0.0228	10.2	-	72	58
0.0268	12.0	-	-	72
		Na_2 Ionic Form[c]		
0.0091	4.1	21	11	-
0.0137	6.1	39	25	14
0.0182	8.2	57	39	26
0.0228	10.2	75	53	39
0.0268	12.0	-	66	50

Pressure Drop in Downflow

0.1 to 0.2 psi/ft at 1.12 gpm/ft² (calculated)

---

[a] Manufacturer's information, unless otherwise indicated. Information on *Duolite* C-3 resin is presented where it is not available for ARC-359.

[b] Determined at SRL - SED, 12/22/77.

[c] NaOH regenerated.

TABLE 4.51

"Duolite" ARC-359 Density and Swelling Data [70]

		Basis of 1 g Air-Dried Resin			
Equilibrated with Solution Sodium Form	Particle Density, g/mL	Weight of Swollen Resin, g	Volume of Swollen Particles, mL	Bulk Volume of Swollen Resin, mL	Bulk Density, g/mL
Water	1.17	1.580	1.348	2.257	0.700
0.01M NaOH	-	1.617	-	-	-
0.05	1.20	1.776	1.480	2.500	0.710
0.1	1.20	1.986	1.655	2.550	0.778
0.5	1.24	2.067	1.667	2.747	0.752
1.0	1.23	2.088	1.698	2.950	0.708
2.0	1.24	2.122	1.711	3.000	0.707
5.0	1.29	2.085	1.616	2.747	0.759
0.01M $NaNO_3$		1.398			
0.05		1.375			
0.1		1.414			
0.5		1.360			
1.0		1.366			
5.0		1.486			
2M $(NH_4)_2CO_3$		1.526			
Ammonium Form					
Water	1.17	1.68	1.44	-	-
$(NH_4)_2CO_3$,					
0.05M	-	1.688	-	-	-
0.1M	1.15	1.681	1.46	2.353	0.714
0.5M	-	1.687	-	2.353	0.717
1.0M	1.16	1.680	1.45	2.353	0.714
2.0M	1.17	1.690	1.44	2.252	0.714

Swelling Data from Glass Column Observations

	Relative Swelling		
		Reference Flowsheet	
	All Upflow		Direction
2M NaOH	1	1	Up
After water rinse	1	-	
Filtered Supernate (composite)	1.11	0.96	Down
After water rinse	1.05	0.98	Down
2M $(NH_4)_2CO_3$ - 2M NH_4OH	0.89	0.94	Up
After water rinse	0.94	0.93	Up

TABLE 4.52

Ion Exchange Capacity of "Duolite" ARC-359 Resin
(Sulfonic acid exchange capacity - 2.49 g eq/kg air-dry resin)

NaOH Concentration, moles/liter	Excess[a] Na^+ Capacity g eq/kg dry resin	Total Na^+ Capacity g eq/kg dry resin	g eq/L wet resin	lb eq/gal wet resin
0.0047	0.776	3.266	1.445	0.0120
0.0114	1.58	4.07	1.732	0.0144
0.0492	2.02	4.51	1.804	0.0150
0.0987	2.59	5.08	1.992	0.0166
0.1926	3.13	5.62	2.153	0.0180
0.497	3.77	6.26	2.276	0.0190
0.964	4.46	6.95	2.356	0.0196
1.975	5.31	7.80	2.600	0.0217
4.979	7.97	10.46	3.804	0.0317

---

a. Excess above sulfonic acid exchange capacity.

TABLE 4.53

Effects of Feed Na^+ and OH^- on Cs^+ Sorption by "Duolite" ARC-359 Resin

Na^+, M	OH^-, M	K_d
1	0.5	343
2	0.5	142
3	0.5	78
4	0.5	57
5	0.5	40
1	1.0	462
2	1.0	199
3	1.0	100
4	1.0	70
5	1.0	45
2	2.0	371
3	2.0	176
4	2.0	110
5	5.0	347
6	5.0	205
7	5.0	132
8	5.0	90
9	5.0	66
10	5.0	48

TABLE 4.54

Effect of Cs^+ Concentration on the Sorption of Cs^+ by "Duolite" ARC-359 Resin from 4.75M $NaNO_3$-1.0M NaOH

$[Cs^+]$, M	K_d(obs)	K_d (calc)
0.0976	6.35	5.81
0.0443	9.01	9.68
0.00922	15.4	17.4
0.00402	19.3	20.1
0.000779	30.3	24.9
0.0000572	50.7	54.6
0.0 (Tracer)	101	98.18

Two-site Equation Parameters

$K_{s_1}^{\equiv}/[Na^+] = 27.7$ $Ex_1 = 0.773$

$K_{s_2}^{\equiv}/[Na^+] = 23262$ $Ex_2 = 0.00333$

TABLE 4.55

Removal of ^{137}Cs and Plutonium by *Duolite* ARC-359 Resin (Feed ^{137}Cs = 2.0 to 2.2 Ci/gal)

		Supernate				*Plutonium*	
Test No.	*Principal Cations in Sludge*	*Volume, CV*	*Flow Rate CV/hr*	*gal/min-ft²*	*^{137}Cs DF*	*Feed, µCi/gal*	*DF*
1	None	20	1	0.22	3.7×10^5	5	60
2	Fe,Al,Mn,U	20	1	0.22	8.0×10^5	27	8
3	Fe,Al,Mn,U	30	2	0.45	4.2×10^5	17	5
4	Fe,U,Mn,Na	40	2	0.45	3.9×10^5	65	38
5	Fe,U,Na,Al	60	3	0.67	3.7×10^5[a]	*b*	-
6	Al,U,Fe,Hg	40	1	0.22	4.2×10^5	*b*	-
7	Al,U,Fe,Ca	40	2	0.44	3.7×10^5	51	30
8	Al,Fe,Ca,Mn	40	1	0.22	6.1×10^5	51	42
9	None	20	1	0.22	2.9×10^5	25,600[c]	300

---

a. Average over first 40 column volumes. Others averaged over entire test.

b. Feed composition uncertain. Product composition 3.4 (in Test 5) and 2.6 (in Test 6) µCi/gal.

c. Saturated with ^{238}Pu.

TABLE 4.56

Strontium Ion Exchange Cycle Schedule

Stream	Throughput		Average Flow Rate		Time Hours	Flow Direction
	CV*	Gallons	CV/hr	gpm/ft^2		
Feed	40	30,500	3,33	1.67	12	Down
Cs First Rinse	10	7,625	3.33	1.67	3	Down
Sr First Rinse	1.5	1,143	3.33	1.67	0.45	Down
Elute	6	4,572	1	0.5	6	Up
Sr 2nd Rinse	3.0	2,286	1	0.5	3	Up
Stand by					6.55	
Total					31	

---

* Column volume; the strontium ion exchange column will have a resin bed of 762 gallons with a sufficient freeboard to allow at least a 75% expansion of the bed during backwash.

TABLE 4.57

Sr Distribution Coefficients for Various Ion Exchange Resins

Resin	Distribution Coefficient
"Amberlite" IRC-50	31
"Amberlite" IRC-84	17
"Amberlite" IRC-718	384
"Chelex" 100*	215
"Dowex" A1	162
"Dowex" CCR-2	20
"Dowex" XFS-4132**	306
"Duolite" C-464	40
"Duolite" ES-467	440

---

* "Chelex" 100 is an analytical grade of "Dowex" A1.

** "Dowex" XFS-4132 is a macroporous version of "Dowex" A1.

TABLE 4.58

Selectivity Series for "Amberlite" IRC-718 Distribution Coefficients K_d for Metal Ions in 1.0M NaOH - 4.75M $NaNO_3$

Ion	K_d meq/g dry resin per meq/mL liquid
Sr	3250
Hg	840
Yb	674
Ca	293
Ba	176
Ag	89
Cr	53
Cu	38
Pb	28

Strontium K_d's in Other Solutions

2M NaOH, 3.75M $NaNO_3$	1205
1M NaOH, 4.15M $NaNO_3$, 0.3M Na_2SO_4	1040
1M NaOH, 4.15M $NaNO_3$, 0.3M Na_2SO_4	2360

TABLE 4.59

Bulk Density of "Ionsiv" IE-95

	TNX Data[55] (lb_m/ft^3)	Manufacturers Data[54] (lb_m/ft^3)
Dry	46.8	40
Hydrated	56.7	46

"Linde Ionsiv" IE-95 is marketed as an acid resistant molecular sieve [54]. Zeolites are also known for stability at higher pH's (<12). They are resistant to high temperature, oxidation/reduction, and ionizing radiation. They do not exhibit osmotic shock nor are they fouled by organics [56].

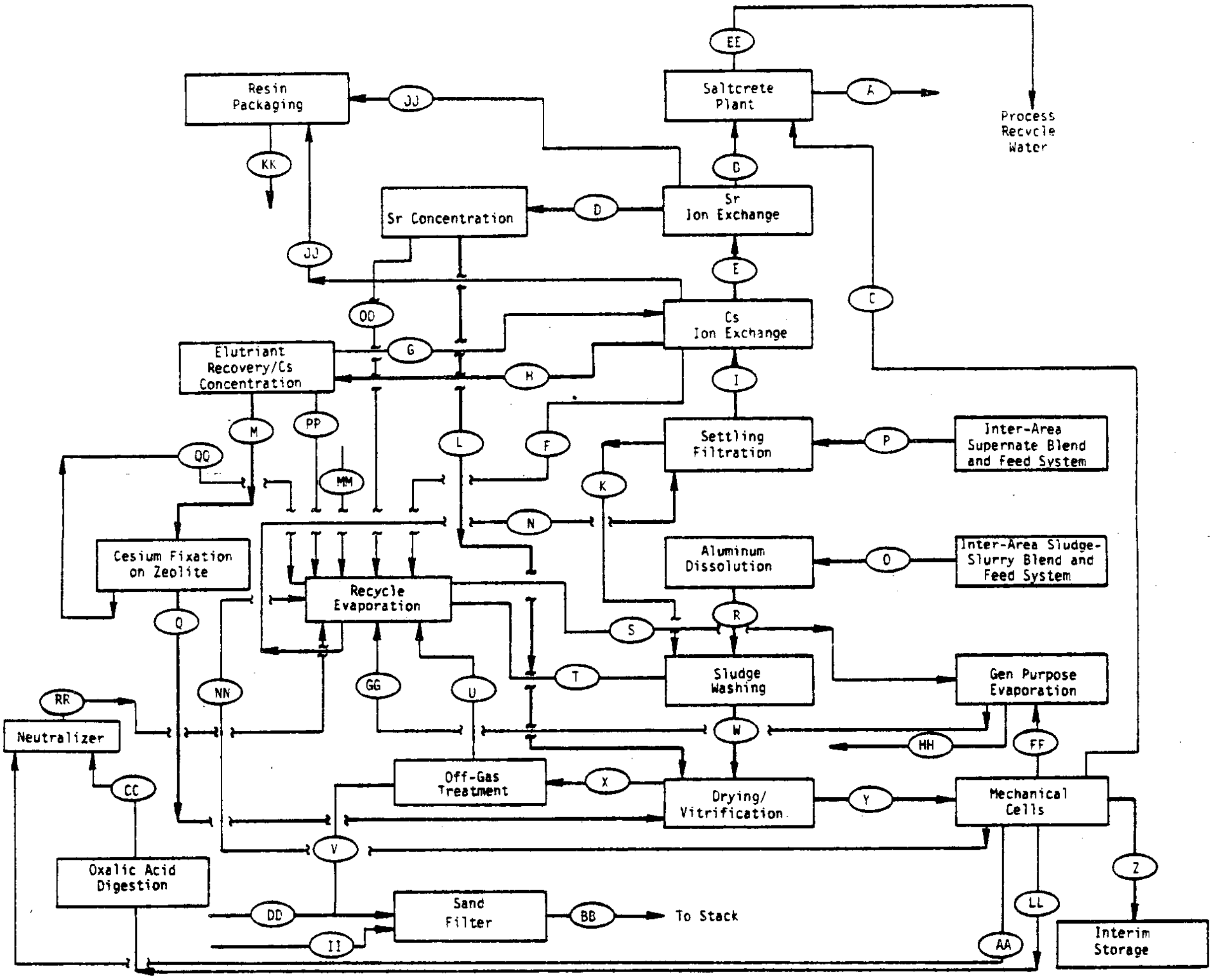
TABLE 4.60

Fixation of Cs-137 on Zeolites

Absorbent	Composition	Size	Cs-137 Sorption*
"Linde" AW-500	Chabazite	20 to 50 Mesh	100% retention for 70 CV 60% retention for 80 CV
"Zeolon" 900	Synthetic Mordenite	20 to 50 Mesh	100% retention for 70 CV 60% retention for 80 CV
"Zeolon" 500	80% Chabazite 20% Erionite	1/16 in. Pellets	No retention after 8 CV
"Vermiculite"		20 to 50 Mesh	No retention after 2 CV

---

* Each column volume (100 ml) of concentrate contained Cs-137 from about 2 liters of SRP waste supernate.



A	Saltcrete to Trench
B	Clarified Supernate
C	Mechanical Cell B Rinses
D	Sr Eluate
E	Clarified Supernate
F	Spent Regenerant & Rinse
G	Elutriant
H	Cs Eluate
I	Clarified Supernate
J	Centrate
K	Recycle Solids
L	Sr Concentrate
M	Cs Concentrate
N	Recycle Concentrate
O	Sludge-Slurry Feed
P	Supernate Feed
Q	Zeolite Slurry
R	Sludge Slurry
S	Recycle Evaporator Condensate
T	Spent Wash Water
U	Recycle Condensate
V	Decontaminated Off-Gas to Sand Filter
W	Washed Sludge Slurry
X	Dryer Off-Gas
Z	Packaged Product to Interim Storage
AA	Spent Etch Solution
BB	Filtered Off-Gas to Stack
CC	Digested Mechanical Cell A Oxalic
DD	Vessel Vent
EE	Evaporator Condensate
FF	Deionizer Purge
GG	General Purpose Evap Concentrate
HH	Overheads to Surface Stream
II	Canyon Air
JJ	Degraded Resin
KK	Resin to Incineration/Storage
LL	Mechanical Cell A Oxalic Acid
MM	Canyon Sump Collection
NN	Mechanical Cell A Rinses
OO	Sr Concentrator Condensate
PP	Cs Concentrator Condensate Purge
QQ	Zeolite Column Rinse
RR	Neutralized Spent Decon Solution

FIGURE 4.1 DWPF Overall Reference Flowsheet

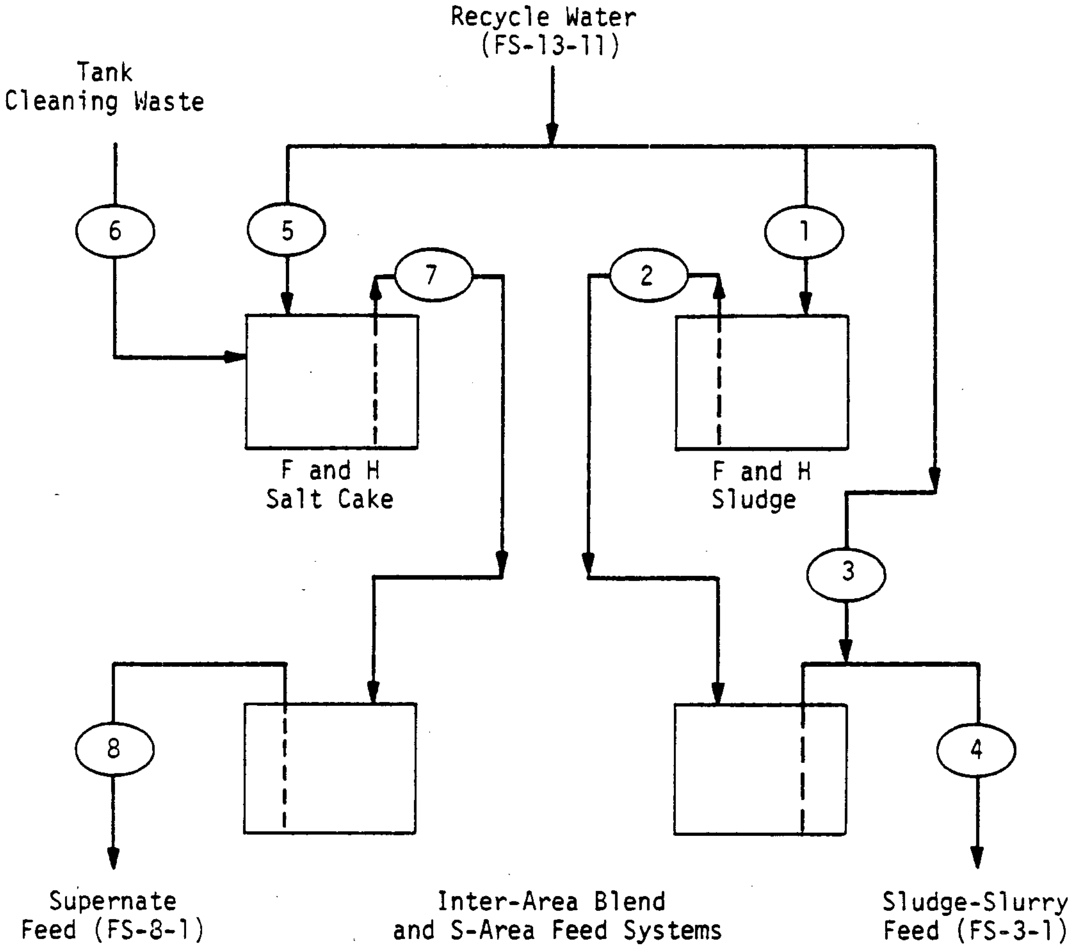
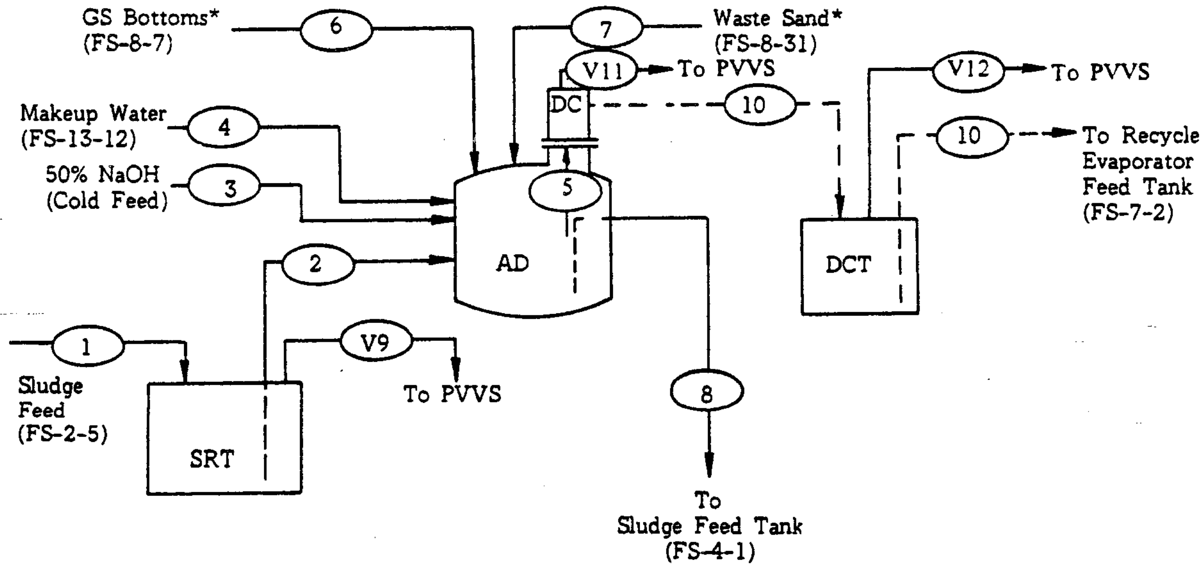


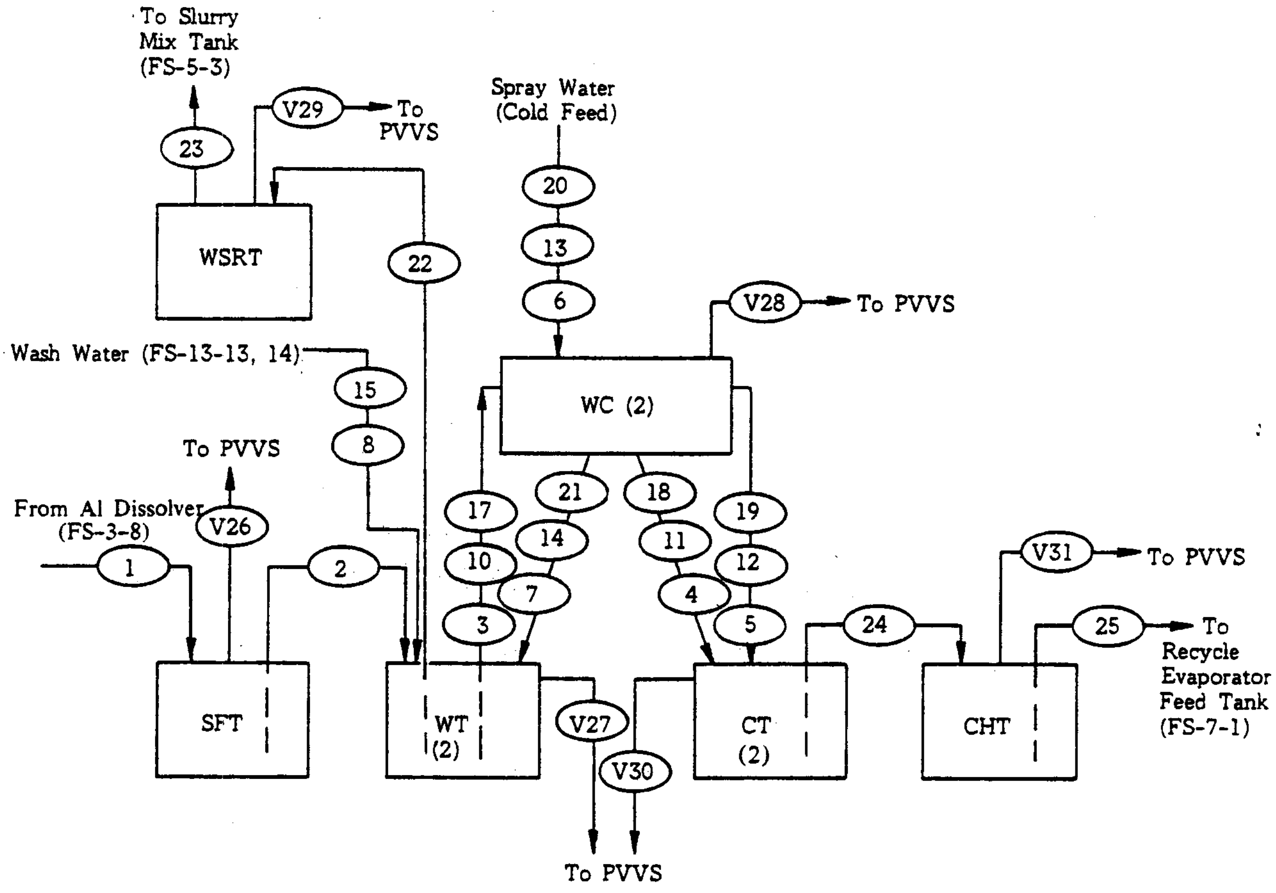
FIGURE 4.2 Sludge and Supernate Feed Preparation Flowsheet (FS-2)



SRT	Sludge Receipt Tank
AD	Aluminum Dissolver
DC	Dissolver Condenser
DCT	Dissolver Condensate Tank
PVVS	Process Vessel Vent System

** These streams are added after the aluminum dissolving step is completed.*

FIGURE 4.3 Aluminum Dissolution Flowsheet (FS-3)



SFT	Sludge Feed Tank
WT	Wash Tank
WC	Wash Centrifuge
CT	Centrate Tank
CHT	Centrate Hold Tank
WSRT	Washed Sludge Run Tank
PVVS	Process Vessel Vent System

FIGURE 4.4 Sludge Washing Flowsheet (FS-4)

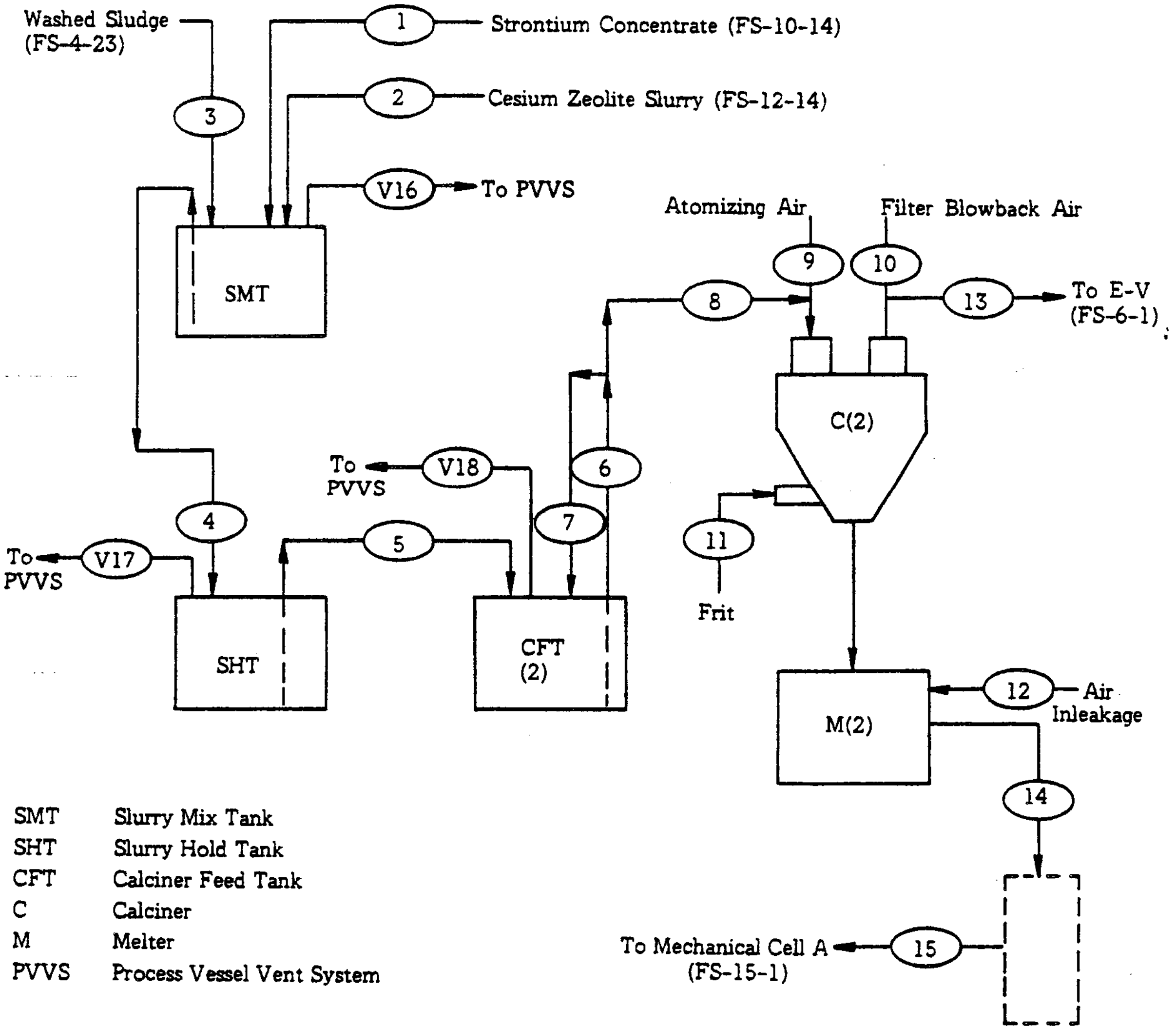
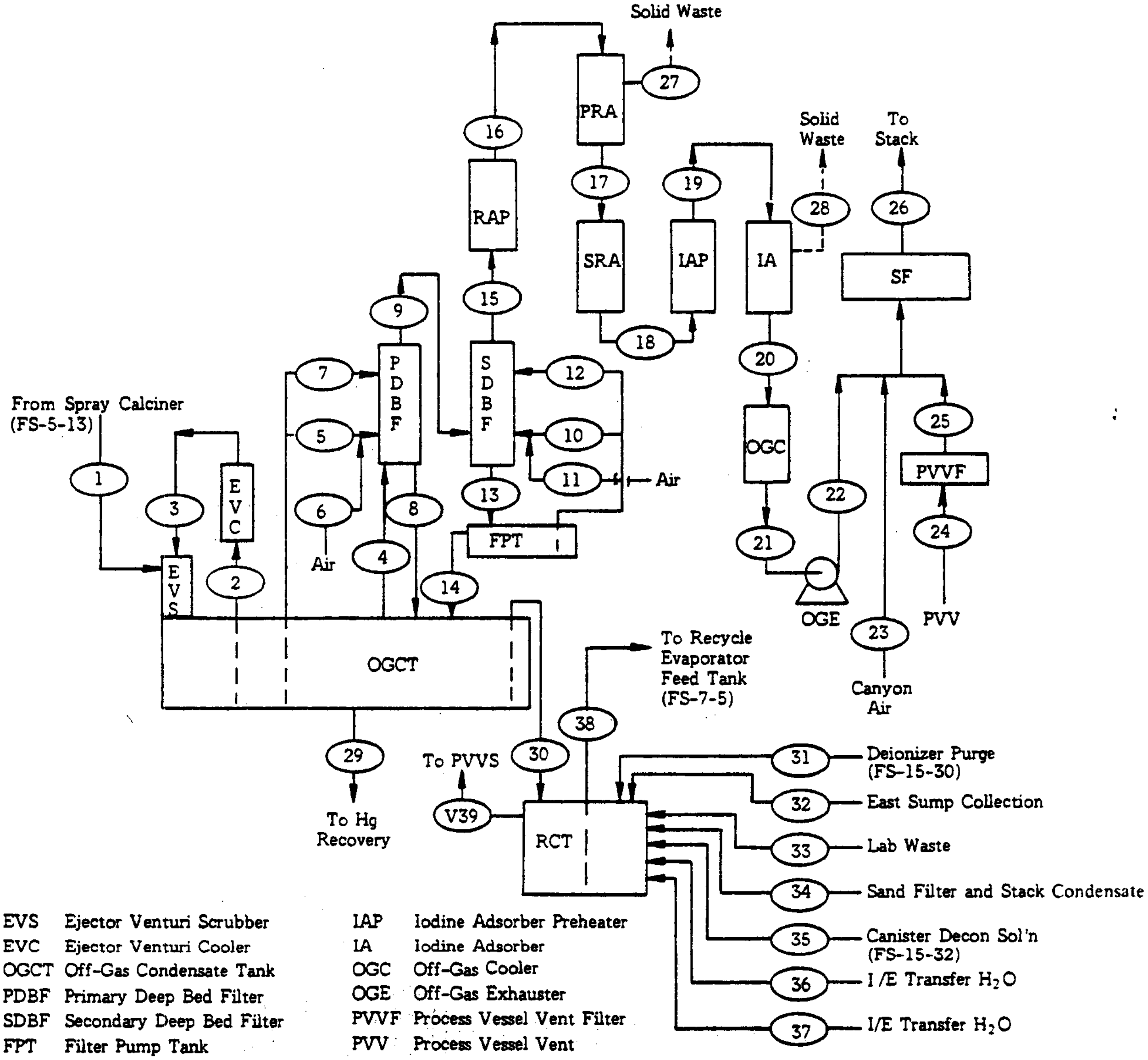
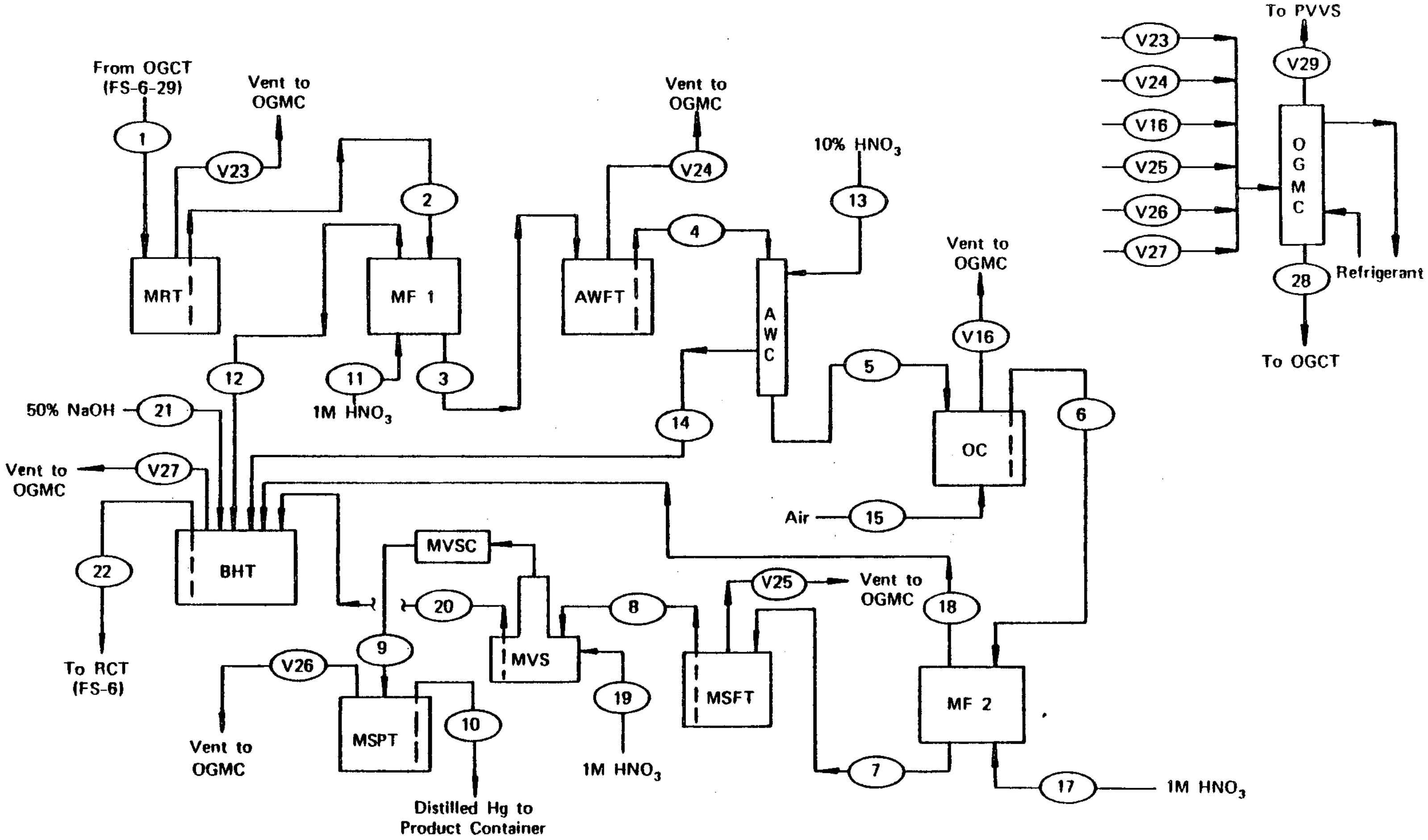


FIGURE 4.5 Spray Calcination/Vitrification Flowsheet (FS-5)



EVS	Ejector Venturi Scrubber	IAP	Iodine Adsorber Preheater
EVC	Ejector Venturi Cooler	IA	Iodine Adsorber
OGCT	Off-Gas Condensate Tank	OGC	Off-Gas Cooler
PDBF	Primary Deep Bed Filter	OGE	Off-Gas Exhauster
SDBF	Secondary Deep Bed Filter	PVVF	Process Vessel Vent Filter
FPT	Filter Pump Tank	PVV	Process Vessel Vent
RAP	Ruthenium Adsorber Preheater	SF	Sand Filter
PRA	Primary Ruthenium Adsorber	RCT	Recycle Collection Tank
SRA	Secondary Ruthenium Adsorber		

FIGURE 4.6 Off-Gas Treatment Flowsheet (FS-6)

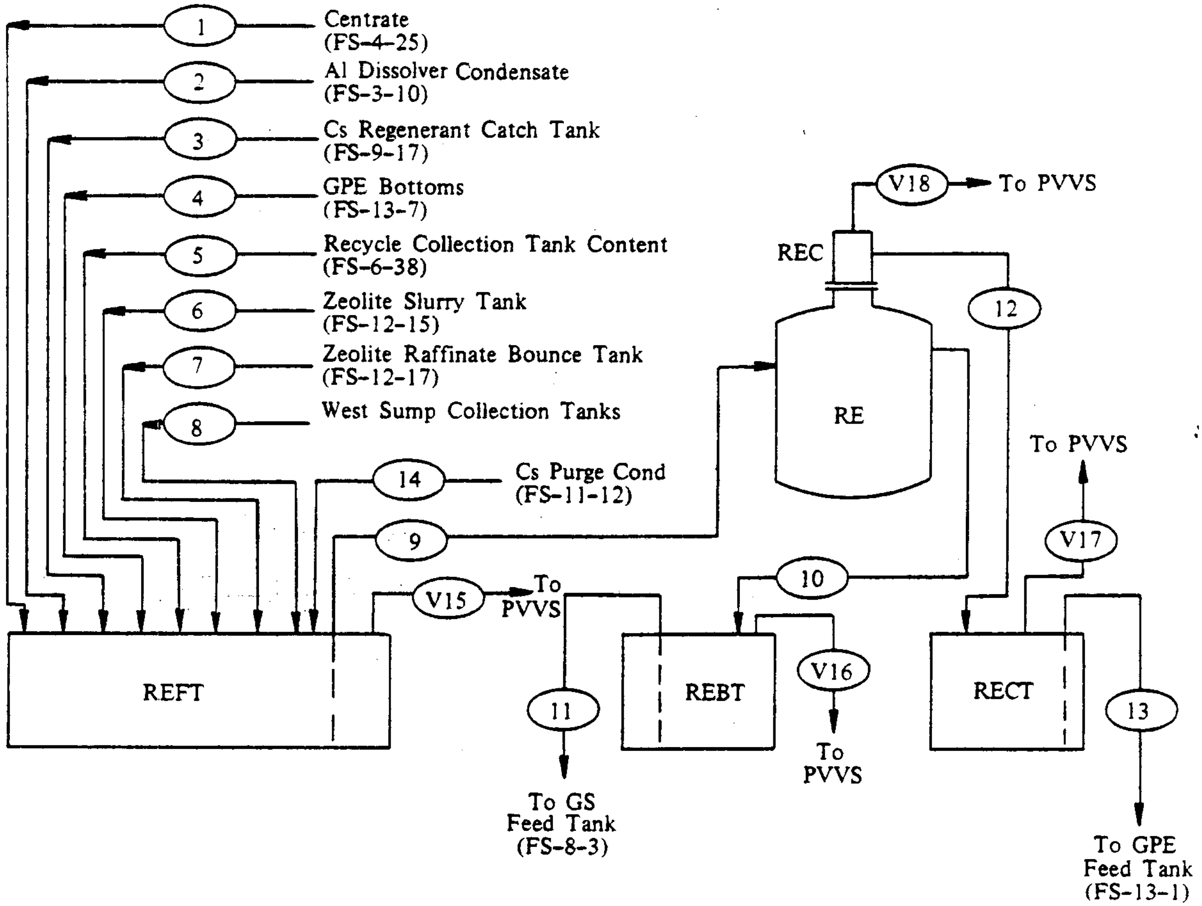


RCT – Recycle Collection Tank
OGCT – Offgas Condensate Tank
MRT – Mercury Receipt Tank
MF 1 – Mercury Filter No. 2

BHT – Backwash Hold Tank
AWFT – Acid Wash Feed Tank
AWC – Acid Wash Column
OT – Oxidation Tank
OGMC – Offgas Mercury Condenser

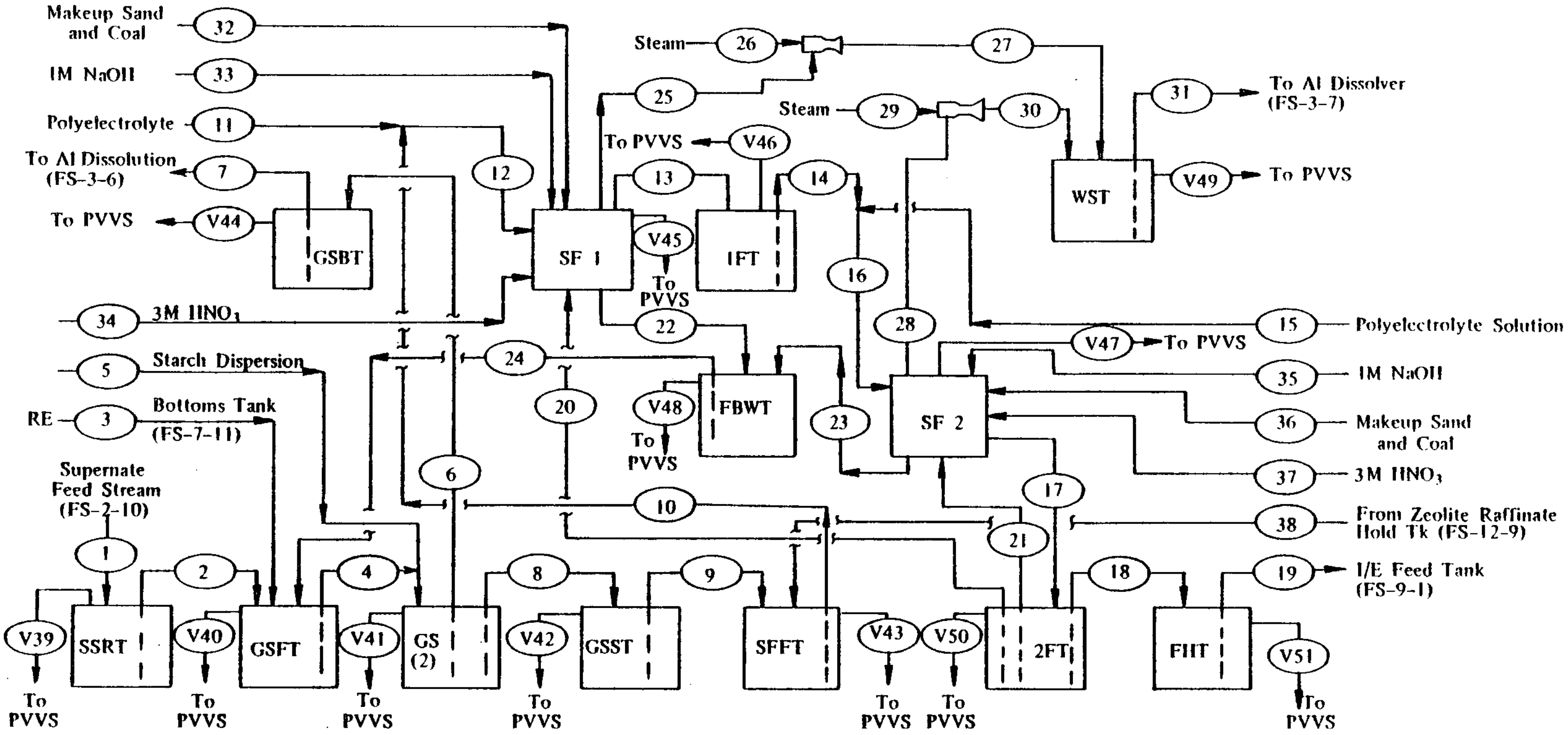
MSPT – Mercury Still Product Tank
MF 2 – Mercury Filter No. 2
MSFT – Mercury Still Feed Tank
MVS – Mercury Vacuum Still
MVSC – Mercury Vacuum Still Condenser

FIGURE 4.6A Mercury Recovery Flowsheet (FS-6A)



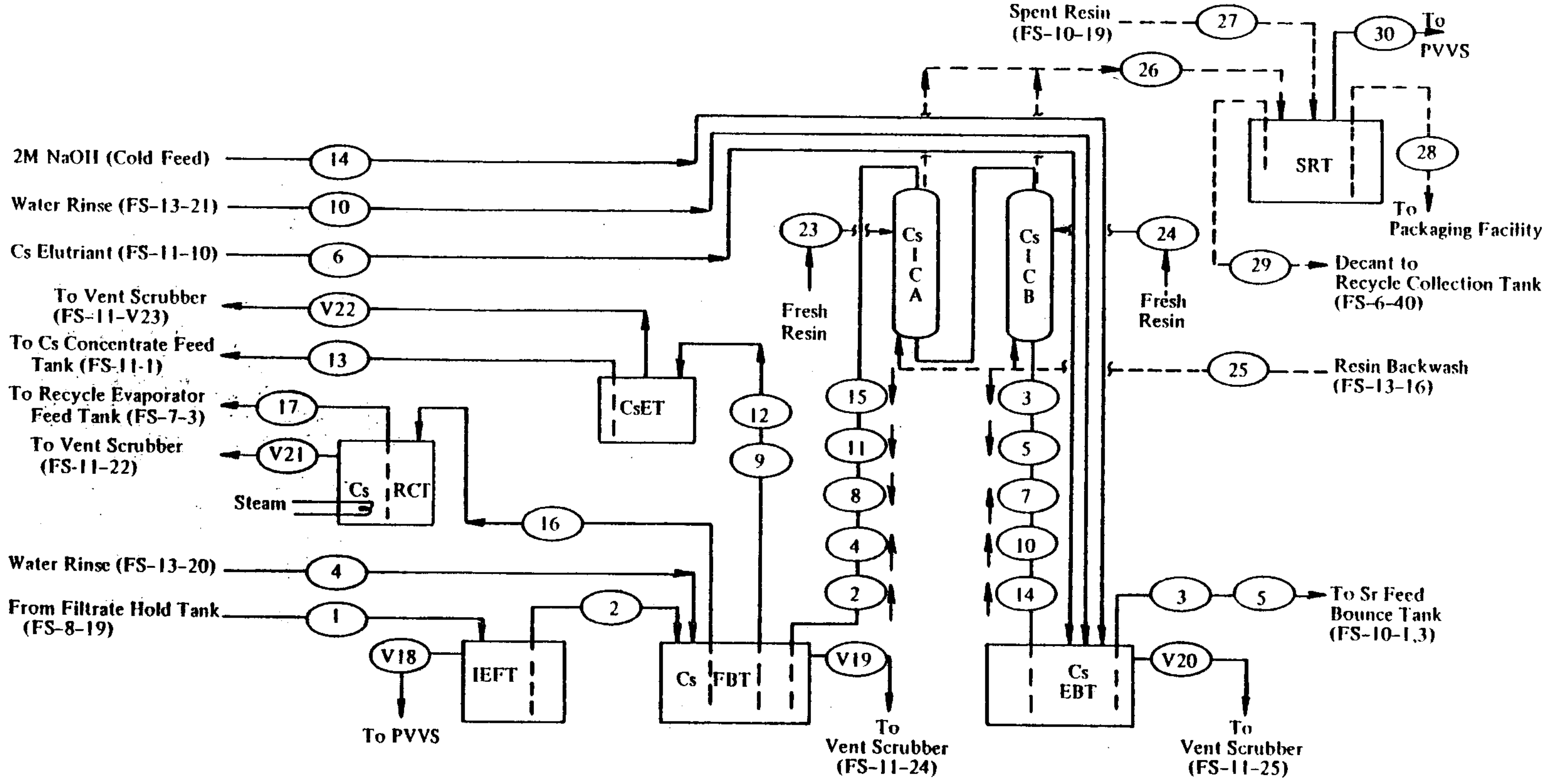
REFT	Recycle Evap Feed Tank
RE	Recycle Evaporator
REBT	Recycle Evap Bottoms Tank
REC	Recycle Evap Condenser
RECT	Recycle Evap Condensate Tank
PVVS	Process Vessel Vent System

FIGURE 4.7 Recycle Evaporation Flowsheet (FS-7)



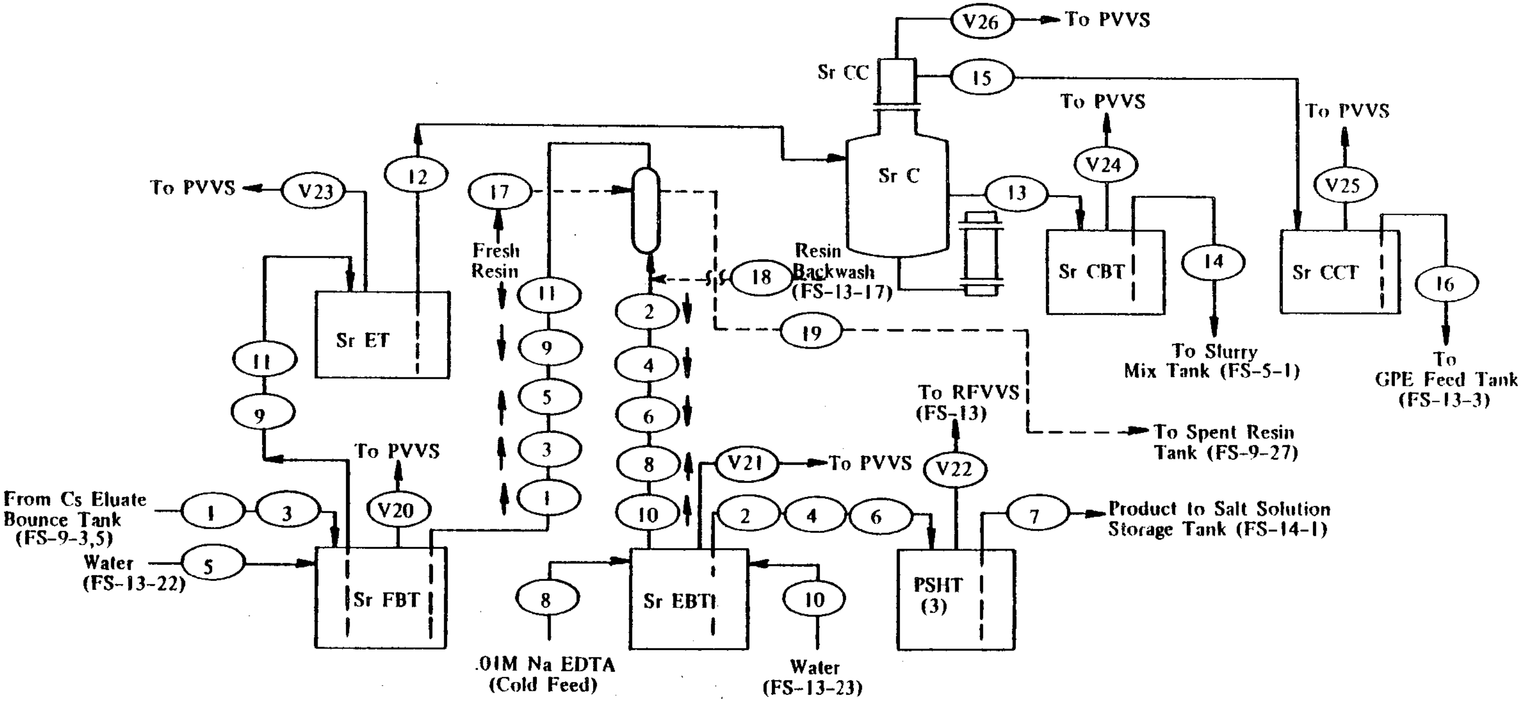
SSRT	Salt Solution Receipt Tank
GSFT	Gravity Settler Feed Tank
GS	Gravity Settler
GSST	Gravity Settler Supernate Tank
SFFT	Sand Filter Feed Tank
GSBT	Gravity Settler Bottoms Tank
SF1	Sand Filter No. 1
IFT	First Filtrate Tank
SF2	Sand Filter No. 2
2FT	Second Filtrate Tank
FBWT	Filter Backwash Tank
WST	Waste Sand Tank
FHT	Filtrate Hold Tank
PVVS	Process Vessel Vent System

FIGURE 4.8 Settling and Filtration Flowsheet (FS-8)



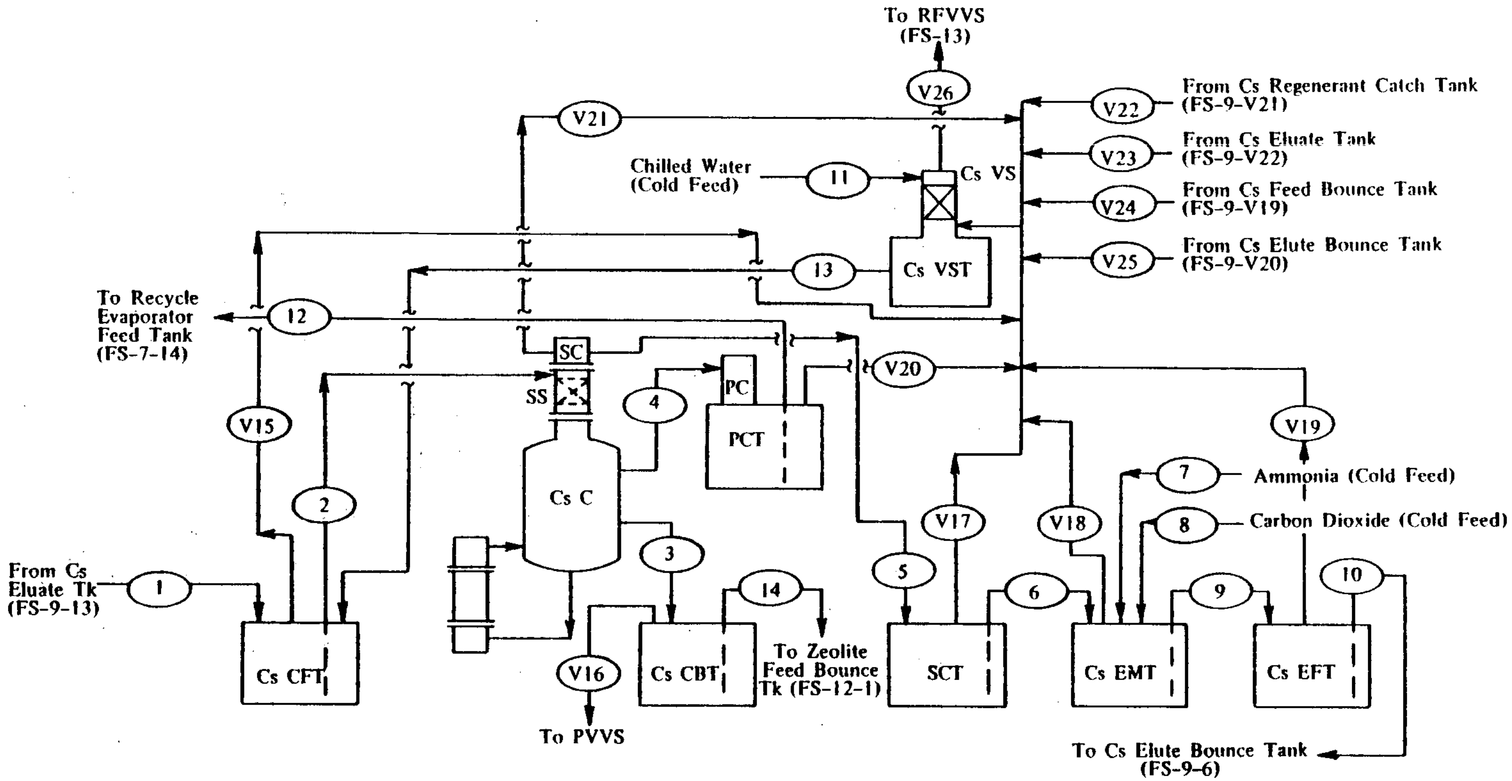
IEFT	Ion Exchange Feed Tank	Cs ICA	Cs Ion Exchange Column A
Cs FBT	Cs Feed Bounce Tank	Cs ICB	Cs Ion Exchange Column B
Cs EBT	Cs Elute Bounce Tank	SRT	Spent Resin Tank
Cs RCT	Cs Regenerant Catch Tank	PVVS	Process Vessel System
Cs ET	Cs Eluate Tank		

FIGURE 4.9 Cesium Ion Exchange Flowsheet (FS-9)



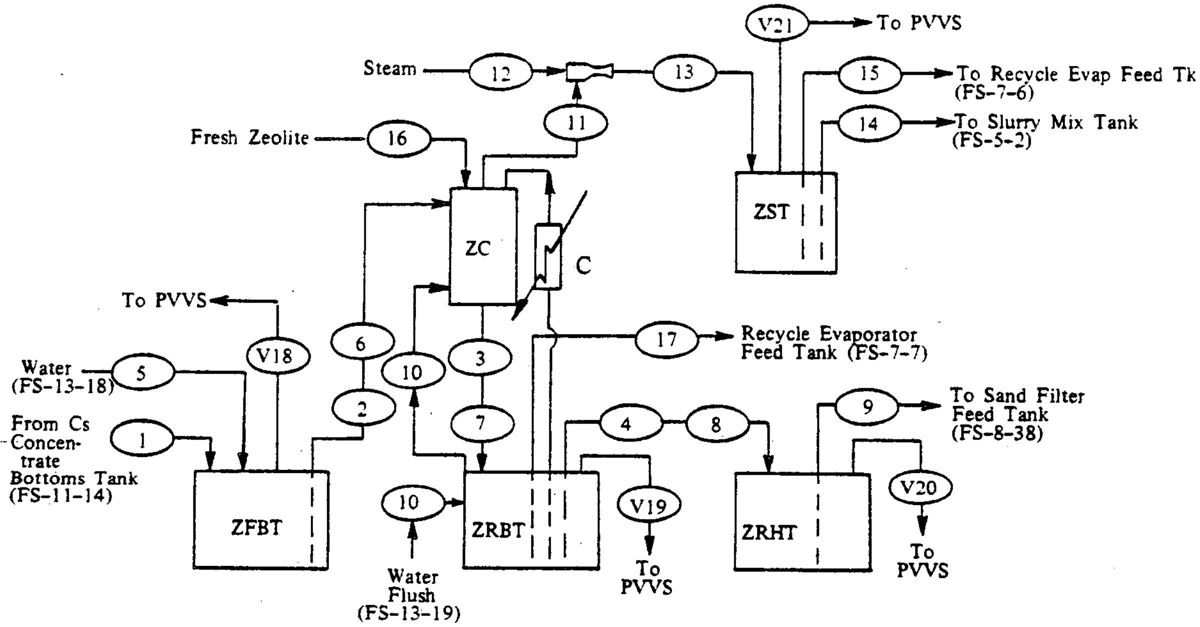
Sr FBT	Strontium Feed Bounce Tank
Sr EBT	Strontium Elute Bounce Tank
Sr ET	Strontium Eluate Tank
Sr IC	Strontium Ion Exchange Column
Sr C	Strontium Concentrator
Sr CBT	Strontium Concentrator Bottoms Tank
Sr CCT	Strontium Concentrator Condensate Tank
PSHT	Product Salt Hold Tank
PVVS	Process Vessel Vent System
RFVVS	Regulated Facility Vessel Vent System

FIGURE 4.10 Strontium Ion Exchange and Concentrator Flowsheet (FS-10)



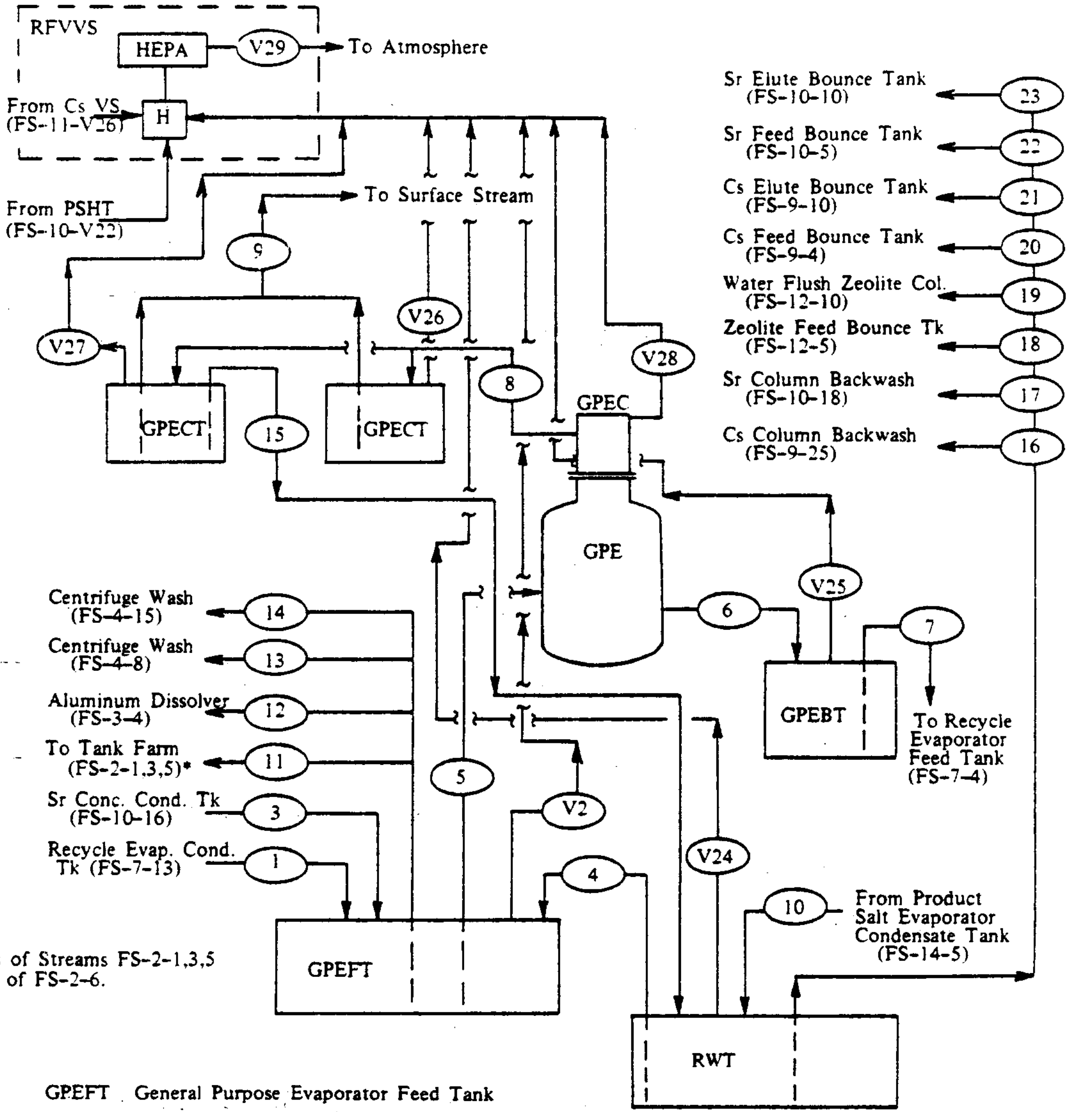
Cs CFT	Cs Concentrator Feed Tank	Cs VS	Cs Vent Scrubber
Cs C	Cs Concentrator	Cs VST	Cs Vent Scrubber Tank
Cs CBT	Cs Concentrator Bottoms Tank	SCT	Stripper Condensate Tank
PC	Purge Condenser	Cs EMT	Cs Elutriant Makeup Tank
PCT	Purge Condensate Tank	Cs EFT	Cs Elutriant Feed Tank
SS	Steam Stripper	PVVS	Process Vessel Vent System
SC	Stripper Condenser	RFVVS	Regulated Facility Vessel Vent System

FIGURE 4.11 Cesium Elutriant Recovery and Cesium Concentration (FS-11)



ZFBT	Zeolite Feed Bounce Tank
ZC	Zeolite Column
ZRBT	Zeolite Raffinate Bounce Tank
ZST	Zeolite Slurry Tank
ZRHT	Zeolite Raffinate Hold Tank
PVVS	Process Vessel Vent System
C	Cooler

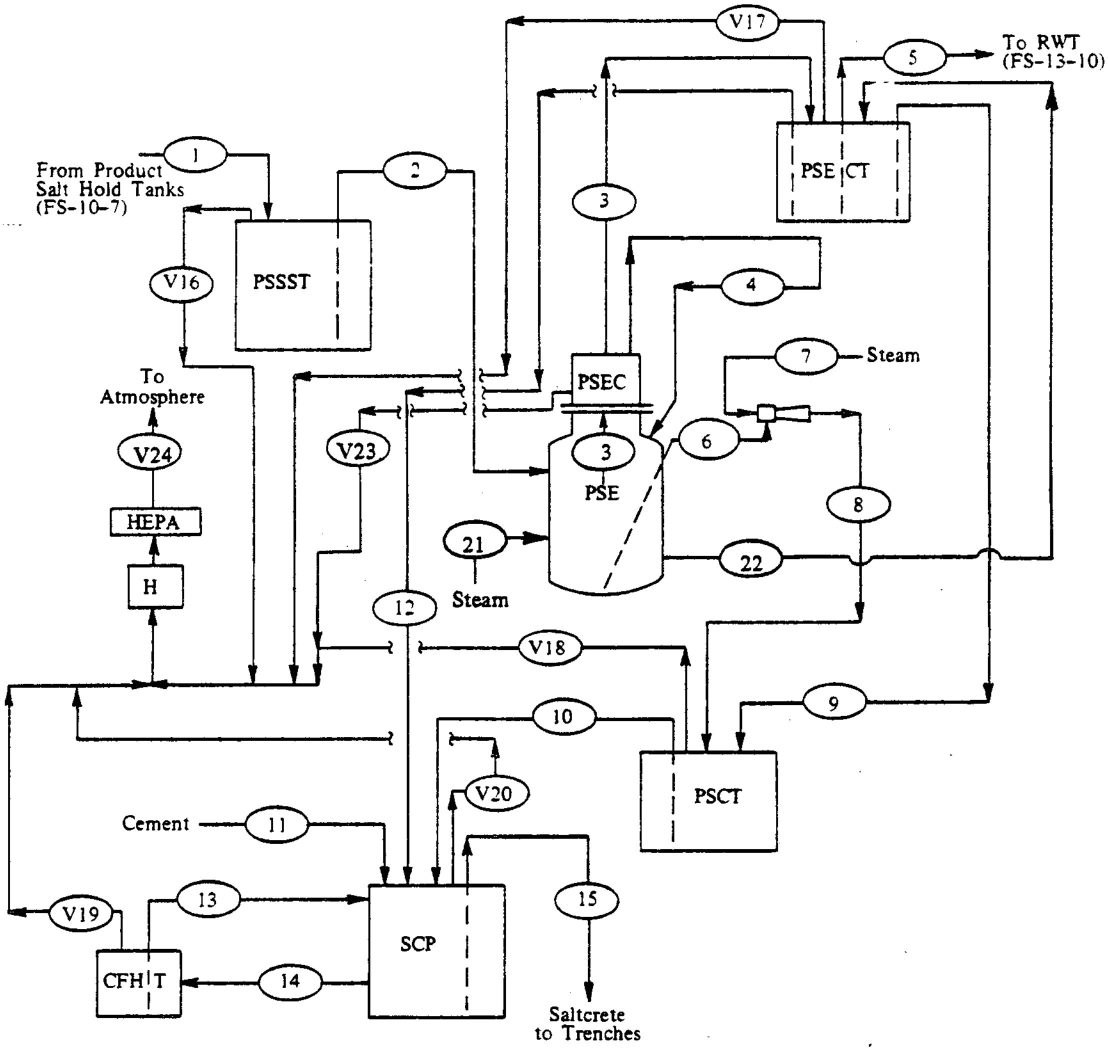
FIGURE 4.12 Cesium Fixation on Zeolite Flowsheet (FS-12)



*The flow in excess of Streams FS-2-1,3,5 is included as part of FS-2-6.

GPEFT	General Purpose Evaporator Feed Tank
GPE	General Purpose Evaporator
GPEBT	General Purpose Evaporator Bottoms Tank
GPECT	General Purpose Evaporator Condensate Tank
RFVVS	Regulated Facility Vessel Vent System
RWT	Recycle Water Tank
HEPA	High Efficiency Air Filter
H	Heater

FIGURE 4.13 General-Purpose Evaporation Flowsheet (FS-13)



PSSST	Product Salt Solution Storage Tank	PSCT	Product Salt Concentrate Tank
PSE	Product Salt Evaporator	SCP	Saltcrete Plant
PSEC	Product Salt Evaporator Condenser	CFHT	Concrete Flush Hold Tank
PSECT	Product Salt Evaporator Condensate Tank	H	Heater
		HEPA	High Efficiency Air Filter

FIGURE 4.14 Product Salt Solution Concentration and Solidification in Concrete (FS-14)

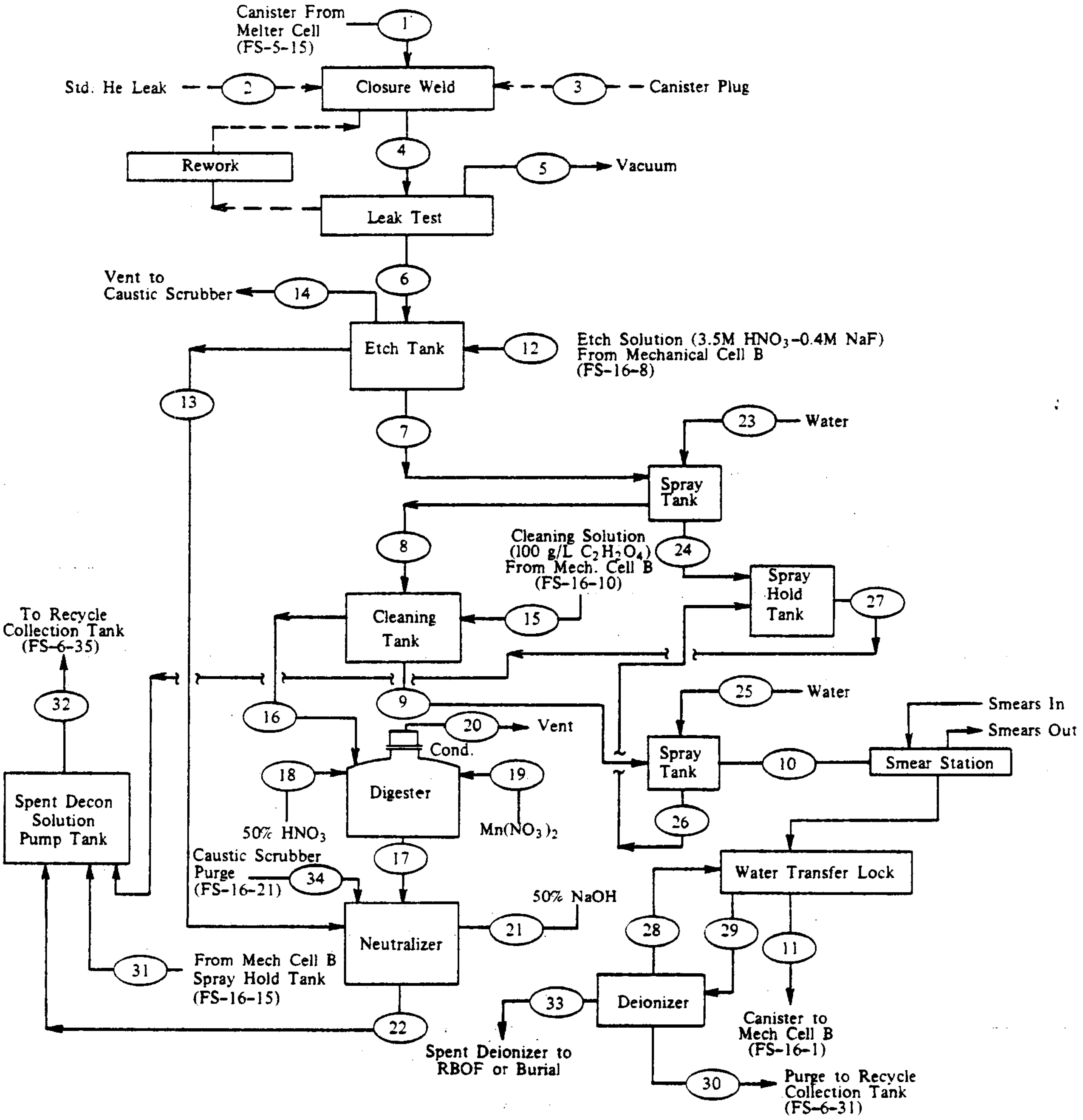


FIGURE 4.15 Mechanical Cell A Flowsheet (FS-15)

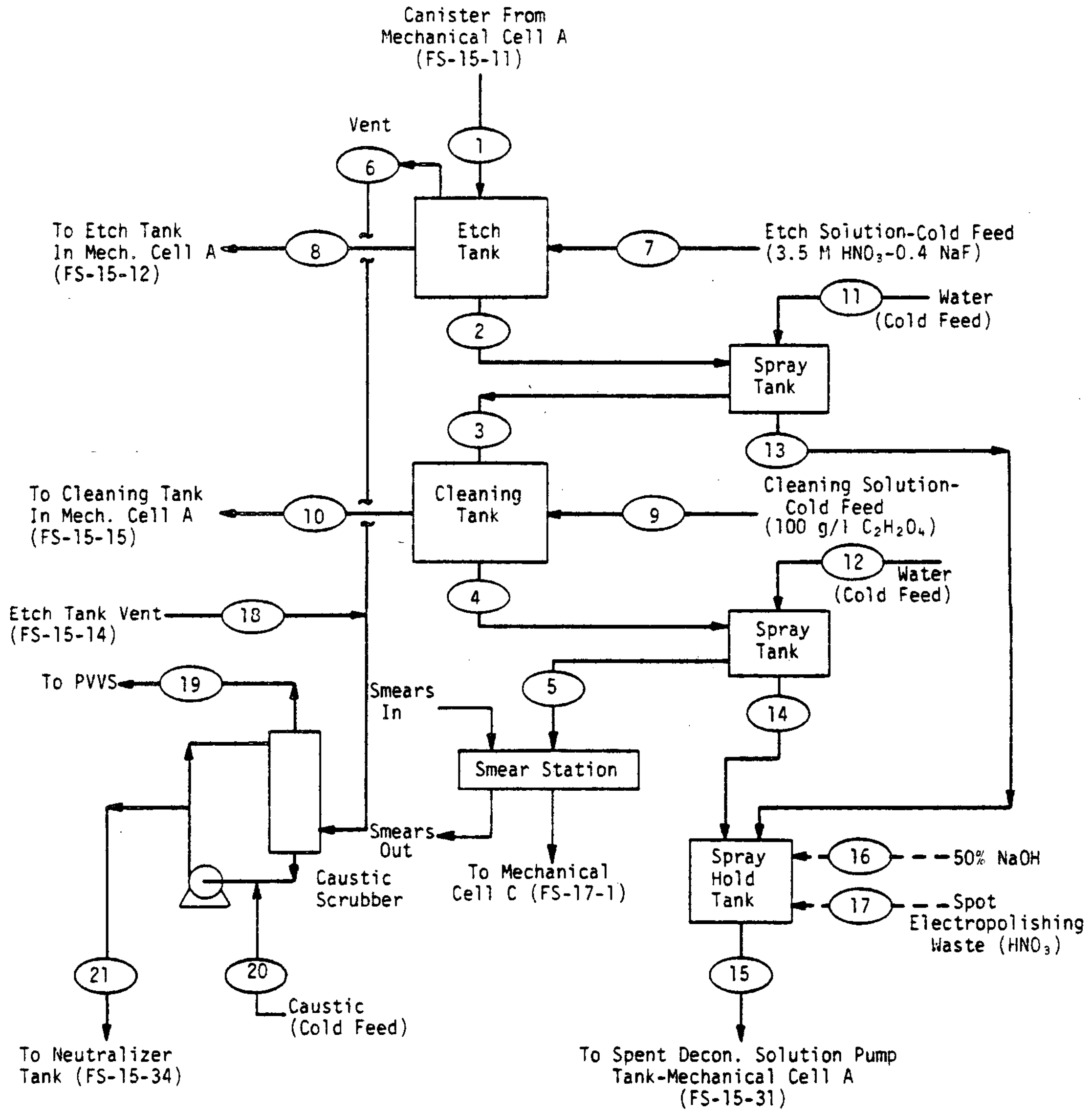


FIGURE 4.16 Mechanical Cell B Flowsheet (FS-16)

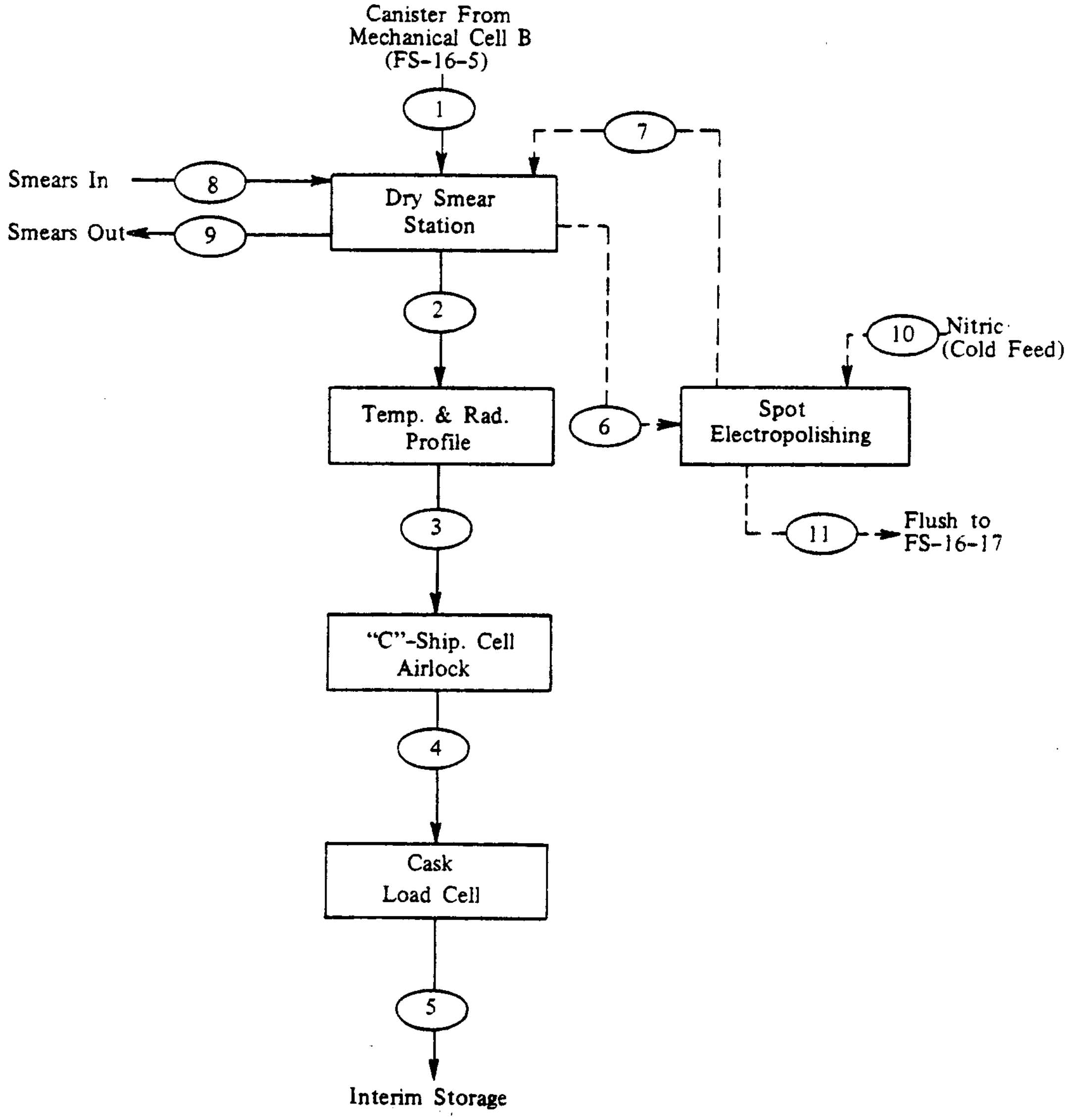


FIGURE 4.17 Mechanical Cell C Flowsheet (FS-17)

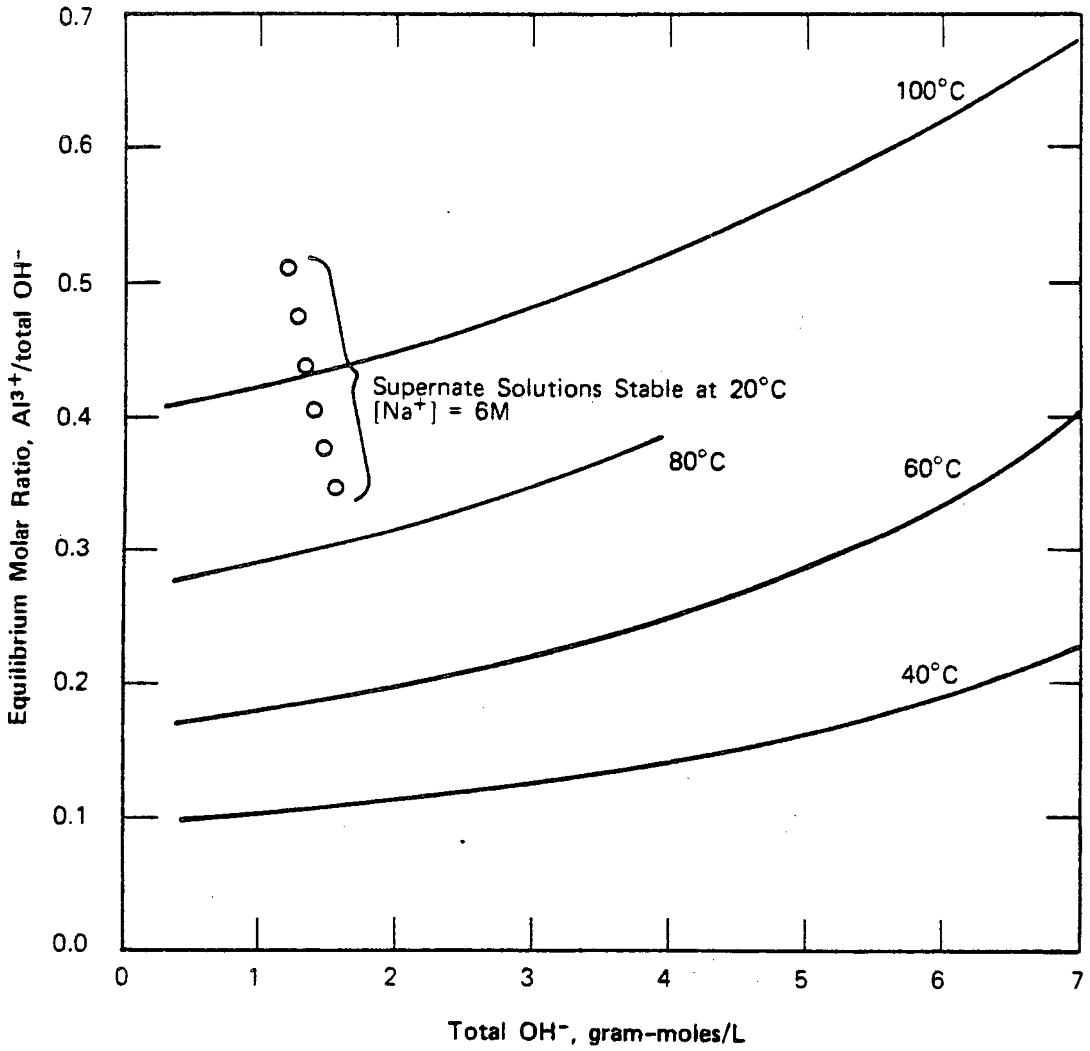


FIGURE 4.18 Solubility of Gibbsite in Caustic. Total OH^- = OH^- + Al^{3+} in solution.

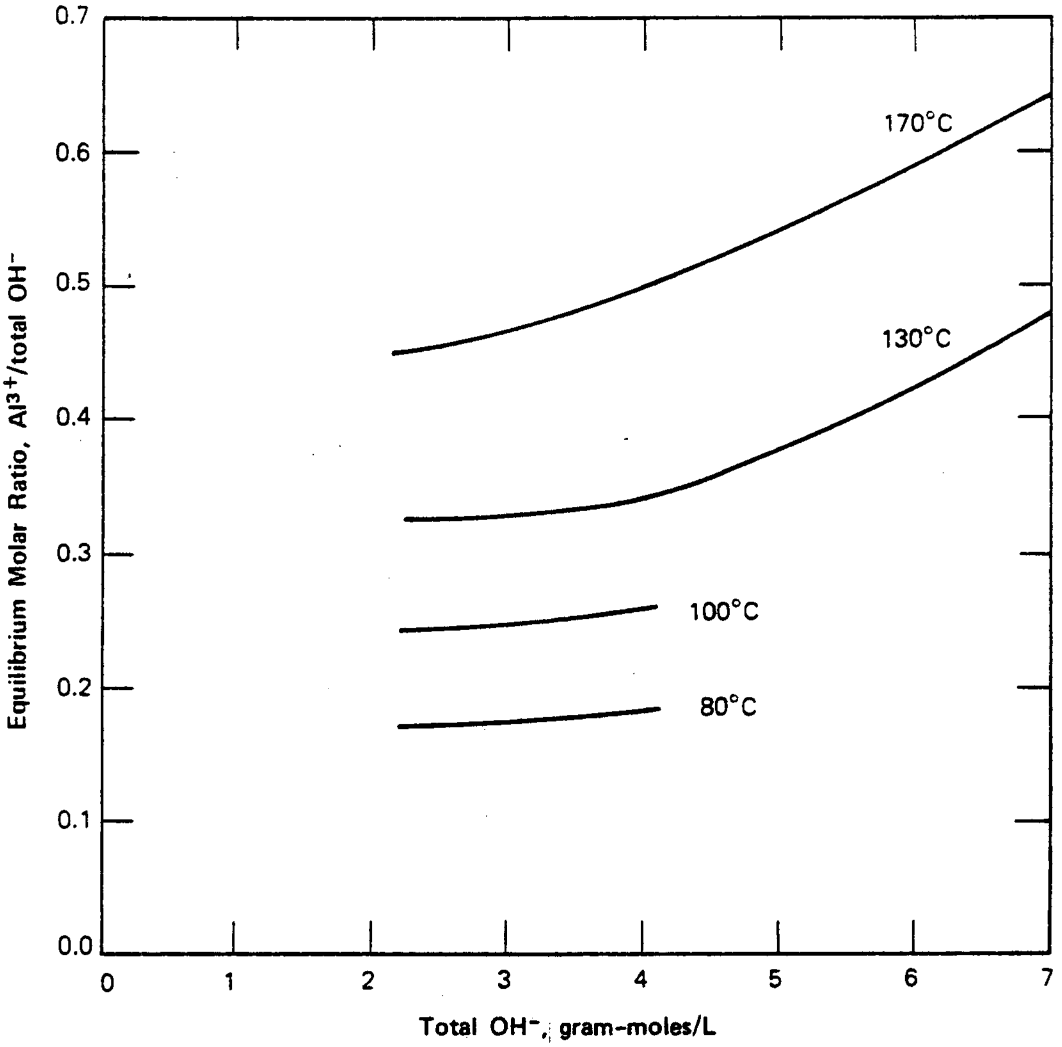


FIGURE 4.19 Solubility of Boehmite in Caustic. Total $OH^- = Al^{3+}$ in solution.

FIGURE 4.20 (Deleted)

FIGURE 4.21 (Deleted)

FIGURE 4.22 (Deleted)

FIGURE 4.23 Large-Scale Sludge Washing Facility

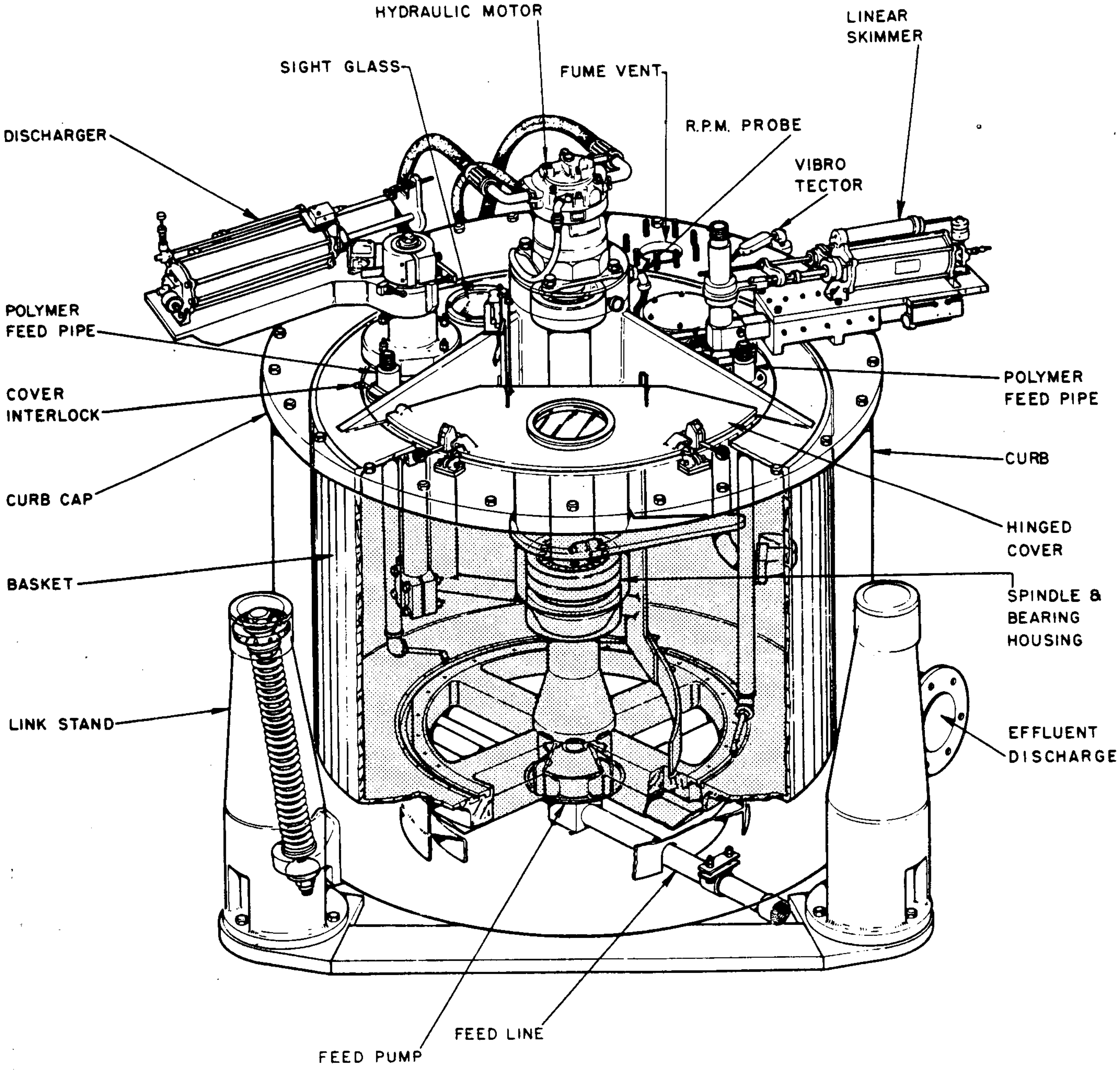
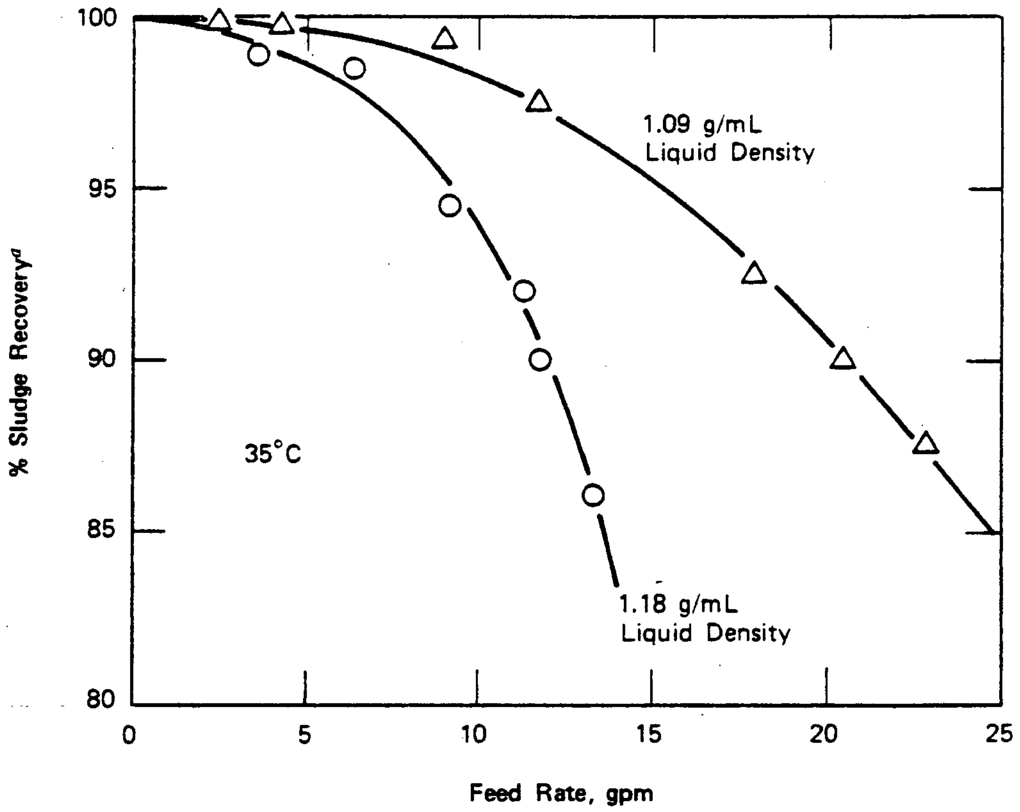


FIGURE 4.24 DeLaval Centrifuge Used in Semiworks Studies (Courtesy of the DeLaval Separator Company)



[a] $\% \text{ Sludge Recovery} = \dfrac{\text{Vol \% Sludge in Feed} - \text{Vol \% Sludge in Centrate}}{\text{Vol \% Sludge in Feed}}$

where volume % sludge is measured by centrifuging 10 mL samples at 5000 g's for 3 minutes

FIGURE 4.25 Sludge Separation in Large-Scale TNX Centrifuge

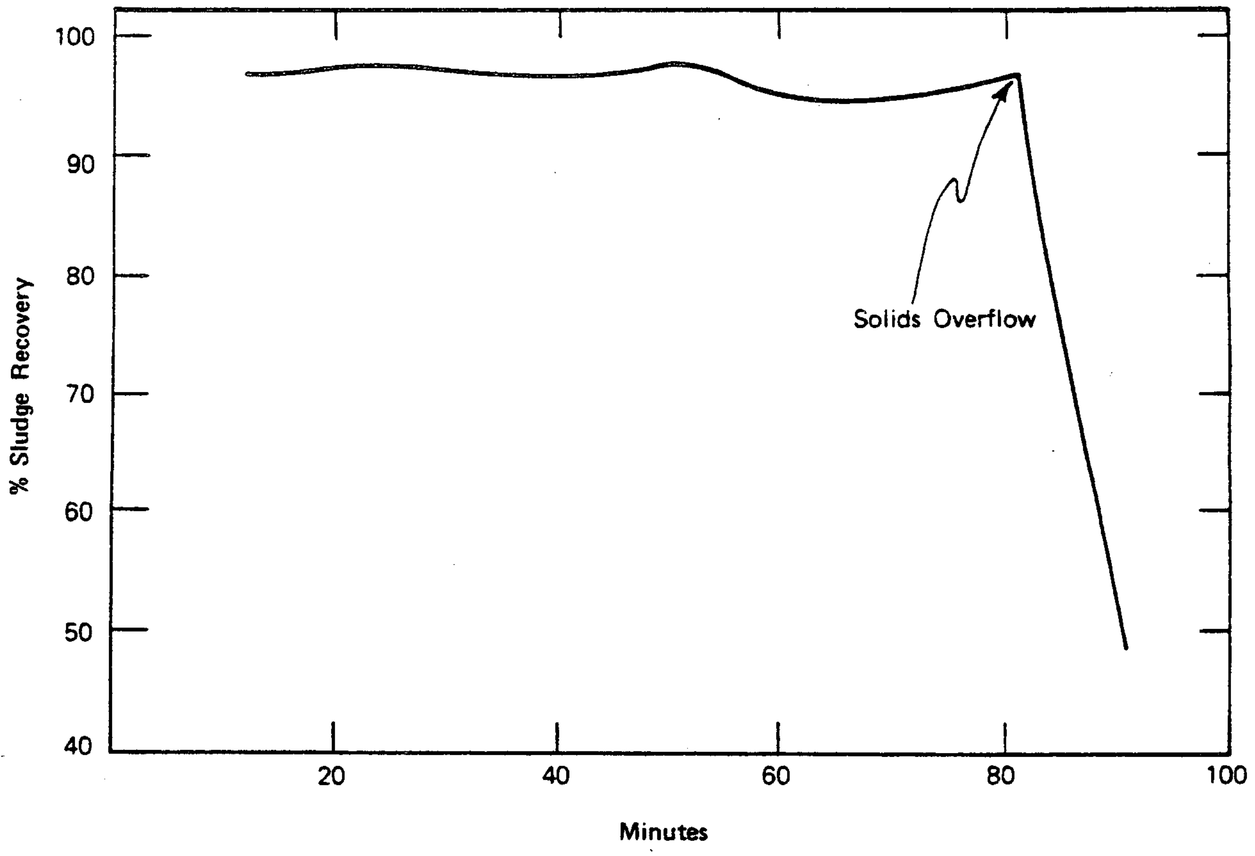


FIGURE 4.26 Sludge Recovery Versus Time in Large-Scale TNX Centrifuge

FIGURE 4.27 Sludge Cake in Large-Scale TNX Centrifuge

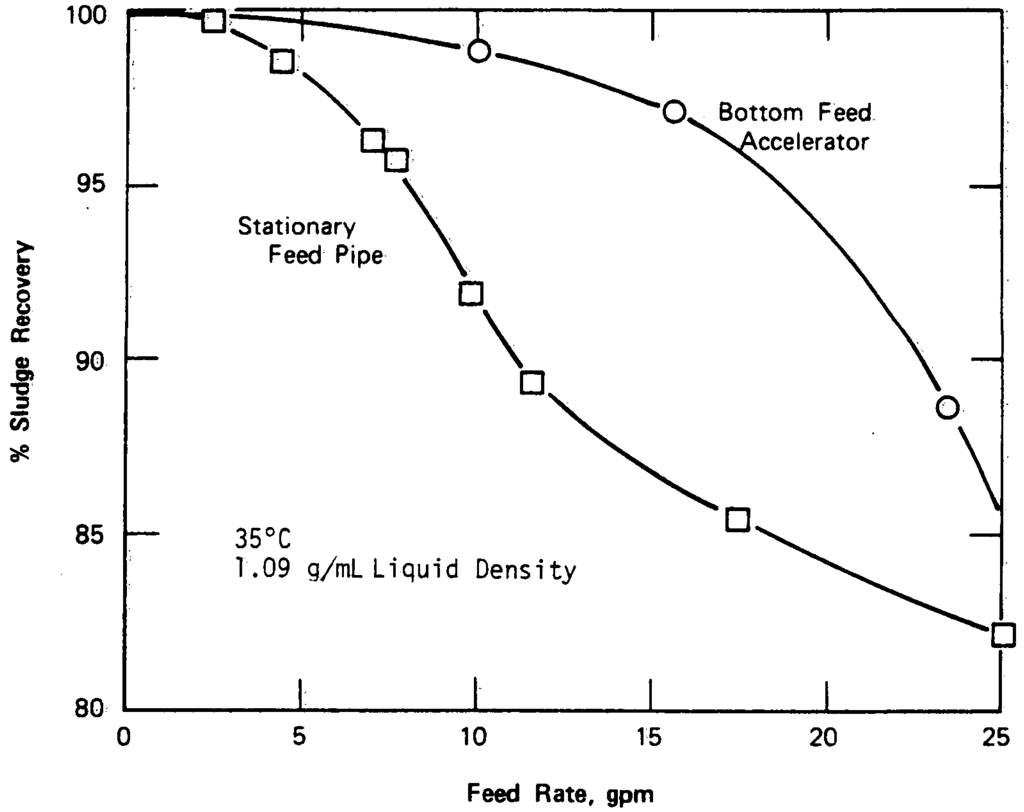


FIGURE 4.28 Effect of Feed Acceleration on Sludge Separation in Large-Scale TNX Centrifuge

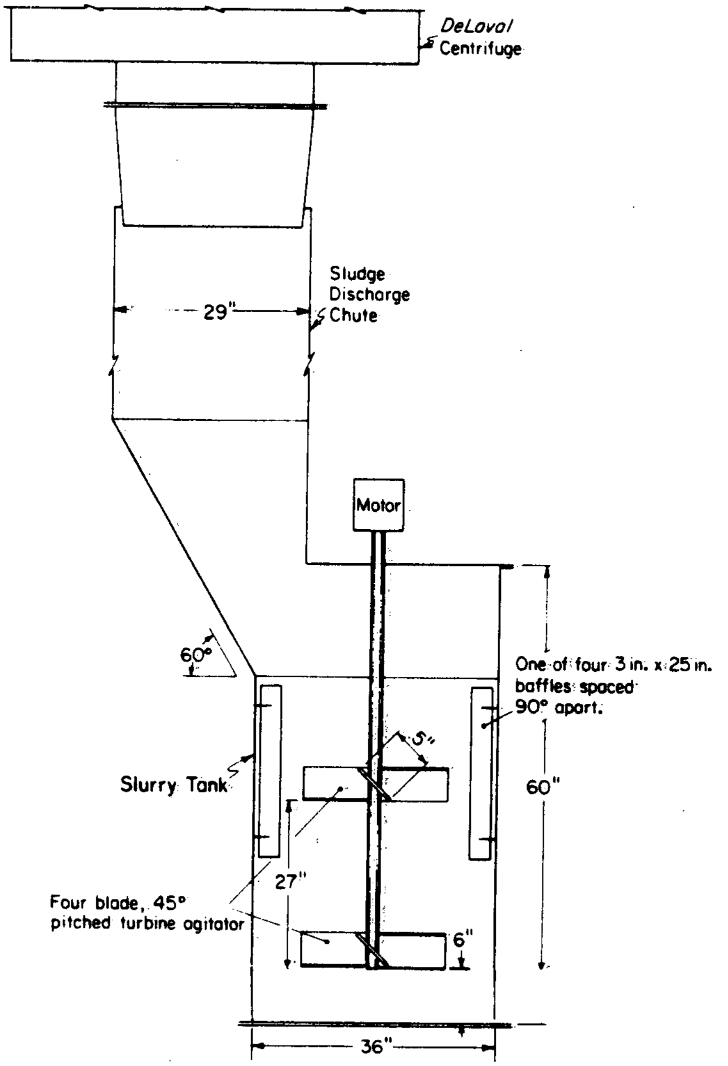


FIGURE 4.29 Large-Scale Slurry Tank

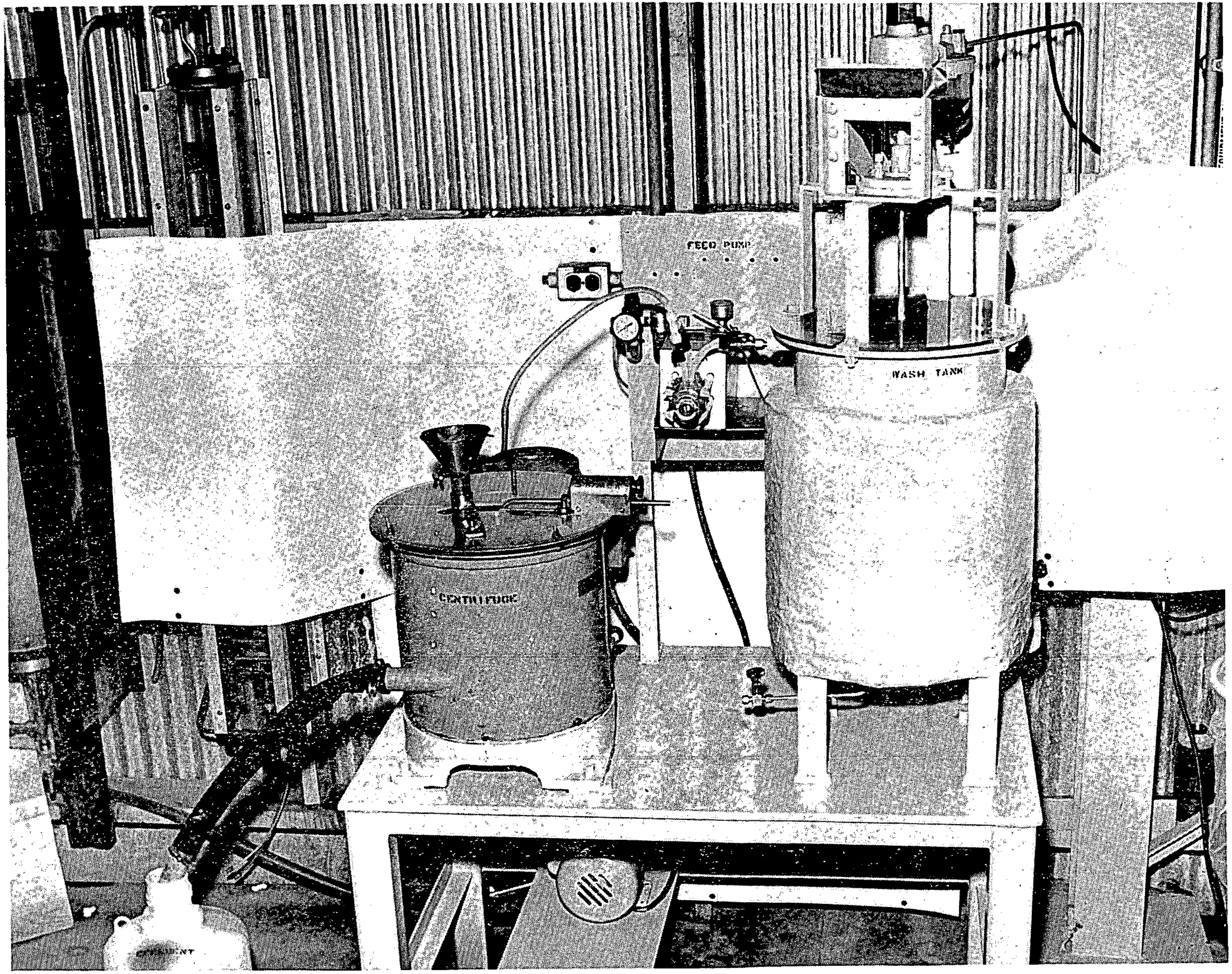


FIGURE 4.30 Small-Scale TNX Test Equipment

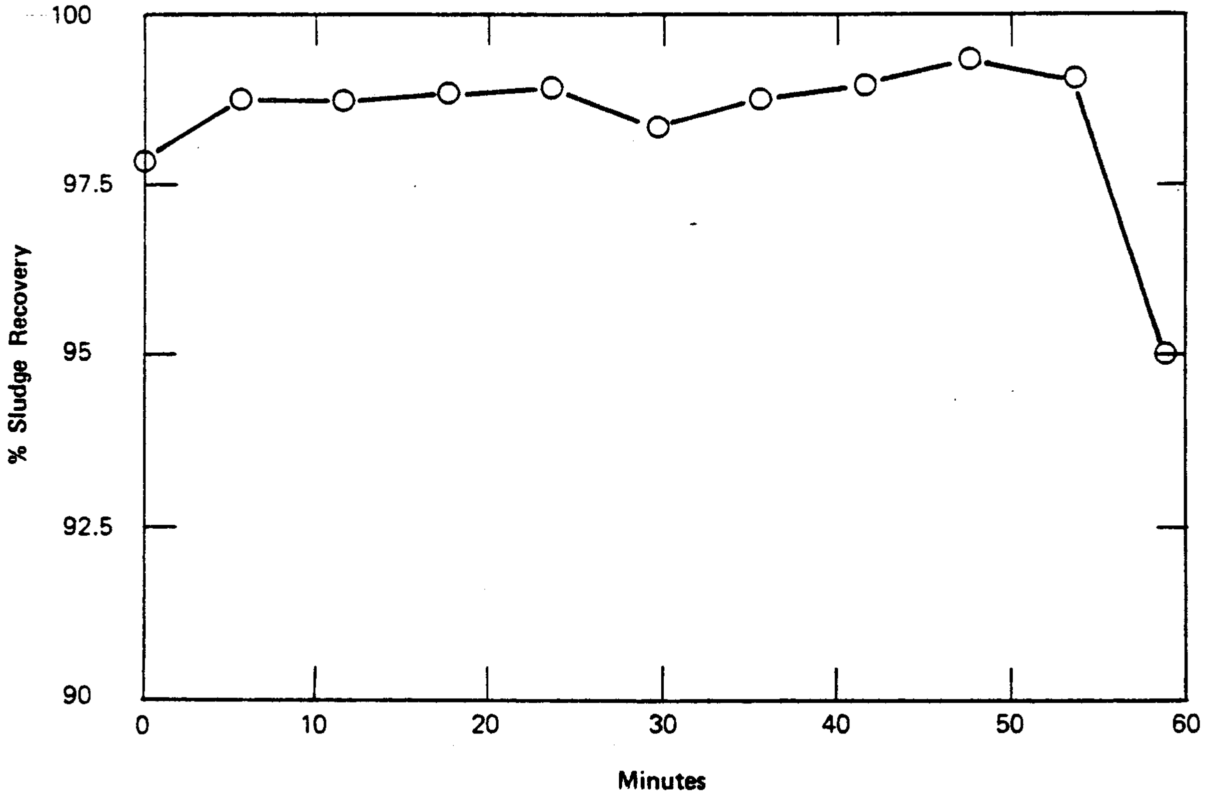


FIGURE 4.31 Sludge Recovery Versus Time in Small-Scale TNX Centrifuge

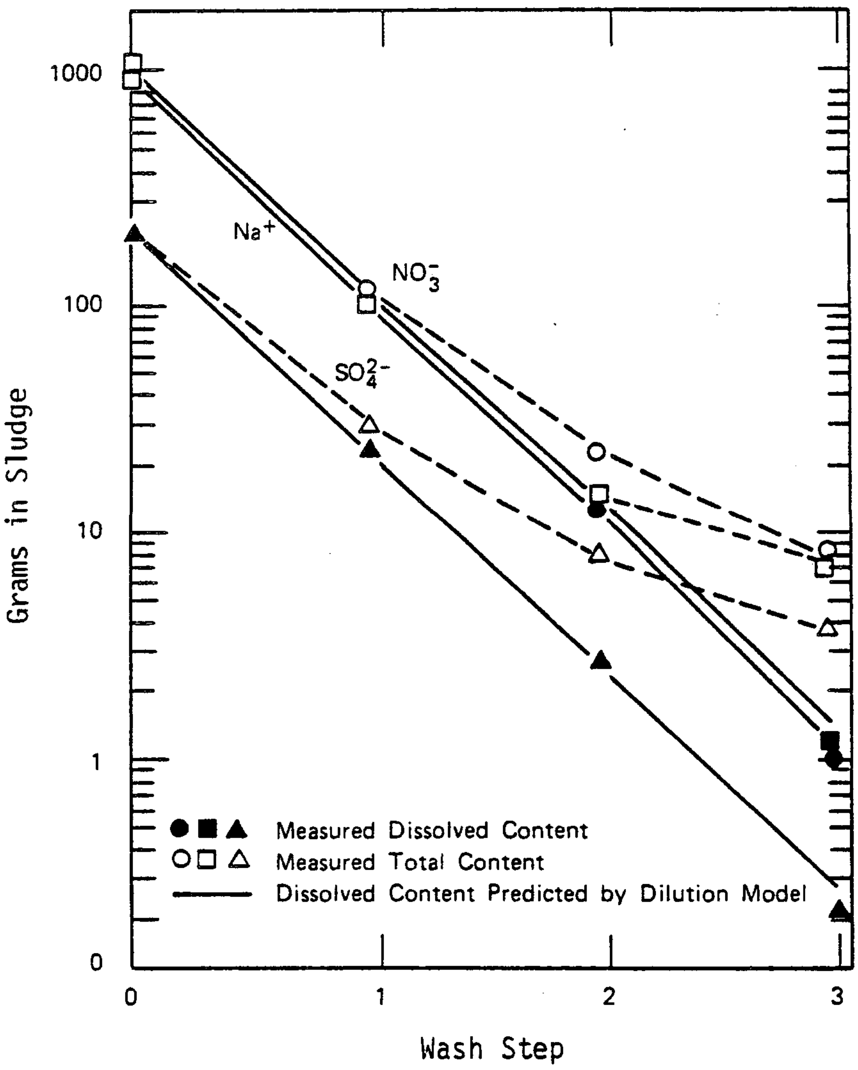


FIGURE 4.32 Na^+, NO_3^-, and SO_4^{2-} Contents in Sludge During Washing

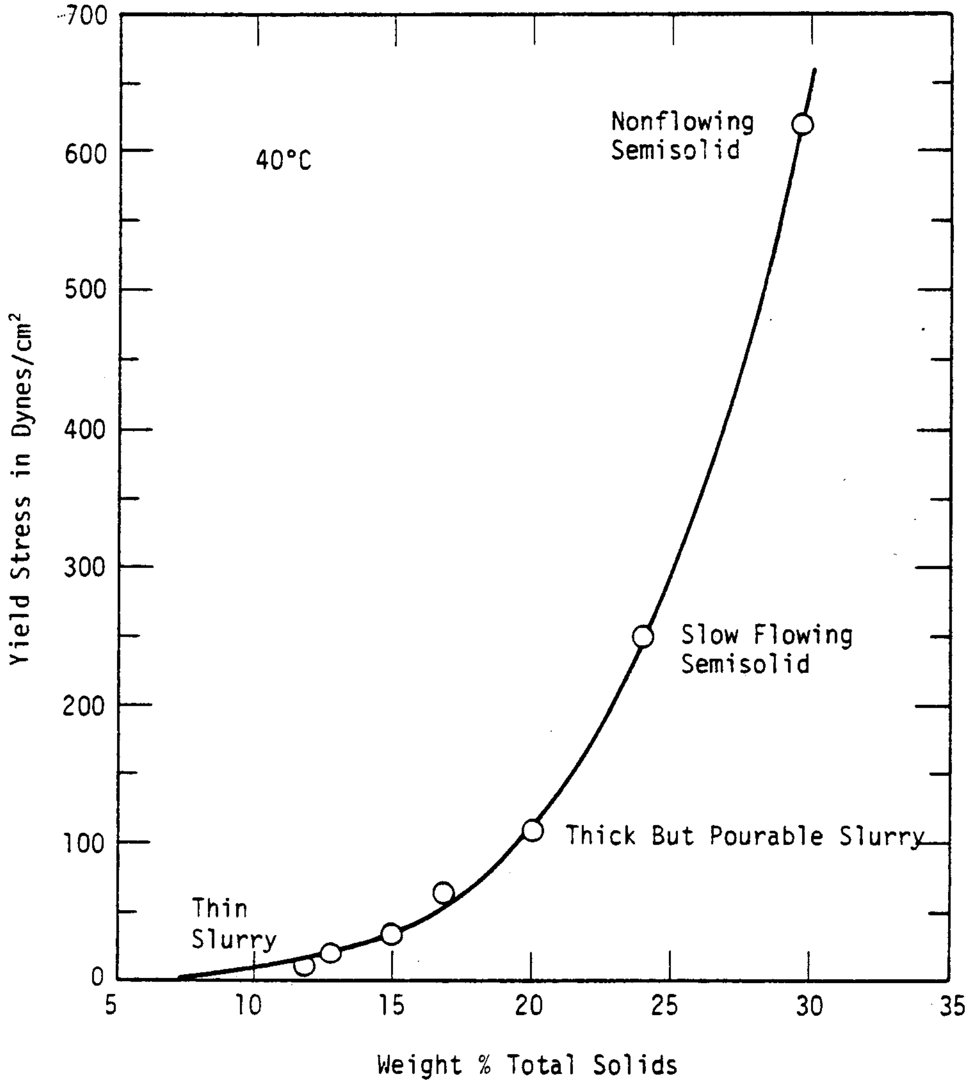


FIGURE 4.33 Yield Stress of Washed Sludge Slurry

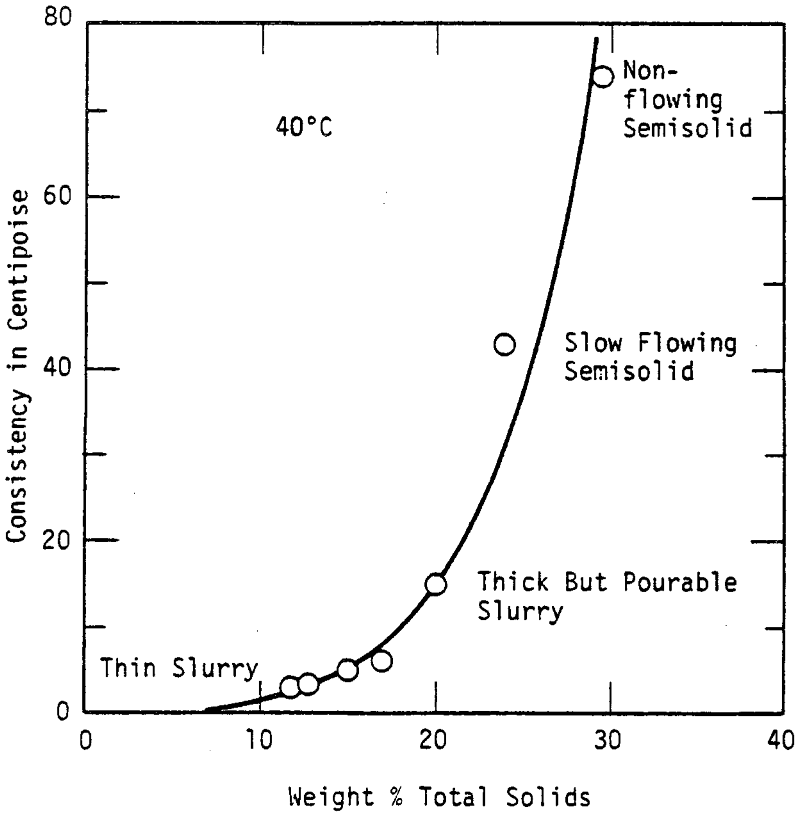


FIGURE 4.34 Consistency of Washed Sludge Slurry

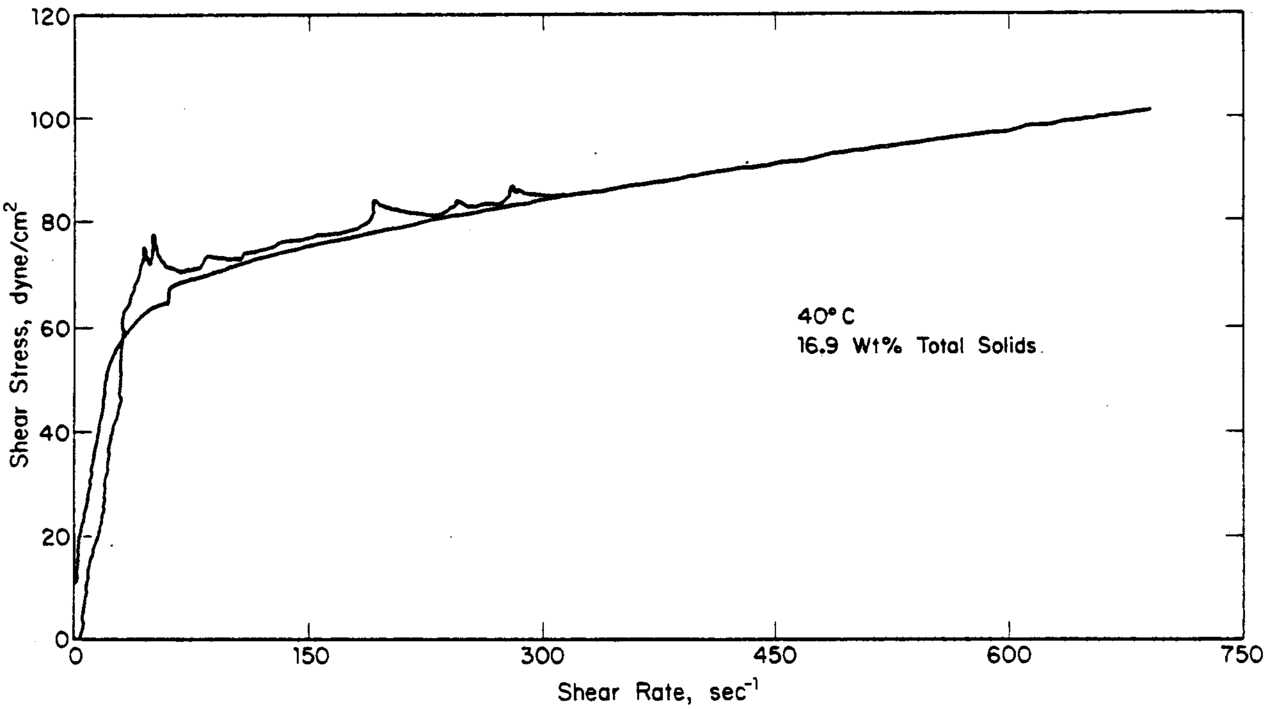


FIGURE 4.35 Washed Sludge Slurry Rheogram

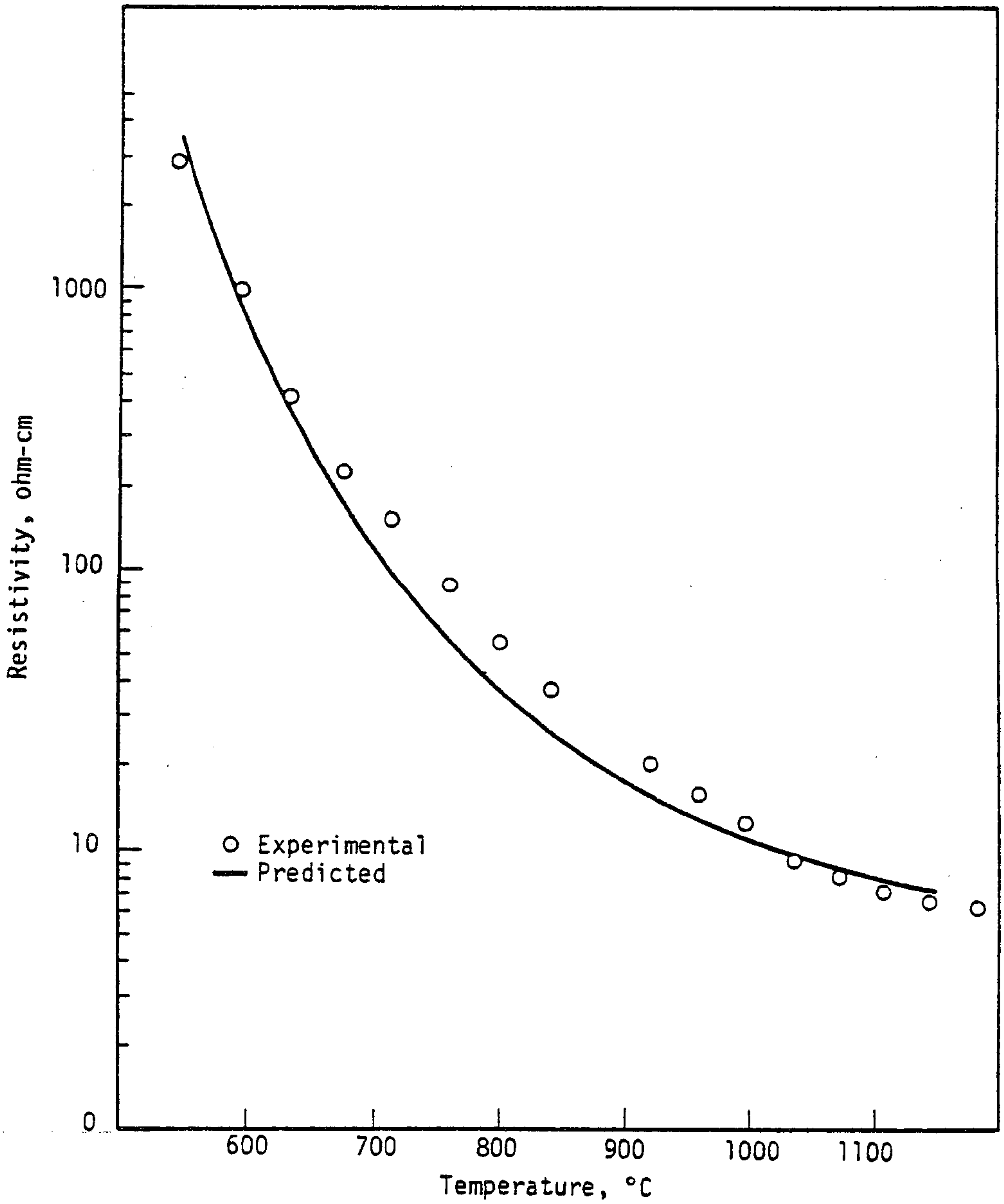


FIGURE 4.36 Resistivity of Melt Containing Frit 21-25 wt % "Composite Sludge"

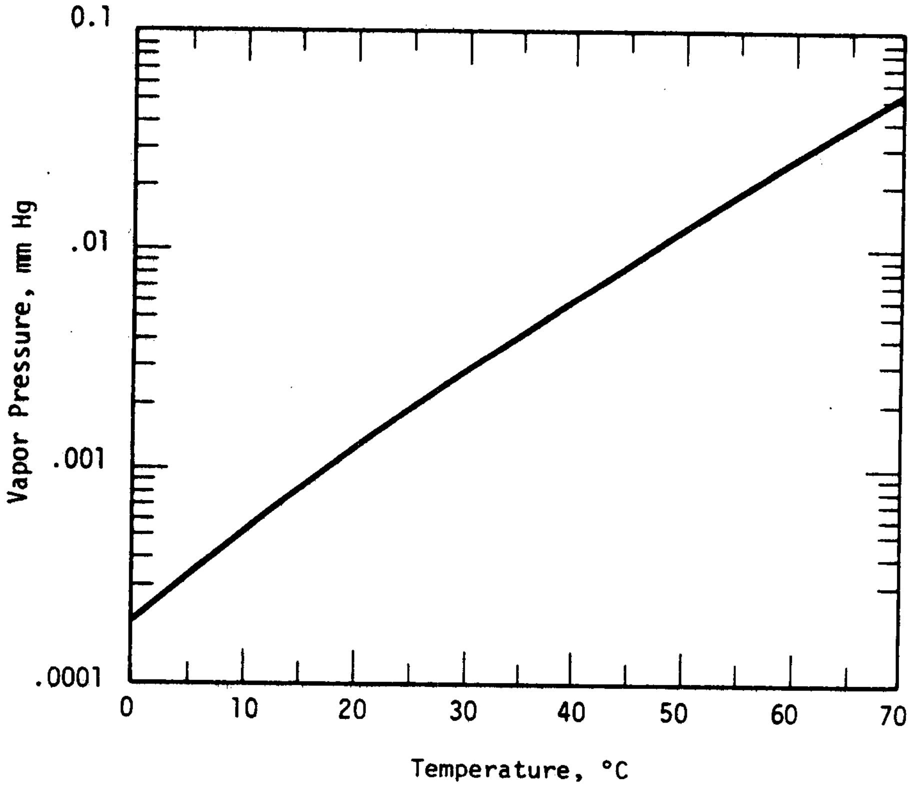


FIGURE 4.37 Vapor Pressure of Mercury

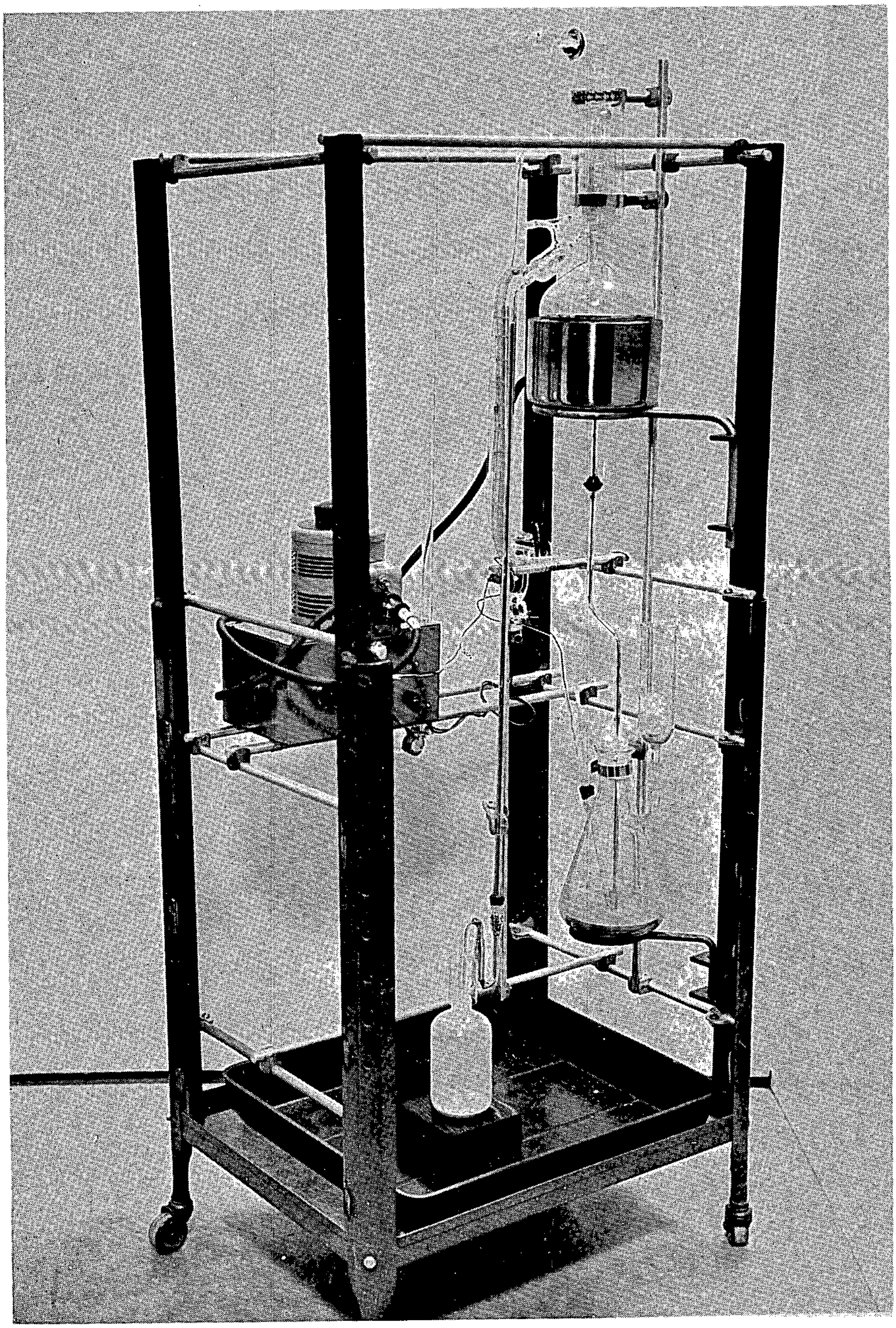


FIGURE 4.38 Savannah River Laboratory Mercury Still

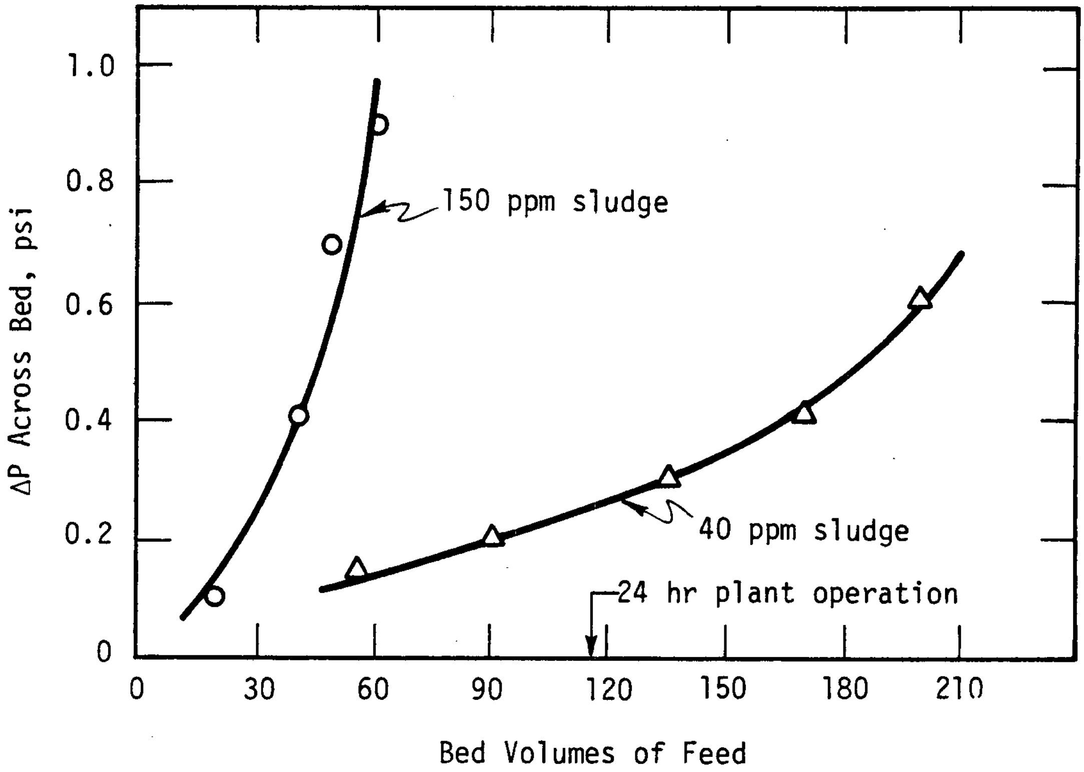
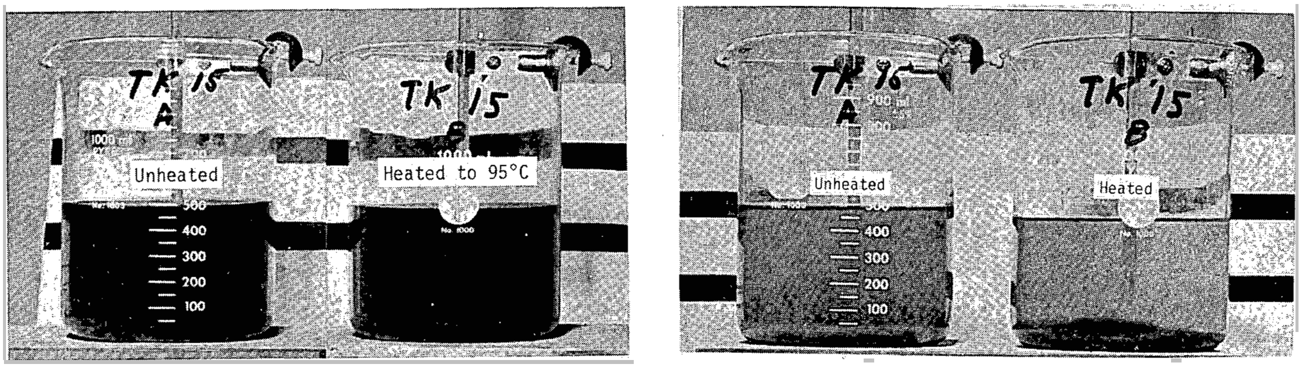
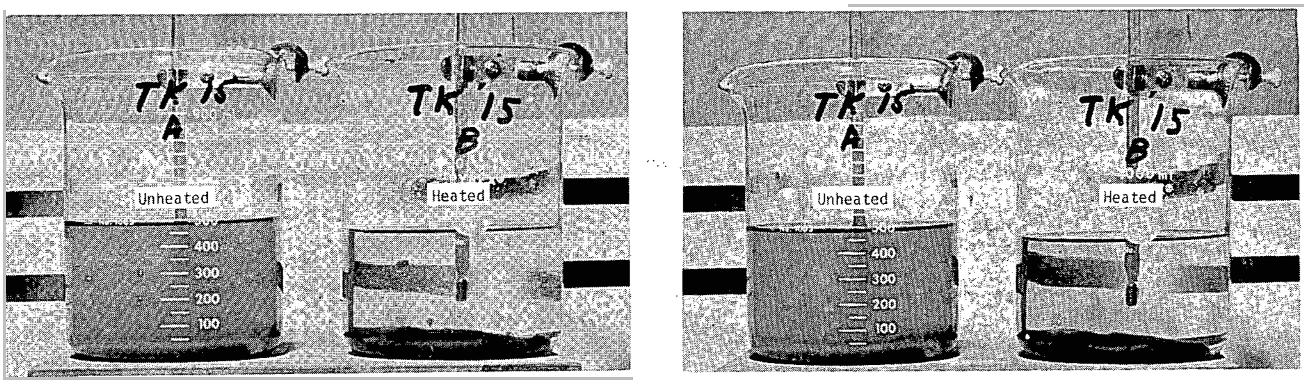


FIGURE 4.39 Effect of GS Product Sludge on Sand Bed ΔP



a. Elapsed Time - 0 minutes

b. Elapsed Time - 8 minutes



c. Elapsed Time - 16 minutes

d. Elapsed Time - 25 minutes

FIGURE 4.40 Effect of Heating on the Settling Rate of Sludge

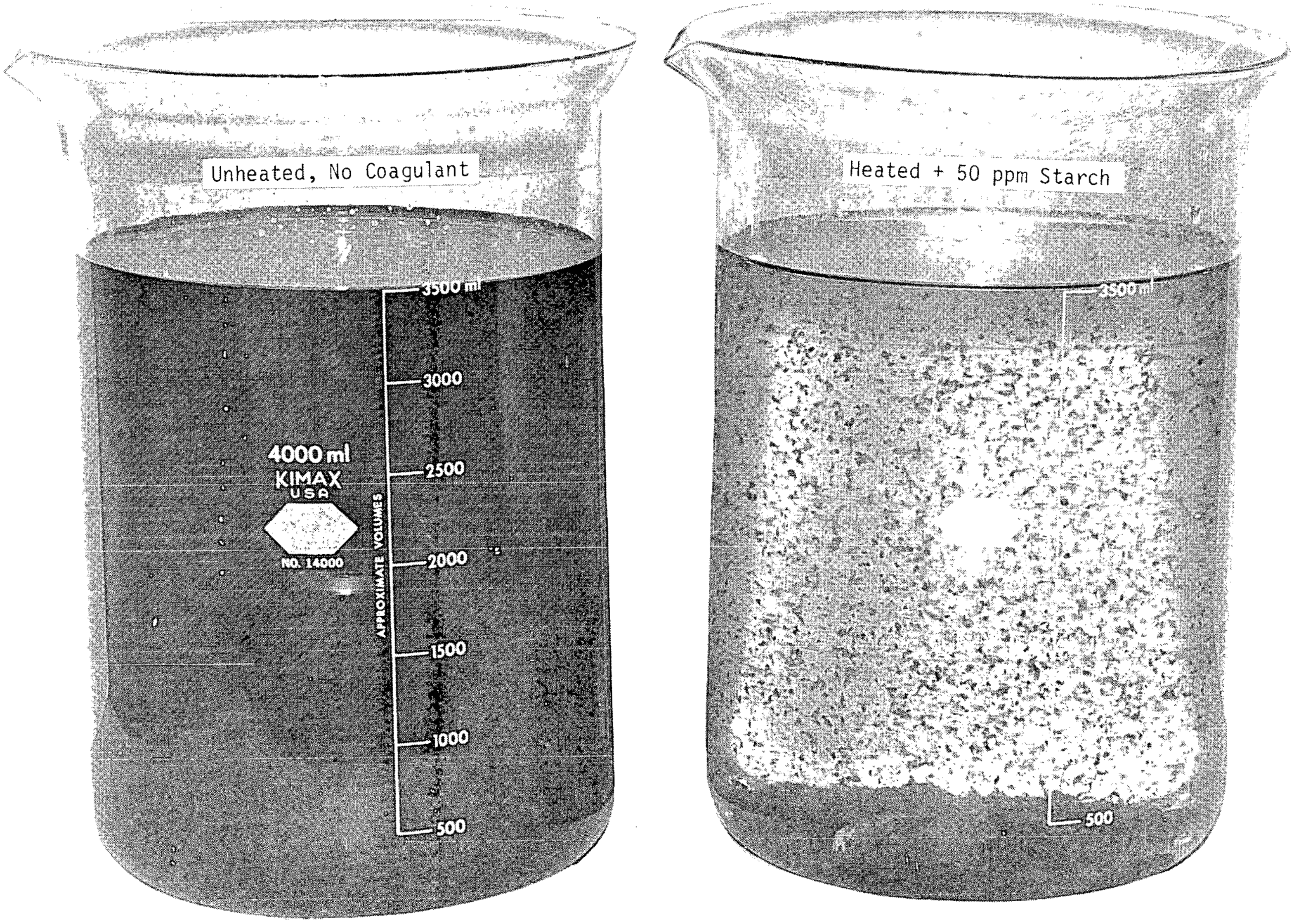


FIGURE 4.41 Destabilization of Colloidal Suspensions with Heat and Starch

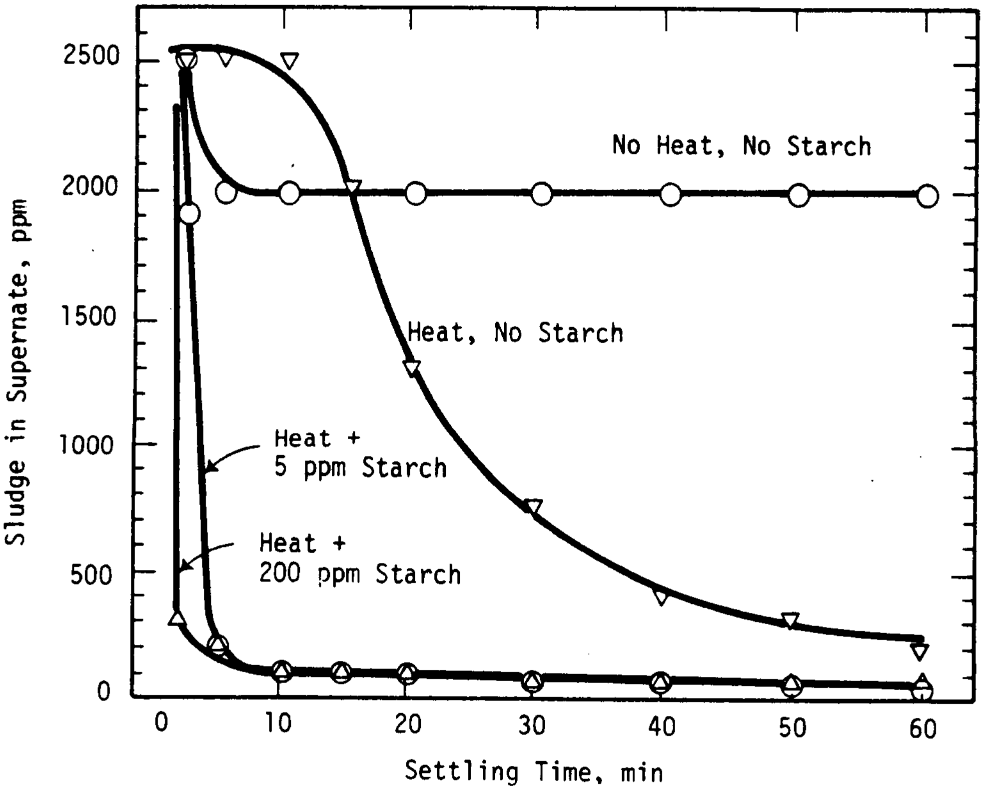


FIGURE 4.42 Effect of Heat and Starch on Agglomeration and Settling Rates

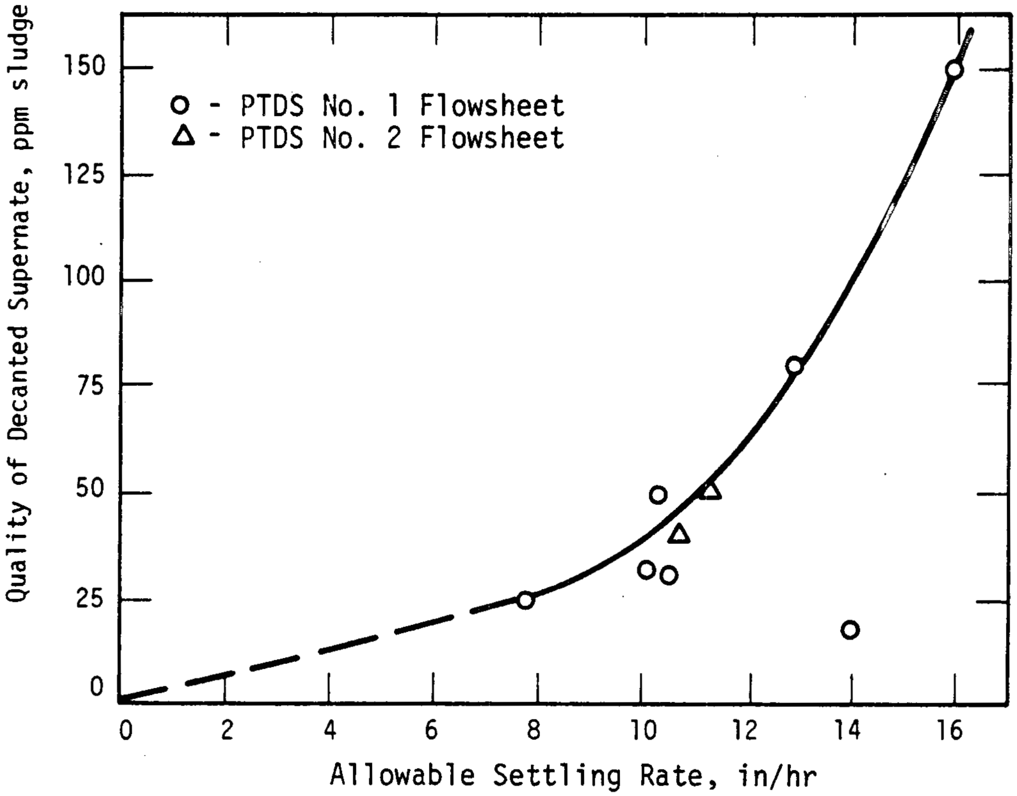


FIGURE 4.43 Allowable Settling Rates - Large-Scale GS Tests

FIGURE 4.44 GS Samples from First Large-Scale Run

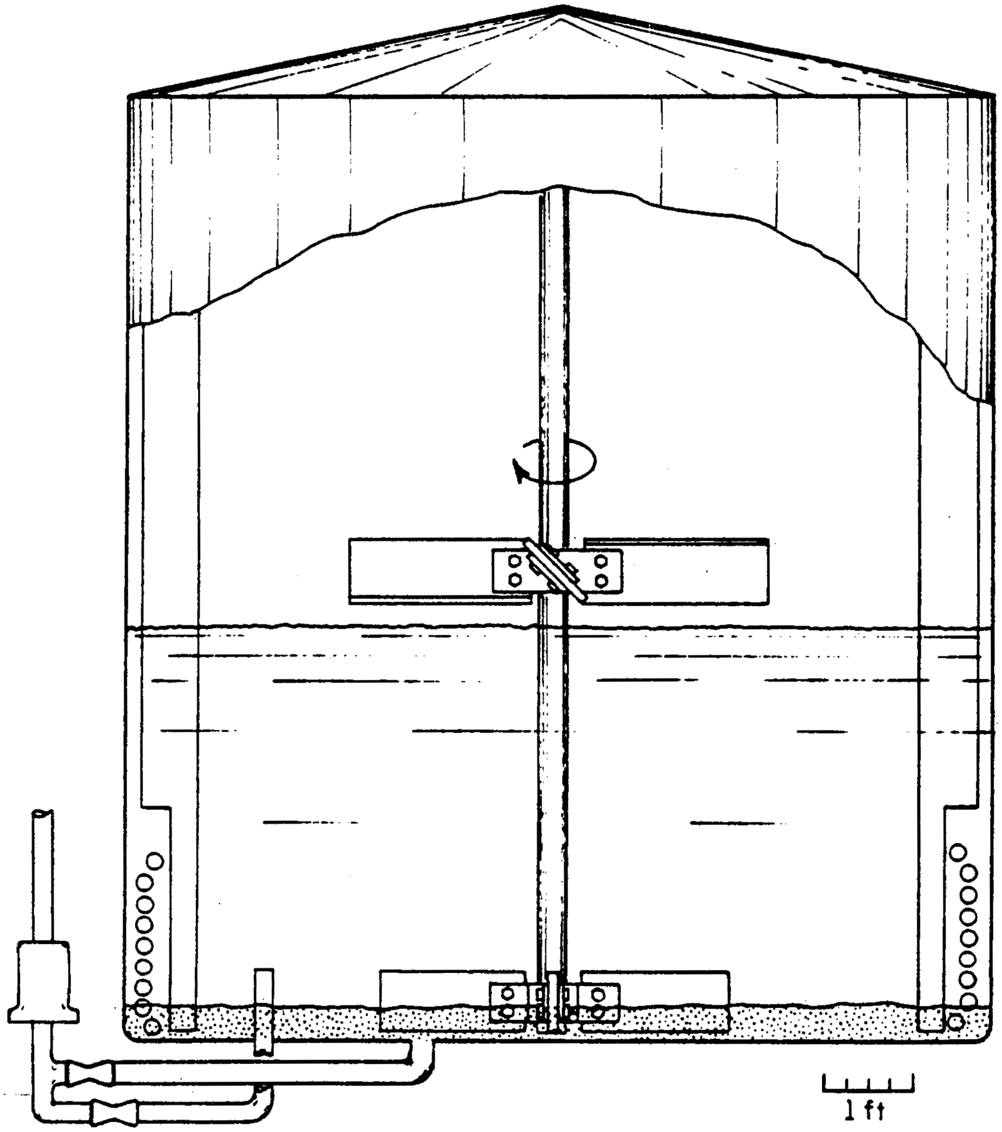


FIGURE 4.45 Semiworks GS Tank W-2

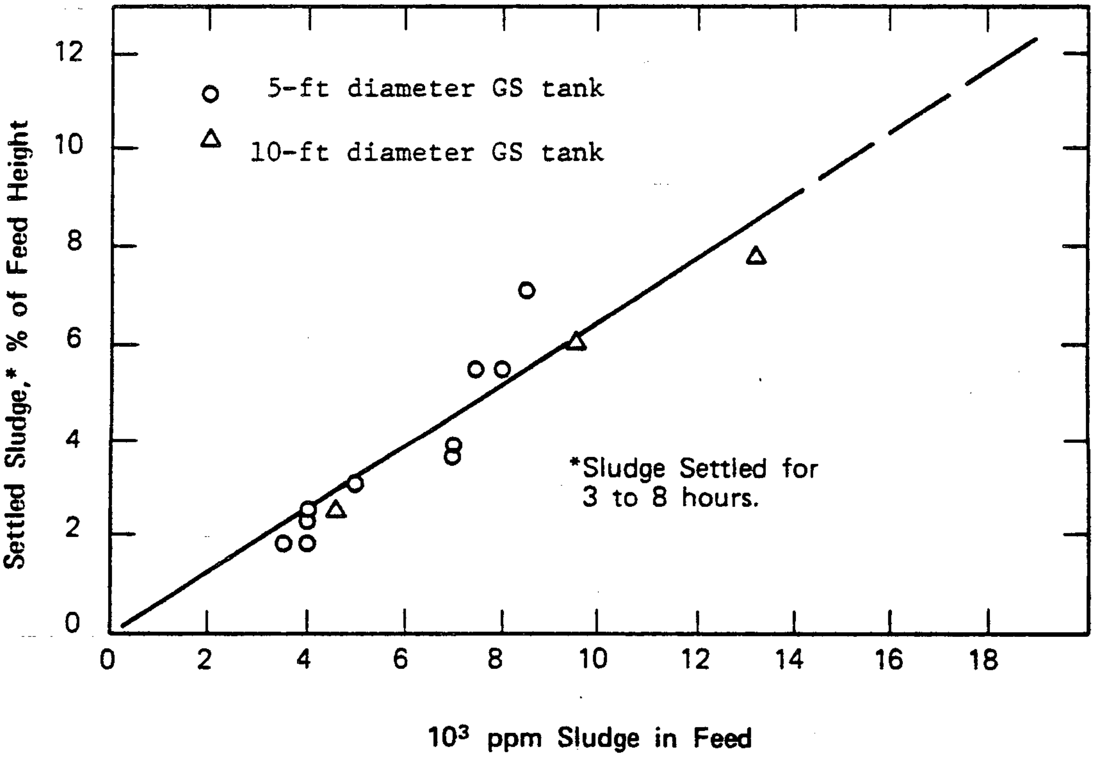
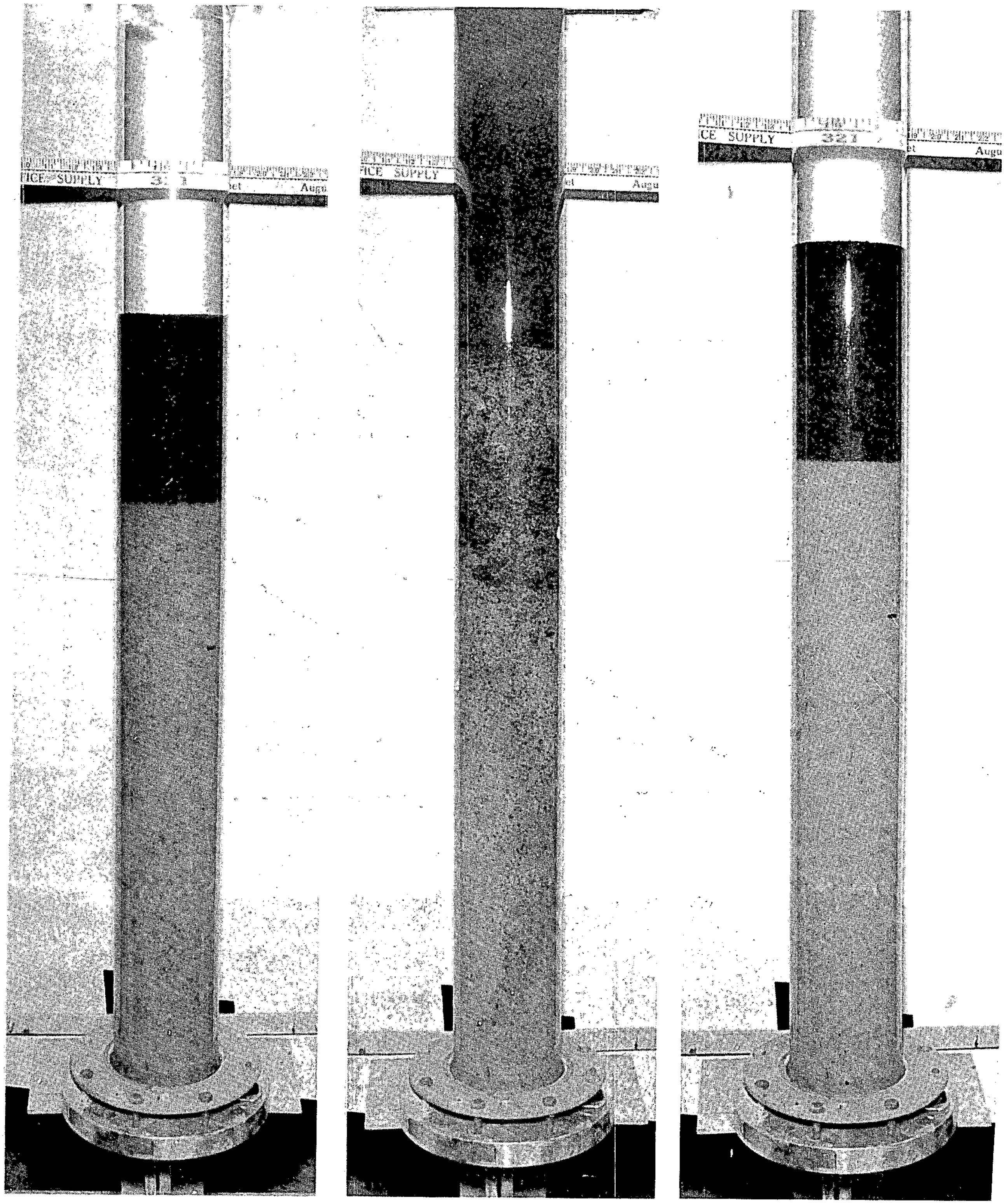


FIGURE 4.46 Effect of GS Feed Sludge on Settled Sludge Height



Downflow Feed Upflow Backwash Resettled Bed

FIGURE 4.47 Sand Filtration - 1/200th Plant Scale

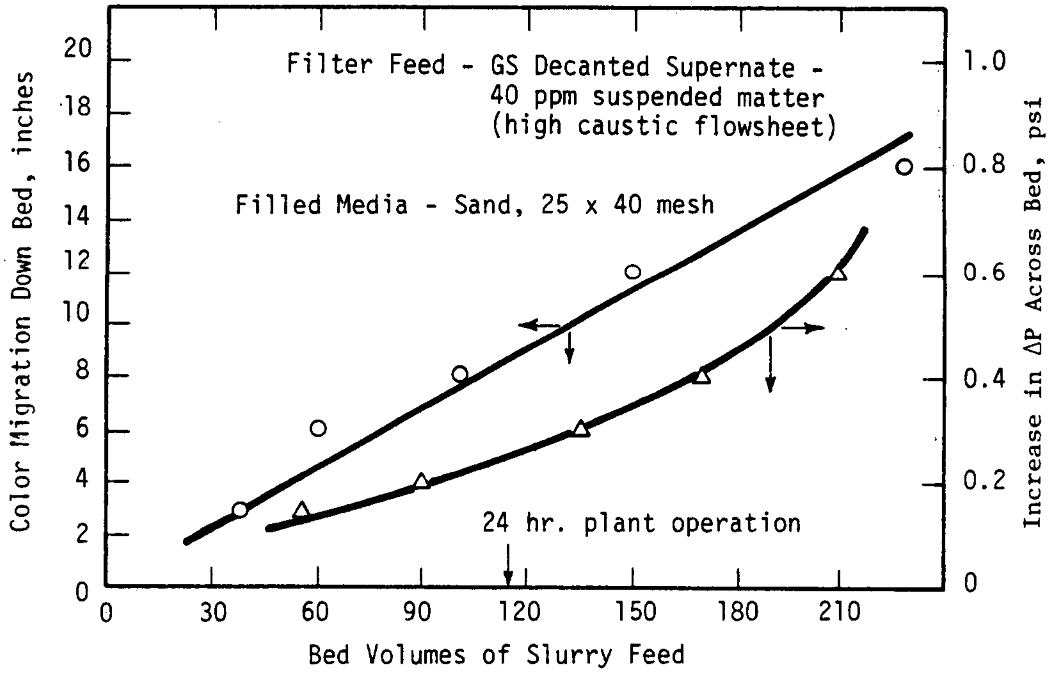


FIGURE 4.48 Sand Filter Performance

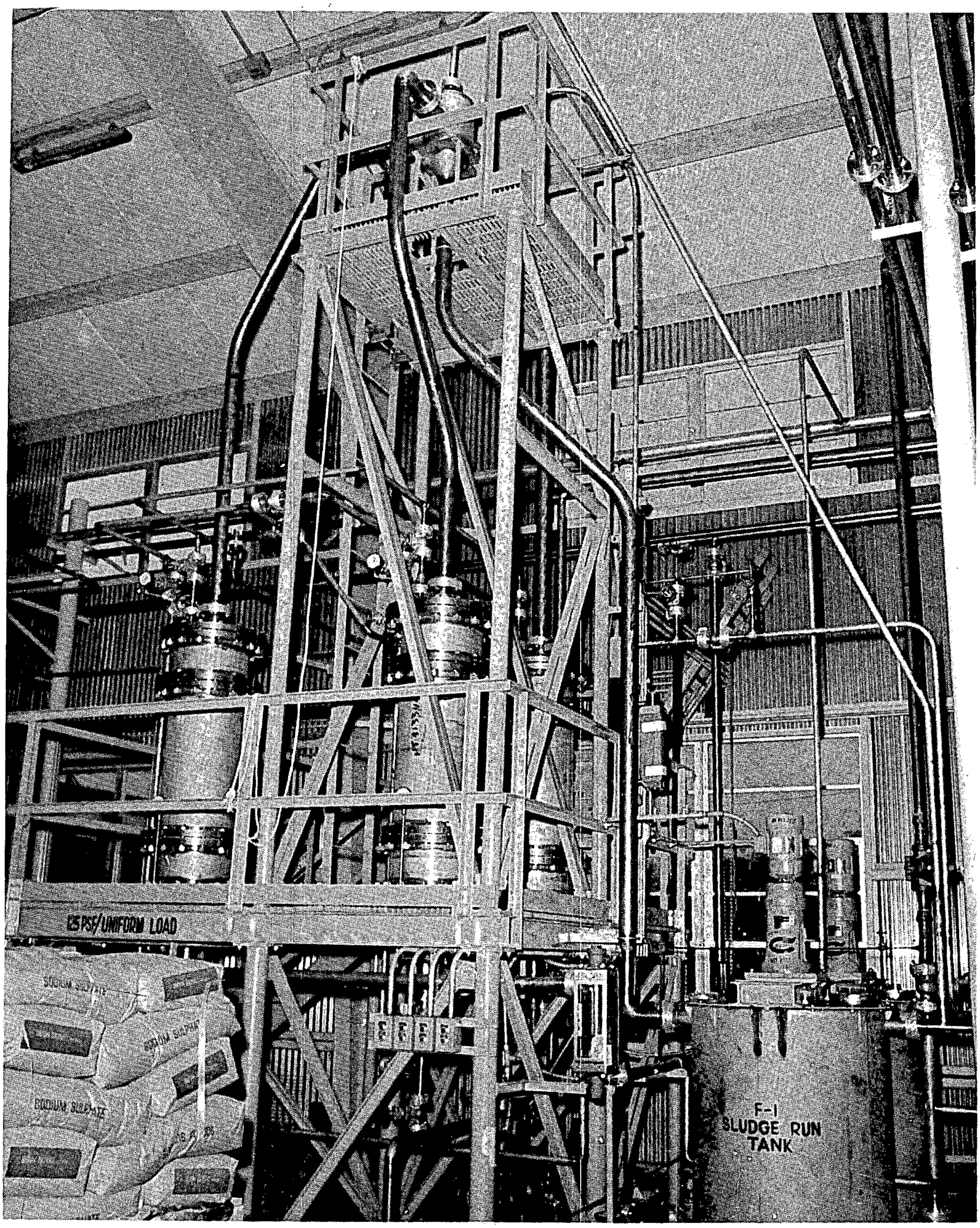


FIGURE 4.49 TNX Sand Filter Facility

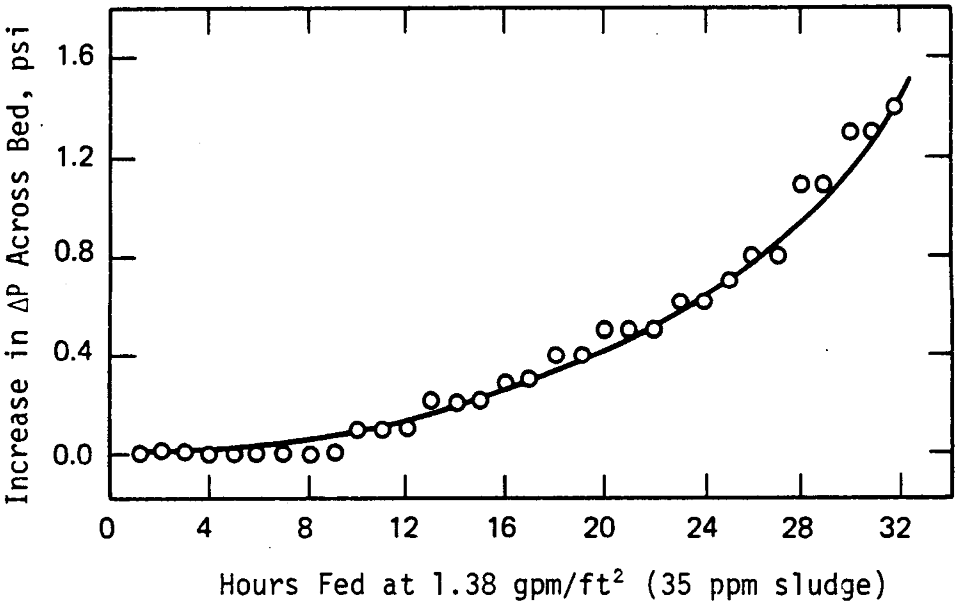


FIGURE 4.50 ΔP Rise in Large-Scale Primary Sand Bed

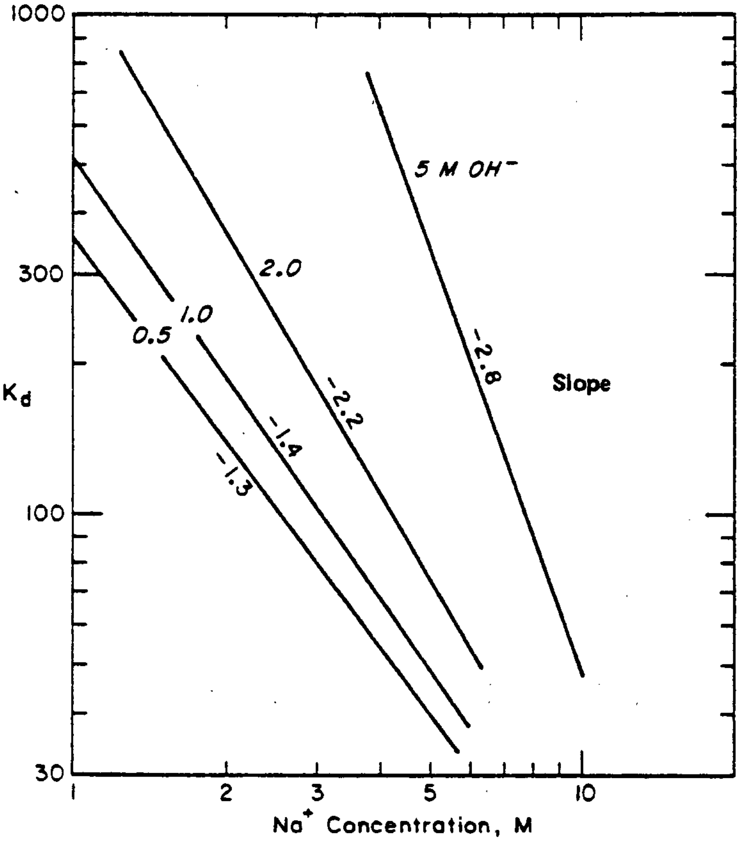


FIGURE 4.51 Cesium - "Duolite" Distribution Coeffficient

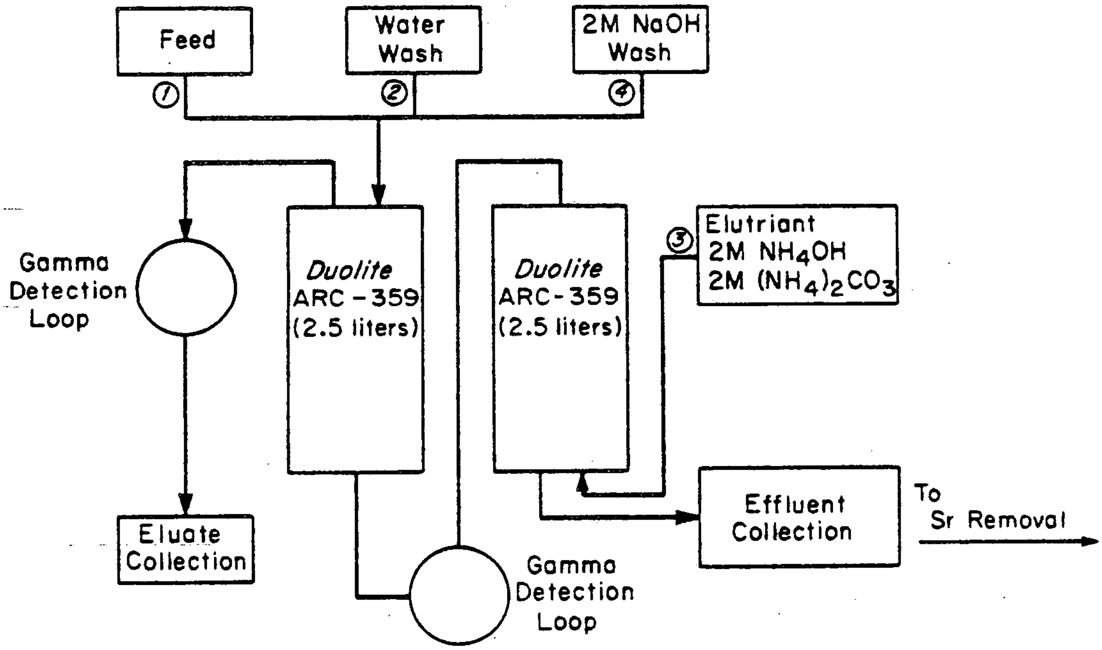


FIGURE 4.52 Apparatus for Ion Exchange Column Tests

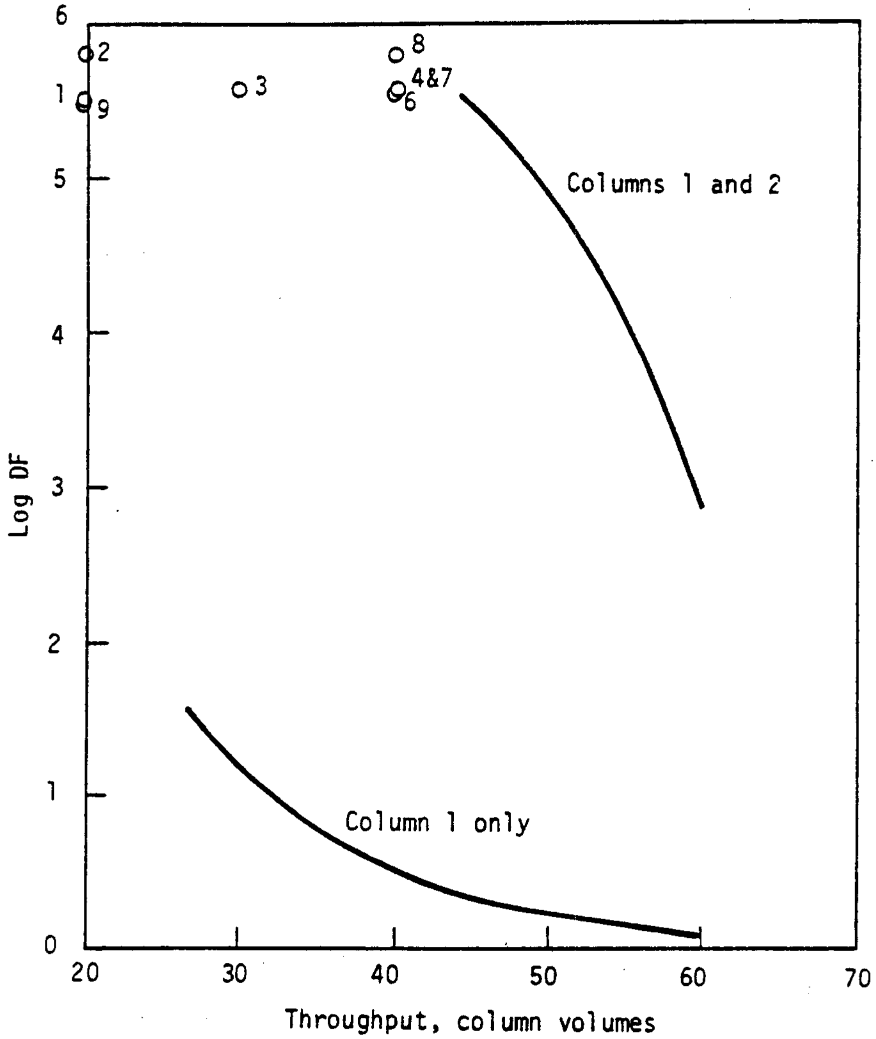


FIGURE 4.53 Cs-137 Decontamination as a Function of Throughput

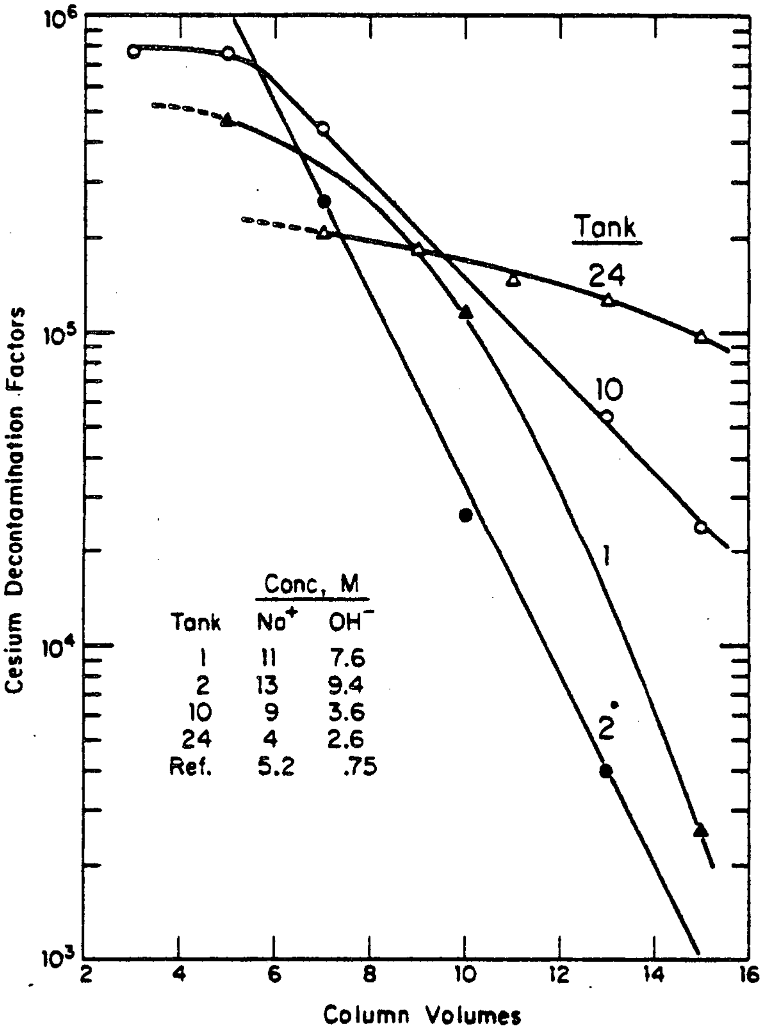


FIGURE 4.54 Cesium Decontamination Factors for SRP Waste Supernate

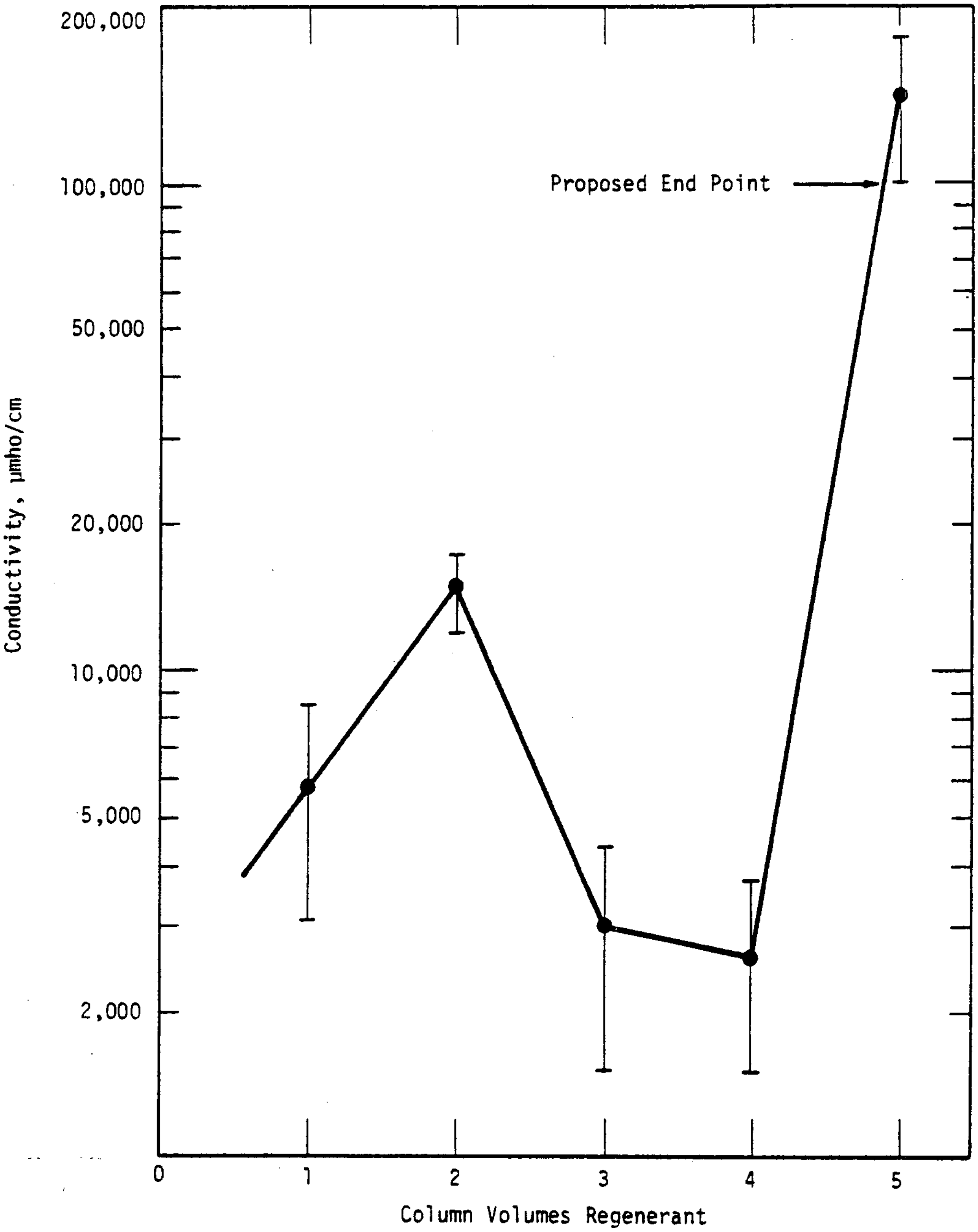


FIGURE 4.55 Electrical Conductivity Versus Regenerant Requirement

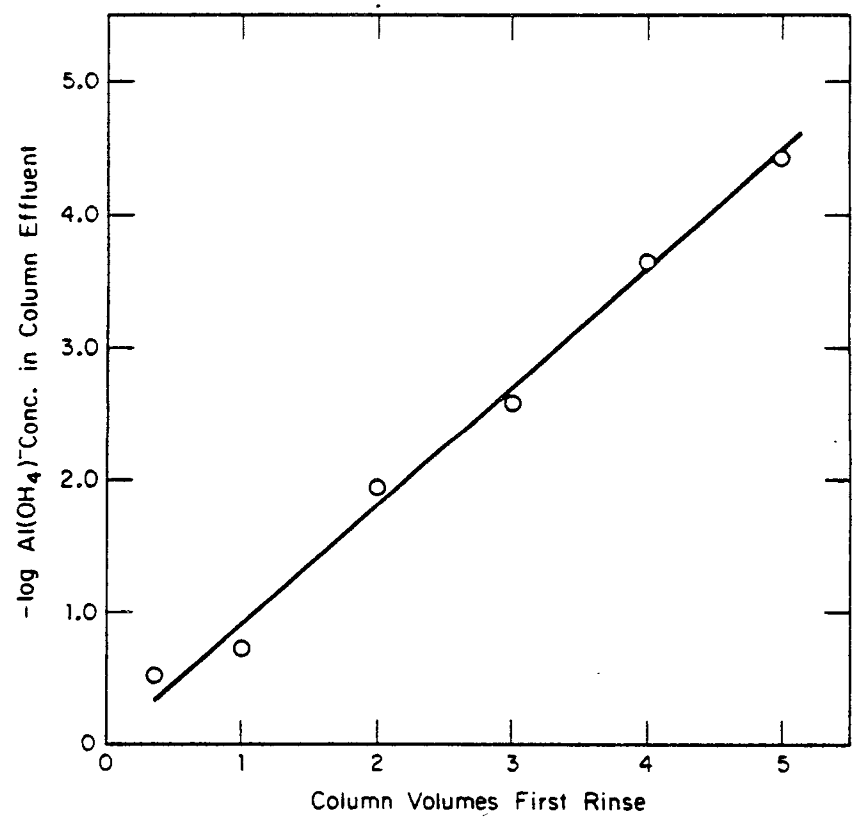


FIGURE 4.56 - Removal of $Al(OH_4)^-$ During First Rinse on 3" x 40" Column

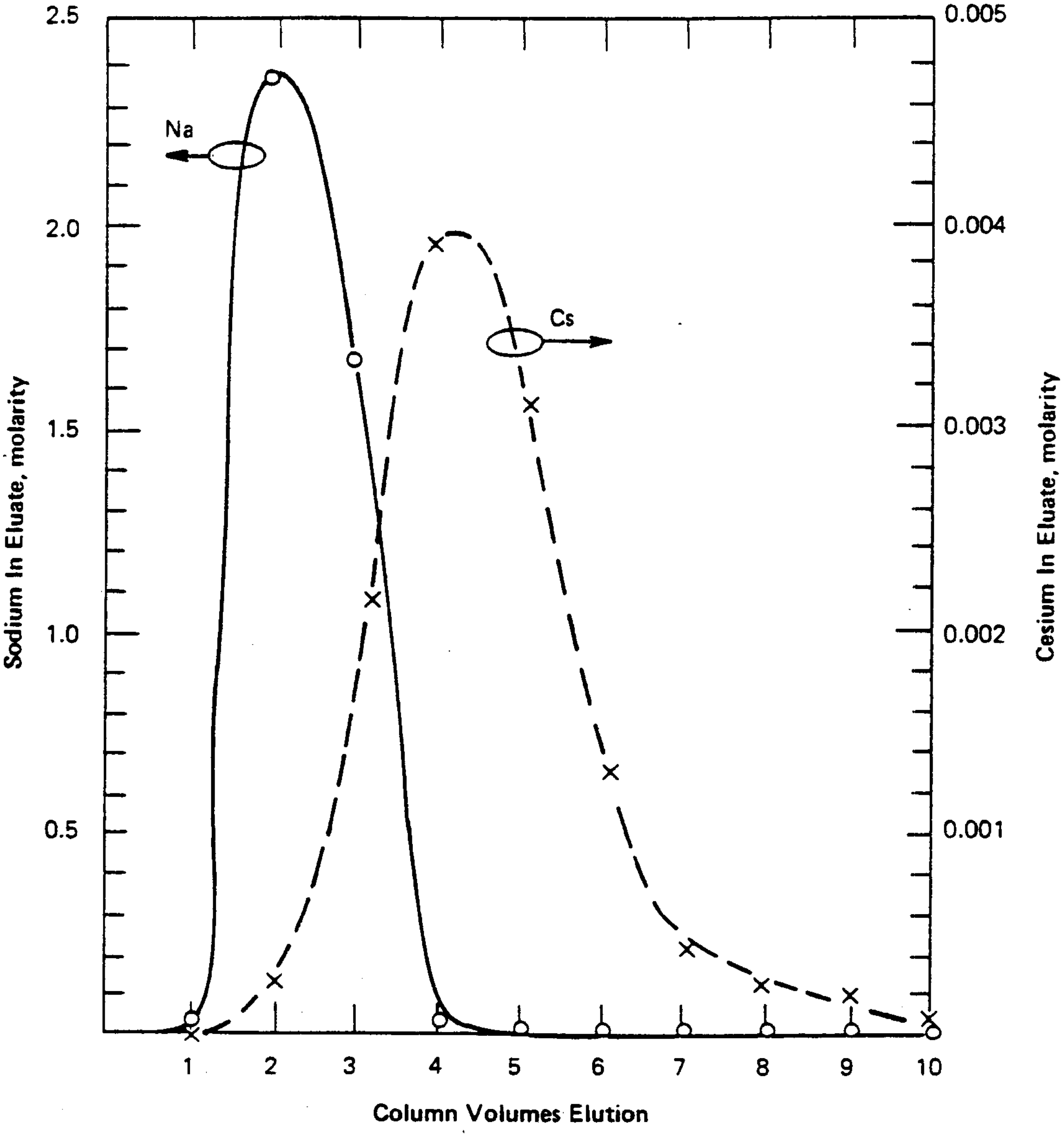
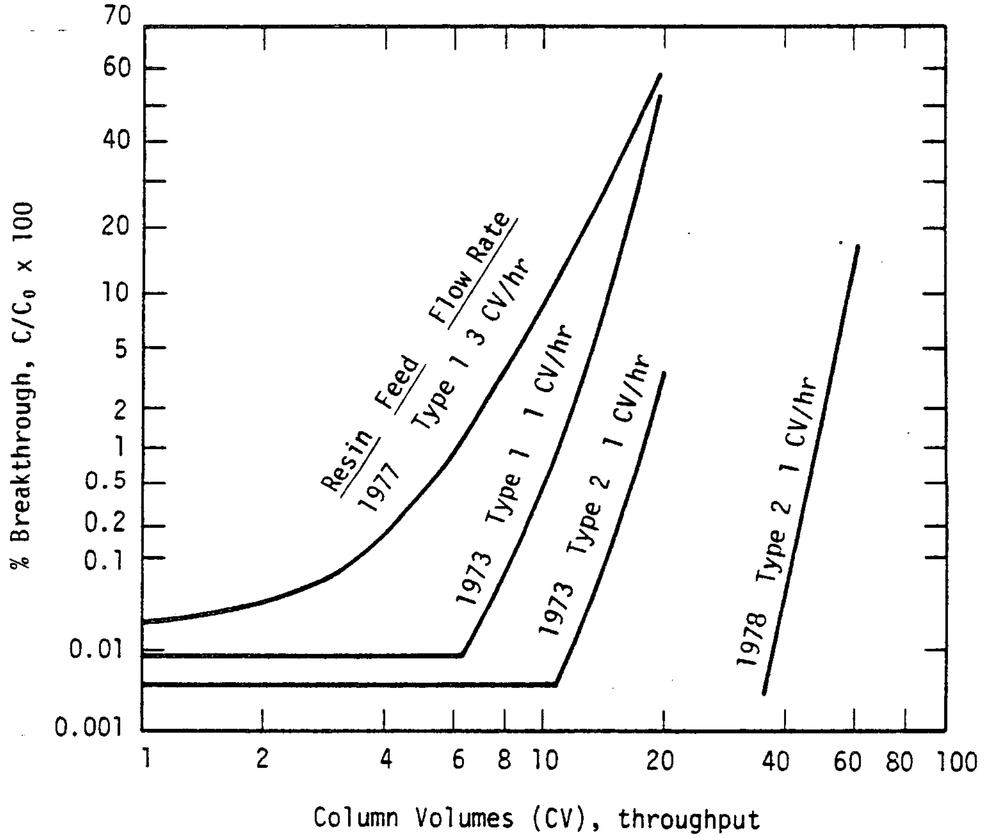


FIGURE 4.57 ICV/HR Elution Following a 60 CV Feed Step, $C_o = 1.87 \times 10^{-4}$M Cs, on 3" x 40" Column



	Na^+	OH^-	NO_3^-	NO_2^-	CO_3^{2-}	SO_4^{2-}	AlO_2^-
Feed Type 1 -	5.3	1.0	2.06	1.13	0.27	0.21	0.41
Feed Type 2 -	5.6	1.60	1.65	0.78	0.42	0.20	0.42

FIGURE 4.58 Effect of Resin Batch Feed Type on First Column 1 Performance: $C_o = 2 \times 10^{-4}M$

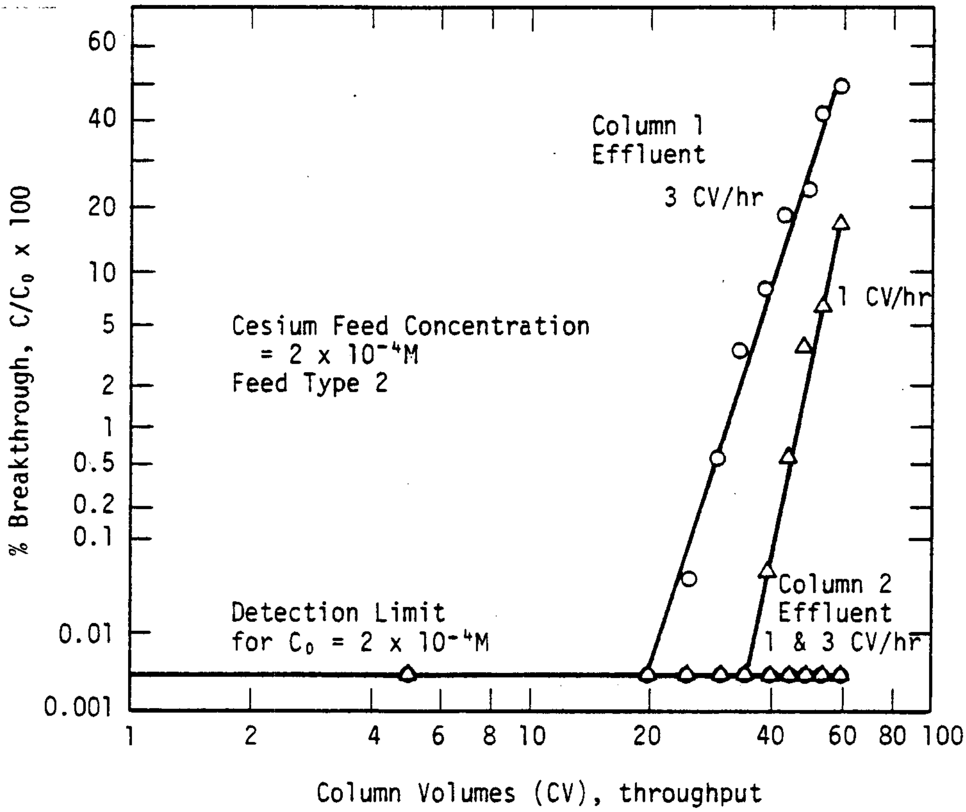


FIGURE 4.59 Typical Breakthrough Curves for 1978 Resin, Using 3" x 40" Columns

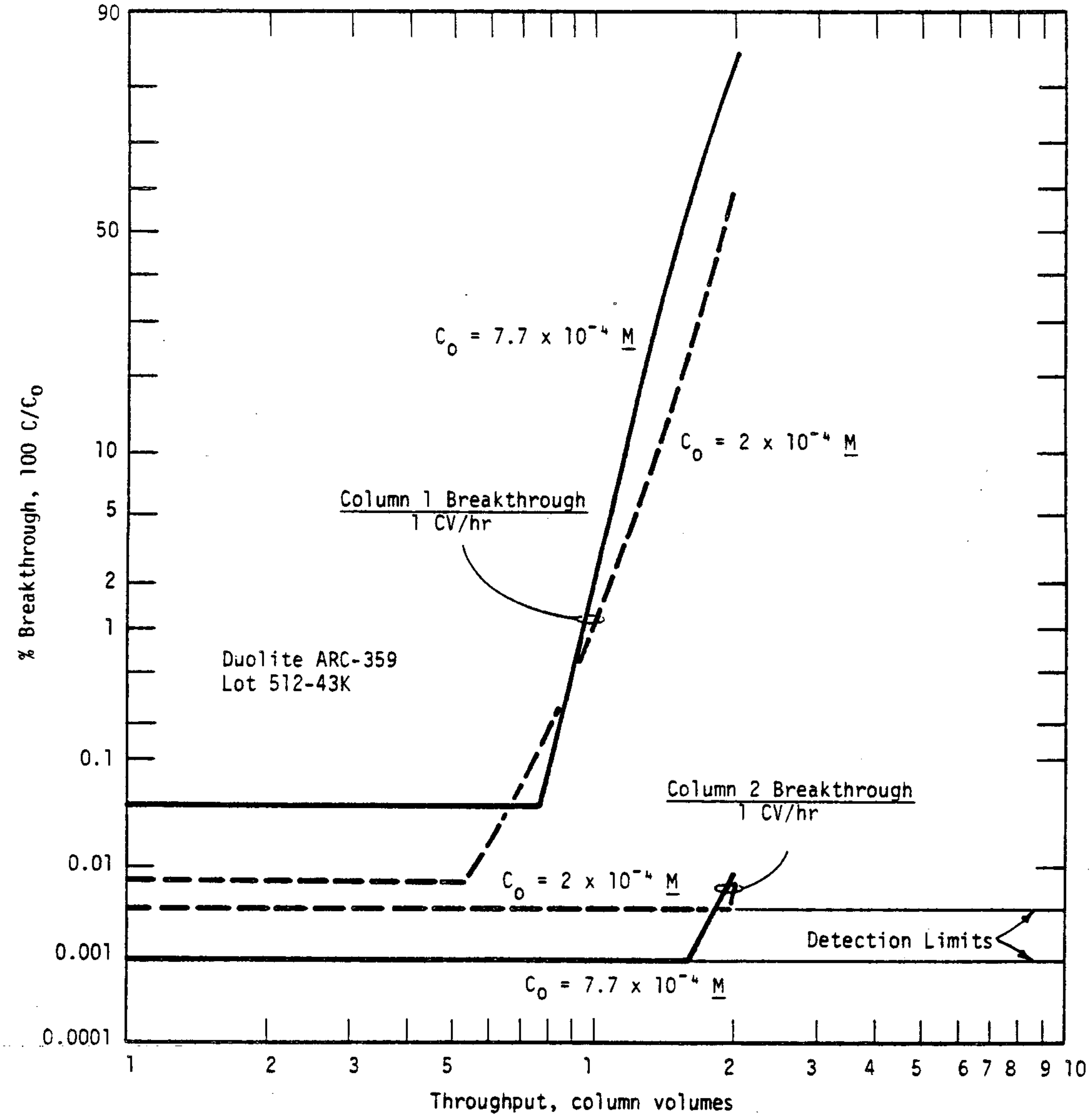


FIGURE 4.60 **TNX Cesium Breakthrough Curves - Effect of Cesium Feed Concentration Using 3" x 40" Column with Feed Feed Type 1**

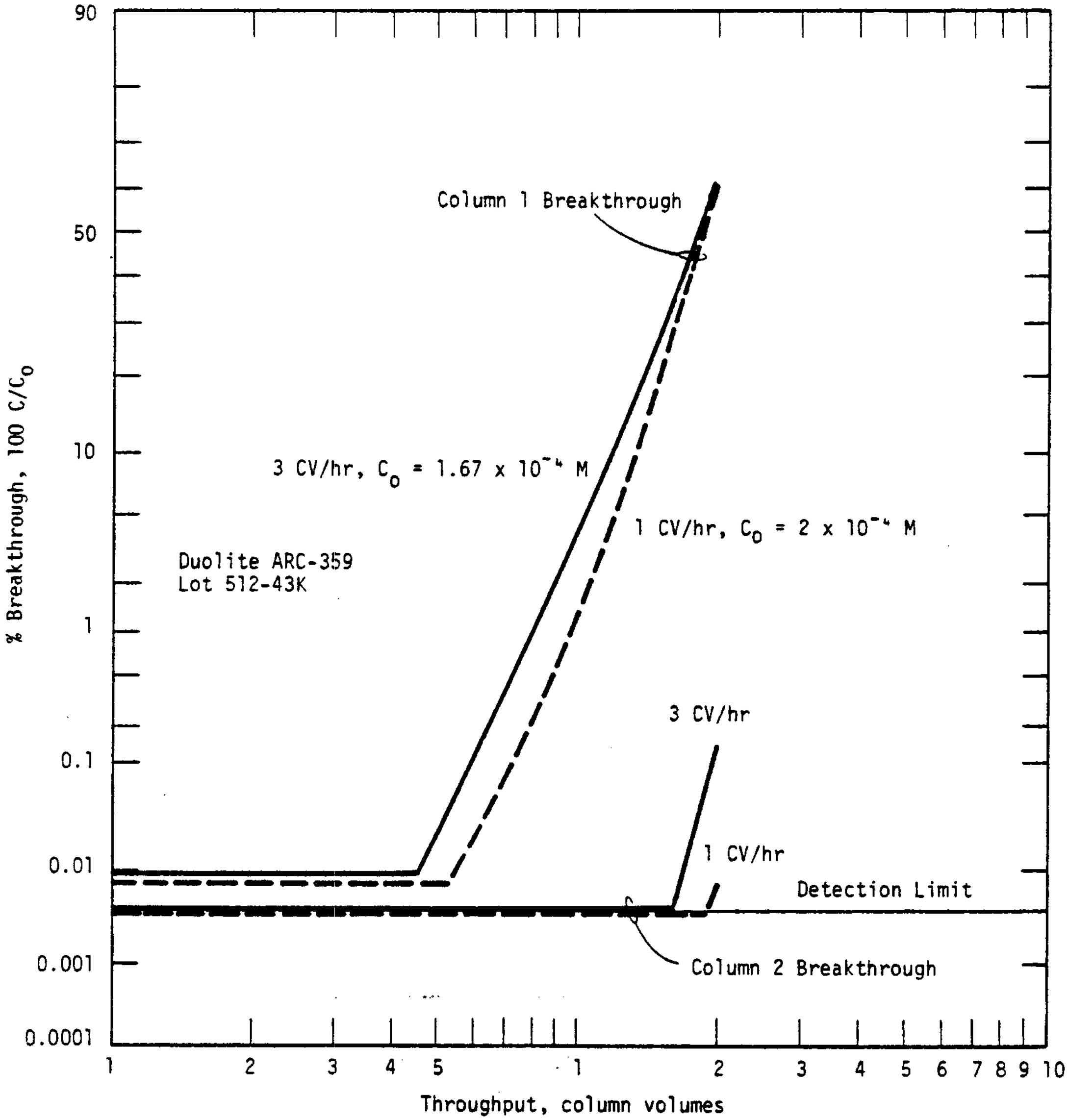


FIGURE 4.61 TNX Breakthrough Curves - Effect of Feed Rate

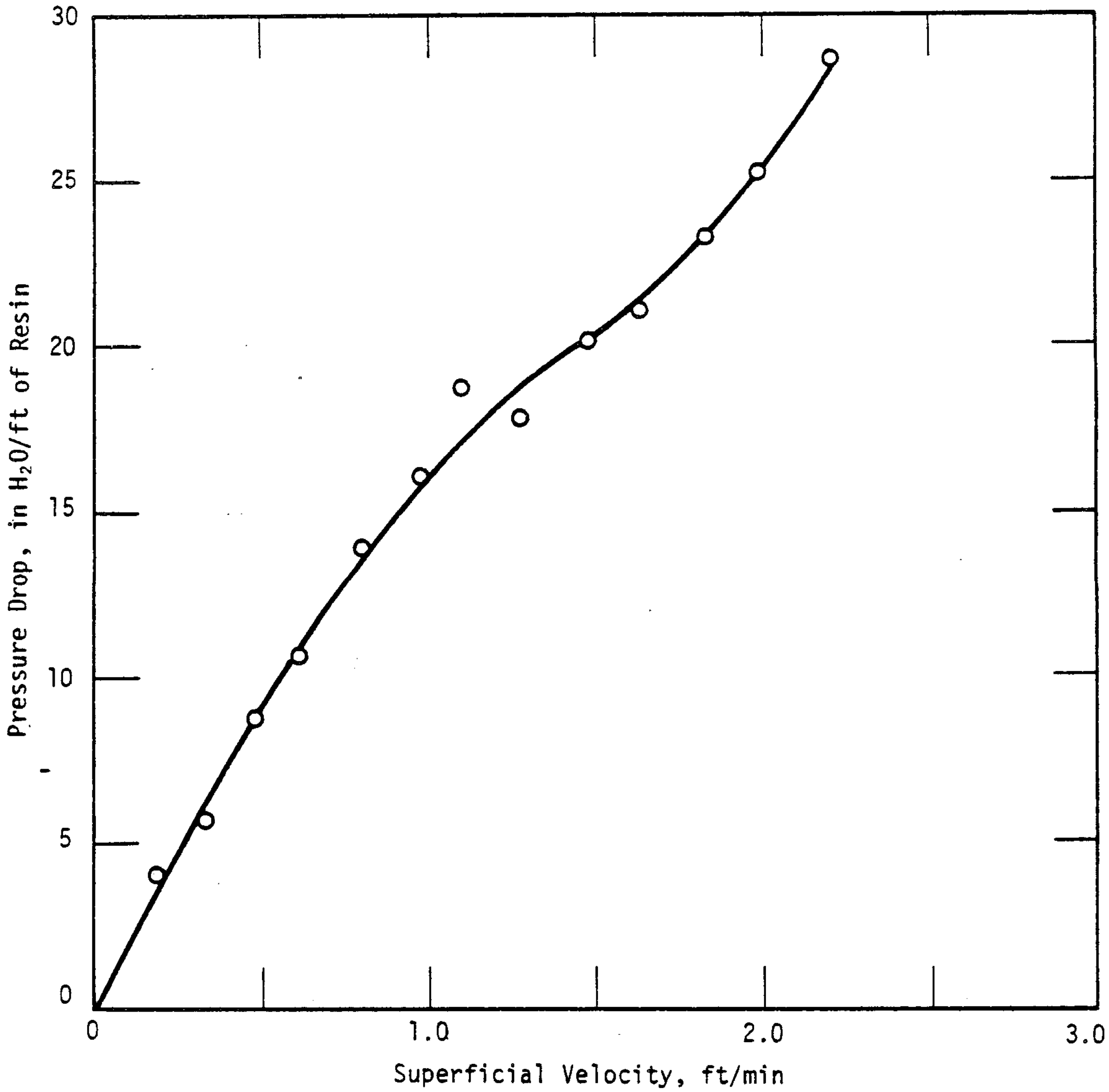


FIGURE 4.62 Downflow Pressure Drop of "Amberlite" IRC-718

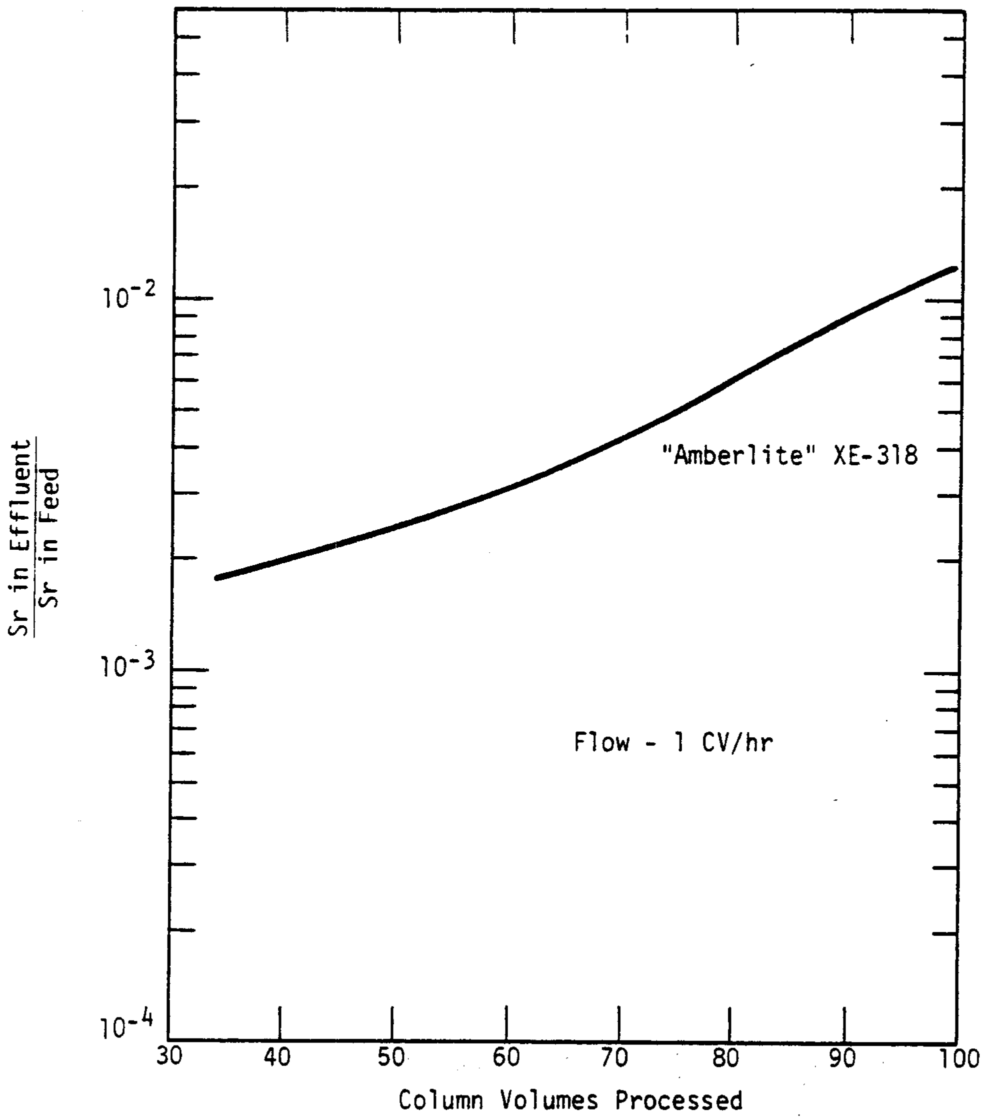


FIGURE 4.63 **Column Test of "Aberlite" XE-318 (Presently manufactured as Amberlite (IRC-718)**

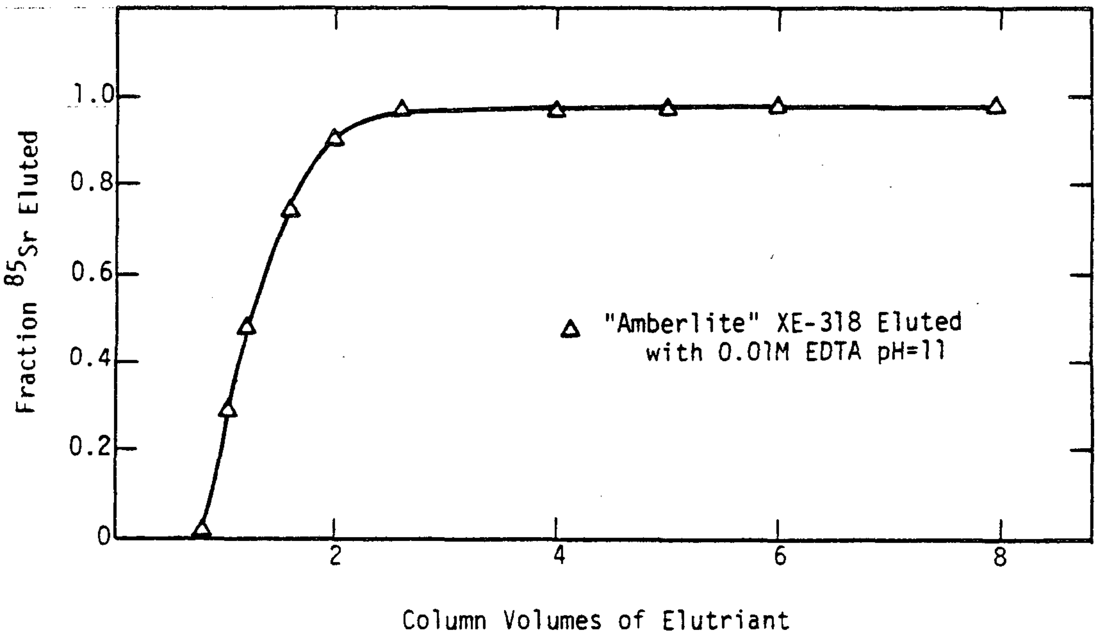


FIGURE 4.64 Elution of "Amberlite" XE-318 with EDTA (Presently manufactured as IRC-718)

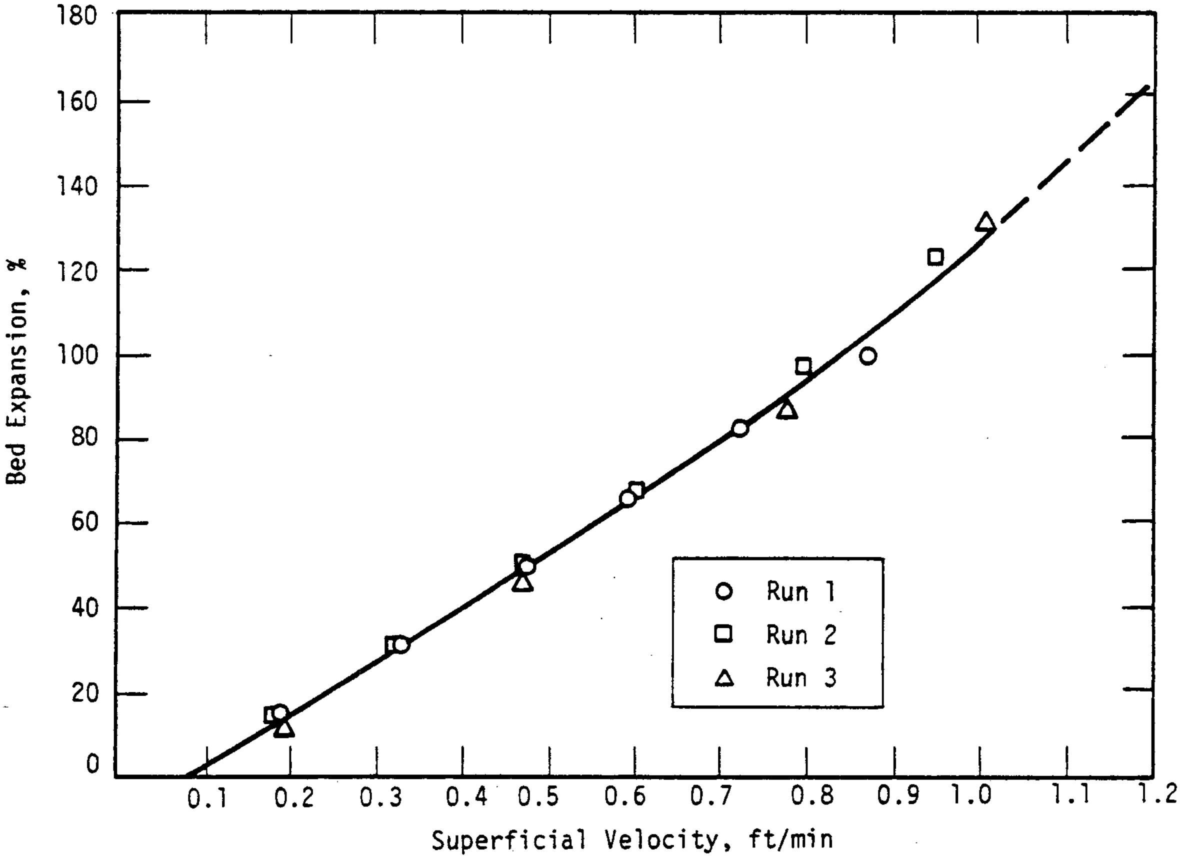


FIGURE 4.65 Upflow Expansion of "Amberlite" IRC-718

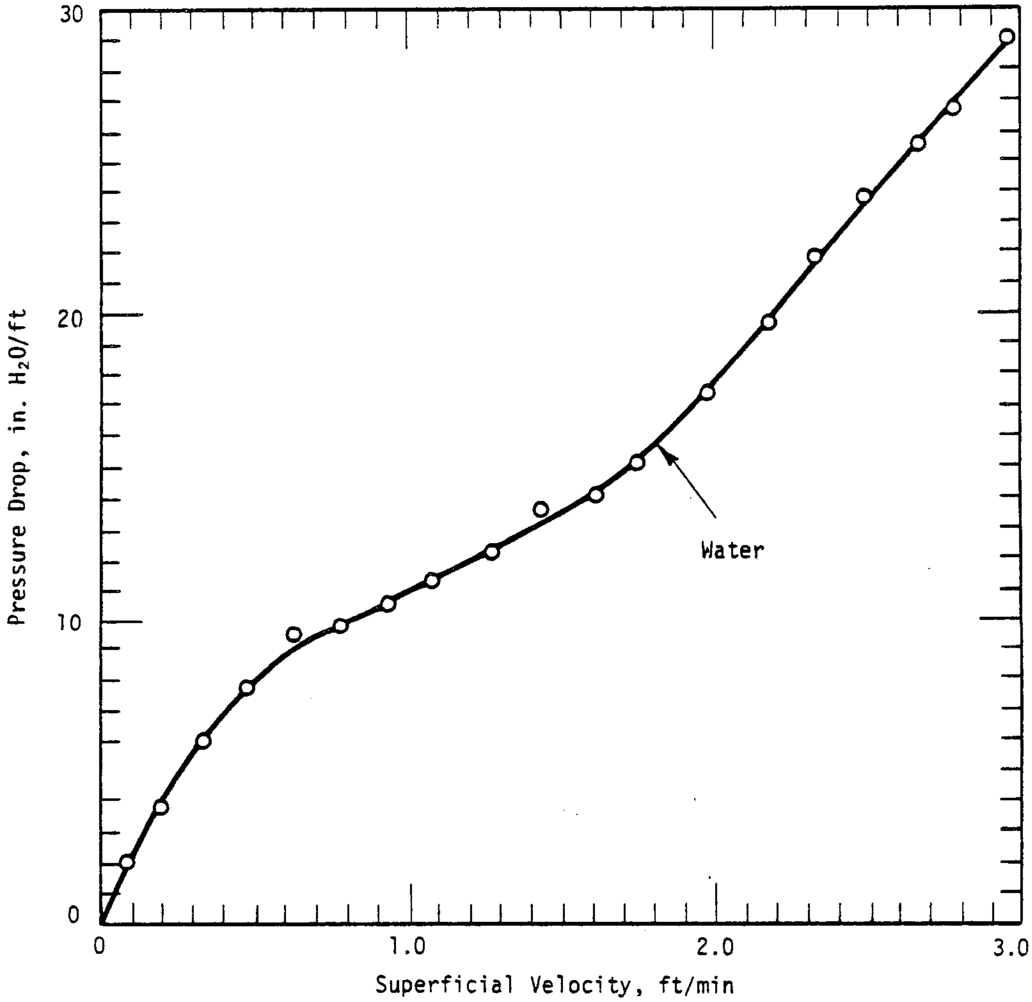


FIGURE 4.66 **Downflow Pressure Drop in "Linde" AW-500 (Presently manufactured as Ionsiv IE-95)**

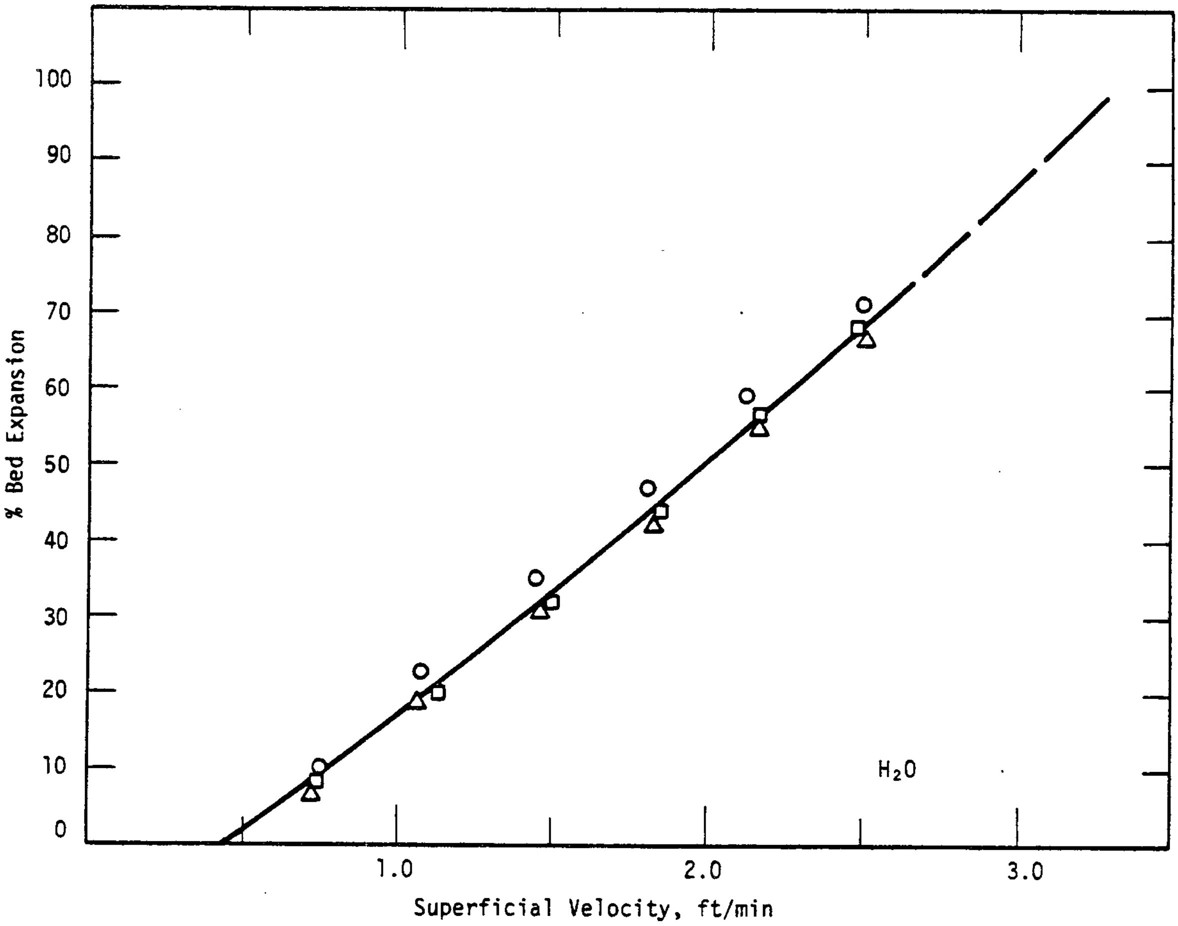


FIGURE 4.67 Upflow Expansion of "Linde" AW-500

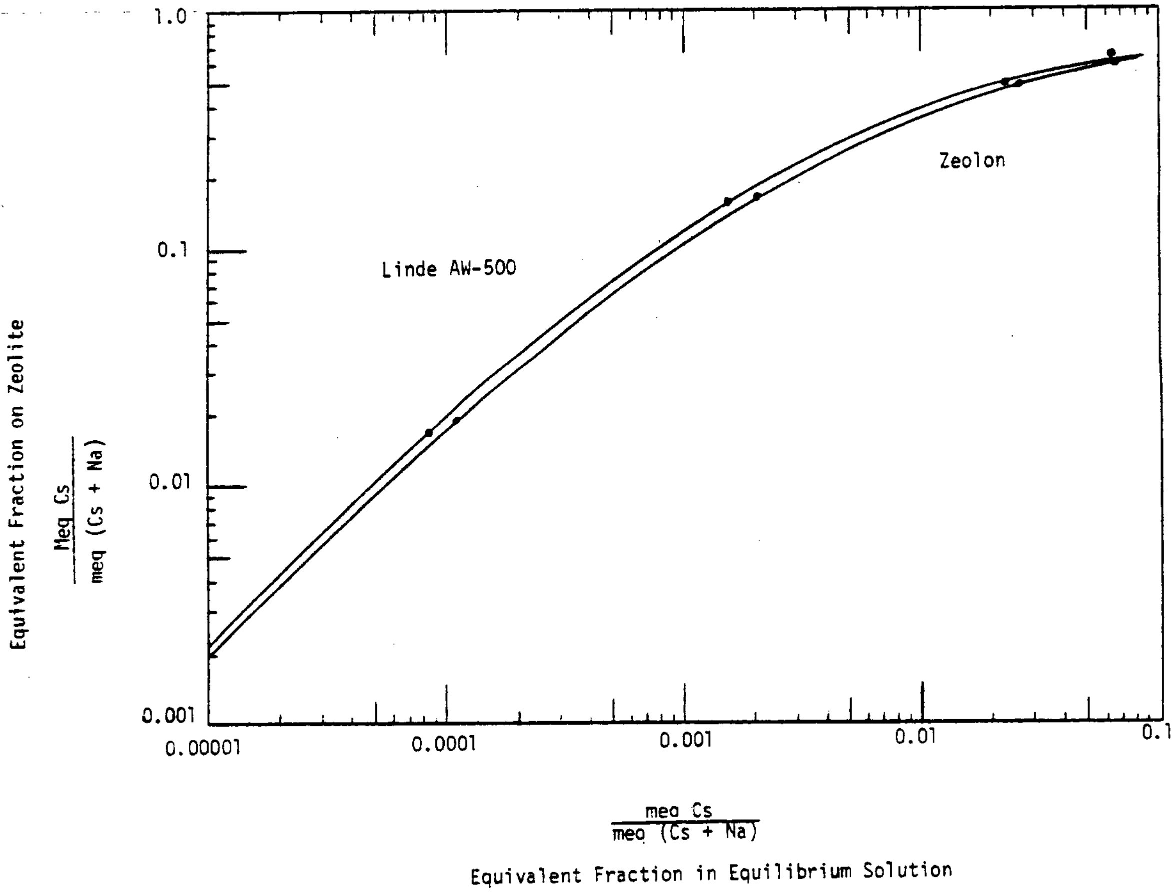


FIGURE 4.68 The Effect of Sodium on the Equilibrium Cesium Loading of "Linde" AW-500 and Norton "Zeolon"

5. PROCESS EQUIPMENT REQUIREMENTS

5. PROCESS EQUIPMENT REQUIREMENTS

5.1 General

High levels of radioactivity require that the equipment be located behind heavy shielding walls. Controls should be provided for remote operation. Remote maintenance is required. Equipment is to have high reliability, low need for maintenance, and capable of remote replacement. Equipment is to be designed with provision for flushing in place and for decontamination and limited contact maintenance after remote removal.

Services (including cold feeds) for all process equipment are shown in tabular form in Tables 5.1 and 5.2.

All cooling coils will be pressurized by an independent water source. Heating coils are pressurized by condensate and air pressure.

5.2 Process Equipment

5.2.1 Aluminum Dissolution (C. T. Randall)

5.2.1.1 General

In this process module, solid aluminum hydroxides in sludge slurry feed are dissolved using NaOH as described in Section 4.5.2. The aluminum-rich liquid phase and the aluminum-depleted insoluble phase are transferred as a slurry to sludge washing where the insoluble phase is separated and washed.

5.2.1.2 Equipment Specifications

5.2.1.2.1 Sludge Receipt Tank

An agitated hold tank receives batch transfers of 1:1 sludge slurry from blend tanks in the H-Area waste tank farm. The tank should be cooled and requires liquid level, specific gravity, and temperature instrumentation as well as sampling capability. This tank should be capable of accommodating 3-5 days feed.

5.2.1.2.2 Aluminum Dissolver

A dissolver which operates at near atmospheric pressure receives batch transfers of analyzed sludge slurry from the sludge receipt tank, 50% NaOH from cold feed, and recycle water to achieve operating conditions specified in Section 4.5.2. The dissolver also receives gravity settler bottoms and waste filter media (sand/coal) after the dissolving step is completed for blending before being transferred to the sludge feed tank. The dissolver consists of an agitated, steam heated tank and a condenser. The capability to reflux condensate or divert it to the dissolver condensate tank should be provided. The condenser should be sized to accommodate the maximum heat duty deliverable by the steam coils. The off-gas system should be air-purged to prevent possible explosive concentrations of ammonia which may be released during dissolving. As an additional safety feature, the dissolver should be vented to relieve excess pressure or overflow to the canyon cell. The dissolver must be cooled and be equipped with a transfer device to transfer the slurry product to the sludge feed tank. Liquid level, specific gravity, temperature, and pressure instrumentation as well as sampling capability are required.

5.2.1.2.3 Dissolver Condensate Tank

A tank should be provided to accommodate drawing off dissolver overheads if required to make concentration adjustments in the dissolver. The tank should be equipped with liquid level, specific gravity, and temperature instrumentation as well as sampling capability. A transfer device is required to transfer the condensate to the recycle evaporator feed tank.

5.2.1.3 Process Control

5.2.1.3.1 Sludge Receipt Tank

Function

- Hold sludge feed slurry for S-Canyon processing.
- Provide a sludge slurry sample point.

Controls

- Liquid level.
- Sample.

Transfers of sludge slurry from H-Area blend tanks are controlled by monitoring liquid level in this tank. Analyses of tank contents for volume percent suspended matter, density of suspended matter, weight percent aluminum in suspended matter and $[OH^-]$ are made to determine the amount of caustic and/or water to add to the dissolver.

5.2.1.3.2 Aluminum Dissolver

Function

- Dissolve insoluble aluminum hydroxides in the sludge slurry feed.
- Cool product slurry before transfer to the sludge feed tank.
- Blend recycled gravity settler bottoms and waste sand/coal with sludge after aluminum dissolution is complete.

Controls

- Liquid level.
- Dissolver pot pressure.
- Pot temperature.
- Automatic steam shut-off actuated by high pot or condenser cooling water temperature or high pot pressure.
- Condenser water/steam interlock.

Calculated quantities of sludge slurry from the sludge hold tank, 50% caustic from cold feed, and water are batched to the dissolver. For dissolution, the caustic concentration is to be increased to 5M while the molar ratio of OH^-/unsoluble aluminum in the sludge is to be 16. Quantities of slurry, caustic, and water are calculated based on analyses of the sludge slurry feed and maximum operating level in the dissolver.

Boiling is required for optimum dissolution of the aluminum hydroxides in the sludge. In operation, the boilup rate should be controlled to prevent overpressurizing the dissolver pot. A pot pressure indicator with high pressure alarm should be provided. Dissolution at the boiling point will be carried out for a specific length of time (30 minutes - 1 hour).

5.2.2 Sludge Washing (D. W. Jones)

5.2.2.1 General

Two parallel batch washing units are to be provided which consist of a wash tank, centrifuge, and centrate tank. In addition, two tanks are required for interim storage of the sludge feed and product. All tanks should be provided with suitable sampling equipment, agitation, and instrumentation for liquid level, specific gravity, and temperature. Tank heating equipment is not required. Cooling coils required only in the sludge feed tank.

5.2.2.2 Equipment Specifications

5.2.2.2.1 Sludge Feed Tank

A large, well-agitated tank is required to receive blended sludge from the aluminum dissolver composed of digested sludge, gravity-settler bottoms, and spent filter media. Sludge content in the slurry is about 12% by volume. Agitation must be sufficient to provide good mixing and maintain sludge, sand, and coal solids in suspension. Two pumps must be provided to transfer a controlled volume of feed rapidly to the two wash tanks at the start of each batch washing cycle.

5.2.2.2.2 Wash Tank

Two agitated tanks of at least 1,000 gallons capacity must be provided to receive and mix the sludge and wash water, supply feed to the centrifuge, and slurry the final washed sludge cake. Sufficient agitation must be provided for rapid cake dispersion and good solids/liquid mixing. Large lumps of cake may enter the wash tank during centrifuge discharge and must not be permitted to settle or collect on tank walls or enter the centrifuge feed system and obstruct feed flow. The mixing volume will range from 150 gallons during washed sludge slurrying to 700 gallons during sludge and wash water contacting. A variable speed pump is required to control centrifuge feed flow over a range of 1-30 gpm, and another pump is required to transfer the washed sludge slurry to the washed sludge run tank at the end of each washing cycle.

5.2.2.2.3 Centrate Tank

Two well-agitated tanks having approvimately the same capacity as a wash tank is required to hold the centrate from the centrifuges. Instrumentation must be provided to permit on-line analysis of effluent conductivity during the final wash. The centrate will contain some sludge (<1 vol %), and sufficient agitation must be provided to prevent solids settling. A pump is required to transfer the centrate to the centrate hold tank after each centrate pass.

5.2.2.2.4 Centrate Hold Tank

A well-agitated tank is required to hold centrate from each centrate tank. A pump is required to transfer the centrate to the recycle evaporator feed tank.

5.2.2.2.5 Washed Sludge Run Tank

This tank receives and blends washed sludge slurry from the two washing units. Tank agitation must be sufficient to maintain sludge solids in suspension and provide good mixing. A pump is required to transfer the slurry to the slurry mix tank. The slurry will contain 45 vol % sludge and is a Bingham plastic fluid having a yield stress of 60 dynes/cm^2 and consistency of 8 centipoise at 40°C. Special care must be exercised in design of mixing, transfer, and storage equipment for this slurry.

5.2.2.2.6 Wash Centrifuge

Large vertical, solid-wall, batch basket centrifuges are required for sludge dewatering in each of the processing steps. These machines are to be driven from the top and discharged through the bottom by a mechanical plow with water spray assist. Technical specifications for the wash centrifuge are listed in Table 5.3. The present design basis is for a 48-in. diameter x 30-in. high basket size with a 120-gallon capacity.

5.2.3 Spray Drying (M. H. Tennant)

5.2.3.1 General

The current concept is that the feed for spray drying will be split to parallel spray dryer, melter, and off-gas systems. The function of the equipment in this module is to convert the sludge slurry to a powder suitable for blending with glass frit prior to vitrification. This section provides the basic data for designing the equipment required to carry out the process (described in Section 4.5.5).

5.2.3.2 Equipment Specifications

5.2.3.2.1 Slurry Mix Tank

A tank is required to combine washed sludge from the washed sludge run tank with the cesium-zeolite slurry and the strontium concentrate. The tank must be equipped with an agitator and suitable devices to monitor liquid level, temperature, and specific gravity. Cooling coils will be required. Suitable transfer devices are required to transfer the slurry (about 17 wt % total solids) to a slurry hold tank.

5.2.3.2.2 Slurry Hold Tank

A well-agitated tank is required for inventory and quality control of spray dryer feed before transfer to the calciner feed tank. The tank must be equipped with an agitator, sampler, cooling coils, and suitable devices to monitor liquid level, specific gravity, and temperature. A transfer device is required to recycle out-of-spec feed to the sludge feed tank. A second transfer device is required to transfer in-spec feed to either of two calciner feed tanks.

5.2.3.2.3 Spray Dryer Feed System

General

The feed system is comprised of a feed tank, a recirculation loop, and a feed drawoff metering system designed to deliver feed at a relatively low flow rate (~1.0 gpm) to the spray dryer atomizing nozzle at pressures ranging from 1 to 2 atm. The concentrated slurry and low flow rates pose potential line, flow metering device, and nozzle blockage problems.

Calciner Feed Tank

A well-agitated vessel is required to receive in-spec batches of sludge slurry from the slurry hold tank for each calciner. The tank must be equipped with an agitator, sampler, and appropriate devices to monitor specific gravity, liquid level, and temperature. Cooling coils are required to maintain the feed slurry at 40°C or less [1]. A transfer pump is required to circulate the feed slurry about the recirculation loop at velocities no less than 5 ft/sec.

Feed Circulation Loop

Since the actual feed rate to the spray dryer nozzle is relatively low, a direct transfer from the feed tank to the spray nozzle would result in failure to maintain the solids in suspension, therefore posing potential problems of pluggage. Consequently, the nozzle feed line should branch off a feed loop that circulates the slurry through the loop back to the feed tank. The pressure in the loop must be controllable and continuously monitored. The drawoff line to the spray dryer feed nozzle, containing a flowmeter and a control valve, must be as short as possible to avoid pluggage. The circulation loop and feed drawoff line must have provisions for flushing to prevent pluggage problems when the feed system is shut down.

Atomizing Nozzle

The key to successful spray drying is proper atomization of the sludge slurry as it is sprayed into the heated chamber. The air rate to the nozzle requires a system that maintains the air flow such that a ratio of air to slurry feed is maintained at approximately 4.00 lb air/gal feed. The slurry should be dispersed into droplets small enough to dry before striking the heated wall. If the particles do not dry, they will stick to the wall producing a scale that reduces heat transfer into the chamber. A droplet mass median diameter of about 70 micrometers is adequate for successful operation of the spray dryer based on work carried out at PNL [1].

An internal-mix atomizing nozzle designed to handle the anticipated slurry feed rate should be used to atomize the waste. A Spraying System Co. Setup No. 84 nozzle was determined by PNL to provide satisfactory performance at flow rates from 20 to 80 gal/hr. Both the fluid orifice and air cap orifice in this nozzle are 1/4 inch in diameter (see Figure 5.1). Larger orifices, up to 1/2 inch in diameter, are currently being tested and evaluated. To minimize orifice wear by abrasion and corrosion, and therefore, extend service life, the nozzle air cap was fabricated from 96% alumina [1].

The internal-mix nozzle will require a pressurized feed system. To assure that sludge slurry is not pumped through the atomizing air lines to areas outside the canyon cell, pressure sensors tied in with the slurry feed pump should be located in the air and slurry lines. In addition, a radiation detector should be positioned at the location where the air line penetrates the cell wall.

The atomizing nozzle should be incorporated into a remotely replaceable assembly to facilitate nozzle changeout. This assembly may include a remotely operated cleanout needle for removing obstructions from the liquid and air cap orifices; however, 1/4-inch or 1/2-inch orifices have not plugged when flush water has been introduced at the end of each shutdown.

An external-mix nozzle is being tested at PNL as a potential replacement for the internal-mix nozzle. Advantages of the external-mix nozzle are: (1) it does not require a pressurized slurry feed system, and (2) it is not subject to rapid wear because the slurry and atomizing air mix after leaving the nozzle. However, problems were experienced in earlier work with nonuniform droplet sizes and poor atomization caused by spray dryer chamber pressure variations resulting from filter blowback. Proper nozzle design is expected to eliminate these problems.

5.2.3.2.4 Spray Drying Chamber

The spray drying chamber is a large externally heated vertical tube into which the atomized sludge slurry is sprayed at the top center (Figure 5.2). A furnace surrounds the chamber and supplies the process heat load. The chamber wall temperature is to be maintained between 550°C and 800°C. However, for maximum capacity the chamber should be run at the highest temperature consistent with the dryer product melting point, equipment life, and existing heater technology. The furnace power output is to be controlled by temperature sensing elements located on the exterior spray chamber wall.

Sludge slurry enters the dryer as small droplets in a stream traveling at very high speed and hence, induces a high degree of turbulence in the chamber. The combination of radiant heat transfer coupled with this violent convective heat transfer allows evaporation and drying at a high rate. Important data relating spray dryer size, slurry feed rate, wall temperature, and power input are listed in Table 5.4.

A scale which reduces dryer capacity, may deposit on the interior spray chamber walls due to this violent convective heat transfer. A side-mounted vibrator is required to keep this wall scale to an inconsequential amount. Two vibrators situated at the chamber midpoint and located 180° apart are recommended for a 3-0 ft diameter chamber. Larger chambers will most likely require additional vibrators. The vibrators are to be designed for remote replacement without requiring dryer shutdown.

The powder produced in the spray chamber falls into the cone below and mixes with powder that is periodically discharged from the filters. Experience both at PNL and at Karlsruhe, Germany has shown that the filters should be as close to the spray drying chamber as possible. All surfaces should be sloped at least 60° from horizontal to prevent powder accumulation. Further assurance of transport is provided by the mild vibration of the lower portion of the spray dryer caused by the spray chamber vibrator.

The spray dryer chamber and associated piping and hardware should be constructed of materials that are resistant to corrosive and erosive attack by the sludge slurry and are unaffected by the elevated operating temperatures. Incoloy® 800H (Huntington Alloys, Inc.) and Hastelloy® C (Cabot Corp.) are recommended materials of construction for these elevated operating temperatures in presence of halides.

Although it is not likely to be needed during normal operation, a pressure/vacuum relief device should be provided to vent the spray dryer to the off-gas system in the event pressure limits are exceeded.

5.2.3.2.5 Off-Gas Filters

Because of the small particle size of the spray-dried sludge, up to 50% of the sludge may be entrained in the spray dryer off-gas. Based on early experiments with various types of dust removal equipment conducted by PNL, sintered metal filters are recommended for primary effluent decontamination. The filter adopted by PNL is shown in Figure 5.3.

During operation entrained sludge particles removed from the off-gas are retained on the filter surface. With time the sludge layer thickness increases, producing a corresponding increase in filter pressure drop. Excessive pressure drop is to be prevented by use of a pulse of air to dislodge the cake. A recommended blowback system is shown in Figure 5.3. The use of a venturi is intended to increase entrainment of filtered off-gas by the blowback air jet, thereby decreasing the amount of external air required.

The filter blowback operation should be designed to minimize dryer chamber pressure surges. Variables which affect these surges are blowback pulse duration, blowback pressure, off-gas line flow resistance, and the number of filters that are pulsed simultaneously.

Since some powder is smaller than the pore size of the filter, some particles penetrate the filter and become lodged inside. Penetration is greatest at the surface but is rapidly reduced by larger particles which bridge over the pores and act as a filter precoat. During filter blowback the precoat is partially removed and some particles are again free to enter the filter. Unfortunately, not all particles are removed during blowback resulting in a slow accumulation. The rate of accumulation can be minimized and thus, filter life maximized by designing for a filter face velocity of 4 ft/min.

The filter design should be sufficiently rugged to prevent accidental breakage during handling and installation and to withstand normal operating conditions. Vibration isolation techniques are recommended to provide resistance to vibration-induced filter failure caused by the spray chamber vibrators. Filter material must be resistant to chloride and fluoride corrosion.

5.2.3.2.6 Glass Frit Addition System

The glass forming frit should be rate fed to the spray dryer cone based on the sludge slurry feed to the atomizing nozzle. Equipment and instrumentation is needed for transporting and controlling this frit addition. The control system should permit operation over a range of feed/frit ratios.

5.2.4 Vitrification (T. A. Willis)

5.2.4.1 General

The function of the melter is to heat the spray dryer product and glass frit to the reference vitrification temperature (1150°C). Two concepts to achieve vitrification have been demonstrated. The first, a continuous, Joule-heated melter, is the reference concept. An alternative vitrification process is in-can melting. Figure 5.4 is a conceptual drawing of a continuous glass melter [5].

5.2.4.2 Equipment Specifications

5.2.4.2.1 Melting Tank Section

This is the section of the continuous glass melter where the dried sludge and glass frit are heated to the reference vitrification temperature (1150°C). The glass in this section must be heated to the reference molten glass temperature and achieve a viscosity of no more than 50 poise. Heating is supplied by the Joule heating effect of passing alternating current (AC) through opposing pairs of electrodes.

The melter tank horizontal surface area shall be 12 to 14 square feet. This is based upon a design capacity of 2.2 tons/day of glass production and on data from glass production of SRP simulated sludge and glass chemicals at Battelle-Pacific Northwest Laboratories [2].

The depth of the melter tank shall be approximately 2-1/2 feet to permit a residence time of at least 12 hours for molten glass at the reference vitrification temperature. There shall be an additional freeboard of 2-1/2 feet above this depth to accommodate the cold cap or possible foam generation. This total depth of 5 feet in the tank is to be refractory lined and have Joule electrodes over the total 5-foot depth.

5.2.4.2.2 Throat Section

This section connects the melting tank with the riser section at the lowermost elevation. The riser shall be lined with the specified molten glass contact refractory. The throat shall be designed with the maximum cross sectional area for glass flow practicable in order to minimize refractory erosion: the slower the molten glass velocity, the lower the resulting erosion of the refractory. The glass temperature in the throat shall be maintained as close to the reference vitrification temperature (1150°C) as possible. Joule electrodes firing through the throat may be necessary to maintain this temperature.

The throat area is probably the most vulnerable area for refractory failure and will probably be the design feature which limits the melter operating lifetime. Precautions should be taken in design to minimize erosion (low velocities), corrosion (minimum refractory temperature to permit glass flow), and "upward drilling" (refractory corrosion on the throat ceiling probably caused by gases accelerating corrosion). Upward drilling may be minimized by making the refractory surface on the "ceiling" of the throat as smooth as possible, by adequate cooling, and by sloping the ceiling of the throat up in the direction of the glass flow by a minimum of 15° from the horizontal.

5.2.4.2.3 Riser Section

Glass rises from the throat (a bottom underflow area) to the pour spout. The riser section will be heated independently of the Joule electrodes in the melter tank section. The molten glass temperature will be maintained as close as possible to the reference molten glass temperature of 1150°C, so that the viscosity will be maintained less than 200 poise.

5.2.4.2.4 Electrodes

Joule heating electrodes will be fabricated of Inconel® 690 (Huntington Alloys, Inc.). The electrical flux on the electrodes will be as uniform as possible over the surface and will not exceed 2 amps/in^2 during operation at steady state. The electrical flux limit of 2 amps/in^2 may be exceeded on startup or some limited transients, but should be held to the minimum practicable above this value.

The electrode temperature will be held to 1050°C or less. If internal cooling of the electrodes is necessary to maintain this 1050°C temperature limit, air cooling is preferred. Operation of the "Inconel" 690 electrodes above 1050°C can result in distortion of the electrode shape and in the metal strength. The melting point of "Inconel" 690 is 1343 to 1376°C.

The electrodes shall extend to the top of the melter tank above the "metal line" ("metal line" is the term for molten glass liquid line). Electrical connections from the power supply to the electrodes shall be at the top of the electrode. In no case shall the electrode penetrate through the refractory wall of the tank.

5.2.4.2.5 Refractories

The melter tank, throat, and riser shall be lined with Monofrax® (The Carborundum Company) K-3 DCL refractory in contact with the molten glass. The refractory shall be at least 6 inches thick. In no portion of the melter shall molten glass be in contact with opposing sides of a refractory. Such contact would cause the refractory brick to be operated at approximately molten glass temperature throughout to cause refractory corrosion.

Cooling shall be applied to the exterior of the refractory. The coolant will be forced through metal jackets surrounding the refractory. The objective of this cooling is to extend the refractory life (particularly the throat section) in order to achieve a melter life of at least two years. The preferable coolant is air as discussed in cooling of electrodes.

There are to be no penetrations through the refractory in the tank, throat, and riser sections below the pour spout level except for one bottom drain freeze valve. The purpose of this requirement is to minimize the risk of accidental dumping of molten glass. This type design is not typical of glass industry designs which have many electrode penetrations of melter walls and floor. Such glass industry designs have led to numerous large (multiton) spills of molten glass onto plant floors.

5.2.4.2.6 Melter Pour Mechanism

The filling of canisters with molten glass from a continuous Joule-heated melter requires a means of starting and stopping the flow of molten glass. The flow of glass must be started to each empty canister and then stopped when the canister is full. The glass flow must remain stopped while the full canister of waste glass is removed and another empty container is moved into position. This operation of filling canisters from the melter is called pouring.

The reference means of pouring is called tilt-pour. The tilt-pour method requires that the entire Joule-heated melter be tilted up to 4 degrees forward to start the pour and then be tilted back to stop the pour. The tilt-pour method is used on the experimental prototype Joule-heated melter at PNL. The connections to the melter must all be flexible connections to accommodate the 4° of melter movement on either side of vertical. The connection between the canister and the spout must be designed such that the volatile products evolved from the glass do not vent to the canyon ventilation system.

An alternative pour technique, involving close-coupling of the pour spout and canister and varying the pressure in the canisters, is under investigation.

5.2.4.2.7 Shutdown Drain

A freeze valve is required in the bottom of the melter to dump the contents of the melter into a ditch can in the event power is to be interrupted of such a duration to result in the melt solidifying. The drain consists of a closure plate, an opening-and-closing mechanism, and a resistance heater. The heater is used to melt the frozen glass in the drain tube before discharging the contents of the melter to the ditch can. The connection between the drain and ditch can should be designed such that the volatile products evolved from the glass melt do not enter the canyon atmosphere.

5.2.4.3 Instrumentation and Control

The power to the electrodes will be controlled by appropriate current and temperature sensing devices. Joule-heating electrodes will be air cooled. Cooling air rate will be controlled by appropriate temperature sensors on the electrodes. The electrode temperature is not to exceed 1050°C. A device is required to monitor the level of the glass melt. Melt level should be maintained as near constant as possible during pouring. Suitable temperature sensors are required throughout the melter to maintain surveillance of the glass-melt temperature, the electrode temperature, and the temperature drop across the refractory. Emergency power is required in the event normal power is lost.

5.2.5 Off-Gas Treatment System (L. F. Landon)

5.2.5.1 General

5.2.5.1.1 Spray Dryer/Melter

A DF of 1000 for particulates generated in the spray dryer is assumed across the sintered metal filters for material balance purposes. However, the design of the scrubbing system should be such that in the event of total bypass of the filters, the scrub system should perform satisfactory at the higher solids load to permit an orderly shutdown of the spray dryer.

Analyses of sludge currently stored in the waste farm indicate significant quantities of chloride and fluoride to be present. Although a thermodynamics study of the melter/spray dryer off-gas system suggests that no HCl and only 3.8% of the fluoride (as HF) will pass the sintered metal filters, materials selection for the part of the off-gas system that contact the scrub solution should assume all these halides enter the scrub as HCl and HF. Suggested materials of construction are discussed in Section 10.

5.2.5.1.2 Process Vessel Vent Filter

Each canyon process vessel is assumed to have a 50 scfm (dry air) vapor sweep drawn from the canyon atmosphere through the tank vapor space via the overflow pipe. All vessel vents are combined into a single header and drawn through a heater and deep bed filter prior to being combined with the canyon air exhaust. It was assumed for curie balance purposes than the vessel vent air purge entered the vessel at a dry bulb temperature of 35°C and a wet bulb temperature of 25.6°C. At discharge, the dry bulb temperature is unchanged but the wet bulb temperature increased to 29.4°C.

5.2.5.1.3 Sand Filter

The canyon atmosphere is combined with the treated spray dryer off-gas and the vessel vent filter effluent and drawn through a sand filter prior to discharge to the atmosphere.

5.2.5.2 Equipment Specifications

5.2.5.2.1 Spray Dryer Off-Gas Duct

The temperature of the vapor duct between the spray dryer and ejector/venturi is to be maintained between 250 and 400°C.

5.2.5.2.2 Ejector/Venturi

- Function: To cool the spray dryer off-gas vapor to 50°C and achieve condensation, solids formation, and coalescing. Design for a inlet vapor temperature of 650°C.

- Operating Conditions: Co-current contacting of the vapor stream with a cooled (40°C) circulating scrub stream. Estimated ΔP across the ejector - 15 in. H_2O.

- Details: The backpressure across the ejector/venturi should be sufficient to route a slip stream (equivalent to the off-gas condensate rate) of the recirculation quench to the recycle collection tank. The ejector/venturies discharge to a common column that routes the condensables and noncondensables into the off-gas condensate tank.

5.2.5.2.3 Pump-Quench Stream

- Function: To circulate a portion of the contents of the off-gas condensate tank through a cooler and to each ejector/venturi.

- Operating Conditions: Flooded suction, 50°C.

- Details: The pump capacity will be about 200 gpm based on a ΔT of 10°C across the cooler. The pump should be spared and on emergency power. Discharge pressure and flow must be monitored.

5.2.5.2.4 Ejector-Venturi Cooler

- Function: To cool liquid circulating from the off-gas condensate tank from 50°C to 40°C.

- Operating Conditions: Process side — 50°C to 40°C
  Available Inlet Cooling Water
  Temp — 32°C

- Instrumentation and Control: The temperature of the process stream and cooling water stream should be monitored at the inlet and discharge of the cooler. Cooling water flow to be automatically controlled to maintain the quench stream entering the ejector/venturies at 40°C. The shell side cooling water pressure is to be at least 15 psig greater than the quench stream pressure.

5.2.5.2.5 Off-Gas Condensate Purge Valve

- Function: To route a portion of the recirculation quench stream (equivalent to the rate at which water vapor is condensed from the spray dryer off-gas stream) to the recycle collection tank.

- Details: The nominal purge rate is about 1.0 gpm. During normal operation, this stream will contain about 0.85 wt %. suspended solids. Total failure of the spray dryer filters could result in a suspended solids concentration of 16 wt %.

- Instrumentation and Control: Suitable liquid level sensors in the off-gas condensate tank must control the purge valve opening such that the liquid level in the off-gas condensate tank remains essentially constant. Because of the low purge rate, the valve should operate intermittently to allow a larger valve opening and consequently minimize the risk of valve pluggage.

5.2.5.2.6 Off-Gas Condensate Tank

- Function: Provide a collection reservoir for the condensables and the source of scrub solution for the first deep bed washable filter and ejector/venturi quench.
- Operating Conditions: Temperature — 50°C.
- Details: The tank bottom must be adequately sloped to allow mercury to drain freely to the mercury collection sump. Sump capacity — 2 liters.
- Instrumentation and Control: This tank requires suitable detection devices to monitor temperature, specific gravity, conductivity, and liquid level of its contents. The tank must be well-agitated to maintain particulates in suspension. A sampling device is required. Suitable high level and low level mercury sensors in the sump will control operation of the mercury pump. The conductivity of the tank contents should be continuously monitored.

5.2.5.2.7 Pump-Mercury Transfer

- Function: To transfer the condensed mercury from the off-gas condensate tank mercury collection sump to the mercury recovery facility.
- Operating Conditions: Flooded suction — 50°C.
- Details: Pump will be handling approximately 1.0 liter of mercury per day. Pump capacity — 25 mL/min over a discharge pressure range of 5-30 psig. The pump will operate intermittently.
- Instrumentation and Control: Suitable high level and low level mercury sensors, monitoring the level of mercury collection sump, will control the operation of the pump. A transfer of mercury should be stopped before all the mercury is discharged so as to prevent transfer of the scrub solution to the mercury recovery facility.

5.2.5.2.8 Pump-Scrub Flow to the DBF No. 1

- Function: To deliver the appropriate amount of scrub solution from the off-gas condensate tank to the spray nozzles in the DBF unit.

- Operating Conditions: Flooded suction — 50°C.

- Details: The pump discharge is split appropriately to the spray nozzle over the top of the de-entrainer pad and to the nozzle that atomizes the scrub onto the underside of the deep-bed filter pad. Design flow to the lower nozzle is 2 gpm and to the upper nozzle 40 gpm. Air is introduced (5 scfm/gpm) into the scrub flow to the lower nozzle to obtain proper atomization. The pump should be on emergency power.

- Instrumentation and Control: Suitable devices to monitor scrub flow and pressure to each spray nozzle are required.

5.2.5.2.9 Deep-Bed Filter No. 1

- Function: Scrub at least 95% of the particulates from the vapor stream.

- Operating Conditions: Temperature — 50°C
  Inlet vapor flow —77 acfm (703 mmHg)
  Solids load in scrub —0.85 wt % (nominal)
  ΔP = 6 in. H_2O (assumed for calculating effluent vapor flow)
  Particle diameter — 0.3 micrometer nominal
  Superficial face velocity — 50-100 ft/min

- Details: The filter should not experience a buildup in pressure drop for a maximum solids content in the recirculating scrub of $\leq$1.0 wt %. The fiber material and/or binder should be sufficiently resistant to radiation to provide a useful life of at least two years in the scrub environment.

- Instrumentation and Control: A suitable device to continuously monitor pressure drop across the filter is required.

5.2.5.2.10 Deep-Bed Filter No. 2

- Function: Scrub at least 95% of the particulates entering the unit in the vapor stream and reduce the vapor temperature to 10°C to condense out mercury vapor.

- Operating Conditions: Temperature — 10°C
  Inlet vapor flow — 90 acfm (692 mm Hg)
  Solids load in scrub — $\sim$0.20 wt % (nominal)
  ΔP — 6 in. H_2O (assumed for calculating effluent vapor flow)
  Superficial face velocity — 50-100 ft/min

- Details: Same as 5.2.5.2.8 and 5.2.5.2.9.

- Instrumentation and Control: Same as 5.2.5.2.8 and 5.2.5.2.9.

5.2.5.2.11 Filter Pump Tank

- Function: To provide a source of refrigerated scrub solution for the DBF #2 such that the temperature of the vapor leaving the filter is at 10°C.

- Operating Conditions: Tank is to contain cooling coils through which brine is circulated from an external refrigeration machine. The mercury and water that is condensed in the DBF #2 is purged to the off-gas condensate tank.

- Instrumentation and Control: The flow of refrigerant to the circulation tank coils is controlled such that the vapor temperature leaving the DBWF #2 is 10°C. The temperature of the vapor exiting the filter and the temperature of the scrub should be monitored. Liquid level monitoring is required.

5.2.5.2.12 Ruthenium Adsorber Pre-Heater

- Function: To raise the temperature of the vapor stream 10°C above its dew point.

- Operating Conditions: ΔP — about 2 in. of water
  Inlet flow conditions —
  12.6 lb-mole/hr noncondensables,
  0.16 lb-mole/hr water vapor

- Instrumentation and Control: The steam flow to the heater is controlled such that the vapor effluent is 10°C above its dew point.

5.2.5.2.13 Primary Ruthenium Adsorber

- Function: To adsorb volatile ruthenium from the vapor stream.
- Details:
  - Adsorbent: Davidson Chemicals Grade 40 - Silica Gel, 6-12 mesh
  - Adsorbent Capacity: 136 g ruthenium/ft^3
  - Bed Depth: 52 in.
  - Superficial Face Velocity: 0.4 ft/sec (max)
  - Pressure Drop: 0.6 in. H_2O/in. of bed at design face velocity
  - Efficiency: 99% for volatile ruthenium, 50% for particulates
- Instrumentation and Control: The pressure drop across the bed should be monitored. The concentration of Ru-106 should be intermittently monitored in the effluent to detect bed breakthrough. The temperature of the adsorbent should be monitored throughout the bed.

5.2.5.2.14 Secondary Ruthenium Adsorber

- Function: To adsorb volatile ruthenium from the vapor stream.
- Details:
  - Adsorbent: Davidson Chemicals Grade 40 - Silica Gel, 6-12 mesh
  - Adsorbent Capacity: 136 g/ft^3
  - Bed Depth: 52 in.
  - Superficial Face Velocity: 0.4 ft/sec (max)
  - Pressure Drop: 0.6 in. H_2O/in. of bed at design face velocity
  - Efficiency: 99% for volatile ruthenium, 50% for particulates
- Instrumentation and Control: Same as 5.2.5.2.13.

5.2.5.2.15 Iodine Adsorber Preheater

- Function: To raise the temperature of the vapor stream to 150°C.
- Operating Conditions: ΔP — 2 in. of water
  Inlet flow conditions —
  12.6 lb-mole/hr noncondensables,
  0.16 lb-mole/hr water vapor

- Instrumentation and Control: The steam flow to the heater is controlled to maintain the vapor at a temperature of 150°C entering the iodine adsorber.

5.2.5.2.16 Iodine Adsorber

- Function: To adsorb I_2 from the off-gas stream.
- Operating Conditions: Temperature — 150°C
  Superficial velocity — ≤ 0.4 ft/sec
- Details:
  - Adsorbent: Ag°Z (silver-exchanged mordenite)
  - Capacity: 100 mg I_2/g of adsorbent
  - Bulk Density: 49.2 lb/ft^3
  - Collection Efficiency: 99% for I_2, 50% for particulates
  - Pressure Drop: 0.5 in. H_2O/in. bed
  - Gas Residence Time: >2 seconds

5.2.5.2.17 Off-Gas Cooler

- Function: Reduce the temperature of the vapor leaving the iodine adsorber to <50°C.
- Operating Conditions: ΔP — 2 in. H_2O
  Inlet flow —
  12.6 lb-mole/hr noncondensables,
  0.16 lb-mole/hr water vapor
  Inlet gas temperature — 150°C

5.2.5.2.18 Off-Gas Exhauster

- Function: To draw the off-gases generated in the spray dryer/melter through the various off-gas treatment subsystems while maintaining a negative pressure of 10 inches of water in the spray dryer.
- Inlet Conditions: 159 acfm at 0.56 atm vacuum. Temp - 50°C.
- Details: Exhauster should be spared and on emergency power.

- Instrumentation and Control: Suitable devices to monitor vapor temperature and pressure at both the inlet and outlet of the exhauster are required. The spare exhauster must come online automatically if the other exhauster fails. Failure of both exhausters should automatically shut off feed to the spray dryer.

5.2.5.2.19 Recycle Collection Tank

- Function: To accumulate one day's volume of miscellaneous water streams (see Figure 4.6).
- Instrumentation and Control: Suitable devices to monitor liquid level and temperature are required. An agitator is required to keep solids in suspension. A transfer device is required to transfer to the recycle evaporator feed tank.

5.2.5.2.20 Process Vessel Vent Filter

- Function: Provide high efficiency filtration of particulate radionuclides entrained into the process vessel vents.
- Operating Conditions: Inlet flow — ~3510 acfm
  Inlet vapor temperature — >10°C above the dew point
- Details: The vapor entering the filter is assumed to be saturated with water vapor and consequently should have its temperature raised at least 10°C above its dew point to avoid condensation in the filter. It is assumed a collection efficiency of at least 99.9% may be attained by the filter. The vessel vent exhaust fans should be spared and on emergency power.
- Instrumentation and Control: Instrument facilities are required to control the temperature of the vapor entering the filter and to monitor the pressure drop across the filter. Exhaust flow from the filter need be monitored.

5.2.5.2.21 Sand Filter

- Function: Provide the final stage high-efficiency filtration for removal of radioactive particulates before discharging the canyon, vessel vent and spray dryer off-gas streams to the environment
- Operating Conditions: Inlet flow — About 3.6×10^5 acfm
  Face velocity — 5 to 6 ft/min

- Details: Condensate collection facilities are required for the sand filter and the tunnels leading to the sand filter. Condensate will be pumped back to the recycle collection tank. The sand filter and associated fanhouse are to be maximum resistance facilities. Exhaust fans should be spared and on emergency power. The sand filter is assumed to be 99.9% efficient for particles of 0.3 micrometer in diameter.

- Instrumentation and Controls: Instrumentation for monitoring and controlling the liquid levels in the sumps and for measuring ventilation flow is required. The pressure drop across the sand filter must be continuously monitored.

5.2.5.2.22 Ventilation Exhaust Stack

- Function: To disperse the exhaust air from the sand filter to the atmosphere.

- Details: Stack height ∿2-1/2 times the height of the adjacent buildings. A stainless steel-lined sump is required in the stack foundation for collection of condensate which is returned to the recycle collection tank. The stack should be at a distance from the adjacent buildings of at least 3 times the height of the adjacent buildings or structures.

- Instrumentation and Control: A system to continuously inventory the quantity of radioactivity being discharged to the environment is required. Details of this system are as follows:

  Sampling Point - at least eight (8) stack duct inside diameters downstream from the last change of stream direction or side stream entry point into the main exhaust stream, and two (2) stack duct diameters below the point of discharge

  Sampler - isokinetic sampler following ANSI Standard N13.1 criteria

  Sample Collection - a primary sample collection system, plus a backup will be required per proposed appendix to 10CFR50 for chemical reprocessing plants

  - Filter paper collectors for particulates
  - Charcoal or other suitable media for radioiodine, radioruthenium, etc. (may require development of improved collection system)

In-situ Stack Monitoring

- Gross beta-gamma detection (minimum) - if individual radionuclides must be identified, a Ge-Li system would be required for gamma emitters. Some development work would be required.
- Alpha detectors (minimum) - if individual TRU radionuclides must be identified, alpha PHA or other detection system development would be required.

After-the-Fact Stack Monitoring - collection media would be analyzed routinely and individual radionuclides quantified.

Alarms and Readout

- Audiovisual alarms from gross beta-gamma and alpha detectors should be provided at the stack, central control room, and Health Protection monitoring console (computer-based)
- Gross-count readout should be at the stack and at the Health Protection monitoring console
- Specific radionuclide data readout, if required, should be at the stack and Health Protection monitoring console

General

- Emergency power is required for all system components
- Calibration and source check facilities should be provided at the stack

5.2.6 Mercury Recovery Facility (L. F. Landon)

5.2.6.1 General

The reference flowsheet shows that about 1.2 lb/hr of mercury will condense and accumulate in the off-gas condensate tank. This mercury will most likely be as a sludge and will require decontamination before being placed in storage. Because of the low capacity of this facility and the need for several valving operations, a shielded facility served by master-slave manipulators is recommended.

5.2.6.2 Mercury Receipt Tank

- Function: To accumulate condensed mercury from the off-gas condensate tank.
- Capacity: One days accumulation of mercury
- Details: A suitable device to continuously inventory the contents.

5.2.6.3 Pump/Mercury Filter #1

- Function: To remove the majority of particulates that have occluded to the mercury.
- Details: The filter is to be located on the discharge side of the mercury pump. The filter media should have a nominal particle removal rating of 40 microns. The filter should be backwashable so that when pressure drop dictates, the solids may be flushed to the backwash hold tank. Pumping capacity - 25-50 mL/min. flooded suction, positive displacement diaphragm pump.
- Instrumentation and Control: The pressure drop across the filter should be continuously monitored.

5.2.6.4 Acid Wash Feed Tank

- Function: To accumulate filtered mercury.
- Instrumentation: A suitable device is required to inventory the contents of the tank.

5.2.6.5 Pump/Acid Wash

- Function: To meter mercury to the top of the acid wash column.
- Operating Conditions: Flooded suction, positive displacement diaphragm pump.
- Pumping Capacity: 10 mL/min.
- Instrumentation and Control: Suitable devices required to vary and monitor the flow rate.

5.2.6.6 Acid Wash Column

- Function: To dissolve contaminants occluded to the mercury not removed by the primary filter.

- Operating Conditions: Temperature - ambient
  Solvent - 10% HNO_3
  Contact time - 3 seconds

- Details: The mercury must be discharged into the top of the acid column in droplets. The column length is to be selected to allow a 3-second contact with the acid as the droplets fall through the mercury column. Inward projections on 90° spacing are required every 1 in. of column height. Each ring of projections should be rotated such that the mercury droplets cannot fall uninterrupted the entire length of the column. Washed mercury overflows a barometric leg into an air sparge tank.

- Material of Construction: The column is to be constructed of glass in order that the operator may observe the mercury droplets.

- Solvent Replacement: The acid must be replaced when the acid concentration falls below 1M. The ability to sample the contents of the column periodically is required. Provisions to drain the acid from the column into the backwash hold tank is required.

5.2.6.7 Backwash Hold Tank

- Function: To accumulate depleted acid from the wash column, filter backflush and acid flushes of the mercury still. Caustic service to this tank is required to neutralize the waste prior to transfer back to the off-gas condensate tank. Cooling coils are required to remove heat of neutralization. A sampler is required.

- Details: A transfer device is required to periodically recycle neutralized wastes back to the off-gas condensate tank.

- Instrumentation and Control: Suitable devices are required to monitor temperature and liquid level.

5.2.6.8 Oxidation Tank

- Function: To oxidize residual contaminants, such as iron and aluminum, to facilitate their removal from the mercury by filtration.

- Operating Conditions: Temperature — ambient
  Sparge gas — air
  Contact period — 8 hours

- Details: Air sparge should be through a fritted plate to achieve good mercury/air contact.

- Instrumentation and Control: Suitable devices are required to monitor air flow to the tank and the liquid level in the tank.

5.2.6.9 Pump Mercury Filter #2

- Function: To pump the mercury through mercury filter #2

- Operating Conditions: Flooded suction, positive displacement diaphragm pump.

- Details: Pumping capacity will be of the order of 25-50 mL/min.

- Instrumentation and Control: The pumping rate and discharge pressure should be monitored.

5.2.6.10 Mercury Filter #2

- Function: To filter out the contaminant oxides formed during air oxidation.

- Operating Conditions: Temperature — ambient.

- Details: Particle removal rating - nominal — 40 microns.

  The filter should be backwashable to facilitate flushing the solids into the backwash tank.

- Instrumentation and Control: The pressure drop across the filter should be continuously monitored.

5.2.6.11 Mercury Still Feed Tank

- Function: To supply filtered feed at a controlled rate to the still

- Instrumentation: Liquid Level

5.2.6.12 Mercury Vacuum Still/Condenser

- Function: To provide a final decontamination step.
- Operating Conditions: System pressure — about 5×10^{-2} torr
  Pot temperature — about 195°C
  Rate — 10 lb/hr
- Details: The condensed mercury is to be received in the mercury still product tank.
- Instrumentation and Control: Suitable devices are required to monitor the pot temperature, vacuum, condensate temperature, power to heaters, and cooling water flow to the condenser.

5.2.6.13 Mercury Still Product Tank

- Function: To accumulate condensate from the vacuum still.
- Instrumentation: Suitable device required to monitor temperature and liquid level.

5.2.7 Recycle Concentration (L. F. Landon)

5.2.7.1 General

The function of this module is to dewater miscellaneous internally generated waste streams for recycle to the gravity settling/filtration module. The design of the continuous evaporators presently used for 221 Canyon service should serve as the design basis for the recycle evaporator. Present design features and specifications of the evaporators presently in service are shown on the following drawings:

D 111221
D 111222
D 118282
D 118283
D 118284
D 118285
D 118286
D 118287
D 137553
D 137599
D 137815
D 164001
S5-2-2095
S5-2-5894

5.2.7.2 Recycle Evaporator Feed Tank

A vessel is to be provided to combine miscellaneous waste streams and provide feed to the evaporator at a controlled rate. The tank is to be equipped with an agitator, sampler, and instrumentation to monitor liquid level, specific gravity, and temperature. A rate pump is required to control the feed rate to the evaporator.

5.2.7.3 Recycle Evaporator

5.2.7.3.1 General

Figure 5.5 is a drawing of the continuous waste evaporator currently in canyon service and should serve as a design basis for the recycle evaporator. The de-entrainment bubble cap trays must be replaced with wire-mesh separators to attain the desired overall decontamination factor (10^6).

5.2.7.3.2 Specifications

- Capacity: 12,578 lb/hr (feed)
- Feed: Specific gravity — 1.03
  Solids content — 6.3 wt % (soluble)
  — 0.079 wt % (insoluble)
- Decontamination Factor: 10^6
- Boiloff Rate: 10,297 lb/hr
- Concentrate: Specific gravity — 1.17
  Temperature — 104°C
  Solids content — 34.8 wt % (soluble)
  — 0.44 wt % (insoluble)
- Steam Pressure: 25 psig maximum
- Steam Consumption: 1.15 lb steam/lb overheads
- Pot Pressure: About 1-4 in. H_2O

5.2.7.3.3 Services

See Figure 5.6.

5.2.7.3.4 Control System

The desired specific gravity is the primary operating parameter. Control philosophy will be as used in the present continuous canyon waste evaporator. Steam flow is set to achieve the desired boilup rate. Feed flow is continuous to achieve the desired specific gravity and is controlled and monitored by a Hackman hat controller. As the feed is fed to the reboiler, concentrate overflows the weir to the bottoms tank, thus maintaining constant specific gravity and liquid level.

5.2.7.4 Recycle Evaporator Bottoms Tank

A tank is to be provided to receive the evaporator concentrate. The tank is to be equipped with an agitator, sampler, cooling coils, and suitable instrumentation to monitor liquid level, specific gravity, and temperature. A transfer device is to be provided to transfer contents to the gravity settler feed tank.

5.2.7.5 Recycle Evaporator Condensate Tank

A tank must be provided to collect the overheads from the evaporator condenser. The tank must be equipped with cooling coils, agitator, sampler, and suitable instrumentation to monitor temperature, specific gravity, and liquid level. A transfer pump is required to transfer condensate to the general-purpose evaporator feed tank for additional decontamination.

5.2.8 Settling and Filtration (E. J. Weber)

5.2.8.1 General

The function of the equipment in this module is to reduce the suspended matter in feed to the ion exchange beds to 1 ppm or less. This section provides the basic data for designing the equipment necessary to carry out the process (described in detail in Section 4.5).

5.2.8.2 Salt Solution Receipt Tank

A tank is required to accumulate the supernate feed from the tank farm. The tank is to be equipped with a sampler, agitator, and suitable devices to monitor temperature, liquid level, and specific gravity. A transfer device is required to transfer contents to the gravity settler feed tank.

5.2.8.3 Gravity Settler Feed Tank

A tank is required to accumulate and blend recycle evaporator bottoms, waste tank supernate, and sand filter backwash. The tank contents may have to be heated as high as 95°C prior to transfer to the gravity settlers. The tank is to be equipped with a sampler, agitator, and suitable devices to monitor temperature, liquid level, and specific gravity. A system of pumps is required to transfer heated slurry to any gravity settler.

5.2.8.4 Gravity Settlers (GS)

The number of gravity settlers required is primarily dependent on the design maximum solids settling rate of 20 inches per hour (1.66 ft/hr). In addition, the total time cycle must include the addition and mixing of starch, the rate of receipt of slurry feed, rate of transfer of supernate and sludge, and time needed to resuspend the sludge. Miscellaneous items, such as supernate requiring rework, sampling, awaiting sample results, etc., should also be considered. Heating will be done in an upstream tank. Cooling with a water jacket should be adequate to reduce temperature of supernate to 25-30°C over the settling period.

Additional specifications include:

- GS bottoms recycle - 7%.
- Cold feed service for receipt of starch solution.
- Standard canyon - flat bottom tank.
- Internal surfaces (other than the tank itself) must not slope more than 30° with the vertical to prevent accumulation of solids.
- Variable speed agitation and baffles similar to those of the TNX W-2 tank design, but slope of the top blades is no more than 30° (to prevent accumulation of solids)
- For top supernate removal, a pump is preferred. Clear supernate above the pump orifice should provide at least 8 hours of filter feed (∿120 inches). Distance below the pump orifice should accommodate several sludge batches (∿30 inches).
- 1 molar caustic rinse of decant pump and its suction pipe. This assumes a "U"-tube decant pipe and will reduce the solids carryover in the supernate.
- Samplers spaced at 5-inch and 10-inch levels below the decant pump orifice. Sampler effluent is recycled to gravity settler feed tank.
- A transfer device for sludge removal with suction orifice about 2 to 4 inches above tank bottom.
- Routine specific gravity and liquid level measurements. However, before the settling phase is initiated, any air used is turned off to the dip legs of these instruments to prevent air bubbles from disturbing settling. Temperatures are to be measured and recorded at these locations:
  - In sludge layer
  - In supernate near decant pump orifice
  - Approximately 2 ft beneath liquid level

Further design consideration includes knowledge of the sludge height in the settler. In the plant, samples will be taken from each slurry batch to monitor the sludge height and assure clean separation of supernate product from the sludge. The sludge concentration is analyzed by centrifuging the slurry feed in a lab unit at 10,000 g's for 3 minutes. Corresponding height of the sludge layer after 3 to 8 hours settling is shown in Figure 4.46. For example, if analysis shows 6000 ppm sludge, a settled sludge height of some 3.9 inches would be expected for 100 inches of slurry feed. Consequently, the decant pump orifice should be located about 10 inches above the tank bottom to provide 6 inches of clear supernate above a single sludge batch. For three batches, the decant orifice would be raised to about 18 inches. Samples obtained from 5 to 10 inches beneath the decant orifice will confirm supernate clarity before product decanting is started.

5.2.8.5 Gravity Settler Supernate Tank

This tank receives the decanted supernate from the gravity settler units. It should be equipped with a sampler, agitator, and detection devices to monitor liquid level, temperature, and specific gravity. A transfer device is required to recycle off-spec supernate back to the gravity settler feed tank. A second transfer device is required to transfer acceptable supernate to the sand filter feed tank.

5.2.8.6 Gravity Settler Bottoms Tank

This tank receives the sludge layer that is jetted from each GS unit. It should be equipped with a sampler, agitator, and detection devices to monitor liquid level, temperature, and specific gravity. A transfer device is required to transfer tank contents to the aluminum dissolver.

5.2.8.7 Sand Filter Feed Tank

This tank receives gravity settler filtrate that meets specifications ($\leq$50 ppm suspended matter) from the gravity settler supernate tank and zeolite column raffinate. The tank should be equipped with an agitator, sampler, and detection devices to monitor liquid level, temperature, and specific gravity. A rate pump is required to feed the No. 1 sand filter at a flow of 1.15 gpm/ft^2 of filter area. The tank must be equipped with cooling coils and chilled water to control the feed temperature at <25°C. Anionic polyelectrolyte solution (see Section 5.2.8.16) is delivered from Cold Feed and blended with the supernate just before entering the sand filter at a rate of 0.05 gpm/ft^2.

5.2.8.8 Sand Filter No. 1

The function of this unit is to reduce the suspended matter in supernate to about 5 ppm. Specifications are as follows:

- Downflow feed rate - 1.2 gpm/ft^2
- Top layer - 8 in. anthracite coal, 20-30 mesh

  Bottom layer - 24 in. sand, 25-40 mesh
- Freeboard above filter - >60%
- Backflush rate - 15 gpm/ft^2 (liquid), 4 scfm/ft^2 (air)

  (Expected backwash frequency - 24 to 48 hours)

Provision for occasional nitric acid (3-4M) flushing of the sand filter is required to dissolve mudballs or other formations which will plug the units. It may also be necessary to dissolve excessive radioactive deposits in the filter which could reduce adsorption efficiency by destruction of polyelectrolyte. If it is determined acid flushing is required after normal backflushings, the supernate is drained, and the filter backflushed with 1M NaOH to remove most of the Al and minimize its possible precipitation in the bed. After draining the NaOH solution, process water is used to backwash residual caustic from the column. Adequate filter venting is necessary during careful acid addition and reaction. When mudballs or other deposits have been dissolved, the column is drained, given a water rinse, followed by a 1M NaOH rinse before resuming routine operations. Acidic backwashes are transferred to the filter backwash tank and made alkaline prior to recycle to GS.

Startup following the nitric acid flush may indicate replacement of filter media is required if ΔP or residual radioactivity remains too high, or adsorption efficiency (filtrate quality) is too low. Provision is therefore required for transfer of anthracite/sand to a suitable storage vessel. From storage, the contents are proportionally blended into the aluminum dissolving facilities. All transfers require fluidizing the media with 1M NaOH solution before jetting. Proper grades of anthracite/sand are needed as replacement to the appropriate filter unit. The new media is also slurried and transferred in 1M NaOH solution, since low pH in the sand filter may precipitate alumina, thus creating excessive ΔP.

Instrumentation requirements associated with the No. 1 sand filter are as follows:

- ΔP.
- Temperature of feed and effluent streams.
- Gamma monitoring just above the anthracite/sand interface external to the filter (to prevent the accumulation of radioactivity that might degrade the polyelectrolyte).

5.2.8.9 First Filtrate Tank

This tank receives the filtrate from sand filter No. 1 and feeds sand filter No. 2. It must be equipped with a sampler, agitator, and detection devices to monitor liquid level, temperature, and specific gravity. Cooling coils and chilled water are required to maintain sand filter feed <25°C. A rate pump feeds the No. 2 sand filter at 1.15 gpm/ft^2. Provisions are required to introduce anionic polyelectrolyte solution into the feed to the No. 2 sand filter just before the inlet to the filter. Polyelectrolyte feed rate is 0.05 gpm/ft^2.

5.2.8.10 Sand Filter No. 2

The function of this unit is to reduce the suspended matter in supernate to 1 ppm or less. Specifications are as follows:

- Downflow feed rate - 1.2 gpm/ft^2
- Top layer - 3 in. anthracite coal, 30-50 mesh

  Bottom layer - 18 in. sand, 40-60 mesh
- Freeboard above filter - >140%
- Backflush rate - 15 gpm/ft^2 (liquid), 4 scfm/ft^2 (air)

Additional specifications are as in Section 5.2.8.8.

5.2.8.11 Second Filtrate Tank

This tank receives the filtrate from the No. 2 sand filter. It must be equipped with a sampler, agitator, and detection devices to monitor liquid level, temperature, and specific gravity. A transfer device is required to transfer off-spec filtrate to the sand filter feed tank. A second transfer device is required to transfer acceptable filtrate to the filtrate hold tank.

5.2.8.12 Filtrate Hold Tank

This tank accumulates acceptable filtrate for subsequent treatment in the ion exchange module. It also serves as the source of solution for backwashing the No. 1 and No. 2 sand filters. The vessel must accommodate an agitator, sampler, and suitable devices to monitor liquid level, temperature, and specific gravity. Two transfer devices are required:

- To backwash the sand filters.
- To transfer acceptable filtrate to the ion exchange feed tank.

5.2.8.13 Filter Backwash Tank

This tank receives backwash slurry from the Sand Filter No. 1 and the Sand Filter No. 2. Contents are periodically transferred to the gravity settler feed tank for subsequent treatment in Gravity Settlers. The tank must contain an agitator, sampler, and suitable devices to monitor liquid level, temperature, and specific gravity. This tank may also receive an occasional nitric acid flush from either sand filter. Consequently, the backwash tank will require caustic cold feed service for neutralization purposes and cooling capability.

5.2.8.14 Waste Sand Tank

This tank receives depleted filter media for subsequent transfer to the aluminum dissolver. The vessel must accommodate an agitator, sampler, and suitable devices to monitor liquid level, temperature and specific gravity. A transfer device is required for slurry transfers to the aluminum dissolver.

5.2.8.15 Preparation of Polyelectrolyte for Addition to the Gravity Settlers

The Flojel-60® (National Starch Corp.) coagulant aid is made up in the Cold Feed Prep Area as an 8% dispersion in 1M NaOH. To a gently stirred 1M NaOH solution, sufficient solid Flojel-60® is slowly sieved in to make the 8% dispersion. After all large lumps are broken and a smooth paste is formed, heat is applied. On heating to 65-70°C for 10-15 minutes, the starch polymer swells (but does not dissolve), and the mixture clarifies sufficiently that objects can be clearly seen through 6 to 8 inches of dispersion. After this clarity is reached and maintained 2 to 4 minutes, the mixture is cooled to room temperature. It should be used within the next two days. When properly prepared, the cooled starch has a pale green to tan translucence. Overheating or heating with large lumps causes the starch to "burn" to opaque brown or black. A sufficient quantity of 8% starch dispersion is added to each GS feed batch to produce 8 to 16 lbs of starch solids per ton of sludge as analyzed by lab centrifuge. A sludge density of 1.3 g/cc is assumed. For 8,000 gallons of feed containing 6,000 ppm of sludge, 3 to 6 gallons of starch dispersion is added.

5.2.8.16 Preparation of Polyelectrolyte for Addition to Sand Filters

Anionic polyelectrolyte stock solution is made up in the Cold Feed Prep Area to a 0.1% strength solution in distilled water. A sufficient weight of the white solid Versa TL® 700, or equivalent, is sieved into cold water with gentle stirring to produce the clear, viscous stock solution. Sufficient stock is subsequently added to 1M NaOH solution in a Cold Feed Tank so that a flow equivalent to 0.05 gpm/ft^2 produces total sand bed feed containing 0.05 ppm of solid polyelectrolyte.

The 0.1% stock solution should be used within 4 days of makeup. Stock solution should not be added to the Cold Feed Tank until ready for operation. Cold Feed Tank solution should run out after 24-36 hours of operation.

5.2.9 Clarified Supernate Decontamination (P. K. Baumgarten and D. A. Whitehurst)

5.2.9.1 General

All tanks should be constructed of stainless steel and include agitators and heating and cooling coils. These tanks should provide for temperature, liquid level, and specific gravity measurement. Sampling lines from the tanks are required. All vent lines containing NH_3 must maintain a wall temperature >70°C.

5.2.9.2 Cesium Ion Exchange

5.2.9.2.1 Cs Ion Exchange Columns

Provide two stainless steel ion exchange columns to hold 1525 gallons of "Duolite" ARC-359 resin each. Each column should have a freeboard space above the resin which will allow at least a 75% expansion of the resin bed. Equip each column with liquid distributors both at the top and bottom of the resin bed. Provide unobstructed transfer lines for adding resin to or removing it from the columns. A Ge(Li) gamma-ray detector is mounted between the columns to monitor the Cs concentration. A similar detector after the second column is used to serve as an operating alarm.

Each I/E column is to have a nozzle for liquid level gaging, resin sampling, solids level gaging, and temperature sensing. A means of gaging the solids level in the column during backwashing or a means of monitoring the solids content of the backwash effluent is required. A variable speed pump is used to pump filtered supernate and first water rinse downflow at a rate of 42 gpm. The upflow steps, elution, second rinse, and regenerant are to use a variable speed pump which has a nominal rate of 30 gpm. A pump for backwashing the resin is to allow for variable linear velocity between 4-10 gpm/ft^2. A system to flush depleted resin to the cesium resin catch tank is required.

5.2.9.2.2 Ion Exchange Feed Tank

This tank is to receive clarified supernate from the filtrate hold tank. The tank should be equipped with cooling coils. A suitable transfer device is required to transfer feed to the cesium feed bounce tank.

5.2.9.2.3 Cesium Feed Bounce Tank

This tank, with three suitable transfer devices, is used to (1) transfer downflow through the columns consecutively 20 column volumes of feed and 5 column volumes of water, and (2) receive and transfer consecutively 10 column volumes of eluate, 3 column volumes of water, and 5 column volumes of regenerant. The eluate and water rinse is pumped to the cesium eluate tank. The regenerant is transferred to the cesium regenerant catch tank. This tank is vented to the cesium vent scrubber.

5.2.9.2.4 Cesium Elute Bounce Tank

This tank, with two suitable transfer devices, is used to (1) consecutively receive 20 column volumes of feed and 3 column volumes of water, and (2) to transfer (upflow) consecutively 10 column volumes of elutriant, 3 column volumes of water, and 5 column volumes of regenerant through the ion exchange columns. The received effluent from downflow operations is transferred on to the strontium ion exchange feed bounce tank. This tank is vented to the cesium vent scrubber.

5.2.9.2.5 Cesium Eluate Tank

Provide a tank to combine the column eluate and column upflow water rinse. A suitable transfer device is required to transfer the tank contents to the cesium concentrator feed tank. This tank should be vented to the cesium vent scrubber.

5.2.9.2.6 Cesium Regenerant Catch Tank

Provide a tank to receive the regenerant effluent. A suitable transfer device is required to transfer the solution to the recycle evaporator feed tank. The tank should be vented to the cesium vent scrubber. This tank should be equipped with steam coils and an agitator.

5.2.9.2.7 Spent Resin Tank

Provide a catch tank to receive depleted resin from the strontium ion exchange column and the cesium ion exchange columns. The tank must be provided with an agitator, sampler, and suitable devices to monitor temperature, liquid level, and specific gravity. The tank requires a transfer device to transfer resin slurry to the resin packaging facility. Provisions to decant to the recycle collection tank must be provided.

5.2.9.2.8 Resin Packaging Facility

Resin packaging facility is to include a dewatering tank, a dryer, and means to package resin in 10-50 lb containers. Moisture in the packaged resin should be less than 10%. Temperatures above 100°C are to be avoided. Drying air should be filtered after use.

5.2.9.2.9 Cold Feed Facilities

Provide tank for preparing a water slurry of "Duolite" ARC-359 resin, with a final volume of 1525 gal. Provide equipment for transferring this slurry to the appropriate I/E column. Allow for makeup of smaller batches to periodically replenish resin lost during backwashing.

Provide facilities to prepare (1) water for column rinses and (2) caustic regenerant (2M NaOH) for regenerating the I/E columns. Suitable transfer devices are required to transfer these cold feeds to the appropriate bounce tanks.

5.2.9.3 Strontium Ion Exchange

5.2.9.3.1 Ion Exchange Column

Following the two cesium columns, a stainless steel ion exchange column with a 760-gallon resin batch and sufficient freeboard to allow at least 75% expansion of the resin is to be used to remove strontium. Provide resin transfer lines for moving the resin in and out of the columns. Provisions should be made to detect resin level during backwash and prevent loss of the resin via operator error. Instrumentation to measure bed temperature, bed and distributor pressure drop, and resin level are required.

Provide for removal of samples of the resin. Normal downflow and upflow rates shall be 1.7 and 0.5 gpm/ft2, respectively. Flow rate measurements in both directions are required. Design backup systems to provide both recycle water and 2M NaOH through the columns in the event of the failure of the primary transfer systems. Plan for valveless operation. Placement and design of the columns should keep the external radiation from exceeding 5×10^{-3} watts-hr/g, to keep radiation-induced resin degradation minimal.

5.2.9.3.2 Strontium Feed Bounce Tank

Provide a bounce tank with two pumps to (1) receive supernate and rinse from the cesium elute bounce tank and transfer to the Sr column and (2) receive Sr column eluate and water rinse and transfer to the strontium concentrator feed tank. Provide appropriate transfer devices. This tank is vented to the process vessel vent system.

5.2.9.3.3 Product Salt Hold Tanks

Provide 3 tanks to receive clarified supernate and water rinses from the strontium elute bounce tank. The tanks are vented to the regulated facility vessel vent system.

5.2.9.3.4 Strontium Elute Bounce Tank

Provide a bounce tank with suitable transfer devices to (1) transfer decontaminated supernate from the Sr ion exchange column to the product salt hold tanks and (2) transfer elutriant/regenerant solution (alkaline EDTA) and water rinses to the Sr ion exchange column. This tank is vented to the process vessel vent system.

5.2.9.3.5 Strontium Eluate Tank

Provide a tank to accumulate eluate and water rinses for feeding the strontium concentrator. Provide the appropriate capacity transfer device for feeding the strontium concentrator. This tank is vented to the process vessel vent system.

5.2.9.3.6 Strontium Concentrator

General

Provide an evaporator to reduce the water content in order to minimize the water load during spray drying. For material balance purposes, the feed is concentrated to 1.0M alkaline EDTA.

Specifications

- Capacity: 1950 lb/hr (feed)
- Feed: Specific gravity — 0.991
  Solids content — 0.25 wt % (soluble)
  — 0.00 wt % (insoluble)
- Decontamination Factor: 10^6
- Boiloff Rate: 1925 lb/hr
- Concentrate: Specific gravity — 1.110
  Temperature — about 102°C
  Solids content — 20.2 wt % (soluble)
  — 0.00 wt % (insoluble)
- Steam Pressure: 25 psig
- Steam Consumption: 1.15 lb steam/lb overheads
- Pot Pressure: 1-4 in. H_2O

5.2.9.3.7 Strontium Concentrator Bottoms Tank

Provide a tank to receive bottoms from the strontium concentrator. Tank should be equipped with cooling coils. Provide a suitable transfer device to transfer concentrate to the slurry mix tank in the spray dryer/melter module. This tank is vented to the process vessel vent system.

5.2.9.3.8 Strontium Concentrator Condensate Tank

Provide a tank to receive overheads from the strontium concentrator. Tank should be equipped with cooling coils. Provide a suitable transfer device to transfer condensate to the recycle evaporator feed tank. This tank is vented to the process vessel vent system.

5.2.10 Cesium Elutriant Recovery/Eluate Concentration

(B. R. Murphree)

5.2.10.1 General

The function of this module is to (1) strip the cesium eluate of NH_3 and CO_2, (2) recover the NH_3 and CO_2 for elutriant makeup, and (3) concentrate the cesium eluate to about 2.0M ($Na_2CO_3 + Cs_2CO_3$).

NOTE: All tanks which contain ammonia are vented through the Cs vent scrubber. All vent lines containing NH_3 must maintain a wall temperature >70°C.

5.2.10.2 Cesium Concentrator Feed Tank

A tank is required to deliver cesium eluate at a controlled rate to the steam stripper. The tank is to be equipped with an agitator, cooling coils, sampler, and suitable devices to monitor temperature, liquid level, and specific gravity.

5.2.10.3 Steam Stripper

Provide countercurrent packed stripping section to remove 99.99% of the CO_2 and NH_3 from the cesium eluate. Steam to the stripper comes from the thermosiphon evaporator. The pressure drop across the stripper must be monitored. Vapor from the stripper must pass through a de-entrainment section en route to a downdraft condenser. The de-entrainer must reduce non-volatile radioactivity by a factor of 10^6. The pressure drop across the de-entrainer should be monitored. Suitable temperature sensors must be incorporated in the packed bed at several levels.

5.2.10.4 Cesium Concentrator

A thermosiphon evaporator is required to concentrate cesium eluate to about 2.0M ($Na_2CO_3 + Cs_2CO_3$). The evaporator is steam heated. Suitable devices should monitor evaporator pot pressure, temperature, specific gravity, and liquid level. Provide heating steam pressure control based on produced specific gravity. Design on basis of supplying elutriant makeup water in overheads to steam stripper.

5.2.10.5 Downdraft Condenser

A downdraft condenser for the vapor stream from the steam stripper de-entrainer is required. Temperature at the inlet and outlet cooling water stream and the condensate stream must be measured. The pressure drop across the condenser must be monitored. An online gamma monitor to survey for cesium carryover from the steam stripper is required. Provide condensate flow rate measurement. The condenser should vent to the cesium vent scrubber.

5.2.10.6 Stripper Condensate Tank

Provide a tank to receive condensate from the downdraft condenser. The tank is to be equipped with an agitator, sampler, cooling coils (to maintain contents <20°C) and suitable systems to monitor liquid level, temperature, specific gravity, electrical conductivity, and pH. An online gamma monitor is required to monitor for cesium carryover into the condensate. The tank should vent to the cesium vent scrubber.

5.2.10.7 Cesium Elutriant Makeup Tank

Provide a tank to receive condensate from the downdraft condenser. The tank should be sized to hold at least one cycle volume of elutriant. The tank is to be equipped with an agitator, sampler, cooling coils (to maintain contents < 20°C), and suitable systems to monitor liquid level, temperature, specific gravity, electrical conductivity, and pH. Provide aqueous ammonia from cold feed. Provide system for sparging tank contents with CO_2 with maximum absorption and minimum disengagement. Tank should be vented to the cesium vent scrubber. Provide pump to transfer adjusted elutriant to the elutriant feed tank.

5.2.10.8 Cesium Elutriant Feed Tank

Provide a tank with a suitable transfer device to transfer adjusted elutriant to the cesium eluate pump tank. The tank should should be vented to the cesium vent scrubber.

5.2.10.9 Cesium Vent Scrubber

Provide a packed bed scrubber to remove >99.9% of the NH_3 by the vent scrubber feed. Provide chilled water downflow in the packed bed. Vent scrubber to the regulated facility vessel vent system. Measure bed temperature. Route liquid effluent to the cesium concentrator feed tank.

5.2.10.10 Purge Condenser

A condenser is required to condense a steam sidestream from the cesium concentrator. Provide temperature measurement for cooling water inlet and outlet and condensate outlet. The pressure drop across the condenser must be monitored. Provide condensate flow rate measurement. Provide online gamma monitor on the condensate stream.

5.2.10.11 Purge Condensate Tank

Provide a tank to receive condensate from the cesium concentrator purge condenser. The tank should contain an agitator, sampler, cooling coils, and suitable instrumentation to monitor temperature, liquid level, and specific gravity. A suitable transfer device is required to transfer the condensate to the recycle evaporator feed tank.

5.2.11 Cesium Fixation on Zeolite

5.2.11.1 General

The function of this module is to (1) load cesium in the cesium concentrator bottoms onto zeolite, (2) transfer cesium-loaded zeolite to be mixed with washed sludge, and (3) recycle the cesium-depleted cesium concentrator bottoms to sand filtration. All tanks are to be equipped with samplers and instrumentation to monitor temperature, liquid level, and specific gravity.

5.2.11.2 Cesium Concentrator Bottoms Tank

Provide a tank equipped with both heating and cooling coils to receive the concentrate from the thermosiphon evaporator. The tank is to be equipped with an agitator, sampler, and suitable devices to monitor temperature, liquid level, and specific gravity. A transfer jet should transfer concentrate to the zeolite feed bounce tank.

5.2.11.3 Zeolite Column

Provide a 4.8 ft diameter by 20 ft high stainless steel ion exchange column. It will hold an 11 ft deep bed of Linde Ionsiv® (Union Carbide Co.) IE-95. Column should be designed to withstand 50 psig. Provide pressure drop measurement across the bed and temperature measurement at several points vertically in the bed.

Provide inlet port at top of column for fresh zeolite slurry. Provide outlet port at bottom of column for removing loaded zeolite. Both ports will be blanked off when not in use. Provide steam jet to transfer zeolite slurry from column to cesium zeolite tank.

5.2.11.4 Zeolite Feed Bounce Tank

Provide a stainless steel bounce tank similar to those used in cesium and strontium ion exchange. Provide a pump to downflow feed the zeolite column. The pump must freewheel for reverse flow. Provide coils for cooling and heating. Provide temperature and level measurement.

5.2.11.5 Zeolite Raffinate Bounce Tank

Provide a stainless steel bounce tank similar to the zeolite feed bounce tank. Provide a pump to upflow water through the column. Pump must freewheel in reverse flow. Provide coils for heating and cooling.

5.2.11.6 Zeolite Raffinate Hold Tank

Provide a tank to receive the zeolite column effluent and column rise. Provide a suitable transfer device to transfer the contents to the sand filter feed tank in the filtration module.

5.2.11.7 Zeolite Slurry Tank

Provide a stainless steel tank to receive and dewater cesium-loaded zeolite slurry. Profile wire screen is desirable on the dewatering inlet. Provide gamma, temperature, and level measurement. Provide agitator and coils for cooling.

5.2.12 General-Purpose Evaporation (L. F. Landon)

5.2.12.1 General

The function of this module is to decontaminate miscellaneous internally generated waste streams for release to the environment. The design of the evaporator will be identical to the recycle evaporator.

5.2.12.2 General-Purpose Evaporator Feed Tank

See Section 5.2.7.2.

5.2.12.3 General-Purpose Evaporator

5.2.12.3.1 General

See Section 5.2.7.3.1.

5.2.12.3.2 Specifications

- Capacity: 10,692 lb/hr (feed)
- Feed: Specific gravity — 0.984
  Solids content — <0.1 wt %
- Decontamination Factor: 10^6
- Boiloff Rate: 9,263 lb/hr
- Concentrate: Specific gravity — 0.955
  Solids content — <1.0 wt %
  Temperature — about 100°C
- Steam Pressure: 25 psig maximum
- Steam Consumption: 1.15 lb steam/lb overhead
- Pot Pressure: 1-4 in. H_2O

5.2.12.3.3 Services

See Figure 5.5.

5.2.12.3.4 Control System

See Section 5.2.7.3.4

5.2.12.4 General-Purpose Evaporator Bottoms Tank

A tank is to be provided to receive the evaporator concentrate. The tank is to be equipped with an agitator, sampler, cooling coils, and suitable instrumentation to monitor liquid level, specific gravity, and temperature. A transfer device is required to transfer contents to the recycle evaporator feed tank.

5.2.12.5 General-Purpose Evaporator Condensate Tanks

Two tanks are to be provided to receive evaporator overheads. Each tank is to be equipped with an agitator, sampler, cooling coils, and suitable instrumentation to monitor liquid level, specific gravity, and temperature. Two transfer devices are to be provided per tank. One is for transferring the condensate to a surface stream. The other is for recycling off-spec condensate back to the feed tank.

These tanks are accountability tanks at which the radioactive and nonradioactive contaminants are accurately inventoried before discharging the condensate to the environment. While one tank is receiving overheads from the evaporator, the contents of the other tank are sampled for accountability analyses.

5.2.12.6 Regulated Facility Vessel Vent Filter Heater

The vapor effluents from the cesium vent scrubber and the product hold tanks are coupled with the vent purge from each vessel in the General Purpose Evaporation Module. The heater is required to raise the temperature of the vapor at least 10°C above its dew point to prevent condensation in the HEPA filter.

5.2.12.7 High Efficiency Particulate Air (HEPA) Filter

A single, 24" x 24" HEPA filter is required to filter the vapor prior to the release to the atmosphere. A DF of 1000 is assumed for particulates. The pressure drop across the filter should be continuously monitored.

5.2.12.8 Regulated Facility Vessel Vent Exhauster

An exhauster is required to draw the vessel vent through the HEPA filter and discharge to the atmosphere.

5.2.13 Product Salt Solution Concentration/Solidification in Concrete (H. W. Bledsoe)

5.2.13.1 General

The purpose of these facilities is to stabilize the clarified supernate from ion exchange by incorporating it in concrete and burying the saltcrete in excavated trenches at least 10 feet above the water table and beneath at least 33 feet of soil overburden. The burial site must be constructed and engineered to meet both NRC and EPA requirements for disposal of radioactive and chemical waste materials. Ground water and leachate monitoring systems must be installed and maintained.

5.2.13.2 Feed Preparation

5.2.13.2.1 General

This section describes the facilities required to prepare a 50 wt % salt solution for feed to the saltcrete plant. The flowsheet (FS-14) and material balance (MB-14) are shown on Figure 4.14 and Table 4.14 respectively.

Each process vessel is assumed to have a vapor space purge drawn from the building atmosphere. All vessel vents, as well as other potentially contaminated ventilation, are combined, heated to above its dew point and drawn through a high efficiency particulate filter before being discharged to the atmosphere.

5.2.13.2.2 Product Salt Solution Storage Tank

A tank is required to accumulate unevaporated decontaminated salt solution from the S-Canyon ion exchange module at the Saltcrete Plant Facility. The tank should accommodate sufficient lag storage between the DWPF and the Saltcrete Facility to minimize influence on canyon attainment. The vessel should have a sampler and appropriate systems to monitor liquid level, specific gravity, and temperature. A suitable transfer device is required to feed the product salt evaporator at a controlled rate.

5.2.13.2.3 Product Salt Evaporator

General

For purposes of this PTDS, it is assumed that the evaporator will be of the bent-tube type, currently used to dewater waste in the interim waste storage facilities.

Specifications

- Capacity: 11,707 lb/hr feed
- Feed: Specific Gravity - 1.17
  Total solids content - 23 wt %
- DF: 10^{6}[a]
- Boiloff rate: 4910 lb/hr
- Concentrate: Specific Gravity - 1.16
  Temperature - 115 to 120°C
  Total Solids Content - 35.0 wt %

Services

See Figure 5.6.

Control System

The desired specific gravity is the primary operating parameter. Control philosophy will be as currently used in the existing waste farm evaporators.

Feed-Rate Control — A remote air operator in the control house is used to adjust a throttling valve which regulates the feed flow to the evaporator.

Liquid-Level Control — The liquid level in the evaporator is controlled by varying the bottoms withdrawal rate with a steam lift. This is an automatic control that controls the flow of steam to the steam lift.

---

[a] To achieve this decontamination factor, the evaporator pot should have at least 66 in. of freeboard and the bubble cap trays (see Figure 5.6) must be replaced with wire mesh separators (or a wire mesh pad added downstream of the bubble caps).

Bottoms Concentration Control — Evaporator pot specific gravity (or temperature) is used to monitor concentration. A panel-mounted temperature recorder-controller varies the steam flow to the evaporator tube bundle by varying a control valve on the steam supply.

Foam Level — Foam level is to be monitored by a differential pressure device. This device is connected to steam-purged dip tubes in the vapor space.

5.2.13.2.4 Product Salt Evaporator Condenser

A shell and tube condenser is required to reduce the vapor temperature to <50°C. Cooling water to the condenser should be at a pressure 15 psig greater than the condensate.

5.2.13.2.5 Product Salt Evaporator Condensate Tank

Sufficient tank capacity is required to receive the overheads from the product salt evaporator. Tank should be equipped with samplers and appropriate instrumentation to monitor liquid level, specific gravity, and temperature. Four transfer devices are required to transfer condensate to (1) the recycle water tank, (2) the saltcrete plant, (3) the product salt concentrate tank and (4) the product salt evaporator for descaling.

5.2.13.2.6 Product Salt Concentrate Tank

The bottoms from the product salt evaporator are steam lifted to a tank sized to accommodate 1 week's concrete production. The tank should be equipped with appropriate instrumentation of monitor liquid level, specific gravity, and temperature. The concentrate temperature will be maintained by a heater (on a circulating loop) high enough to prevent salt crystallization. The tank should have an agitator and a sampler. A suitable transfer device is required to transfer the concentrate to the saltcrete plant. The vapor space should be vented through a condenser with the condensate being recycled back into the tank.

5.2.13.3 Saltcrete Preparation

5.2.13.3.1 General

The concentrated salt solution will be mixed with cement to produce a mixture containing 56.5 wt % cement, 15.2 wt % salt, and 28.3 wt % water. The mixture will be pumped to the disposal trenches from the concrete plant. The consistency of the concrete is critical. Pumped concrete must be well-mixed before feeding into the pump and occasionally remixing is required in the hopper by means of stirrers. The set-time of the saltcrete should be significantly long to preclude the premature set-up of the mixture during pumping operations. All equipment must have water flush service. The concrete plant should be centrally located to the disposal site.

5.2.13.3.2 Plant Capacity

The concrete plant should be capable of producing and pumping a nominal 70 yd^3 of concrete per hour. This would easily satisfy the desired disposal rate of 1000 yd^3 of saltcrete/week. Ready-mix plants of the type required for this type of operation are available in numerous designs with capacities ranging from 10 to 300 yd^3/hr. Piston pumps with 9-inch pipes may deliver on the order of 70 yd^3 per hour over horizontal distances up to 1500 feet. Pumping is economical only if it can be used over long uninterrupted periods because at the beginning of each pump cycle the pipes have to be lubricated with mortar and at the end of the cycle considerable effort is required to clean the pipes. Consequently, a nominal transfer frequency of twice per week is planned. A pipe cleaning "pig" is required to clean transfer pipes.

5.2.13.3.3 Facility Description

The building to contain the evaporator and concrete plant equipment will be of normal construction. Thick walls for biological shielding are not necessary because the radiation level from 15 year aged clarified supernate from ion exchange is very low. Evaporation, mixing and pumping operations must be sufficiently remotable and within controlled ventilation zones to ensure that operating personnel are not exposed to body exposure rates in excess of 0.5 mrem/hr or are they required to wear respiratory protection during normal operation.

Required services for this facility include steam, cooling water, flush water, electrical and normal lighting.

5.2.13.4 Reference Disposal Site

5.2.13.4.1 General Design Criteria

- The initial disposal site size should be scoped based on the waste inventory on hand at startup of the DWPF.
- The disposal site will require a water table depth below grade of approximately 60 feet (this may require mounding with backfill).
- The site must be constructed and engineered to meet both NRC and EPA requirements for disposal of radioactive waste and hazardous (chemical) waste materials.
- Trenches must have a 5-foot impermeable blanket of soil (10^{-7} cm/sec) on the bottom and top. A similar blanket is required on the sides of the site.
- Disposal site must have a minimum of 33 feet of soil overlying the top of the saltcrete monoliths.

5.2.13.4.2 Concrete Monoliths

The trenches are to be designed to accommodate approximately one weeks production of saltcrete.

5.2.13.4.3 Disposal Facility Design

Pit Excavation and Construction

Assuming that the sediments underlying the reference disposal site do not meet the Resource Conservation and Recovery Act proposed 10^{-7} cm/s permeability requirement for use as a natural inplace liner, a conceptual excavation and construction plan to fulfill this requirement is outlined below.

- The entire disposal site is excavated. Sides are sloped at approximately 1-1/2:1.

- A minimum 5-ft-thick liner of selected material ($\leq 10^{-7}$ cm/s permeability) is placed across the bottom of the entire excavation and up the sides.

- Overlying this impermeable blanket, a minimum 12-inch-thick permeable leachant drainage and collecting system is constructed. This system will consist of a graded sand and gravel drainage blanket which slopes a minimum of 1% toward collecting sumps and wells that provide accumulation and removal of leachate.

- Controlled placement of the selected backfill ($\leq 10^{-7}$ cm/s) is continued for an additional 25 ft above the drainage system (actually must backfill >25 ft so not to disturb leachate collection system when trenches are later excavated).

- The remainder of the pit above the impermeable material is backfilled with non-selective site material.

Trench Excavation

The site will be re-excavated to the top of the impermeable backfill and individual trenches excavated for placement of the concrete/salt mixture. The conceptual development of the disposal trenches include:

- Excavation of a pit 25-ft deep with side slopes of approximately 1-1/2:1, depending on soil stability.

- Excavation of a series of trenches (length to be determined) approximately 20 ft wide x 25 ft deep within the bottom of the pit.

- Saltcrete poured to a depth of 20 ft in a trench.

- After the saltcrete in a single trench has set, it will be covered with 5 ft of $\leq 10^{-7}$ cm/s permeability material.

- As trenches are completed and filled with saltcrete, portions of the completed site are backfilled, providing the 33 ft of design overburden.

Figure 5.7 is a conceptual sectional view of the disposal site.

5.2.14 Product Packaging/Testing/Decontamination/Interim Storage (J. P. Howell and W. N. Rankin)

5.2.14.1 General Equipment and Cell Considerations

The cell arrangement of "A", "B", and "C" mechanical cells should be isolated from the rest of the canyon processing cells to eliminate contamination transfer. A separate ventilation system, crane, and equipment maintenance facility are required for the mechanical cells. Access to the cells from "clean" areas is required for introduction of canisters, welding accessories, machine tools, sample removal, dry smear transfer, etc. Storage space should be allocated in "A" cell for glass-filled canisters based on cell design, process equipment, and glass-pour mode of operation.

Low amounts of transferable contamination in the mechanical cells can be maintained by providing contamination barriers (distance, physical barriers, differential pressure operation) in the spray dryer melter area. The spray dryer will likely be the main contributor of transferable contamination into the relatively "clean" mechanical cells.

The mechanical cells and equipment should be designed, if possible, for remote operation and contact maintenance. "B" and "C" cells should be designed for scheduled personnel entry to decontaminate the equipment and cells.

Cell viewing windows, closed circuit television (CCTV), and master-slave manipulator through-tubes should be installed at strategic locations to assist processing and maintenance requirements. Manipulators should be positioned in those locations as specified by equipment design.

5.2.14.2 Mechanical Cell A

5.2.14.2.1 Canister Closure and Testing

A portable surface pyrometer should be provided for measuring canister surface temperatures before and after joint preparation and welding operations. The instrument range should be 0 to 500°C with remote readout. Viewing windows and manipulators should be positioned to facilitate these measurements.

Provide space for possible ultrasonic NDT examination of the glassform structure through the canister wall.

To verify weld integrity, SRP-EED is developing nondestructive test equipment. Process parameter control will be the primary verification technique for use with the solid state resistance upset weld. However, in the event that criteria is set forth that cannot be met by process parameter control, SRP-EED is developing an ultrasonic delta-scan technique for weld verification. Such an inspection criteria is not the reference process. However, it may be required in conjunction with the helium leak test or at some time prior to any future canister removal from the interim storage facility.

Equipment and techniques are being developed to helium leak test the canister prior to decontamination. This leak test will supplement process parameter control as a means of verifying the weld integrity and will ensure that a leaktight weld was attained. Watertight integrity of the weld is required to prevent inleakage of liquid during decontamination. Leaktight integrity of the weld is also required to prevent the escape of radioactivity in Mechanical Cell A to rework canisters that fail to meet leak specifications.

SRP-EED is developing the criteria, equipment, and instrumentation for canister closure preparation, closure method, and closure weld testing [5,6]. The design basis process for the closure is a solid-state resistance weld of a plug in a 4 to 6-inch-diameter opening. The welder is capable of exerting 75,000 pounds of force on a plug while simultaneously delivering about 200,000 amps for about 1-1/2 seconds. The welding parameters to be recorded remotely are force, motion, current, and weld time. CCTV should be supplied for viewing the welding operations [6].

5.2.14.2.2 Preliminary Canister Decontamination and Transfer

General

The initial canister decontamination should produce a DF of 10^2 to 10^3 of the transferable contamination before transfer into Mechanical Cell B. Decontamination solutions are circulated about the canister during each etch and cleaning cycle. Residence time for each decontamination cycle is one hour. Decontamination solution for this initial decontamination come from the final decontamination operation in Mechanical Cell B where they were initially used.

Etch Tank

Provide a tank to accommodate a canister about which HNO_3-NaF may be circulated. Appropriate cooling and heating systems are required to maintain the temperature of the etch solution at 50°C. A transfer device is required to transfer the spent etch solution to the neutralizer tank. The tank should be vented through a caustic scrubber.

Cleaning Tank

Provide a tank, similar to the etch tank, to accommodate a canister about which oxalic acid may be circulated. Appropriate cooling and heating systems are required to vary the temperature of the cleaning solution between 35°C and 90°C. A transfer device is required to transfer the spent cleaning solution to the digestor tank.

Spray Tank (2)

Following each decontamination step, the canister is transferred to its respective spray tank in which the canister is rinsed. Suitable transfer devices are required to transfer the rinse water to the spray hold tank.

Spray Hold Tank

Provide a tank to accommodate the canister rinse waste from each spray tank. The tank is to be equipped with a suitable liquid level device. A transfer device is required to transfer rinses to the spent decon solution pump tank.

Digester

A tank, equipped with heating and cooling coils, is required in which the spent cleaning solution can be digested to destroy the oxalic acid. Nitric acid and manganese nitrate service to this tank are required. A condenser is required to condense and recycle the condensables evolved during digestion. A transfer device is required to transfer the digested solution to the neutralizer tank. The tank should be equipped with suitable devices for monitoring liquid level, specific gravity and temperatures. A sampler is required.

Neutralizer

Provide a tank with cooling coils in which the spent etching solution and digested cleaning solution may be neutralized. A transfer device is required to transfer the neutralized solution to the spent decon solution pump tank. The tank must be equipped with appropriate devices to measure liquid level, specific gravity and temperature . A sampler and agitator are required.

Spent Decon Solution Pump Tank

Provide a pump tank by which the spent decon solutions and rinse water may be transferred to the recycle collection tank for dewatering in the Recycle Evaporator.

5.2.14.3 Mechanical Cell B

5.2.14.3.1 General

Final canister decontamination is designed to produce an additional DF of 10^2 to 10^3 of the remaining canister transferable surface contamination. Process decon solutions used in this cell are transferred to Mechanical Cell A where they are used for preliminary decontaminating of another canister. Canisters should air dry by their own self-heating in a relatively clean area before dry smearing the surface and transfer into Mechanical Cell C.

5.2.14.3.2 Etch Tank

Size and function of the tank the same as in Mechanical Cell A. Tank is vented to a caustic scrubber. A suitable transfer device is required to transfer the spent etch solution to Mechanical Cell A.

5.2.14.3.3 Cleaning Tank

Size and function of this tank the same as in Mechanical Cell A. A suitable transfer device is required to transfer the spent cleaning solution to Mechanical Cell A.

5.2.14.3.4 Spray Tank (2)

Size and function of these tanks the same as in Mechanical Cell A.

5.2.14.3.5 Spray Hold Tank

Provide a tank to hold the spray water from the spray tanks. Tank should be equipped with an agitator, sampler and suitable devices to measure liquid level, specific gravity and temperature. A transfer device is required to transfer contents to the spent decon solution pump tank.

5.2.14.3.6 Caustic Scrubber

The etch tanks (Mechanical Cell A & B) should be vented to a caustic scrubber to prevent hydrogen fluoride from entering the process vessel vent system. HF and HNO_3 in air over etch tank contents assuming saturation at 50°C is as follows

	Partial Pressure, mmHg	Concentration, ppm	
		Volume	Weight
HF	0.06	80	57
HNO_3	0.06	80	180
H_2O	80	100,000	69,500
Air	Balance	Balance	Balance

5.2.14.4 Mechanical Cell C

Provide remote equipment to measure canister radiation levels, surface temperature, and surface transferable contamination. Remote readout is required on the radiation meters and the surface pyrometers. Provide ability for introducing "clean" smear papers into "C" cell and removing "dirty" smear paper from the cell for counting. The radiation monitor should be equipped with a gamma detector for canister radiation profile survey one foot from the surface. The surface temperature measuring equipment should have a range of 0-500°C and be capable of measurements at the canister quarterpoints along its length.

5.2.15 Interim Storage

Provide reinforced concrete facilities to store 6500 canisters that encapsulate the glass waste. The facilities should be designed to withstand natural catastrophes such as earthquakes, flooding, and tornadoes. Provide for removal of fission product decay heat by natural convection air cooling around containers. The maximum glass temperature is 500°C to avoid devitrification. Filtration of the cooling air exhausted from the building is not required. A system is required to divert the building air to a HEPA filter bank automatically in the event of airborne contamination. Also, the normal building exhaust should be blocked in this emergency mode. Provision should be made for remote transfer of canister from "C" cell to the storage facility. Provide air samplers to continuously monitor exhaust air for airborne activity.

TABLE 5.1. DWPF Services and Equipment

SERVICES PROCESS EQUIPMENT	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air			
Aluminum Dissolving (FS-3)																							
Sludge Receipt Tank	x	x		x			x	x	x														
Aluminum Dissolver	x	x	x	x			x		x		x	x											
Dissolver Cond. Tank		x		x			x	x	x														
Dissolver Condenser		x					x																
Settling and Filtration (FS-8)																							
Salt Solution Receipt Tank	x	x		x			x	x	x														
Filter Backwash Tank	x			x			x	x	x														
Gravity Settler Feed Tank	x		x	x			x	x	x														
Gravity Settler	x	x		x[a]			x	x	x[b,c]								x[d]						
Gravity Settler Supernate Tank	x			x			x	x	x														
Sand Filter Feed Tank	x			x		x	x	x		x													
Sand Filter-(SF) No. 1					x		x								x[e]								
First Filtrate Tank	x	x		x		x	x	x															
Gravity Settler Bottoms Tank	x			x			x	x	x														
Sand Filter (SF) No. 2					x		x								x[e]								
Waste Sand Tank	x				x		x					x											

a - Recirculated to GS feed tank during settling period
b - Sludge layer
c - Supernate layer
d - Sludge layer
e - In backwash to filter bottom

TABLE 5.1. DWPF Services and Equipment (Contd)

SERVICES PROCESS EQUIPMENT	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air			
Second Filtrate Tank	x			x			x	x	x														
Filtrate Hold Tank	x			x			x	x	x	x													
Sludge Washing (FS-4)																							
Sludge Feed Tank	x	x		x			x	x	x														
Wash Tank	x			x		x	x	x	x														
Wash Centrifuge							x					x											
Centrate Tank	x			x			x	x	x														
Centrate Hold Tank	x			x			x	x	x														
Washed Sludge Run Tank	x			x			x	x	x														
Recycle Evaporation (FS-7)																							
Recycle Evap Feed Tank	x			x		x	x	x															
Recycle Evaporator (RE)		x	x	x							x	x[a]											
RE Bottoms Tank	x	x		x			x	x	x														
RE Condenser		x					x																
RE Condensate Tank	x	x		x			x	x	x														

a - Spraydown of de-entrainer.

TABLE 5.1. DWPF Services and Equipment (Contd)

SERVICES PROCESS EQUIPMENT	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air			
Supernate Decontamination (FS-9,10)																							
Ion Exchange Feed Tank	x			x		x	x	x		x													
Cs Feed Bounce Tank				x		x	x[a]	x															
Cs Eluate Tank	x	x		x			x[a]	x	x														
Cs Regenerant Catch Tank	x	x	x	x			x[a]	x	x														
Cs Ion Exchange Columns A&B				x																			
Cs Elute Bounce Tank				x		x	x[a]	x															
Sr Feed Bounce Tank				x		x	x	x															
Sr Ion Exchange Column				x																			
Sr Elute Bounce Tank				x		x	x	x															
Sr Eluate Tank	x			x		x	x	x															
Strontium Concentrator		x	x	x							x												
Strontium Concentrator Bottoms Tank	x	x		x			x	x	x														
Sr Conc. Condensate Tank	x	x		x			x	x	x														
Spent Resin Tank	x			x	x		x	x															
Product Salt Hold Tank	x			x			x[b]	x	x														

a. These tanks vent to the Regulated Facility Vessel Vent System via the Cesium Vent Scrubber

b. Vents into the Regulated Facility Vessel Vent System

TABLE 5.1. DWPF Services and Equipment (Contd)

PROCESS EQUIPMENT \ SERVICES	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air			
Cs Elut. Rec/Cs Conc. (FS-11)																							
Purge Condensate Tank	x	x		x			x[a]	x	x														
Cesium Vent Scrubber							x[a]			x													
Stripper Condenser		x					x[a]																
Cs Elutriant Makeup Tank	x	x		x			x[a]	x	x														
Stripper Condensate Tank	x	x		x			x[a]	x	x														
Cs Concentrator		x	x				x[a]		x		x												
Purge Condenser		x																					
Cs Concentrator Feed Tank	x	x		x		x	x[a]	x															
Cesium Vent Scrubber Tank	x			x				x	x														
Steam Stripper																							
Cs Elutriant Feed Tank	x	x		x		x	x[a]	x															
Cs Conc. Bottoms Tank	x	x		x		x	x	x															
Cesium Fixation on Zeolite (FS-12)																							
Zeolite Feed Bounce Tank		x		x		x	x	x															
Zeolite Column		x			x																		
Zeolite Raffinate Bounce Tank	x	x		x			x	x	x														
Zeolite Slurry Tank	x	x		x			x	x	x														
Zeolite Raffinate Hold Tank	x	x		x			x	x	x														

a. These tanks vent to the Regulated Facility Vessel Vent System via the Cesium Vent Scrubber.

TABLE 5.1. DWPF Services and Equipment (Contd)

PROCESS EQUIPMENT / SERVICES	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air			
Sump System																							
Sump Collection Tank	x			x	x		x	x				x											
General Purpose Evaporation (FS-13)																							
GPE Feed Tank	x			x		x	x^{a}	x															
GP Evaporator		x	x								x	x^{b}											
GPE Condenser		x					x^{a}	x															
GPE Bottoms Tank	x	x		x			x^{a}	x	x														
GPE Condensate Run Tanks	x	x		x			x^{a}	x	x														
Recycle Water Tank				x			x^{a}																
Decontaminated Salt Solution Evaporation and Solidification in Concrete (FS-14)																							
Product Salt Solution Storage Tank	x			x		x	x^{c}	x															
Product Salt Evaporator (PSE)		x	x				x^{c}				x	x^{b}		x									
PSE Concentrate Tank	x	x	x	x			x^{c}	x	x			x											
PSE Condensate Tank	x	x		x			x^{c}	x	x														
Saltcrete Plant							x^{c}					x											
Concrete Flush Hold Tank	x	x	x				x^{c}		x			x											
Heater			x									x											

a. These tanks vent to Regulated Facility Vessel Vent System
b. Spraydown of de-entrainer
c. These facilities vent to a separate vent system (see FS-14)

TABLE 5.1. DWPF Services and Equipment (Contd)

PROCESS EQUIPMENT / SERVICES	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air		
Spray Drying/Vitrification (FS-5)																						
Slurry Mix Tank	x	x		x			x	x	x													
Slurry Hold Tank	x	x		x			x	x	x													
Calciner Feed Tank	x	x		x		x	x	x				x										
Calciner		x										x[g]			x[a]							
Calcine Filters															x[b]							
Vibrators															x							
Melter												x[h]				x				x[f]		
Dryer Off-Gas Treatment (FS-6)																						
Off-Gas Vapor Duct																x						
Off-Gas Condensate Tank	x			x		x[c]		x				x										
Hg Collection Sump									x													
Primary Deep Bed Filter													x[e]		x							
Secondary Deep Bed Filter													x[e]		x							
Filter Pump Tank	x			x		x[d]													x			
Recycle Collection Tank	x	x		x			x	x	x													

a - Atomizing air
b - Sintered metal filter blowback air
c - Scrub transfer to DBF #1 and to cooler
d - Scrub transfer to DBF #2
e - Spraydown of pads
f - To cool electrodes
g - To cool calciner chamber induction heater coils
h - To cool melter shell

TABLE 5.1. DWPF Services and Equipment (Contd)

PROCESS EQUIPMENT / SERVICES	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air			
Ruthenium Adsorber Preheater			x																				
Iodine Adsorber Preheater			x																				
Stack Discharge				x																			
Ejector Venturi Cooler		x																					
Off-Gas Cooler		x																					
Mercury Recovery (FS-6A)																							
Mercury Receipt Tank						x	x																
Mercury Filter #1												x			x								
Oxidation Tank							x											x					
Mercury Filter #2												x			x								
Mercury Still Feed Tank						x	x																
Mercury Vacuum Still																x							
Mercury Still Condenser		x																					
Mercury Still Product Tank				x			x	x	x														
Backwash Hold Tank	x			x	x		x	x	x														
Acid Wash Feed Tank				x					x														
Acid Wash Column				x																			
Mechanical Cell A (FS-15)																							
Etch Tank	x[a]	x		x		x	x[b]	x															
Cleaning Tank	x[a]	x	x	x		x	x	x															
Transfer Lock				x					x														
Digester	x	x	x	x			x	x	x														

a - Agitation by solution circulation
b - Vents to the Caustic Scrubber

TABLE 5.1. DWPF Services and Equipment (Contd)

PROCESS EQUIPMENT / SERVICES	Agitator	Cooling Water	Steam	Sampler	Transfer Jet	Rate Pump	Vessel Vent	Overflow	Transfer Pump	Chilled Water	Anti-Foam	Process Water	Deionized Water	Steam Lift	Process Air	Electrical Heater	Mixer	Air Sparge	Refrigerant	Cooling Air
Digestor Condenser		x					x													
Neutralizer	x	x		x			x	x	x											
Spray Tank	x			x			x	x	x			x								
Spray Hold Tank	x			x			x	x	x											
Spent Decon Sol'n Pump Tank	x			x			x	x	x											
Mechanical Cell B (FS-16)																				
Etch Tank	x[a]	x		x		x	x[b]	x												
Cleaning Tank	x[a]	x	x	x		x	x	x												
Spray Tank	x			x		x	x	x				x								
Spray Hold Tank	x			x		x	x	x												

a - Agitation by solution circulation
b - Vents to Caustic Scrubber

TABLE 5.2

Cold Feed Services

Module	Vessel	Service
Aluminum Dissolution	Aluminum Dissolver	50% NaOH Anti-foam
Settling/Filtration	Gravity Settler	Starch Dispersion (Flojel®-60) 8% dispersion in 1M NaOH
	Sand Filter No. 1	1M NaOH 3-4M HNO_3 Sand, 25-40 mesh Anthracite, 20-30 mesh Polyelectrolyte (Versa TL® 700) - 0.1% in distilled water
	Sand Filter No. 2	1M NaOH 3-4M HNO_3 Sand, 40-60 mesh Anthracite, 30-50 mesh Polyelectrolyte (Versa TL® 700) - 0.1% in distilled water
Cesium and Strontium Ion Exchange	Cs IE Columns A and B	Duolite ARC-359 Resin
	Sr IE Column	Amberlite IRC-718 Resin
	Cs Elute Bounce Tank	2M NaOH
	Sr Elute Bounce Tank	0.01M NaEDTA - 0.001M NaOH
Cs Elutriant Recovery/ Cs Concentration	Cs Elutriant Makeup Tank	8M NH_4OH (aqueous) Carbon Dioxide (gas)
	Cs Vent Scrubber	Chilled Water
Spray Calcination/ Vitrification	Calciner	Frit
Mercury Recovery	Acid Wash Column	3M HNO_3
	Backwash Hold Tank	50% NaOH
Mechanical Cell A	Digester	50% HNO_3 $Mn(NO_3)_2$
	Neutralizer	50% NaOH
	Spray Tanks	Spray Water
	Smear Station	Paper Smears
Mechanical Cell B	Etch Tank	3.5M HNO_3 - 0.4M NaF
	Caustic Scrubber	NaOH
	Cleaning Tank	100 g/L $C_2H_2O_4$
	Spray Hold Tank	50% NaOH
	Spray Tanks	Spray Water
	Smear Station	Paper Smears
Mechanical Cell C	Spot Electropolishing	HNO_3
	Smear Station	Paper Smears
Cs Fixation on Zeolite	Zeolite Column	Zeolite Water
Sludge Washing	Centrifuge	Spray Water
Product Salt Solution Concentration and Solidification in Concrete	Saltcrete Plant	Cement

TABLE 5.3

Technical Specifications for Wash Centrifuge

Type	Top-driven, bottom-unloaded, solid-wall batch basket centrifuge
Basket Size	Minimum basket size of 48 inches in diameter by 30 inches high with 120 gallon capacity
Speed	Maximum bowl speed when plowing — 100 rpm
Centrifugal Force	900 g's minimum at liquid pool surface
Separation	98% minimum solids recovery over each of the dewatering steps and two wash steps
Drive	300 ft-lb minimum torque required at discharge speed
Discharger	Single, knife-edge, scraping-type plow with high pressure hydraulic spray system
Skimmer	Single linear skimming device
Feed System	Complete or nearly complete acceleration of feed required before entry into basket
Cake Density	100 lb/ft^3 maximum bulk density of wet cake in basket

TABLE 5.4

PNL Spray Dryer Basic Data

Spray Dryer Size, in.	Waste Type	Feed Rate, gal/hr	Wall Temp., °C[e]	Power Input, kW
21[a]	SRP	3.96	∿700-750	45
21	SRP	7.93	∿700-750	50
21	SRP	13.2	∿700-750	68
21	SRP	14.5	∿700-750	71
21	LWR	19.8	700	∿80[c]
36[b]	LWR	55.5	800	225[d]
36	SRP	79.3	770	284
36	SRP	66.1	790	262
36	SRP	46.2	810	211

---

a. 21-in.-diameter x 6 ft 6-in.-long chamber; 35.7 ft^2 heat transfer area.

b. 36-in.-diameter x 10 ft 0-in.-long chamber; 94.3 ft^2 heat transfer area.

c. Maximum heater output. Wall temperature could not be maintained above 19.8 gal/hr feed rate.

d. Maximum output of heaters rated at 390 kW.

e. Estimated wall temperature based on furnace temperature and PNL experience.

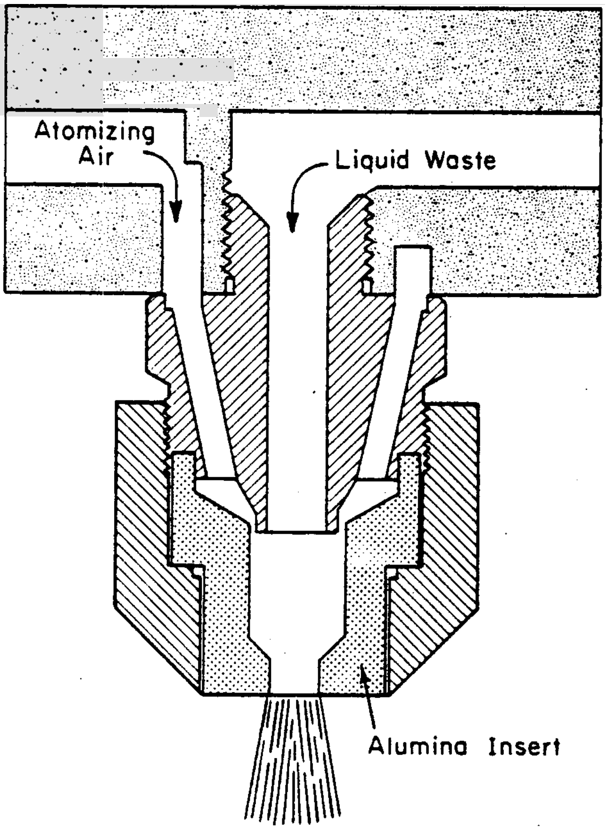


FIGURE 5.1   High-Capacity Atomizing Nozzle

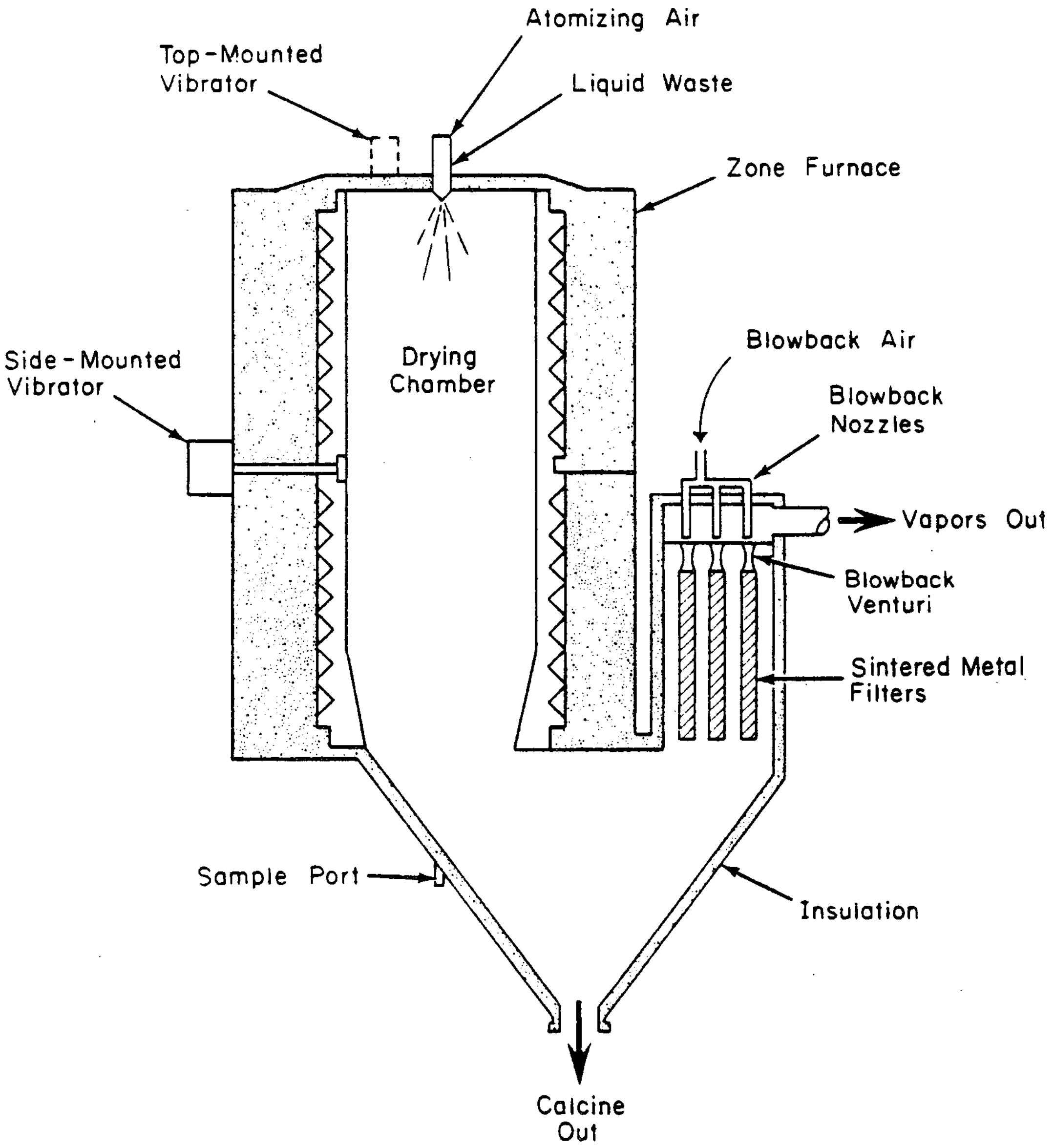


FIGURE 5.2 Conceptual Developmental Spray Dryer

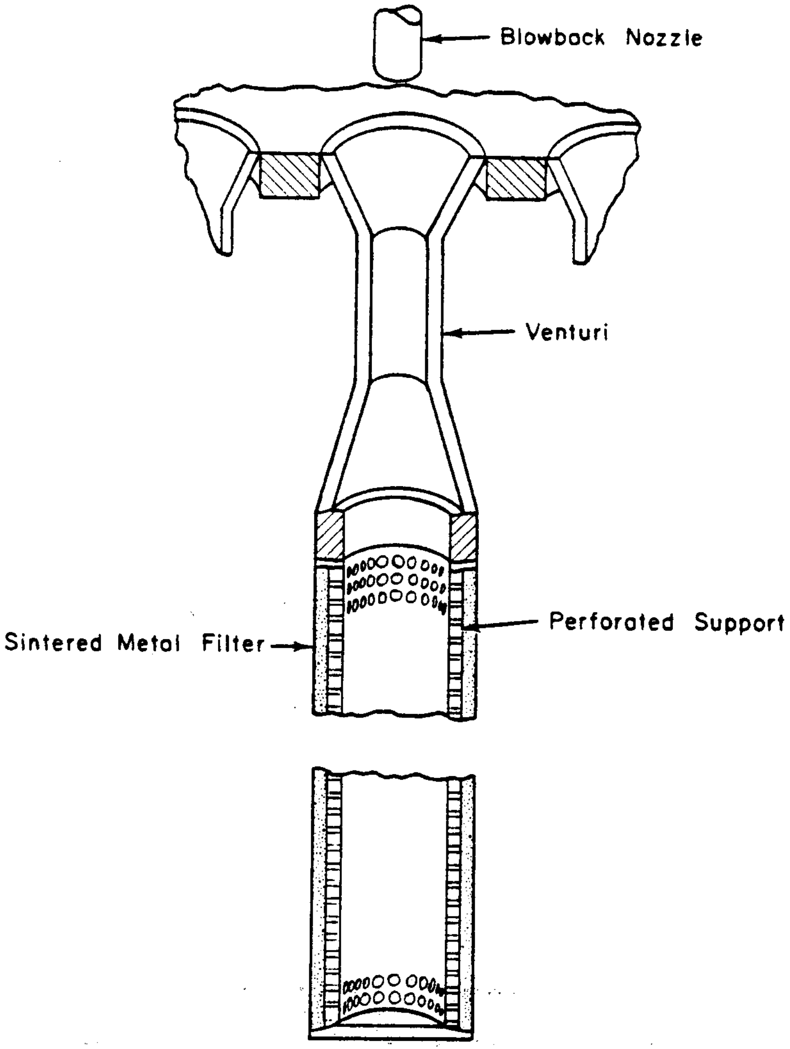


FIGURE 5.3 Spray-Dryer Filter Assembly

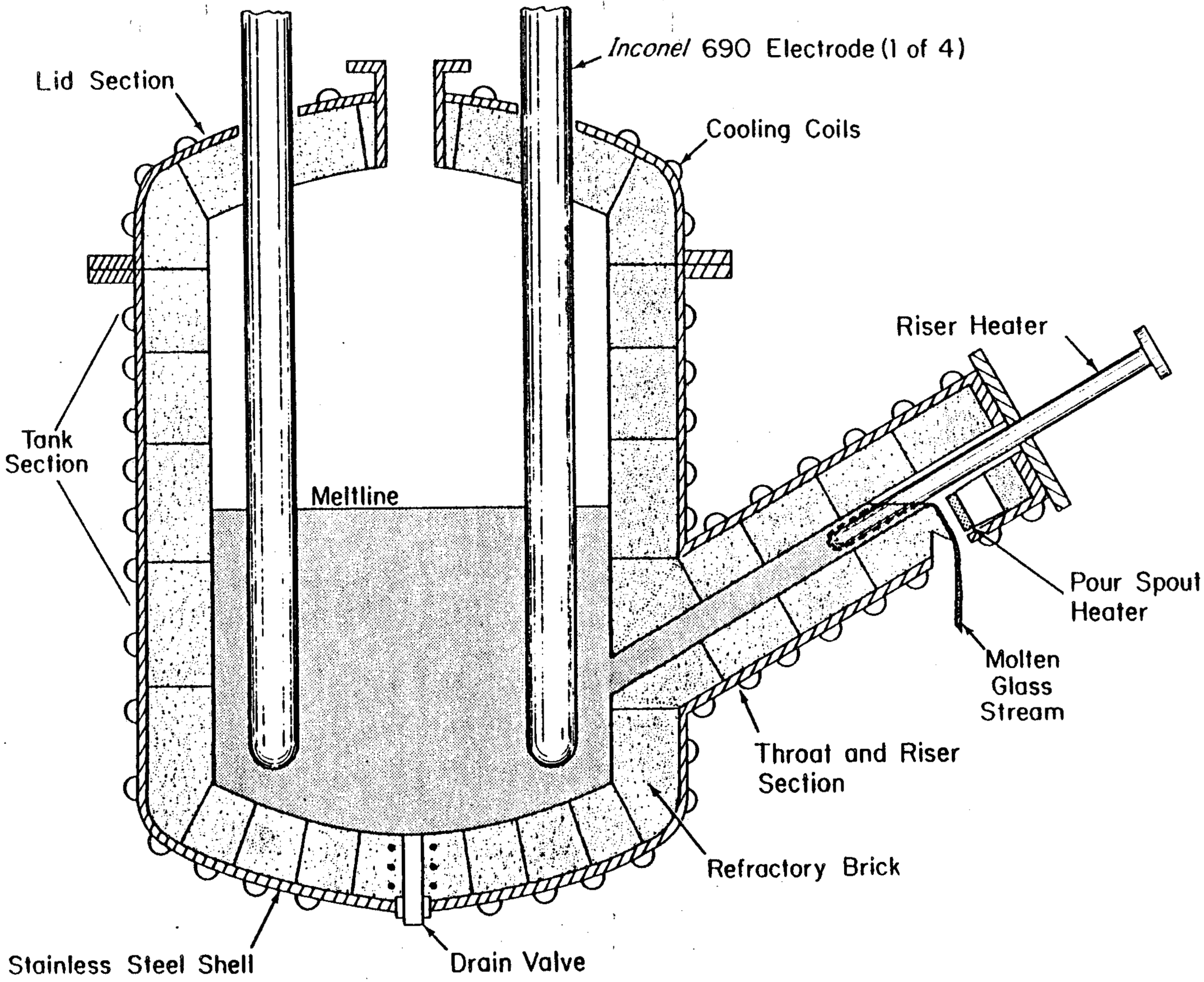


FIGURE 5.4 Joule-Heated Continuous Glass Melter

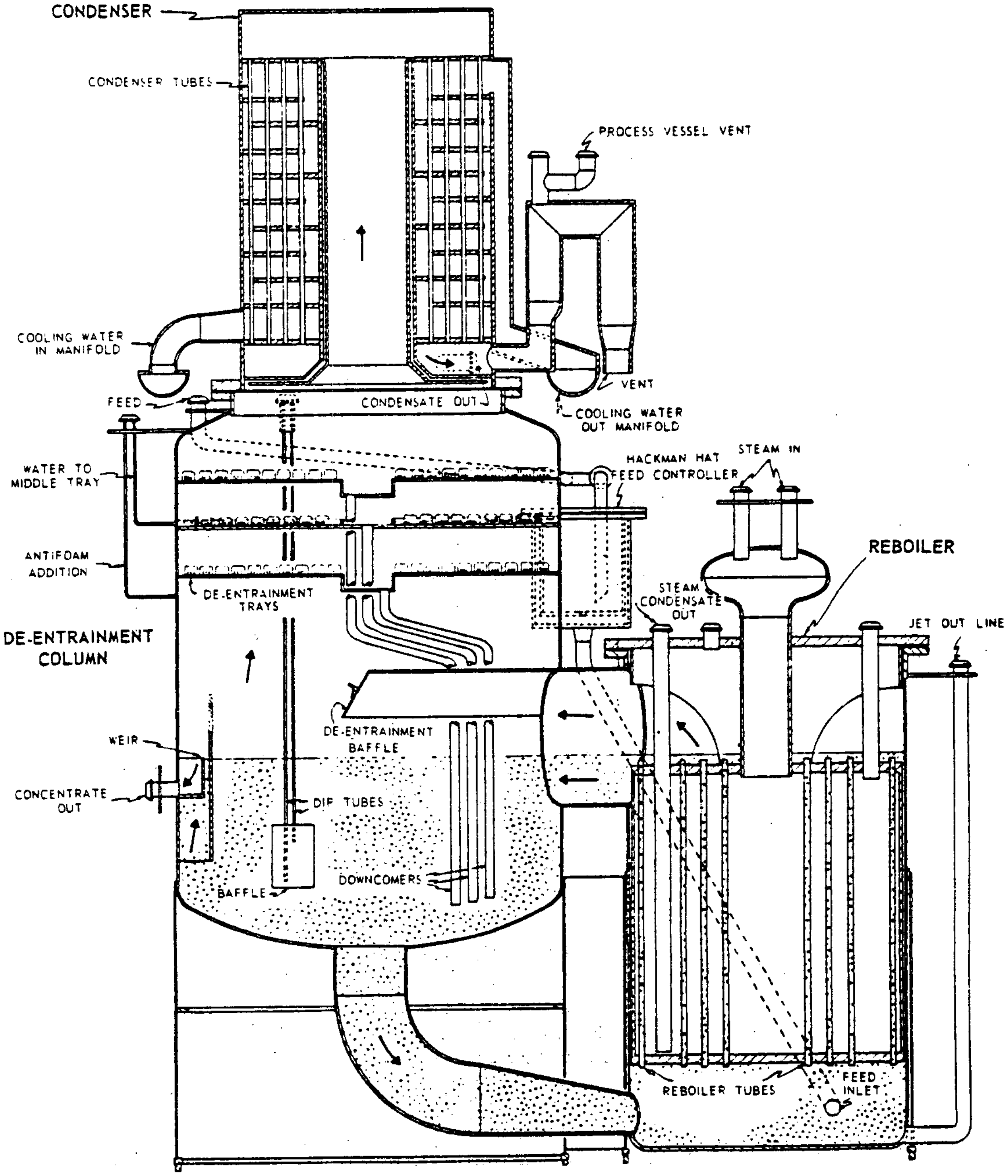


FIGURE 5.5 Continuous Evaporator

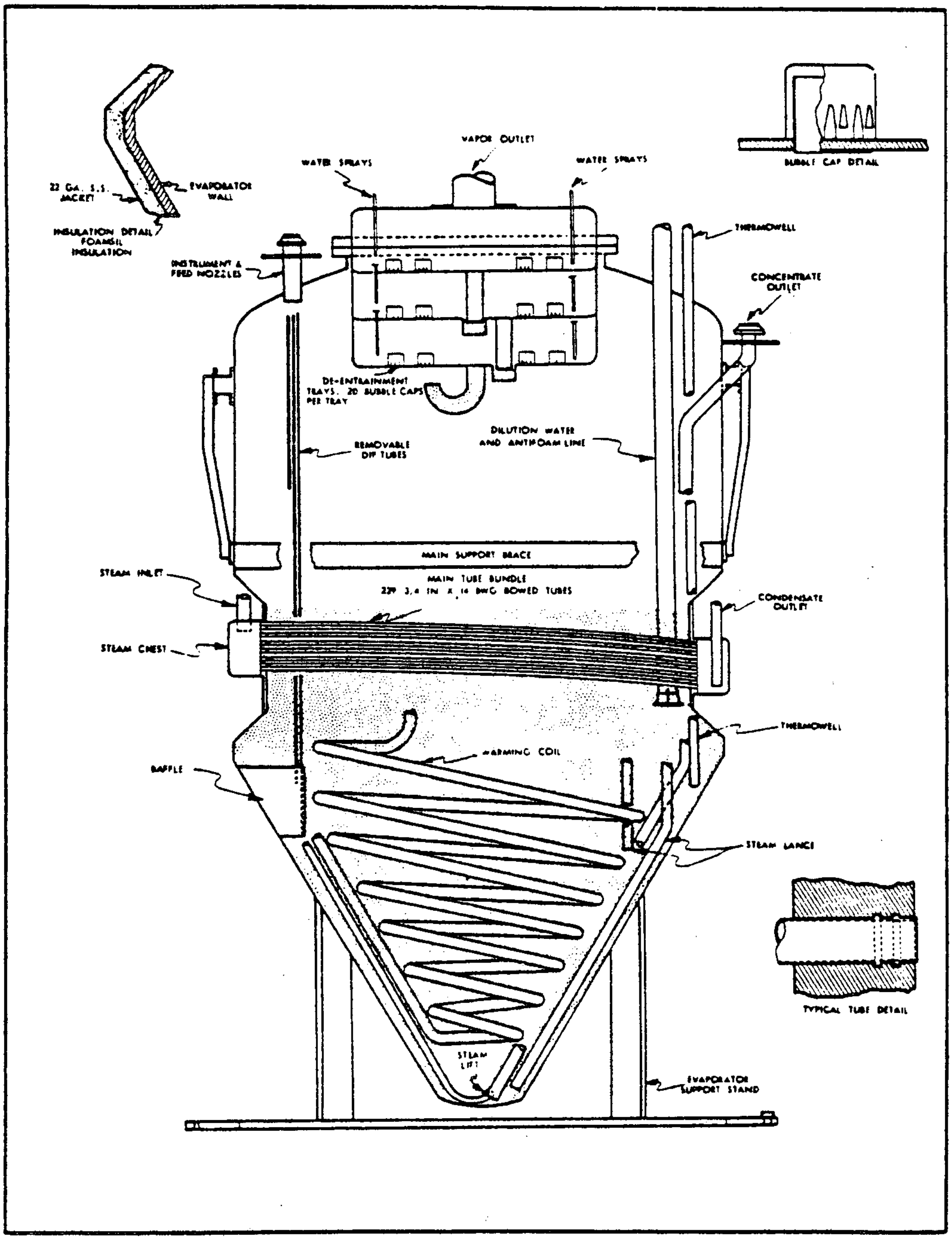


FIGURE 5.6 Bent-Tube Evaporator

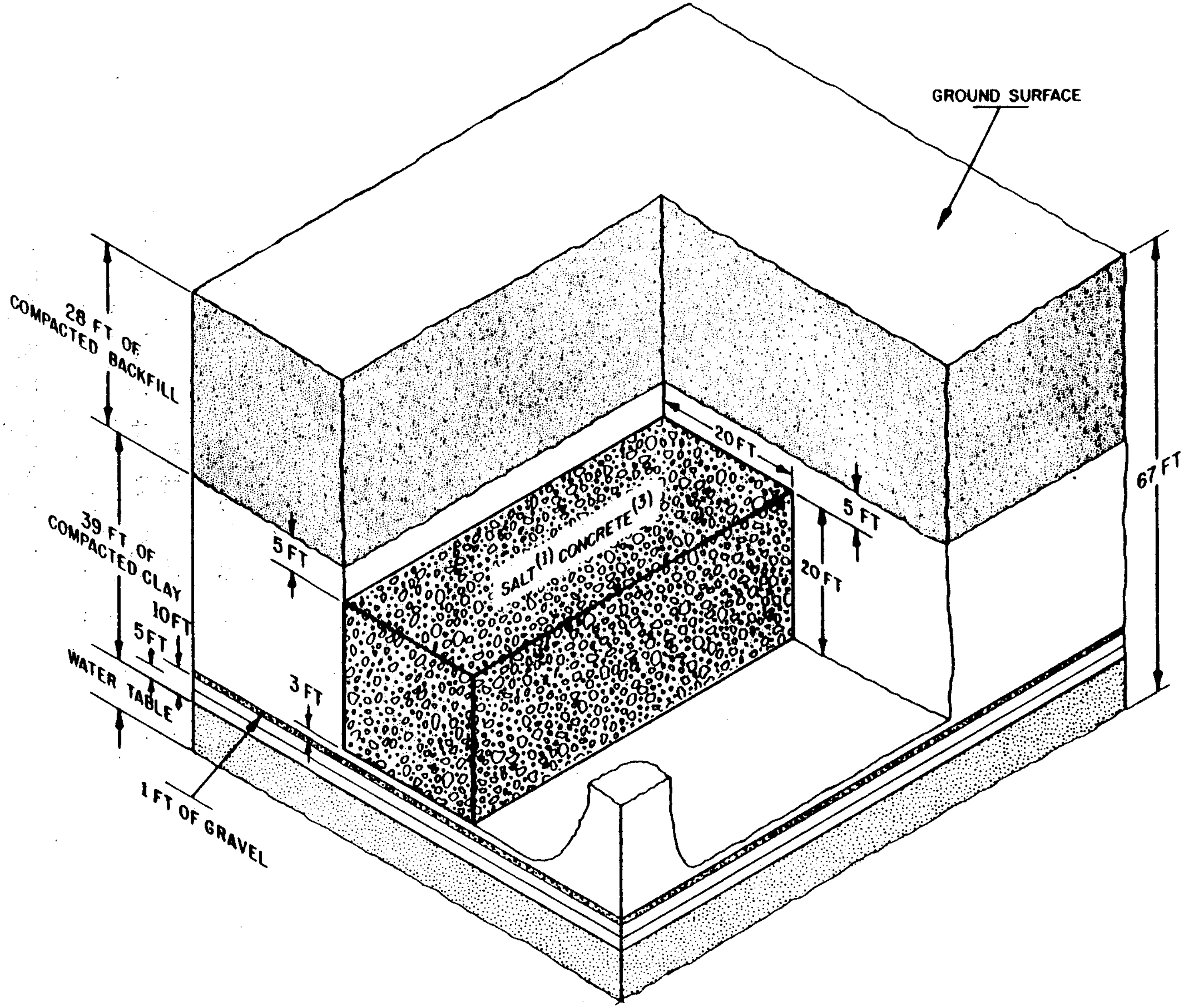


FIGURE 5.7 Disposal of Decontaminated Salt

5.3 REFERENCES

1. W. F. Bonner, H. T. Blair, and L. S. Romero. *Spray Solidification of Nuclear Waste.* ERDA Report BNWL-2059, Battelle Northwest Laboratories, Richland, WA (1976).

2. H. L. Hull and T. A. Willis. Trip Report, Battelle, Pacific Northwest Laboratories. *Continuous Electric Melting Tests, August 24-September 1, 1977.* Internal Report DPST-77-450, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (September 20, 1977).

3. C. B. Goodlett. *Concentration of Radioactive Wastes.* USAEC Report DP-1135, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (1968).

4. C. B. Goodlett. *Transfer of Radioactive Slurries.* USAEC Report DP-1136, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (1968).

5. *Defense Waste Solidification Program.* Minutes of Meeting of Memorandum from J. W. Joseph-L. E. WEisner to R. T. Huntoon, August 17-18, 1977 (September 8, 1977).

6. *Defense Waste Solidification Program, Conceptual Designs of Mechanical Cell Equipment.* Memorandum from SRP-EED to R. T. Huntoon (October 24, 1977).

7. J. A. Ayers. *Decontamination of Nuclear Reactors and Equipment.* Ronald Press, 1970.

8. R. S. Ondrejcin to A. J. Hill. *Carbon Steel and Stainless Steel Attack from Sludge Dissolution.* Internal Report DPST-67-471, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (December 15, 1976).

9. R. S. Ondrejcin to J. D. Ellett. *Removal of Phosphate from Heat Exchangers.* Internal Report DPST-66-492, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (August 19, 1966).

10. *Defense Waste Solidification Program, Conceptual Designs of Mechanical Cell Equipment.* Memorandum from SRP-EED to R. T. Huntoon (October 24, 1977).

6. PROCESS CONTROL

6.1 General

The radioactive nature of defense waste requires that processing be achieved with minimum exposure of operating personnel to radiation and protection of the environment. Conducting this process in a remotely operated facility is an integral part of this philosophy, but makes instrumentation and control of the process difficult.

Analytical support to monitor and control the process will be provided by on-line instrumentation wherever practical. If the critical analyses can not be done on-line, sufficient hold-up capacity is required to facilitate off-line analysis to be performed.

In addition to providing support for on-line process control analyses and critical off-line analyses, analytical facilities will be required to provide a multitude of analyses required to characterize feed streams, to perform material balances, inventory discharges to the environment, etc.

Tables 6.1 and 6.2 summarize the type of on-line and off-line analyses currently considered required to control and audit the process. Estimates of the concentration of radioactivity in process streams are available in Appendix 13.7. Estimates of other measurements are available from the appropriate material balance flowsheet in Section 4. Solution temperatures will range from ambient to 100 unless specifically noted.

Where steam jets are used for solution transfer, steam flow and pressure should be monitored. Where transfer pumps are used, amperage, voltage and power should be monitored. The amperage, voltage, power and rpm should be monitored for all tank agitators.

TABLE 6.1

DWPF On-Line Process Control Measurements[a]

Process Module	Process Stream or Vessel	On-Line Measurement
Aluminum Dissolving	Sludge Receipt Tank	LL, Sp G, T
	Aluminum Dissolver	LL, Sp g, T(105-107°C), P
	Dissolver Condensate Tank	LL, Sp G, T
	Condenser Cooling Water	T_{in}, T_{out}, F
	Steam to Dissolver Coils	F, P
Sludge Washing	Sludge Feed Tank	LL, Sp G, T
	Centrifuge	T (Spindel Bearing). RPM (50-1400) A, E, W, % Cake Loading, V
	Centrifuge Feed (FS-4-3, 10, 17)	F (1-60 gpm, 7.4 gpm nominal
	Centrate (FS-4-4, 11, 18)	C^b (500-20,000 umho/cm) Tu (5000 ppm)
	Wash Tank	Sp G, LL, T
	Spray Water	F, P
	Washed Sludge Run Tank	LL, Sp G, T
	Centrate Tank	LL, Sp G, T
	Centrate Hold Tank	LL, Sp G, T
	Centrifuge Skimmer	Position
	Centrifuge Discharger	Position
Spray Drying/ Vitrification	Slurry Mix Tank	LL, Sp G, T
	Slurry Hold Tank	LL, Sp G, T
	Calciner Feed Tank	LL, Sp G, T
	Feed Loop	F (>5 ft/sec), P
	Calciner Feed (FS-5-8)	F (1.0 gpm), P
	Atomizing Air (FS-5-9)	F (2.38×10^2 lb/hr)[c], P, T
	Off-Gas (FS-5-13)	P, T (as measured at filters)
	Frit Feed (FS-5-11)	F (1.83×10^2 lb/hr)

---

a.
LL - Liquid Level
Sp G - Specific Gravity
T - Temperature
P - Pressure
F - Flow
A - Amperage
E - Voltage
W - Power
V - Vibration
C - Conductivity
Tu - Turbidity
ET - Elapsed Time
FL - Foam Level
M - Weight

b. Final Wash

c. 4 lbs atomizing air/gal feed slurry

d. 65 lb frit/35 lb of solids and salts in feed on a dry basis

TABLE 6.1, (Contd)

Process Module	Process Stream or Vessel	On-Line Measurement
	Sintered Metal Filters	T, ΔP (about 15" H_2O)
	Spray Dryer Chamber	T (profile, 600-900°C), P(-15"H_2O)
	Filter Air Blowback	T, P, ET
	Spray Dryer Cone	T (profile, 300-400°C)
	Spray Dryer Heaters	A, E, W
	Melter	P and T (vapor space)
	Melt	T (1150°C), LL, FL
	Melter Electrodes	A, E, W, T (1050°C)
	Electrode Cooling Air	F, T, P (in), T (out)
	Melter Shell Cooling Water	F, T, P (in), T (out)
	Riser Heater	E, W, T (1050°C)
	Riser Melt	T (1000°C)
	Tilt Pour	Position
	Canister	T (300-950°C), W
	Canister Contents	LL, W
Off-Gas Treatment	Vapor Duct	T (about 350°C)
	Off-Gas Condensate Tank	LL, Sp G, T (scrub), T (vapor), C
	Mercury Sump	LL (high and low)
	Quench Stream Pump	A, E, W
	Quench Stream (FS-6-2)	T, P
	Quench Stream (FS-6-3)	T, P, F (177 gpm)
	Cooling Water to Cooler	F, P, T (in), T (out)
	Recycle Collection Tank	LL, Sp G, T
	DBF #1 Scrub Pump	A, E, W
	Scrub to DBF #1 Atomizing Nozzle	F, P, T
	Atomizing Air to DBF #1 Atomizing Nozzle	F, P
	Scrub to DBF #1 Spray Nozzle	F, P, T
	DBF #1	ΔP (5-10" H_2O)
	Filter Pump Tank	LL, Sp G, T, C
	DBF #2 Scrub Pump	A, E, W
	Scrub to DBF #2 Atomizing Nozzle	F, P, T
	Atomizing Air to DBF #2 Atomizing Nozzle	F, P
	Scrub to DBF #2 Spray Nozzle	F, P
	DBF #2	ΔP (5-10" H_2O)
	Brine to Filter Pump Tank Coils	F, T, P

TABLE 6.1, (Contd)

Process Module	Process Stream or Vessel	On-Line Measurement
	Vapor from DBF #2 (FS-6-15)	T
	Ruthenium Adsorber Preheater	ΔP (2" H_2O)
	Steam to Ruthenium Adsorber Preheater	P, T, F
	Vapor from Heater (FS-6-16)	T
	Primary Ru Adsorber	ΔP (30" H_2O) T (1st 6" of adsorbent)
	Vapor from Primary Ru Adsorber (FS-6-17)	T, Ru
	Secondary Ru Adsorber	ΔP (30" H_2O)
	Vapor from Secondary Ru Adsorber (FS-6-18)	T
	Iodine Adsorber Preheater	ΔP (2" H_2O)
	Steam to Heater	T, F, P
	Vapor from Heater (FS-6-19)	T (150°C)
	Iodine Adsorber	ΔP (48" H_2O)
	Vapor from I_2 Adsorber (FS-6-20)	T (150°C), I_2
	Off-Gas Cooler	T
	Exhausters	A, E, W
	Exhauster Effluent (FS-6-22)	F, P, Hg, T
	Canyon Air	F, T
	Process Vessel Vent Filter	ΔP
	Vessel Vent (FS-6-24)	T
	Vessel Vent (FS-6-25)	F
	Sand Filter	ΔP
	Stack Effluent (FS-6-26)	F, I_2, Ru, α, β-γ
Mercury Recovery	Mercury Receipt Tank	LL
	1st Mercury Pump	A, E, P
	Inlet Stream to Hg Filter No. 1	F, P
	Mercury Filter No. 1	ΔP
	Acid Wash Feed Tank	LL, P (vapor)
	Acid Wash Pump	A, E, P
	Inlet Stream to Acid Wash Column	F
	Oxidation Tank	LL, P (vapor)
	2nd Mercury Pump	A, E, W
	Inlet Stream to Hg Filter No. 2	F, P
	Mercury Filter No. 2	ΔP
	Mercury Still Feed Tank	LL, P (vapor)
	Mercury Still	LL, T, P
	Still Heater	A, E, W
	Cooling Water to Condenser	F, T, P
	Backwash Hold Tank	LL, T, Sp G
	Filter Backwash	F, P
	Mercury Still Product Tank	LL, T
	Air Flow to Oxidation Tank	F

TABLE 6.1 (Contd)

Process Module	Process Stream of Vessel	On-Line Measurement
Recycle Evaporation	Recycle Evaporation Feed Tank	LL, Sp G, T
	Evaporator Feed (FS-7-9)	F
	Recycle Evaporator	LL, Sp G, T, P (vapor)
	De-entrainer	ΔP
	Cooling Water to Condenser	F, T, P
	RE Condensate Tank	LL, Sp G, T
	RE Bottoms Tank	LL, Sp G, T
	Steam to Evaporator	F, T, P
Settling and Filtration	Salt Solution Receipt Tank	LL, Sp G, T
	GS Feed Tank	LL, Sp G, T
	GS Feed (FS-8-4)	F, T
	Gravity Settler	LL, T, Sludge/Supernate Interface
	Starch (FS-8-5)	F, T
	GS Bottoms Tank	LL, Sp G, T
	Steam to GS Feed HX	F, P, T
	Cooling Water to GS	F, T
	GS Supernate Tank	LL, Sp G, T
	Sand Filter Feed Tank	LL, Sp G, T
	Sand Filter Feed (FS-8-10)	F, P, T
	Polyelectrolyte (FS-8-11)	F, P, T
	Sand Filter No. 1	ΔP, Gamma Level
	First Filtrate Tank	LL, Sp G, T
	Sand Filter Feed (FS-8-14)	F, P, T
	Polyelectrolyte Feed (FS-8-15)	F, P, T
	Sand Filter No. 2	ΔP, Gamma Level
	Second Filtrate Tank	LL, Sp G, T
	Filtrate Hold Tank	LL, Sp G, T
	Filter Backwash Tank	LL, Sp G, T
	Filter Air Blowback	F, P
	Filter Filtrate Backwash (FS-8-20, 21)	F, P, T
	Waste Sand Tank	LL, Sp G, T
Cesium Ion Exchange	Ion Exchange Feed Tank	LL, Sp G, T
	Feed to Cesium Feed Bounce Tank	F, P, T
	Cs Feed Bounce Tank	LL, Sp G
	Cesium Ion Exchange Columns	ΔP, T, Resin Level
	Primary and Secondary Column Effluents (during load cycle)	^{137}Cs
	Water Rinse (FS-9-4)	F, T, P
	Cs Elute Bounce Tank	LL, Sp G
	Elutriant (FS-9-6)	F, T, P
	Eluate (FS-9-9)	^{137}Cs
	Water Rinse (FS-9-10)	F, T, P

TABLE 6.1 (Contd)

Process Module	Process Stream of Vessel	On-Line Measurement
	Regenerant (FS-9-14)	F, T, P
	Regenerant (FS-9-15)	C
	Column Backwash (FS-9-25)	F, P
	Column Backwash (Effluent)	Suspended Solids
	Cs Eluate Tank	LL, Sp G, T
	Cooling Water to Cs ET	F, T
	Cs Regenerant Catch Tank	LL, Sp G, T
	Spent Resin Tank	LL, Sp G, T
Strontium Ion Exchange	Sr Feed Bounce Tank	LL, Sp, T
	Feed to Ion Exchange (FS-10-1, 3)	F, P, T
	Sr Ion Exchange Column	ΔP
	Water Rinse (FS-10-5)	F, T, P
	Sr Elute Bounce Tank	LL, Sp G
	Elutriant (FS-10-8)	F, P, T
	Water Rinse (FS-10-10)	F, P, T
	Product Salt Hold Tanks	LL, Sp G, T
	Sr Eluate Tank	LL, Sp G, T
	Feed to Concentrator (FS-10-12)	F
	Sr Concentrator	LL, Sp, T, P (vapor)
	Steam to Concentrator	F, T, P
	Cooling Water to Condenser	F, P, T
	Sr Concentrator Bottoms Tank	LL, Sp G, T
	Sr Concentrator Condensate Tank	LL, Sp G, T
	Column Backwash (FS-10-18)	F,P
	Column Backwash (Effluent)	Suspended Solids
Cs Elutriant Recovery/Cs Concentration	Cs Concentrator Feed Tank	LL, Sp G, T
	Evaporator Feed (FS-11-2)	F
	Cs Concentrator	LL, Sp G, T, P
	Steam to Concentrator	F, T, P
	Cooling Water to Purge Condenser	F, T, P
	Purge Condensate Tank	LL, Sp G, T
	Condensate (FS-11-4)	^{137}Cs
	Stripper Condenser	ΔP, T
	Cooling Water to Stripper Cond.	F, T, P
	Stripper Condensate (FS-11-5)	^{137}Cs
	Stripper Condensate Tank	LL, Sp G, T
	Cs Elutriant Makeup Tank	LL, Sp G, T
	Aqueous Ammonia (FS-11-7)	F

TABLE 6.1 (Contd)

Process Module	Process Stream or Vessel	On-Line Measurement
	Cs Concentrator Bottoms Tank	LL, T, Sp G
	Cooling Water to Cs CBT	F, P, T
	Carbon Dioxide (FS-11-8)	F, P, T
	Cs Elutriant Feed Tank	LL, Sp G, T
	Cs Vent Scrubber Tank	LL, Sp G, T
	Cesium Vent Scrubber	ΔP
	Chilled Water to Vent Scrubber (FS-11-11)	F, T, P
	Scrubber Vapor Effluent (FS-11-V26)	F, T, NH_3, CO_2
Cs Fixation on Zeolite	Zeolite Feed Bounce Tank	LL, Sp G, T
	Feed to Zeolite Column (FS-12-2)	F, T, P
	Zeolite Column	ΔP, T (vertical profile)
	Cooling Water to Column	F, T, (in and out), P
	Zeolite Column Effluent (FS-12-3)	^{137}Cs, T
	Column Water Rinse (FS-12-5)	F, P
	Zeolite Raffinate Bounce Tank	LL, Sp G, T
	Column Backwash (FS-12-10)	F, P
	Zeolite Slurry Tank	LL, Sp G, T, ^{137}Cs
	Cooling Water to ZST	F, P, T(in and out)
	Zeolite Raffinate Hold Tank	LL, Sp G, T
General Purpose Evaporator	General Purpose Evaporator Feed Tank	LL, Sp G, T
	Evaporator Feed (FS-13-5)	F
	General Purpose Evaporator	LL, Sp G, T, P (vapor)
	De-entrainer	ΔP
	Steam to Evaporator	F, T, P
	Cooling Water to Condenser	F, T, (in and out), P
	GPE Bottoms Tank	LL, Sp G, T
	GPE Condensate Tanks	LL, Sp G, T
	Heater	T
	Steam to Heater	F, P
	HEPA	ΔP, gamma
	Flow from HEPA (FS-13-V29)	F
Product Salt Solution Concentration and Solidification in Concrete	Product Salt Solution Storage Tank	LL, Sp G, T
	Product Salt Evaporator (PSE)	LL, Sp G, T, P (vapor)
	Feed to Product Salt Evaporator (FS-14-2)	F
	Steam to Evaporator	F, P, T
	De-entrainer	ΔP
	Cooling Water to Condenser	F, P, T, (in and out)
	PSE Condensate Tank	LL, Sp G, T
	PSE Concentrate Tank	LL, Sp G, T
	Feed to SCP (FS-14-10)	F
	Steam to Lift	F, P
	Concrete Flush Hold Tank	LL, Sp G, T
	Steam to Heater	F, P
	HEPA	ΔP, gamma
	Flow from HEPA (FS-14-V22)	F

TABLE 6.1 (Contd)

Process Module	Process Stream or Vessel	On-Line Measurement
Mechanical Cell A	Leak Test Station	Helium
	Etch Tank	LL, Sp G, T
	Cleaning Tank	LL, Sp G, T
	Deionizer	ΔP
	Deionizer Prefilter	ΔP
	Deionizer Effuent (FS-15-28)	C, β-γ
	Deionizer Feed (FS-15-29)	F, P, T, β-γ
	Digester	LL, Sp G, T
	Steam to Digester Coils	F, P, T
	Cooling Water to Digester and Condenser	F, T, P
	Spray Water	F, P
	Spray Hold Tank	LL, Sp G, T
	Neutralizer	LL, Sp G, T
	Spent Decon Solution Pump Tank	LL, Sp G, T
	Cooling Water to Neutralizer	F, P, T
	Deionizer Purge	F
Mechanical Cell B	Spray Water	F, P
	Etch Tank	LL, Sp G, T
	Cleaning Tank	LL, Sp G, T
	Spray Hold Tank	LL, Sp G, T
	HF Scrubber Scrub	F
Mechanical Cell C	Canister	T (profile), Gamma (profile
Interim Storage Facility	Ventilation	F, β-γ[a]

---

[a] Of the particulate air sampler filter paper.

TABLE 6.2

DWPF Off-Line Analyses (Unless otherwise specified, the desired uncertainty is ± 10%

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
Waste Blending	Sludge-Slurry[b] (FS-2-4)	Intrarea Blend	OH^-	0.25 M	1 yr
			Fe	20 wt %	
			Al (insoluble)	12 wt %	
			Al (soluble)	3.3 wt %	
			Mn	5.0 wt %	
			U	2.3 wt %	
			Ca	1.5 wt %	
			Hg (insoluble)	1.2 wt %	
			Hg (soluble)	0.05 wt %	
			Ni	2.8 wt %	
			C	1.3 wt %	
			Si	0.25 wt %	
			I	0.21 wt %	
			NO_3^- (insoluble)	0.78 wt %	
			NO_3^- (soluble)	33.3 wt %	
			NO_2^- (soluble)	10.0 wt %	
			SO_4^{2-} (insoluble)	0.39 wt %	
			SO_4^{2-} (soluble)	7.0 wt %	
			Cl^- (insoluble)	0.70 wt %	
			Cl^- (soluble)	0.19 wt %	
			F^- (insoluble)	0.055 wt %	
			F^- (soluble)	0.009 wt %	
			CO_3^{2-} (insoluble)	2.2 wt %	
			CO_3^{2-} (soluble)	4.4 wt %	
			Na (Insoluble)	2.3 wt %	
			Na (soluble)	32.3 wt %	
			Solids	50 Vol. %	
			Insolubles	9 wt %	
			Fission Products	Tables 2.7-2.10	
			Actinides	Tables 2.7-2.10	
			Tritium	Tables 2.7-2.10	
			Sp G	1.14	
			Heat Content	Table 2.7-2.10	
Waste Blending (Tank Farm)	Supernate (FS-2-8)	Interarea Blend Tank	OH^-	0.7 M	1/80d
			Suspended Solids	1000 ppm (Vol.)	
			Na^+	4.6 M	
			I	10^{-6} M	
			NO_3^-	2.0 M	
			NO_2^-	1.0 M	
			AlO_2^-	0.5 M	
			CO_3^{2-}	0.25 M	
			SO_4^{2-}	0.30 M	

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
			$C_2O_4^{2-}$	0.003 M	
			Cl^-	0.02 M	
			F^-	0.002 M	
			Hg	10^{-3} M	
			Fission Products	Tables 2.3-2.6	
			Actinides	Tables 2.3-2.6	
			Tritium	Tables 2.3-2.6	
			Sp G	1.22	
			Heat Content	Table 2.3-2.6	
			^{137}Cs	2 x 10^9d/m/mL	
			Total Cesium	9 x 10^{-2} g/gal	
			^{90}Sr	3 x 10^7d/m/mL	
			Total Pu	3 x 10^{-9}g/gal	
			K	Trace	
			Rb	2.5 x 10^{-4}g/gal	
			Fe	Trace	
			Ni	Trace	
Al Dissolving	Sludge-Slurry Slurry (FS-4-23)	Sludge Receipt Tank	OH^-	0.3 g-moles/1 sludge	1/3d
			Al (insoluble)	0.5 g-mole/1 sludge	
	Dissolvent	Al Dissolver	Al (insoluble)	0.07 g mol/1-* sludge[a]	1/3d
Sludge Washing	Centrifuge Feed (FS-4-3, 10, 17)	Sludge Feed Tank	Water Content	60-80 wt %	1/d
			Dissolved Salt	15-30 wt %	
			Sludge	10-20 Vol. %	
	Washed Sludge Slurry (FS-4-23)	Washed Sludge Run Tank	Na^{+}[a]	0.1-10 wt %	1/d
			SO_4^{2-}[a]	0.1-5 wt %	
			NO_3^{-}[a]	0.1-10 wt %	
			Water Content	83 wt %	
			Dissolved Salt	0.4 wt %	
Spray Drying/ Vitrification	Spray Dryer Feed (FS-5-5)	Slurry Hold Tank (Accountability sample)	Solids	$\sim$17 wt % $\pm$ 1%	1/batch
			Fission Products	See Appendix 13.7	
			Actinides	See Appendix 13.7	
			Na	$\sim$1 wt %	
			Fe	20 w	
			Al	3.5 wt %	
			Ca	1.5 ey %	
			Mn	5.5 wt %	
			Ni	3.0 wt %	
			U	2.5 wt %	

---

*Prior to addition of GS Bottoms and Waste Filter Media.

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
			Si	1.0 wt %	
			C	1.0 wt %	
			Hg	3.0 wt %	
			I	0.4 wt %	
			Cl^-	0.74 wt %	
			F^-	0.06 wt %	
			Heat Content	See Appendix 13.7	
	Frit (Cold Feed) (FS-5-11)	Cold Feed	SiO_2	53 wt % ± 2%	1/batch
			Na_2O	19 wt % ± 2%	
			B_2O_3	10 wt % ± 2%	
			CaO	5 wt % ± 2%	
			Li_2O	4 wt % ± 2%	
			TiO_2	10 wt % ± 2%	
Off-Gas System	Condensate (FS-6-30)	Off-Gas Condensate Collection Tanks	Conductivity	10^3-10^4 µmho/cm	1/2 d
			pH	4-6	
			Dissolved Salts	< .01 wt %	
			Solids	0.8 wt %	
			Cl^-	Trace	
			F^-	5×10^{-4} wt %	
	Spray Dryer Off-Gas (FS-6-1)		Beta-gamma	10^3 µCi/ft^3	1/wk
	Inlet to PRA (FS-6- 16)	Stream FS-6-16	Beta-gamma	10 µCi/ft^3	1/wk
			^{106}Ru	6 µCi/ft^3	
			Total Ru	1 µg/ft^3	
	PRA Effluent (FS-6-17)	Stream FS-6-17	^{106}Ru	0.5 µCi/ft^3	1/wk
			Total Ru	0.01 µg/ft^3	
	Inlet to IA (FS-6-19)	Stream FS-6-19	^{129}I	0.06 µCi/ft^3	1/wk
			Total I	10^3 g/ft^3	
	IA Effluent (FS-6-20)	Stream FS-6-20	Total I	8 µg/ft^3	1/wk
			^{129}I	6×10^{-4} µCi/ft^3	
	Exhauster Effluent (FS-6-22)	Stream FS-6-22	Beta-gamma	0.05 µCi/ft^3	1/wk
			Hg	12 ppm	
	Vessel Vent-Filtered	FS-6-25	Beta-gamma	7×10^{-5} µCi/ft^3	1/wk
	Canyon Air-Unfiltered	FS-6-23	Beta-gamma	1.7×10^{-6} µCi/ft^3	1/wk
	Stack Effluent	FS-6-26 (Accountability)	Alpha	10^{-10} µCi/ft^3	1/d
			Beta-gamma	10^{-6} µCi/ft^3	
			Fission Products	See Appendix 13.7	
			Actinides	See Appendix 13.7	
			Tritium	See Appendix 13.7	

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
Recycle Evaporation	Evaporator Feed	RE Feed Tank	Total salts	7.0 wt %	1/d
			OH^-	0.8 M	
			Beta-gamma	6×10^8 d/m/mL	
			Sg G	1.03	
			Solids	0.08 wt %	
	Evaporator Bottoms (FS-7-11)	RE Bottoms Tank	Total Salts	35 wt %	1/d
			Solids	0.5 wt %	
			OH^-	5.0 M	
			Beta-gamma	4×10^9 d/m/mL	
			Sp G	1.17	
	Evaporator Condensate (FS-7-13)	RE Condensate Tank	pH	7-9	1/d
			Beta-gamma	10^3 d/m/mL	
Gravity Settling/ Filtration	GS Feed (FS-8-4)	GS Feed Tank	Centrifuged Solids	5000 ppm	3/d
			OH^-	1.7 M	
			^{90}Sr	10^8 d/m/mL	
			Total Pu	10^{-2} g/gal	
	Starch (FS-8-5)	Cold Feed	OH^-	1 M	1/d
			Viscosity	70 cp	
	GS Supernate (FS-8-8)	GS Supernate Tank	Centrifuged Solids	50 ppm	3/d
			OH^-	1.8 M ± 5%	
			^{90}Sr	10^7 d/m/mL	
			Total Pu	8.4×10^{-4} g/gal	
	Polyelectrolyte (FS-8-11)	Cold Feed	OH^-	1.0 M	1/d
			Viscosity	35 cp*	
	Sand Filter Filtrate (FS-8-13, 17)	1st and 2nd Filtrate Tanks	Solids	1-5 ppm	3/d
			OH^-	1.6 M + 5%	
			^{90}Sr	10^6 d/m/mL	
			Total Pu	10^{-4} g/gal	
			Si	<5 ppm	
	NaOH	Cold Feed	OH^-	1.0 M ± 5%	3/d
	Backwash Slurry	Filter Backwash Tank	Solids	1200 ppm	1/d
	Filter Media	Cold Feed	Particle Size	Anthracite, 20-50 mesh Sand, 25-60 mesh	1/3 mo

---

*Stock solution before dilution in 1.0 M OH^-

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
Cesium Ion Exchange	Column Feed (FS-9-2)	IE Feed Tank	^{137}Cs	10^9 d/m/mL	3/80 d
			Total Cs	7×10^{-2} g/gal	
			Total Pu	10^{-5} g/gal	
			Dissolved Salts	27 wt % ± 2%	
			Al	0.7 M ± 5%	
			Na	4.5 M ± 2%	1/wk
			K	Trace	2/mo
			OH^-	1.6 M	1/wk
			Rb	10^{-5} g/gal	2/mo
			Fission Products	See Appendix 13.7	
			Cl^-	Trace	3/80d
			^{90}Sr	3×10^6 d/m/mL	
	Column Effluent (FS-9-3)	Cs Elute Bounce Tank	^{137}Cs	2×10^5 d/m/mL	1/d
			K	Trace	2/mo
			Total Pu	2×10^{-7} g/gal	1/d
			Fission Products	See Appendix 13.7	1/2d
			Rb	Trace	2/mo
	Elutriant (FS-9-6)	Cs Elutriant Makeup Tank	NH_4OH	2 M	1/d
			$(NH_4)_2CO_3$	2 M	
			Alpha	10^2 d/m/mL	
			Beta-gamma	10^6 d/m/mL	
	Water Rinse (FS-9-4, 10)	Recycle Water Tank	pH	7-9	1/d
			Conductivity	10 µmho/cm	
			Alpha	<1 d/m/mL	
			Beta-gamma	<1 d/m/mL	
			^{137}Cs	<1 d/m/mL	
			Total Cesium	10^{-11} g/gal	
	Eluate (FS-9-9)	Cs Eluate Tank	^{137}Cs	2×10^9 d/m/mL	2/mo
			Total Pu	2.4×10^{-5} g/gal	
			Na	0.4M	2/mo
			Al	<0.01 M	1/wk
			NH_3	5 wt %	1/d
			Organic	0.1 wt %	1/wk
			K	Trace	2/mo
			Rb	10^{-19} g/l	2/mo
	Regenerant (Feed) (FS-9-14)	Cold Feed	OH^-	2 M + 5%	2/d
			Total Cesium	Trace	
	NaOH	Cold Feed	OH^-	19 M	1/batch
	Regenerant (Effluent) FS-9-15	Cs Regenerant Catch Tank	pH	10-14	2/d
			^{137}Cs	Trace	1/mo
			Conductivity	10^5 µmho/cm	2/d
			Total Pu	Trace	1/mo
			NH_3	0.8 wt %	1/d

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
	Fresh Resin	Cold Feed	Cesium Capacity	K_d = 50-200 (dry)	2/batch
			Particle Size	20-80 mesh	
			Moisture Retention	50%	
			Dynamic Test	*	
	Degraded Resin	Cs IX Columns	Moisture Retention	>50%	1/80d
			Al	<1%	
			Kd		
Strontium Ion Exchange	Column Feed (FS-10-1)	Sr Feed Bounce Tank or Cs Elute Bounce Tank	^{90}Sr	3×10^6 d/m/mL	1/wk
			Fe	Trace	2/mo
			Ni	Trace	
			Hg	Trace	
			EDTA	10^{-4} M	
	Column Effluent (FS-10-2)	Product Salt Hold Tank	Total Pu	1.8×10^{-7}	1/tankful
			^{90}Sr	3×10^3 d/m/mL	
			Fe	Trace	2/mo
			Ni	Trace	
			Hg	Trace	1/tankful
			Beta-gamma	10^8 d/m/mL	
			^{137}Cs	2×10^5 d/m/mL	
	Elutriant/ Regenerant	Cold Feed	EDTA	10^{-2} M ± 5%	1/batch
			OH^-	0.1 M ± 5%	
	Sr Concentrator Feed (FS-10-12)	Sr Eluate Tank	^{90}Sr	10^7 D/m/mL	2/d
			Dissolved Salts	0.25 wt %	1/d
			Sp G	0.99	
	Sr Concentrator Bottom (FS-10-13)	Sr Concentrator Bottom Tank	Dissolved Salts	20 wt %	1/d
			Sp G	1.1	
	Sr Concentrator Condensate (FS-10-15)	Sr Concentrator Condensate Tank	^{90}Sr	10^3 d/m/mL	1/d
			Beta-gamma	2×10^3 d/m/mL	
			EDTA	10^{-5} M	
	Resin (Fresh)	Cold Feed	Sr Capacity	K_D = 200	2/batch
			Particle Size	20 - 50 mesh	
			Moisture Retention	65%	
			Dynamic Test		4/batch
	Degraded Resin	Sr IX Column	Sr Capacity		1/4mo
	Water Rinse (FS-10-5, 10)	Recycle Water Tank	EDTA	10^{-5} M	1/d

---

*Lab test of resin performance with tracers. Cs DF $\geq 10^4$

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
Cesium Elutriant Recovery/ Cesium Concentration	Purge Condensate (FS-11-4)	PC Tank	^{137}Cs	3×10^7 d/m/mL	1/d
			pH	7	
			Beta-gamma	10^7 d/m/mL	
			NH_3	Trace	
	Downdraft Condenser Condensate (FS-11-5)	Cs Condensate Run Tank	^{137}Cs	2×10^3 d/m/mL	3/d
			NH_4^+	6 M	
			CO_3^{2-}	2 M	
			Beta-gamma	4×10^3 d/m/mL	
	Scrubber Vent	FS-11-22	NH_3	2 ppm	3/d
Cesium Fixation	Column Feed (FS-12-2)	Cs Concentrator Bottoms Tank	Dissolved Salts	18 wt %	1/d
			NH_4^+	10^{-4} M	
			CO_3^{2-}	2 M	
			^{137}Cs	3×10^{10} d/m/ml	
			Total Pu	3×10^{-4} g/gal	
			Na^+	4 M	
	Column Effluent (FS-12-3)	Zeolite Raffinate Bounce Tank	^{137}Cs	10^8 d/m/mL	1/d
			Total Pu	10^{-6} g/gal	
	Fresh Zeolite	Cold Feed	Particle Size	20-50 mesh	1/2 mo
			^{137}Cs Capacity		
	Zeolite Raffinate (FS-12-9)	Zeolite Raffinate Hold Tank	^{137}Cs	10^8 d/m/mL	1/d
General Purpose Evaporation	Evaporator Feed (FS-13-5)	GPE Feed Tank	Total Salts	<0.1 wt %	1/d
			pH	9-10	
			Beta-gamma	10^3 d/m/mL	
			Conductivity	100-200 µmho/cm	
			Sp G	1.0	
	Evaporator Bottoms (FS-13-6)	GPE Bottoms Tank	Total Salts	<0.1 wt %	1/d
			Sp G	1.03	
			Beta-gamma	10^4 d/m/mL	
	Evaporator Condensate (FS-13-8)	GPE Condensate Tanks (Accountability Sample)	pH	7-8	1/batch
			Alpha	< 1 d/m/mL	
			Beta-gamma	<10d/m/mL	
			Solids	<0.01 wt %	
			Dissolved Salts	Trace	
			Fission Products	See Appendix 13.7	
			Actinides	See Appendix 13.7	
			Tritium	See Appendix 13.7	
			Hg	<1 ppm	

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
Product Salt Solution Concentration/ Solidification in Concrete	Evaporator Feed	Product Salt Solution Storage Tank	Dissolved Salts	23 wt %	1/wk
			OH^-	1.4 M	
			Sp G	1.2	
			Fission Products	See Appendix 13.7	
			Actinides	See Appendix 13.7	
			Heat Content	See Appendix 13.7	
			Hg	10^{-4} M	
			Na	2.5 M	
			AlO_2^-	0.3 M	
			NO_3^-	1.3 M	
			NO_2^-	0.6 M	
			SO_4^{2-}	0.15 M	
			$C_2O_4^-$	0.002 M	
			F^-	0.001 M	
			Cl^-	0.01 M	
			Tritium	See Appendix 13.7	
	Evaporator Condensate (FS-14-3)	PSE Condensate Tank	Beta-Gamma	10^2 d/m/mL	2/wk
			pH	7-9	
Mechanical Cell A	Spent Cleaning Sol'n after HNO_3 and Mn adjustment	Digester Tank	H^+	1.0	1/run
			Mn^{2+}	0.01 M	
	Digested Oxalic acid (FS-15-17)	Digester Tank	H^+	0.4 M	1/run
	Blend of Spent Decon Solutions (FS-15-13, 17)	Neutralizer Tank	H^+	2.0 M	1/batch
	Neutralized Spent Decon Sol'n (FS-15-22)	Neutralizer Tank	OH^-	0.17 M	1/batch
	Deionizer Feed and Effluent (FS-15-28, 29)	FS-15-28, 29	Beta-gamma		2/wk
			Conductivity		
			Turbidity		
	Mechanical Cell A Spent Decon Wash (FS-15-32)	Spent Decon Sol'n Pump Tank	OH^-	0.10 M	1/batch
			Dissolved Salts	10 wt %	
			Solids	0.9 wt %	
	Canister Smears	Canister Surface	Alpha	10^2 d/m/dm^2	1/canister
			Beta-gamma	10^3 d/m/dm^2	

Table 6.2 (Contd)

Module	Process Stream	Sampling Location	Analyses	Approximate Concentration	Sample Frequency[a]
Mechanical Cell B	Etch Solution (FS-16-7)	Cold Feed	H^+ F^-	3.5 M 0.4 M	1/batch
	Cleaning Solution (FS-16-7)	Cold Feed	$H_2C_2O_4$	1.0 M	1/batch
	Scrub Solution	Scrubber Pump Tank	OH^-	2 M	1/day
	Canister Smears	Canister Surface	Alpha Beta-gamma	$<10d/m/dm^2$ $<100d/m/dm^2$	1/canister
Mechanical Cell C	Canister Smears	Canister Surface	Alpha Beta-gamma	$<10d/m/dm^2$ $<100d/m/dm^2$	1/canister
Interim Storage	Air Exhaust	Building Exhaust	Beta-gamma[c]	Trace	Daily

---

a. To avoid repetition, sample frequency is given only when it differs from that for the analysis described on the previous line.

b. Concentrations are on a dry basis.

c. Analysis of particulate air filter.

7. RADIONUCLIDE CONTENT, ACTIVITIES, AND HEAT GENERATION

(J. R. Chandler)

7.1 General

The radionuclide concentrations of each process stream must be known in order to specify biological shielding requirements, process cooling requirements, and environmental releases. The concentrations have been computed for each process stream of the reference flowsheet by using a computer model of the flowsheet.

7.2 Calculational Basis

The radionuclide calculations assume the following:

- Both SRP and non-SRP reactor fuels will be processed.
- Five SRP assemblies will be processed: Mark 16B, Mark 22, Mark 31A, Mark 31B, Mark 53A.
- Non-SRP reactor fuels (RBOF fuels) are two years old when processed. They have a plutonium content equal to 0.32% of their U-235 content. Non-SRP fuels have the same relative radionuclide composition as a Mark 16B assembly that has been irradiated 330 MWD, and the fission product activity at processing is 60 Ci/gallon. Liquid waste is generated at 808 gallons/kg of U-235 processed, and the fractions of isotopes lost to waste are the same as for the Mark 16B fuel.
- Pu-238 scrap will be processed. The plutonium distribution of the Pu-238 scrap is the same as the plutonium distribution in a Mark 53A. The Pu-238 waste generation factors are 0.17% plutonium lost to waste and 1500 gallons/kg of scrap processed.
- Pu-239 scrap will be processed. The plutonium distribution in Pu-239 scrap is the same as for a Mark 31A. The Pu-239 waste generation factors are 0.02% plutonium lost to waste and 475 gallons/kg of scrap processed.
- The waste generation rates are based on the average of production schedules for FY-1988, 1989, and 1990.

7.3 Reference Waste Composition

Radionuclide concentrations in spent SRP assemblies were determined with reactor production-depletion calculations [1]. Typical irradiation conditions (Table 7.1) were assumed. Radionuclide concentrations were calculated for SRP assemblies that have cooled 180 days following irradiation. Separation factors (Table 7.2) were applied to the radionuclide concentrations in cooled assemblies to determine the radionuclide concentrations in liquid waste. The radionuclide content of plutonium scrap and non-SRP fuels was based on the assumptions in Section 7.2.

The design basis waste blend is a blend of liquid wastes generated during reprocessing of the various spent fuels. The relative amount of each type of waste in a unit volume of waste blend is proportional to the volume of waste generated from each fuel assembly (Table 7.3). Waste blend factors in Table 7.3 are based on the estimated waste volumes for FY-1988, 1989, and 1990.

Tables 7.4 through 7.39 list the radionuclide concentrations in the reference waste blend and individual assembly wastes for five and fifteen-year ages. Results for activity, decay heat, and radiation source spectra are provided in Appendix 13.7.

7.4 Curie Balance

A computer model of the reference flowsheet was developed by using the SHIELD [1] system. The computer model simulates the flow of radionuclides through the DWPF. The activity, decay heat, and radiation source spectra of each process stream were calculated from the radionuclide concentrations (see Appendix 13.7).

7.5 References

1. D. R. Finch, J. R. Chandler and J. P. Church, "The SHIELD System, Transactions of The American Nuclear Society, Volume 32, American Nuclear Society, Lagrange Park, IL (November 1979).

TABLE 7.1

Calculational Bases (Beyond FY-1988)

	Mark 16B	Mark 22	Mark 31A	Mark 31B	Mark 53A
U-235 (kg/assy)	3.360	3.200	0.671	0.456	-
U-238 (kg/assy)	0.767	0.480	332.85	225.95	-
U-234 (kg/assy)	0.087	0.065	-	-	-
U-236 (kg/assy)	1.680	0.960	-	-	-
Power (MW/assy)	6.0	5.1	2.0-3.1*	2.0-3.1*	Varies
Fission Exposure (MWD/assy)	∿1188	∿1005	∿126	∿106	∿41**
Days Irradiated	198	197	55	44	
Days Cooled†	180	180	180	180	180
Liquid Waste/Assy (gal/assy)					
High-heat	330	220	27	18	
Low-heat	234	156	231	157	588
Total	564	376	258	175	588

---

* The power increases in Mark 31 assemblies during a subcycle.

** Time when 80% plutonium content is Pu-238.

† Elapsed time between the end of the assembly irradiation and processing of the assembly into its product and waste fractions.

TABLE 7.2

Fraction of Radioactivity in Spent SRP Fuel Lost to High-Level Waste During Fuel Reprocessing

	Percent Loss to Waste				
Element	Mark 16B	Mark 22	Mark 31A	Mark 31B	Mark 53A
Tritium	28	28	28	28	28
Noble Gases	0	0	0	0	0
Other F.P.	100	100	100	100	100
Uranium	0.15*	0.15*	0.02**	0.02**	100
Neptunium	3.5	3.5	6.0	6.0	0.10
Plutonium	100	100	0.22**	0.22**	0.17
Am, Cm, etc.	100	100	100	100	100

---

* Average of analyses on waste for calendar years 1976 and 1977. The majority of analyses were less than the minimum detectable concentration. Consequently, this fraction is conservative.

** Average of analyses on waste for calendar years 1976 and 1977.

TABLE 7.3

Volume Proportion of Wastes

Assembly	Fraction
Mark 16B	0.2153
Mark 22	0.1453
Mark 31A	0.2894
Mark 31B	0.0652
Mark 53A	0.0212
RBOF	0.2213
Pu-238 Scrap	0.0114
Pu-239 Scrap	0.0309

TABLE 7.4
ISOTOPIC CONTENT (g/gal) OF THE REFERENCE DWPF WASTE BLEND – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	4.26019E-07	PD104	8.64074E-04	XE132	2.35813E-20	GD155	1.30750E-04
HE 3	2.32451E-07	PD105	6.81407E-03	CS133	4.68765E-02	GD156	6.50450E-04
V 51	6.79024E-06	PD106	4.34656E-03	CS134	3.00427E-04	GD157	4.87881E-06
CR 51	1.14100E-25	PD107	2.09577E-03	CS135	5.83109E-03	GD158	1.58802E-04
CO 60	1.69776E-05	PD108	1.22695E-03	CS136	1.55437E-47	GD160	1.03774E-05
NI 60	1.58477E-05	PD110	4.18309E-04	CS137	4.14043E-02	TB159	2.31577E-05
GE 72	3.45245E-07	AG109	6.84910E-04	BA134	1.44157E-03	TB160	1.12366E-14
GE 73	1.19943E-06	AG110	3.17722E-07	BA136	1.50784E-04	DY160	7.13650E-07
GE 74	3.00133E-06	CD110	5.92157E-05	BA136M	1.36352E-54	DY161	3.90848E-06
GE 76	1.99902E-05	CD111	2.79572E-04	BA137	7.68151E-03	DY162	2.32828E-06
AS 75	6.90685E-06	CD112	1.92783E-04	BA137M	6.30852E-09	TL208	4.25099E-16
SE 77	3.71328E-05	CD113	1.31985E-05	BA138	5.06234E-02	PB208	1.08773E-10
SE 78	9.35315E-05	CD114	3.14496E-04	BA140	5.84158E-46	PB212	2.50770E-13
SE 79	2.30713E-04	CD115M	4.25722E-18	LA139	4.85938E-02	BI212	2.37837E-14
SE 80	5.49828E-04	CD116	1.45332E-04	LA140	8.81114E-47	PO216	1.00098E-18
SE 82	1.10977E-03	IN115	1.17909E-04	CE140	4.78970E-02	RN220	3.77900E-16
BR 81	9.33773E-04	IN115M	1.61756E-24	CE141	1.42920E-19	RA224	2.18837E-12
KR 82	3.98934E-44	SN116	2.78324E-05	CE142	4.50575E-02	TH228	4.26729E-10
RB 85	4.72724E-03	SN117	1.44149E-04	CE144	3.50521E-04	U232	2.69707E-08
RB 87	1.16053E-02	SN118	1.54881E-04	PR141	4.49054E-02	U234	8.31739E-05
SR 88	1.68277E-02	SN119	1.50422E-04	PR143	2.01776E-43	U235	2.79875E-03
SR 89	2.02530E-13	SN120	1.56054E-04	PR144	1.47905E-08	U236	2.02066E-03
SR 90	2.42201E-02	SN121M	6.27675E-08	PR144M	7.39509E-11	U238	9.73937E-02
Y 89	2.25271E-02	SN122	1.74399E-04	ND142	1.59533E-04	NP236	1.48004E-10
Y 90	6.30234E-06	SN123	3.66071E-09	ND143	5.36025E-02	NP237	1.41275E-03
Y 91	4.30688E-12	SN124	2.61283E-04	ND144	4.60641E-02	PU236	1.33328E-08
ZR 90	3.55724E-03	SN125	2.11143E-62	ND145	2.96341E-02	PU237	4.25334E-20
ZR 91	2.82557E-02	SN126	6.02840E-04	ND146	2.40488E-02	PU238	4.94366E-03
ZR 92	2.89983E-02	SB121	1.62128E-04	ND147	1.77932E-53	PU239	1.28858E-02
ZR 93	5.04046E-02	SB123	2.05150E-04	ND148	1.39110E-02	PU240	2.21561E-03
ZR 94	3.21979E-02	SB124	4.63770E-16	ND150	5.57380E-03	PU241	9.37535E-04
ZR 95	5.30919E-11	SB125	9.15235E-05	PM147	2.95350E-03	PU242	1.75532E-04
ZR 96	3.23190E-02	SB126	2.86732E-12	PM148	4.79556E-20	AM241	3.54677E-04
NB 95	6.13422E-11	SB126M	2.17922E-14	PM148M	5.34819E-18	AM242	1.98571E-12
NB 95M	3.71614E-14	TE122	2.46383E-06	SM147	9.51622E-03	AM242M	1.66087E-07
MO 95	3.29041E-02	TE124	1.14658E-06	SM148	2.10916E-03	AM243	3.24943E-06
MO 96	1.33560E-04	TE125	2.62288E-04	SM149	8.22754E-04	CM242	1.19022E-05
MO 97	3.14555E-02	TE125M	1.30006E-06	SM150	1.16680E-02	CM243	1.21035E-06
MO 98	3.17515E-02	TE126	1.14032E-05	SM151	1.04883E-03	CM244	2.26464E-07
MO100	3.45624E-02	TE127	3.87258E-12	SM152	4.21144E-03	CM245	4.34151E-09
TC 99	3.26185E-02	TE127M	1.10628E-09	SM154	7.47603E-04	CM246	1.94202E-10
RU100	2.96093E-04	TE128	3.11610E-03	EU151	4.38967E-05	CM247	7.90585E-13
RU101	2.92742E-02	TE129	1.24029E-23	EU152	2.35921E-06	CM248	1.80504E-14
RU102	2.47762E-02	TE129M	1.34220E-20	EU153	2.32324E-03	BK249	1.93382E-18
RU103	7.99150E-17	TE130	1.12822E-02	EU154	2.59742E-04	CF249	1.08567E-16
RU104	1.22329E-02	I127	1.29172E-03	EU155	1.15505E-04	CF250	1.60688E-17
RU106	1.00094E-04	I129	5.39474E-03	EU156	1.07532E-40	CF251	4.67546E-18
RH103	2.61748E-04	I131	7.72500E-72	GD152	3.66983E-07	CF252	3.49888E-19
RH103M	1.57114E-19	XE131	3.27580E-10	GD154	1.36112E-04	CF253	3.25972E-52
RH106	9.38730E-11						

TABLE 7.5
ISOTOPIC CONTENT (Ci/gal) OF THE REFERENCE DWPF WASTE BLEND – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	4.11819E-03	SB124	8.11850E-12	PM147	2.74033E 00	NP237	9.95629E-07
CR 51	1.05005E-20	SB125	9.59539E-02	PM148	7.88353E-15	PU236	7.08286E-06
CO 60	1.92656E-02	SB126	2.39799E-07	PM148M	1.14314E-13	PU237	5.13459E-16
SE 79	1.60901E-05	SB126M	1.71285E-06	SM147	2.16561E-10	PU238	8.46088E-02
RB 87	1.01639E-09	TE125M	2.34324E-02	SM148	6.37639E-16	PU239	8.00776E-04
SR 89	5.72018E-09	TE127	1.02289E-05	SM149	1.57650E-16	PU240	5.03760E-04
SR 90	3.42725E 00	TE127M	1.04430E-05	SM151	2.67326E-02	PU241	9.45889E-02
Y 90	3.42814E 00	TE129	2.58451E-16	EU152	4.27329E-04	PU242	6.69900E-07
Y 91	1.05567E-07	TE129M	4.07058E-16	EU154	7.01956E-02	AM241	1.21734E-03
ZR 93	2.04302E-04	I129	9.41621E-07	EU155	5.55674E-02	AM242	1.60576E-06
ZR 95	1.11519E-06	CS134	3.89351E-01	EU156	5.92438E-36	AM242M	1.61381E-06
NB 95	2.40446E-06	CS135	6.72295E-06	GD152	7.85563E-18	AM243	6.48493E-07
NB 95M	1.41628E-08	CS136	1.14876E-42	TB160	1.26854E-10	CM242	3.94138E-06
TC 99	5.52993E-04	CS137	3.59192E 00	TL208	1.25174E-07	CM243	6.24646E-07
RU103	2.56369E-12	BA136M	3.67602E-43	PB212	3.48357E-07	CM244	1.83173E-05
RU106	3.34438E-01	BA137M	3.39756E 00	BI212	3.48383E-07	CM245	7.47313E-10
RH103M	5.12641E-12	BA140	4.26284E-41	PO216	3.48543E-07	CM246	5.96514E-11
RH106	3.34438E-01	LA140	4.90578E-41	RN220	3.48543E-07	CM247	7.33300E-17
PD107	1.08103E-06	CE141	4.07131E-15	RA224	3.48543E-07	CM248	7.65768E-17
AG110	1.49791E-03	CE142	1.08177E-09	TH228	3.49748E-07	BK249	3.22863E-15
CD115M	1.08472E-13	CE144	1.11827E 00	U232	5.79569E-07	CF249	4.46101E-16
IN115	7.34195E-16	PR143	1.35759E-38	U234	5.19423E-07	CF250	1.75625E-15
IN115M	9.80365E-18	PR144	1.11831E 00	U235	6.04857E-09	CF251	7.41342E-18
SN121M	3.71442E-06	PR144M	1.34195E-02	U236	1.30703E-07	CF252	1.88103E-16
SN123	3.01474E-05	ND144	5.45281E-14	U238	3.27326E-08	CF253	9.43781E-48
SN126	1.71285E-06	ND147	1.43856E-48	NP236	1.54961E-12		

TOTAL ACTIVITY 2.04 01 Ci/gal

HEAT GENERATION, watts/gal
Primary 4.30 -02
Gamma 1.75 -02

TABLE 7.6
ISOTOPIC CONTENT (g/gal) OF THE REFERENCE
DWPF WASTE BLEND – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.42065E-07	RH103	2.61748E-04	I127	1.29152E-03	GD157	4.67881E-06
HE 3	4.16406E-07	RH103M	2.69654E-47	I129	5.39474E-03	GD158	1.58802E-04
V 51	6.79024E-06	RH106	5.83639E-14	XE131	3.27580E-10	GD160	1.03774E-05
CR 51	3.21021E-65	PD104	8.64074E-04	XE132	2.35813E-20	TB159	2.31577E-05
CU 60	4.54134E-06	PD105	6.81407E-03	CS133	4.68765E-02	TB160	6.96593E-30
NI 60	2.82831E-05	PD106	4.44654E-03	CS134	1.03856E-05	DY160	7.13650E-07
GE 72	3.45245E-07	PD107	2.09977E-03	CS135	5.83107E-03	DY161	3.90848E-06
GE 73	1.19943E-06	PD108	1.22655E-03	CS137	3.28879E-02	DY162	2.32826E-06
GE 74	3.00133E-06	PD110	4.18309E-04	BA134	1.73161E-03	TL208	9.08850E-16
GE 76	1.99902E-05	AG109	6.84970E-04	BA136	1.50764E-04	PB208	9.95923E-10
AS 75	6.90685E-06	AG110	1.37705E-11	BA137	1.61979E-02	PB212	5.36119E-13
SE 77	3.71328E-05	CD110	5.95324E-05	BA137M	5.01124E-09	BI212	5.08489E-14
SE 78	9.35315E-05	CD111	2.79572E-04	BA138	5.06274E-02	PO216	2.13913E-18
SE 79	2.30688E-04	CD112	1.92783E-04	LA139	4.85938E-02	RN220	8.07585E-16
SE 80	5.49828E-04	CD113	1.31985E-05	CE140	4.78570E-02	RA224	4.67662E-12
SE 82	1.10977E-03	CD114	3.14456E-04	CE141	2.26560E-53	TH228	9.08933E-10
BR 81	9.33773E-04	CD115M	9.46611E-43	CE142	4.50515E-02	U232	3.56764E-08
KR 82	3.98934E-44	CD116	1.45332E-04	CE144	4.77144E-08	U234	8.31716E-05
RB 85	4.72724E-03	IN115	1.17909E-04	PR141	4.49054E-02	U235	2.79875E-03
RB 87	1.16053E-02	IN115M	3.59672E-49	PR144	2.01323E-12	U236	2.02066E-03
SR 88	1.68277E-02	SN116	2.78324E-05	PR144M	1.00665E-14	U238	5.73937E-02
SR 89	1.45232E-34	SN117	1.44149E-04	ND142	1.59533E-04	NP236	1.47995E-10
SR 90	1.89256E-02	SN118	1.54881E-04	ND143	5.36025E-02	NP237	1.41274E-03
Y 89	2.25271E-02	SN119	1.50422E-04	ND144	4.64147E-02	PU236	1.17226E-05
Y 90	4.92463E-06	SN120	1.56054E-04	ND145	2.96341E-02	PU237	3.40803E-44
Y 91	7.43341E-31	SN121M	5.46372E-08	ND146	2.40468E-02	PU238	4.56819E-03
ZR 90	8.85301E-03	SN122	1.74399E-04	ND148	1.39110E-02	PU239	1.28821E-02
ZR 91	2.92557E-02	SN123	1.09784E-17	ND150	5.57380E-03	PU240	2.21326E-03
ZR 92	2.89983E-02	SN124	2.61283E-04	PM147	2.10253E-04	PU241	5.85064E-04
ZR 93	5.04042E-02	SN126	6.02836E-04	PM148	1.14379E-46	PU242	1.75530E-04
ZR 94	3.21979E-02	SB121	1.62135E-04	PM148M	1.27549E-44	AM241	6.98483E-04
ZR 95	8.68188E-28	SB123	2.05193E-04	SM147	1.22559E-02	AM242	1.89721E-12
ZR 96	3.23190E-02	SB124	2.52398E-34	SM148	2.10916E-03	AM242M	1.58683E-07
NB 95	1.00311E-27	SB125	7.22536E-06	SM149	8.22754E-04	AM243	3.24637E-06
NB 95M	6.07684E-31	SB126	2.86729E-12	SM150	1.16680E-02	CM242	3.84269E-10
MO 95	3.29041E-02	SB126M	2.17920E-14	SM151	9.73450E-04	CM243	9.49041E-05
MO 96	1.33560E-04	TE122	2.46383E-06	SM152	4.21144E-03	CM244	1.54445E-07
MO 97	3.14555E-02	TE124	1.14858E-06	SM154	7.47603E-04	CM245	4.33797E-05
MO 98	3.17515E-02	TE125	3.47783E-04	EU151	1.19275E-04	CM246	1.93917E-10
MO100	3.45624E-02	TE125M	1.02633E-07	EU152	1.38372E-06	CM247	7.90585E-13
TC 99	3.26175E-02	TE126	1.14074E-05	EU153	2.32324E-03	CM248	1.80504E-14
RU100	2.96093E-04	TE127	3.16811E-22	EU154	1.15949E-04	BK249	6.09242E-22
RU101	2.82742E-02	TE127M	5.04946E-20	EU155	2.72278E-05	CF249	1.08734E-16
RU102	2.47762E-02	TE128	3.11610E-03	GD152	3.66963E-07	CF250	9.45874E-18
RU103	1.37157E-44	TE129	1.49298E-56	GD154	2.79902E-04	CF251	4.63951E-18
RU104	1.22329E-02	TE129M	1.61564E-53	GD155	2.19027E-04	CF252	2.52801E-20
RU106	1.04883E-07	TE130	1.12822E-02	GD156	6.50450E-04		

TABLE 7.7
ISOTOPIC CONTENT (Ci/gal) OF THE REFERENCE
DWPF WASTE BLEND – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.33957E-03	SN126	1.71264E-06	SM147	2.78558E-10	PU236	6.22749E-07
CO 60	5.15334E-03	SB124	4.41834E-30	SM148	6.37639E-16	PU237	4.11414E-40
SE 79	1.60884E-05	SB125	7.57513E-03	SM149	1.57650E-16	PU238	7.81826E-02
RB 87	1.01639E-09	SB126	2.39797E-07	SM151	2.48114E-02	PU239	8.00545E-04
SR 89	4.10187E-30	SB126M	1.71284E-06	EU152	2.50636E-04	PU240	5.03227E-04
SR 90	2.67805E 00	TE125M	1.84988E-03	EU154	3.13355E-02	PU241	5.90277E-02
Y 90	2.67374E 00	TE127	8.36729E-16	EU155	1.30969E-02	PU242	6.69893E-07
Y 91	1.82202E-26	TE127M	8.54241E-16	GD152	7.85563E-18	AM241	2.39737E-03
ZR 93	2.04301E-04	TE129	3.11105E-49	TB160	7.86653E-26	AM242	1.53417E-06
ZR 95	1.82362E-23	TE129M	4.89988E-45	TL208	2.67619E-07	AM242M	1.54187E-06
NB 95	3.93193E-23	I129	5.41620E-07	PB212	7.44834E-07	AM243	6.47883E-07
NB 95M	2.31599E-25	CS134	1.34596E-02	BI212	7.44833E-07	CM242	1.27250E-06
TC 99	5.52975E-04	CS135	6.72293E-06	PO216	7.44848E-07	CM243	4.89787E-07
RU103	4.39488E-40	CS137	2.85310E 00	RN220	7.44848E-07	CM244	1.24921E-05
RU106	3.50439E-04	BA137M	2.69903E 00	RA224	7.44848E-07	CM245	7.46702E-10
RH103M	8.79840E-40	CE141	6.45350E-49	TH228	7.44962E-07	CM246	5.95641E-11
RH106	3.50439E-04	CE142	1.08177E-09	U232	7.66644E-07	CM247	7.33299E-17
PD107	1.08103E-06	CE144	1.52224E-04	U234	5.19408E-07	CM248	7.65765E-17
AG110	6.49212E-08	PR144	1.52229E-04	U235	6.04857E-09	BK249	1.01717E-18
CD115M	2.41191E-38	PR144M	1.82671E-06	U236	1.30703E-07	CF249	4.45146E-16
IN115	7.34195E-16	ND144	5.49430E-14	U238	3.27326E-08	CF250	1.03380E-15
IN115M	2.17989E-42	PM147	1.55052E-01	NP236	1.94949E-12	CF251	7.35642E-18
SN121M	3.23329E-06	PM148	1.88024E-41	NP237	5.95626E-07	CF252	1.35907E-17
SN123	9.04113E-14	PM148M	2.72628E-40				

TOTAL ACTIVITY 1.13 01 Ci/gal

HEAT GENERATION, watts/gal
Primary 2.37 -02
Gamma 9.99 -03

TABLE 7.8
ISOTOPIC CONTENT (g/assembly) OF A MARK 16B
FUEL ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.47125E-04	RH106	6.23782E-06	XE131	2.14981E-07	GD154	1.62445E-01
HE 3	1.45913E-04	PD104	5.03037E-01	XE132	1.52496E-17	GD155	8.67645E-02
V 51	7.34124E-03	PD105	5.18880E 00	CS133	4.26809E 01	GD156	5.78364E-01
CR 51	1.23359E-22	PD106	2.98399E 00	CS134	3.69554E-01	GD157	9.03857E-04
CO 60	1.83544E-02	PD107	1.19834E 00	CS135	4.97482E 00	GD158	1.07979E-01
NI 60	1.71328E-02	PD108	6.14540E-01	CS136	7.53274E-45	GD160	5.21368E-03
GE 72	2.33137E-04	PD110	2.13602E-01	CS137	3.83288E 01	TB159	1.27421E-02
GE 73	9.52072E-04	AG109	2.83570E-01	BA134	1.73123E 00	TB160	1.09468E-11
GE 74	2.55114E-03	AG110	3.00148E-04	BA136	1.21181E-01	DY160	7.06967E-04
GE 76	1.81883E-02	CD110	5.56179E-02	BA136M	6.60977E-52	DY161	1.30395E-03
AS 75	6.02024E-03	CD111	1.57658E-01	BA137	7.90823E 00	DY162	9.19086E-04
SE 77	3.39537E-02	CD112	1.14911E-01	BA137M	5.84000E-06	TL208	6.31212E-13
SE 78	8.56460E-02	CD113	2.06861E-03	BA138	4.71080E 01	PB208	1.44516E-07
SE 79	2.12387E-01	CD114	2.05647E-01	BA140	4.40520E-43	PB212	3.72360E-10
SE 80	5.11361E-01	CD115M	1.84516E-15	LA139	4.50570E 01	BI212	3.53155E-11
SE 82	1.03647E 00	CD116	5.84944E-02	LA140	6.64414E-44	PO216	1.48637E-15
BR 81	8.66867E-01	IN115	6.16389E-02	CE140	4.45458E 01	RN220	5.61153E-13
KR 82	3.44110E-41	IN115M	7.01082E-22	CE141	1.25780E-16	RA224	3.24956E-09
RB 85	4.46553E 00	SN116	2.86528E-02	CE142	4.19378E 01	TH228	6.33865E-07
RB 87	1.10355E 01	SN117	9.61687E-02	CE144	3.66226E-01	U232	4.15349E-05
SR 88	1.60027E 01	SN118	1.07912E-01	PR141	4.15670E 01	U234	1.05835E-01
SR 89	2.06277E-10	SN119	1.03207E-01	PR143	1.56908E-40	U235	2.82737E 00
SR 90	2.32048E 01	SN120	1.08121E-01	PR144	1.54531E-05	U236	2.81254E 00
Y 89	2.14466E 01	SN121M	5.02937E-05	PR144M	7.72642E-08	U238	1.10435E 00
Y 90	6.03811E-03	SN122	1.21555E-01	ND142	2.11755E-01	NP237	1.93946E 00
Y 91	4.41730E-09	SN123	2.63429E-06	ND143	5.15381E 01	PU236	2.17594E-09
ZR 90	3.26435E 00	SN124	1.92459E-01	ND144	4.51439E 01	PU238	7.08519E 00
ZR 91	2.68098E 01	SN125	7.68383E-60	ND145	2.72912E 01	PU239	1.58095E 01
ZR 92	2.74062E 01	SN126	4.72867E-01	ND146	2.28885E 01	PU240	3.17580E 00
ZR 93	3.79035E 01	SB121	1.12110E-01	ND147	1.29171E-50	PU241	1.30215E 00
ZR 94	3.02229E 01	SB123	1.45841E-01	ND148	1.27725E 01	PU242	2.55154E-01
ZR 95	5.32241E-08	SB124	4.98548E-13	ND150	4.94913E 00	AM241	3.53736E-01
ZR 96	3.01005E 01	SB125	6.76375E-02	PM147	2.47603E 00	AM242	1.84354E-09
NB 95	6.14954E-08	SB126	2.24912E-09	PM148	5.24169E-17	AM242M	1.54194E-04
NB 95M	3.72541E-11	SB126M	1.70938E-11	PM148M	5.84528E-15	AM243	8.42214E-03
MO 95	3.06633E 01	TE122	2.63866E-03	SM147	7.37383E 00	CM242	1.28017E-06
MO 96	1.71165E-01	TE124	1.22531E-03	SM148	2.51137E 00	CM243	1.56304E-05
MO 97	2.91080E 01	TE125	1.87640E-01	SM149	4.52717E-01	CM244	5.87070E-04
MO 98	2.93191E 01	TE125M	9.60765E-04	SM150	1.17684E 01	CM245	1.12333E-05
MO100	3.17857E 01	TE126	9.02907E-03	SM151	5.10331E-01	CM246	5.02816E-07
TC 99	2.99326E 01	TE127	3.19033E-09	SM152	3.85170E 00	CM247	2.04227E-09
RU100	3.76417E-01	TE127M	9.11292E-07	SM154	6.05153E-01	CM248	4.65408E-11
RU101	2.57133E 01	TE128	2.67286E 00	EU151	1.56459E-02	BK249	5.06532E-15
RU102	2.23489E 01	TE129	9.25751E-21	EU152	1.64809E-03	CF249	2.85422E-13
RU103	6.23528E-14	TE129M	1.00182E-17	EU153	2.26188E 00	CF250	4.20939E-14
RU104	1.01482E 01	TE130	1.00461E 01	EU154	3.14912E-01	CF251	1.22478E-14
RU106	6.65124E-02	I127	1.03573E 00	EU155	8.15482E-02	CF252	9.16571E-16
RH103	2.04227E-01	I129	4.65304E 00	EU156	7.04902E-38	CF253	8.53918E-49
RH103M	1.22587E-16	I131	5.06570E-69	GD152	4.31826E-04		

TABLE 7.9
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 16B
FUEL ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.35555E 00	SB124	8.72728E-09	ND147	1.04463E-45	U238	3.71157E-07
CR 51	1.13525E-17	SB125	7.09119E 01	PM147	2.29702E 03	NP237	1.36683E-03
CO 60	2.08279E 01	SB126	1.88098E-04	PM148	8.61667E-12	PU236	1.15594E-02
SE 79	1.48121E-02	SB126M	1.34356E-03	PM148M	1.24936E-10	PU238	1.21260E 02
RB 87	9.66485E-07	TE125M	1.73170E 01	SM147	1.67801E-07	PU239	9.82467E-01
SR 89	5.82602E-06	TE127	8.42596E-03	SM148	7.59232E-13	PU240	7.22079E-01
SR 90	3.28358E 03	TE127M	8.60230E-03	SM149	1.08756E-13	PU241	1.31375E 02
Y 90	3.28443E 03	TE129	1.92907E-13	SM151	1.30073E 01	PU242	9.73771E-04
Y 91	1.08274E-04	TE129M	3.03828E-13	EU152	2.98521E-01	AM241	1.21411E 00
ZR 93	1.53632E-01	I129	8.12160E-04	EU154	8.51054E 01	AM242	1.49078E-03
ZR 95	1.11797E-03	CS134	4.78938E 02	EU155	3.92306E 01	AM242M	1.49825E-03
NB 95	2.41046E-03	CS135	5.73574E-03	EU156	3.88360E-33	AM243	1.68082E-03
NB 95M	1.41981E-05	CS136	5.56708E-40	GD152	5.24413E-15	CM242	4.23925E-03
TC 99	5.08106E-01	CS137	3.32494E 03	TB160	1.23621E-07	CM243	8.06664E-04
RU103	1.39755E-09	BA136M	1.78146E-40	TL208	1.85866E-04	CM244	4.74845E-02
RU106	2.22234E 02	BA137M	3.14539E 03	PB212	5.17323E-04	CM245	1.93361E-06
RH103M	3.79962E-09	BA140	3.21443E-38	BI212	5.17300E-04	CM246	1.54446E-07
RH106	2.22234E 02	LA140	3.69925E-38	PO216	5.17559E-04	CM247	1.89429E-13
PD107	6.16947E-04	CE141	3.58305E-12	RN220	5.17560E-04	CM248	1.97443E-13
AG110	1.41505E 00	CE142	1.00687E-06	RA224	5.17560E-04	BK249	8.45689E-12
CD115M	4.70136E-11	CE144	1.16838E 03	TH228	5.19516E-04	CF249	1.16849E-12
IN115	3.83912E-13	PR143	1.05571E-35	U232	8.92538E-04	CF250	4.60066E-12
IN115M	4.24908E-15	PR144	1.16842E 03	U234	6.60945E-04	CF251	1.94202E-14
SN121M	2.97625E-03	PR144M	1.40207E 01	U235	6.11043E-06	CF252	4.92754E-13
SN123	2.16945E-02	ND144	5.34387E-11	U236	1.81925E-04	CF253	2.47233E-44
SN126	1.34356E-03						

TOTAL ACTIVITY	1.91 04 Ci/assy	HEAT GENERATION, watts/assy	
		Primary	4.23 01
		Gamma	1.74 01

TABLE 7.10
ISOTOPIC CONTENT (g/assembly) OF A MARK 16B
FUEL ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.97237E-04	RH103	2.04227E-01	TE130	1.00461E 01	GD155	1.49088E-01
HE 3	2.95801E-04	RH103M	2.10395E-44	I127	1.03573E 00	GD156	5.78364E-01
V 51	7.34124E-03	RH106	6.53627E-11	I129	4.65304E 00	GD157	9.03857E-04
CR 51	3.47072E-62	PD104	5.03037E-01	XE131	2.14981E-07	GD158	1.07979E-01
CO 60	4.90960E-03	PD105	5.18880E 00	XE132	1.52456E-17	GD160	5.21368E-03
NI 60	1.05767E-02	PD106	3.05043E 00	CS133	4.26809E 01	TB159	1.27421E-02
GE 72	2.33137E-04	PD107	1.19834E 00	CS134	1.27752E-02	TB160	6.78623E-27
GE 73	9.52072E-04	PD108	6.14540E-01	CS135	4.57482E 00	DY160	7.06967E-04
GE 74	2.55114E-03	PD110	2.13602E-01	CS137	3.04434E 01	DY161	1.30395E-03
GE 76	1.81983E-02	AG109	2.83570E-01	BA134	2.08800E 00	DY162	5.19084E-04
AS 75	6.02024E-03	AG110	1.30088E-08	BA136	1.21161E-01	TL208	1.42267E-12
SE 77	3.39587E-02	CD110	5.59171E-02	BA137	1.57916E 01	PB208	1.51805E-06
SE 78	8.56460E-02	CD111	1.57658E-01	BA137M	4.63876E-06	PB212	8.39214E-10
SE 79	2.12365E-01	CD112	1.14911E-01	BA138	4.71080E 01	BI212	7.95961E-11
SE 80	5.11361E-01	CD113	2.06861E-03	LA139	4.50570E 01	PO216	3.34849E-15
SE 82	1.03647E 00	CD114	2.05647E-01	CE140	4.45458E 01	RN220	1.26416E-12
BR 81	8.66867E-01	CD115M	4.10279E-40	CE141	1.59389E-50	RA224	7.32058E-09
KR 92	3.44110E-41	CD116	5.84944E-02	CE142	4.19378E 01	TH228	1.42282E-06
RB 85	4.46553E 00	IN115	6.16389E-02	CE144	4.58521E-05	U232	5.59715E-05
RB 87	1.10355E 01	IN115M	1.55889E-46	PR141	4.15670E 01	U234	1.05833E-01
SR 88	1.60027E 01	SN116	2.86928E-02	PR144	2.10354E-09	U235	2.82737E 00
SR 89	1.47919E-31	SN117	9.61687E-02	PR144M	1.05175E-11	U236	2.81254E 00
SR 90	1.81322E 01	SN118	1.07912E-01	ND142	2.11755E-01	U236	1.10435E 00
Y 89	2.14466E 01	SN119	1.03207E-01	ND143	5.15361E 01	NP237	1.93946E 00
Y 90	4.71820E-03	SN120	1.08121E-01	ND144	4.55100E 01	PU236	1.91316E-06
Y 91	7.62394E-28	SN121M	4.37789E-05	ND145	2.72912E 01	PU238	6.54705E 00
ZR 90	8.33815E 00	SN122	1.21555E-01	ND146	2.28885E 01	PU239	1.58049E 01
ZR 91	2.68058E 01	SN123	7.90018E-15	ND148	1.27745E 01	PU240	3.17244E 00
ZR 92	2.74062E 01	SN124	1.92459E-01	ND150	4.94913E 00	PU241	8.12597E-01
ZR 93	3.79032E 01	SN126	4.72862E-01	PM147	1.76240E-01	PU242	2.55152E-01
ZR 94	3.02229E 01	SB121	1.12117E-01	PM148	1.25010E-43	AM241	8.33455E-01
ZR 95	8.70356E-25	SB123	1.45843E-01	PM148M	1.39404E-41	AM242	1.76135E-09
ZR 96	3.01005E 01	SB124	2.71325E-31	SM147	9.67345E 00	AM242M	1.47321E-04
NB 95	1.00561E-24	SB125	5.33967E-03	SM148	2.51137E 00	AM243	8.41423E-03
NB 95M	6.09202E-28	SB126	2.24910E-09	SM149	4.52717E-01	CM242	3.56754E-07
MO 95	3.06633E 01	SB126M	1.70936E-11	SM150	1.17664E 01	CM243	1.22559E-05
MO 96	1.71165E-01	TE122	2.63866E-03	SM151	4.73655E-01	CM244	4.00372E-04
MO 97	2.91080E 01	TE124	1.22531E-03	SM152	3.85110E 00	CM245	1.12241E-05
MO 99	2.93191E 01	TE125	2.50822E-01	SM154	6.05153E-01	CM246	5.02080E-07
MO100	3.17857E 01	TE125M	7.58481E-05	EU151	5.63263E-02	CM247	2.04227E-09
TC 99	2.99816E 01	TE126	9.03233E-03	EU152	5.66632E-04	CM248	4.65406E-11
RU100	3.76417E-01	TE127	2.60970E-19	EU153	2.26188E 00	BK249	1.59581E-18
RU101	2.57133E 01	TE127M	7.45440E-17	EU154	1.40577E-01	CF249	2.84811E-13
RU102	2.23489E 01	TE128	2.67286E 00	EU155	1.92229E-02	CF250	2.47781E-14
RU103	1.07016E-41	TE129	1.11436E-53	GD152	4.31826E-04	CF251	1.21536E-14
RU104	1.01482E 01	TE129M	1.20592E-50	GD154	3.36778E-01	CF252	6.62237E-17
RU106	6.96945E-05						

TABLE 7.11
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 16B
FUEL ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.90663E 00	SN123	6.50611E-11	PM148	2.05459E-38	NP237	1.36682E-03
CO 60	5.57124E 00	SN126	1.34355E-03	PM148M	2.97966E-37	PU236	1.01634E-03
SE 79	1.48105E-02	SB124	4.74966E-27	SM147	2.20138E-07	PU238	1.12050E 02
RB 87	9.66485E-07	SB125	5.59818E 00	SM148	7.59232E-13	PU239	9.82184E-01
SR 89	4.17776E-27	SB126	1.88057E-04	SM149	1.08756E-13	PU240	7.21315E-01
SR 90	2.56578E 03	SB126M	1.34355E-03	SM151	1.20725E 01	PU241	8.19838E 01
Y 90	2.56645E 03	TE125M	1.36710E 00	EU152	1.75088E-01	PU242	9.73759E-04
Y 91	1.86873E-23	TE127	6.89246E-13	EU154	3.79912E 01	AM241	2.86064E 00
ZR 93	1.53631E-01	TE127M	7.03672E-13	EU155	9.24780E 00	AM242	1.42432E-03
ZR 95	1.82817E-20	TE129	2.32209E-46	GD152	9.24413E-15	AM242M	1.43146E-03
NB 95	3.94174E-20	TE129M	3.65727E-46	TB160	7.66362E-23	AM243	1.67924E-03
NB 95M	2.32176E-22	I129	8.12159E-04	TL208	4.18918E-04	CM242	1.18138E-03
TC 99	5.08289E-01	CS134	1.65566E 01	PB212	1.16553E-03	CM243	6.32508E-04
RU103	3.42906E-37	CS135	5.73572E-03	BI212	1.16553E-03	CM244	3.23836E-02
RU106	2.32866E-01	CS137	2.64103E 03	PO216	1.16555E-03	CM245	1.93203E-06
RH103M	6.86486E-37	BA137M	2.49842E 03	RN220	1.16555E-03	CM246	1.54220E-07
RH106	2.32867E-01	CE141	5.67951E-46	RA224	1.16555E-03	CM247	1.89429E-13
PD107	6.16946E-04	CE142	1.00687E-06	TH228	1.16615E-03	CM248	1.97442E-13
AG110	6.13302E-05	CE144	1.59044E-01	U232	1.20276E-03	BK249	2.66431E-15
CD115M	1.04537E-35	PR144	1.59050E-01	U234	6.60927E-04	CF249	1.16599E-12
IN115	3.83812E-13	PR144M	1.90856E-03	U235	6.11043E-06	CF250	2.70814E-12
IN115M	9.44802E-40	ND144	5.38722E-11	U236	1.81924E-04	CF251	1.92709E-14
SN121M	2.59073E-03	PM147	1.63458E 02	U238	3.71157E-07	CF252	3.56024E-14

TOTAL ACTIVITY 1.07 04 Ci/assy
HEAT GENERATION, watts/assy
Primary 2.39 01
Gamma 9.36 00

TABLE 7.12
ISOTOPIC CONTENT (g/assembly) OF A MARK 22 ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.93815E-04	RH106	5.44518E-08	I131	4.31952E-69	EU156	5.93123E-36
HE 3	1.23504E-04	PD104	1.54543E 00	XE131	1.83169E-07	GD152	3.95244E-04
V 51	4.44962E-03	PD105	4.55923E 00	XE132	1.29532E-17	GD154	1.50729E-01
CR 51	7.47699E-23	PD106	2.58601E 00	CS133	3.74358E 01	GD155	8.49207E-02
CO 60	1.11256E-02	PD107	1.05413E 00	CS134	3.56049E-01	GD156	5.01326E-01
NI 60	1.03851E-02	PD108	5.38737E-01	CS135	5.08438E 00	GD157	8.70097E-04
GE 72	2.17811E-04	PD110	1.85587E-01	CS136	7.13617E-45	GD158	9.45481E-02
GE 73	8.87407E-04	AG109	2.45935E-01	CS137	3.37736E 01	GD160	4.62456E-03
GE 74	2.35901E-03	AG110	2.90866E-04	BA134	1.67258E 00	TB159	1.12894E-02
GE 76	1.64387E-02	CD110	5.42639E-02	BA136	1.11714E-01	TB160	1.07740E-11
AS 75	5.46009E-03	CD111	1.40140E-01	BA136M	6.26179E-52	DY160	7.05377E-04
SE 77	3.06616E-02	CD112	1.03414E-01	BA137	5.50836E 00	DY161	1.15977E-03
SE 78	7.72167E-02	CD113	2.15073E-03	BA137M	5.14620E-06	DY162	7.90109E-04
SE 79	1.88195E-01	CD114	1.85380E-01	BA138	4.15064E 01	TL208	3.12517E-13
SE 80	4.52518E-01	CD115M	1.61951E-15	BA140	3.75357E-43	PB208	7.21739E-06
SE 82	9.13960E-01	CD116	8.94893E-02	LA139	3.57260E 01	PB212	1.84358E-10
BR 81	7.65163E-01	IN115	5.38401E-02	LA140	5.66130E-44	BI212	1.74849E-11
KR 82	3.13463E-41	IN115M	6.15345E-22	CE140	3.92389E 01	PO216	7.35914E-16
RB 85	3.94019E 00	SN116	2.80514E-02	CE141	1.07806E-16	RN220	2.77829E-13
RB 87	9.72928E 00	SN117	8.70731E-02	CE142	3.69384E 01	RA224	1.60887E-09
SR 88	1.41184E 01	SN118	5.77493E-02	CE144	3.20763E-01	TH228	3.13825E-07
SR 89	1.77553E-10	SN119	9.36124E-02	PR141	3.66849E 01	U232	2.05328E-05
SR 90	2.04504E 01	SN120	9.79969E-02	PR143	1.33860E-40	U234	7.71155E-02
Y 89	1.89077E 01	SN121M	4.53310E-05	PR144	1.35347E-05	U235	2.83326E 00
Y 90	5.32142E-03	SN122	1.10061E-01	PR144M	6.76725E-08	U236	1.72995E 00
Y 91	3.80753E-09	SN123	2.34331E-06	ND142	1.82830E-01	U238	6.83473E-01
ZR 90	2.88564E 00	SN124	1.73771E-01	ND143	3.69591E 01	NP236	3.82997E-07
ZR 91	2.36327E 01	SN125	6.56024E-60	ND144	3.87252E 01	NP237	1.45100E 00
ZR 92	2.41649E 01	SN126	4.24557E-01	ND145	2.39953E 01	PU236	1.07564E-05
ZR 93	5.18810E 01	SB121	1.01075E-01	ND146	1.93052E 01	PU237	1.10066E-16
ZR 94	2.66422E 01	SB123	1.31788E-01	ND147	1.10038E-50	PU238	5.61043E 00
ZR 95	4.59453E-08	SB124	4.95120E-13	ND148	1.12664E 01	PU239	1.27884E 01
ZR 96	2.65309E 01	SB125	6.07161E-02	ND150	4.36312E 00	PU240	2.31312E 00
NB 95	5.30850E-08	SB126	2.02143E-09	PM147	2.09935E 00	PU241	1.10576E 00
NB 95M	3.21591E-11	SB126M	1.53633E-11	PM148	4.94459E-17	PU242	2.00201E-01
MO 95	2.70191E 01	TE122	2.65881E-03	PM148M	5.51354E-15	AM241	3.00972E-01
MO 96	1.66398E-01	TE124	1.24152E-03	SM147	6.26752E 00	AM242	1.69227E-09
MO 97	2.56643E 01	TE125	1.68946E-01	SM148	2.28954E 00	AM242M	1.41542E-04
MO 98	2.58589E 01	TE125M	8.62450E-04	SM149	4.21347E-01	AM243	7.49903E-05
MO100	2.80152E 01	TE126	8.01984E-03	SM150	1.06648E 01	CM242	1.10274E-06
TC 99	2.64213E 01	TE127	2.81264E-09	SM151	4.98912E-01	CM243	1.42457E-05
RU100	3.19915E-01	TE127M	8.03409E-07	SM152	3.24242E 00	CM244	5.88304E-06
RU101	2.26531E 01	TE128	2.38520E 00	SM154	5.32970E-01	CM245	1.36821E-07
RU102	1.97641E 01	TE129	7.57010E-21	EU151	1.92358E-02	CM246	5.83114E-09
RU103	5.33817E-14	TE129M	8.62496E-18	EU152	1.48257E-03	CM247	2.83859E-11
RU104	8.95785E 00	TE130	8.89542E 00	EU153	2.05031E 00	CM248	7.35239E-13
RU106	5.80605E-02	I127	9.27379E-01	EU154	2.91760E-01	BK249	4.99911E-19
RH103	1.74843E-01	I129	4.13756E 00	EU155	7.97488E-02	CF249	2.74509E-17
RH103M	1.04949E-16						

TABLE 7.13
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 22
ASSEMBLY – 5 YEARS

```
ISOTOPE   CONCENTRATION    ISOTOPE   CONCENTRATION    ISOTOPE   CONCENTRATION    ISOTOPE   CONCENTRATION
-------   -------------    -------   -------------    -------   -------------    -------   -------------
 H  3      2.84022E 00     SN126      1.20754E-03     ND144      4.58407E-11      U236      1.11859E-04
CR 51      6.88094E-18     SB124      8.66726E-09     ND147      8.89856E-46      U238      2.29706E-07
CO 60      1.26249E 01     SB125      6.36554E 01     PM147      1.94757E 03     NP236      5.04510E-09
SE 79      1.31248E-02     SB126      1.69056E-04     PM148      8.12827E-12     NP237      1.02259E-03
RB 87      8.52090E-07     SB126M     1.20754E-03     PM148M     1.17857E-10     PU236      5.71419E-03
SR 89      5.01474E-06     TE125M     1.55449E 01     SM147      1.42639E-07     PU237      1.32870E-12
SR 90      2.89382E 03     TE127      7.42845E-03     SM148      6.92169E-13     PU238      9.60202E 01
 Y 90      2.89457E 03     TE127M     7.58392E-03     SM149      1.01219E-13     PU239      7.94724E-01
 Y 91      9.33274E-05     TE129      1.66080E-13     SM151      1.27163E 01     PU240      5.25932E-01
ZR 93      2.10286E-01     TE129M     2.61575E-13     EU152      2.68541E-01     PU241      1.11561E 02
ZR 95      9.65073E-04      I129      7.22256E-04     EU154      7.88529E 01     PU242      7.64045E-04
NB 95      2.08080E-03     CS134      4.61436E 02     EU155      3.83660E 01     AM241      1.03301E 00
NB 95M     1.22564E-05     CS135      5.86203E-03     EU156      3.26776E-33     AM242      1.36846E-03
TC 99      4.47929E-01     CS136      5.27359E-40     GD152      8.46104E-15     AM242M     1.37532E-03
RU103      1.71049E-09     CS137      2.92993E 03     TB160      1.21670E-07     AM243      1.49659E-05
RU106      1.93995E 02     BA136M     1.68768E-40     TL208      9.20230E-05     CM242      3.65171E-03
RH103M     3.42434E-09     BA137M     2.77171E 03     PB212      2.56129E-04     CM243      7.35201E-04
RH106      1.93995E 02     BA140      2.73894E-38     BI212      2.56118E-04     CM244      4.75843E-04
PD107      5.42703E-04     LA140      3.15204E-38     PO216      2.56246E-04     CM245      2.35512E-08
AG110      1.37129E 00     CE141      3.07101E-12     RN220      2.56246E-04     CM246      1.79111E-09
CD115M     4.12641E-11     CE142      8.86839E-07     RA224      2.56246E-04     CM247      2.63290E-15
IN115      3.35251E-13     CE144      1.02333E 03     TH228      2.57211E-04     CM248      3.11915E-15
IN115M     3.72945E-15     PR143      9.00632E-36      U232      4.41225E-04     BK249      8.34633E-16
SN121M     2.68257E-03     PR144      1.02337E 03      U234      4.81568E-04     CF249      1.12382E-16
SN123      1.92981E-02     PR144M     1.22802E 01      U235      6.12316E-06
```

TOTAL ACTIVITY 1.68 04 Ci/assy

HEAT GENERATION, watts/assy
Primary 3.69 01
Gamma 1.57 01

TABLE 7.14
ISOTOPIC CONTENT (g/assembly) OF A MARK 22 ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.66946E-04	RU106	6.08384E-05	TE129M	1.03821E-50	GD154	3.12258E-01
HE 3	2.50373E-04	RH103	1.74843E-01	TE130	8.89542E 00	GD155	1.45871E-01
V 51	4.44962E-03	RH103M	1.80123E-44	I127	9.27079E-01	GD156	5.01326E-01
CR 51	2.10366E-62	RH106	5.70570E-11	I129	4.13756E 00	GD157	8.70097E-04
CO 60	2.97598E-03	PD104	1.54543E 00	XE131	1.83189E-07	GD158	9.45481E-02
NI 60	1.85342E-02	PD105	4.55923E 00	XE132	1.29532E-17	GD160	4.62458E-03
GE 72	2.17811E-04	PD106	2.64401E 00	CS133	3.74358E 01	TB159	1.12894E-02
GE 73	8.87407E-04	PD107	1.05413E 00	CS134	1.23084E-02	TB160	6.67913E-27
GE 74	2.35901E-03	PD108	5.38737E-01	CS135	5.08438E 00	DY160	7.05377E-04
GE 76	1.64387E-02	PD110	1.89587E-01	CS137	2.68266E 01	DY161	1.15977E-03
AS 75	5.46009E-03	AG109	2.45935E-01	BA134	2.01632E 00	DY162	7.90109E-04
SE 77	3.06616E-02	AG110	1.26065E-08	BA136	1.11714E-01	TL208	7.03304E-13
SE 78	7.72167E-02	CD110	5.45538E-02	BA137	1.24551E 01	PB208	7.51329E-07
SE 79	1.88174E-01	CD111	1.40140E-01	BA137M	4.08787E-06	PB212	4.14869E-10
SE 80	4.52518E-01	CD112	1.03414E-01	BA138	4.15084E 01	BI212	3.93488E-11
SE 82	9.13960E-01	CD113	2.15073E-03	LA139	3.57280E 01	PO216	1.65534E-15
BR 81	7.65163E-01	CD114	1.85380E-01	CE140	3.92389E 01	RN220	6.24939E-13
KR 82	3.13463E-41	CD115M	3.60103E-40	CE141	1.70855E-50	RA224	3.61895E-05
RB 85	3.94019E 00	CD116	8.94893E-02	CE142	3.69384E 01	TH228	7.03377E-07
RB 87	9.72928E 00	IN115	5.38401E-02	CE144	4.36633E-05	U232	2.76692E-05
SR 88	1.41184E 01	IN115M	1.36824E-46	PR141	3.66849E 01	U234	7.71133E-02
SR 89	1.27321E-31	SN116	2.80514E-02	PR144	1.84240E-09	U235	2.83326E 00
SR 90	1.59799E 01	SN117	8.70731E-02	PR144M	9.21184E-12	U236	1.72955E 00
Y 89	1.89077E 01	SN118	5.77493E-02	ND142	1.82830E-01	U238	6.83473E-01
Y 90	4.15813E-03	SN119	9.36124E-02	ND143	3.69551E 01	NP236	3.82974E-07
Y 91	6.57155E-28	SN120	5.79969E-02	ND144	3.90459E 01	NP237	1.45099E 00
ZR 90	7.35716E 00	SN121M	3.54590E-05	ND145	2.39953E 01	PU236	9.45740E-07
ZR 91	2.36327E 01	SN122	1.10061E-01	ND146	1.93052E 01	PU237	8.81914E-41
ZR 92	2.41649E 01	SN123	7.02752E-15	ND148	1.12684E 01	PU238	5.18430E 00
ZR 93	5.18805E 01	SN124	1.73771E-01	ND150	4.36312E 00	PU239	1.27847E 01
ZR 94	2.66422E 01	SN126	4.24994E-01	PM147	1.49428E-01	PU240	2.31068E 00
ZR 95	7.51325E-25	SB121	1.01081E-01	PM148	1.17924E-43	PU241	6.90041E-01
ZR 96	2.65309E 01	SB123	1.31790E-01	PM148M	1.31502E-41	PU242	2.00158E-01
NB 95	8.68081E-25	SB124	2.69459E-31	SM147	8.21784E 00	AM241	7.08335E-01
NB 95M	5.25886E-28	SB125	4.79327E-03	SM148	2.28954E 00	AM242	1.61683E-05
MO 95	2.70191E 01	SB126	2.02142E-09	SM149	4.21347E-01	AM242M	1.35232E-04
MO 96	1.66398E-01	SB126M	1.53632E-11	SM150	1.06648E 01	AM243	7.49197E-05
MO 97	2.56643E 01	TE122	2.69881E-03	SM151	4.63058E-01	CM242	3.27481E-07
MO 98	2.58589E 01	TE124	1.24152E-03	SM152	3.24242E 00	CM243	1.11701E-05
MO100	2.80152E 01	TE125	2.25683E-01	SM154	5.32970E-01	CM244	4.01213E-06
TC 99	2.64204E 01	TE125M	6.80865E-05	EU151	5.50957E-02	CM245	1.36709E-07
RU100	3.19915E-01	TE126	8.02279E-03	EU152	8.69553E-04	CM246	5.82259E-09
RU101	2.26531E 01	TE127	2.30015E-19	EU153	2.05031E 00	CM247	2.83858E-11
RU102	1.97641E 01	TE127M	6.57191E-17	EU154	1.30251E-01	CM248	7.35222E-13
RU103	9.16184E-42	TE128	2.38520E 00	EU155	1.87952E-02	BK249	1.57495E-22
RU104	8.95785E 00	TE129	9.59384E-54	GD152	3.95244E-04	CF249	2.74047E-17

TABLE 7.15
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 22
ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.61382E 00	SN123	5.78744E-11	PM148	1.93851E-38	NP236	5.04480E-09
CO 60	3.37703E 00	SN126	1.20754E-03	PM148M	2.81077E-37	NP237	1.02258E-03
SE 79	1.31234E-02	SB124	4.71699E-27	SM147	1.87013E-07	PU236	5.02411E-04
RB 87	8.52090E-07	SB125	5.02531E 00	SM148	6.92169E-13	PU237	1.06464E-36
SR 89	3.59601E-27	SB126	1.69055E-04	SM149	1.01219E-13	PU238	8.87273E 01
SR 90	2.26122E 03	SB126M	1.20754E-03	SM151	1.18024E 01	PU239	7.94495E-01
Y 90	2.26181E 03	TE125M	1.22720E 00	EU152	1.57504E-01	PU240	5.25376E-01
Y 91	1.61077E-23	TE127	6.07650E-13	EU154	3.52005E 01	PU241	6.96190E 01
ZR 93	2.10285E-01	TE127M	6.20368E-13	EU155	9.04359E 00	PU242	7.64035E-04
ZR 95	1.57815E-20	TE129	1.99916E-46	GD152	8.46104E-15	AM241	2.43118E 00
NB 95	3.40266E-20	TE129M	3.14866E-46	TB160	7.54266E-23	AM242	1.30745E-03
NB 95M	2.00424E-22	I129	7.22255E-04	TL208	2.07093E-04	AM242M	1.31401E-03
TC 99	4.47915E-01	CS134	1.59516E 01	PB212	5.76381E-04	AM243	1.49518E-05
RU103	2.93569E-37	CS135	5.86202E-03	BI212	5.76380E-04	CM242	1.08444E-03
RU106	2.03276E-01	CS137	2.32727E 03	PO216	5.76393E-04	CM243	5.76474E-04
RH103M	5.87715E-37	BA137M	2.20160E 03	RN220	5.76393E-04	CM244	3.24516E-04
RH106	2.03276E-01	CE141	4.86821E-46	RA224	5.76393E-04	CM245	2.35320E-08
PD107	5.42703E-04	CE142	8.86839E-07	TH228	5.76488E-04	CM246	1.78849E-09
AG110	5.94335E-05	CE144	1.39300E-01	U232	5.54579E-04	CM247	2.63290E-15
CD115M	9.17525E-36	PR144	1.39305E-01	U234	4.81574E-04	CM248	3.11909E-15
IN115	3.35251E-13	PR144M	1.67163E-03	U235	6.12316E-06	BK249	2.62948E-19
IN115M	8.29258E-40	ND144	4.62204E-11	U236	1.11859E-04	CF249	1.12192E-16
SN121M	2.33509E-03	PM147	1.38624E 02	U238	2.29706E-07		

TOTAL ACTIVITY 9.44 03 Ci/assy

HEAT GENERATION, watts/assy
Primary 2.07 01
Gamma 8.25 00

TABLE 7.16
ISOTOPIC CONTENT (g/assembly) OF A MARK 31A ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.68403E-05	RH103M	4.91203E-17	I129	7.84609E-01	EU155	2.75554E-02
HE 3	1.54957E-05	RH106	3.17259E-08	I131	2.81154E-69	EU156	4.00088E-38
V 51	1.80039E-03	PD104	2.51804E-02	XE131	1.19224E-07	GD152	1.75078E-05
CR 51	3.02531E-23	PD105	1.47867E 00	XE132	8.62444E-18	GD154	5.17793E-03
CO 60	4.50139E-03	PD106	1.18954E 00	CS133	5.28151E 00	GD155	2.93296E-02
NI 60	4.20180E-03	PD107	7.27074E-01	CS134	6.38567E-03	GD156	1.20495E-01
GE 72	9.25505E-05	PD108	4.83706E-01	CS135	5.90742E-01	GD157	2.50909E-03
GE 73	2.18633E-04	PD110	1.62057E-01	CS136	6.85020E-45	GD158	4.46584E-02
GE 74	4.40341E-04	AG109	3.07350E-01	CS137	4.59243E 00	GD160	4.07892E-03
GE 76	2.21161E-03	AG110	6.32794E-05	BA134	3.73244E-02	TB159	6.36976E-03
AS 75	9.33979E-04	CD110	1.03570E-02	BA136	3.30615E-02	TB160	2.12157E-12
SE 77	3.90755E-03	CD111	9.83102E-02	BA136M	6.01067E-52	DY160	9.66308E-05
SE 78	1.00851E-02	CD112	6.39183E-02	BA137	6.53631E-01	DY161	1.95500E-03
SE 79	2.51379E-02	CD113	7.02305E-03	BA137M	6.95764E-07	DY162	1.10911E-03
SE 80	5.64404E-02	CD114	9.25052E-02	BA138	5.25261E 00	TL208	8.38584E-15
SE 82	1.12441E-01	CD115M	2.13931E-15	BA140	1.85951E-43	PB208	9.21207E-13
BR 81	9.68738E-02	CD116	3.95666E-02	LA139	5.11455E 00	PB212	4.94653E-16
KR 82	9.89891E-42	IN115	4.24447E-02	LA140	2.80462E-44	BI212	4.69174E-17
RB 85	4.29481E-01	IN115M	8.12851E-22	CE140	5.01340E 00	PO216	1.97299E-21
RB 87	1.04173E 00	SN116	3.34758E-03	CE141	3.72212E-17	RN220	7.44865E-19
SR 88	1.50715E 00	SN117	4.03945E-02	CE142	4.66872E 00	RA224	4.31342E-15
SR 89	3.87131E-11	SN118	4.02414E-02	CE144	4.60033E-02	TH228	8.35955E-13
SR 90	2.16483E 00	SN119	4.01159E-02	PR141	4.74043E 00	U232	1.55524E-11
Y 89	2.00451E 00	SN120	4.09255E-02	PR143	6.18930E-41	U234	1.42444E-17
Y 90	5.63311E-04	SN121M	1.17056E-05	PR144	1.94114E-06	U235	1.20018E-01
Y 91	8.06868E-10	SN122	4.52521E-02	PR144M	9.70551E-09	U236	3.73764E-03
ZR 90	2.91041E-01	SN123	1.25431E-06	ND142	2.42106E-03	U238	7.02619E 01
ZR 91	2.57611E 00	SN124	6.06533E-02	ND143	6.15452E 00	NP237	1.21204E-02
ZR 92	2.71837E 00	SN125	1.09614E-59	ND144	4.25173E 00	PU236	8.01340E-12
ZR 93	3.04886E 00	SN126	1.19937E-01	ND145	3.14643E 00	PU238	1.26153E-04
ZR 94	3.15703E 00	SB121	4.25176E-02	ND146	2.53766E 00	PU239	7.96173E-01
ZR 95	1.05536E-08	SB123	5.11988E-02	ND147	5.90120E-51	PU240	4.58509E-02
ZR 96	3.32827E 00	SB124	6.08374E-14	ND148	1.55832E 00	PU241	5.12023E-03
NB 95	1.21936E-08	SB125	2.39017E-02	ND150	7.37665E-01	PU242	2.13369E-04
NB 95M	7.38690E-12	SB126	5.70460E-10	PM147	4.81671E-01	AM241	7.33668E-02
MO 95	3.35309E 00	SB126M	4.33560E-12	PM148	6.64771E-18	AM242	4.78547E-10
MO 96	1.41172E-03	TE122	2.06319E-04	PM148M	7.41318E-16	AM242M	4.00256E-05
MO 97	3.35843E 00	TE124	9.87409E-05	SM147	1.33410E 00	AM243	4.04810E-06
MO 98	3.44525E 00	TE125	6.18577E-02	SM148	7.53457E-02	CM242	2.09258E-07
MO100	3.83255E 00	TE125M	3.39514E-04	SM149	1.71816E-01	CM243	4.89169E-07
TC 99	3.59495E 00	TE126	2.22512E-03	SM150	1.01167E 00	CM244	6.52966E-08
RU100	9.07126E-03	TE127	1.10461E-09	SM151	2.58838E-01	CM245	3.72061E-10
RU101	3.30128E 00	TE127M	3.15523E-07	SM152	5.74904E-01	CM246	3.51380E-12
RU102	3.06317E 00	TE128	4.66552E-01	SM154	1.38257E-01	CM247	3.66001E-15
RU103	2.49846E-14	TE129	4.07571E-21	EU151	9.92142E-03	CM248	1.92585E-17
RU104	2.09848E 00	TE129M	4.41058E-18	EU152	4.84575E-04	BK249	1.05654E-23
RU106	3.38285E-02	TE130	1.46087E 00	EU153	2.62127E-01	CF249	5.80164E-22
RH103	8.18332E-02	I127	2.39626E-01	EU154	1.03197E-02		

TABLE 7.17
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 31A
ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.56124E-01	SN126	3.40776E-04	PR144M	1.76121E 00	U234	8.89569E-20
CR 51	2.78415E-18	SB124	1.06446E-09	ND144	5.03256E-12	U235	2.59380E-07
CO 60	5.10803E 00	SB125	2.50588E 01	ND147	4.77240E-46	U236	2.41763E-07
SE 79	1.75314E-03	SB126	4.77386E-05	PM147	4.46846E 02	U238	2.36140E-05
RB 87	9.12344E-08	SB126M	3.40776E-04	PM148	1.09280E-12	NP237	8.54180E-06
SR 89	1.09340E-06	TE125M	6.11948E 00	PM148M	1.58451E-11	PU236	4.25701E-05
SR 90	3.06332E 02	TE127	2.91737E-03	SM147	3.03601E-08	PU238	2.15905E-03
Y 90	3.06412E 02	TE127M	2.97843E-03	SM148	2.27784E-14	PU239	4.94775E-02
Y 91	1.97774E-05	TE129	8.49292E-14	SM149	4.12754E-14	PU240	1.04251E-02
ZR 93	1.23578E-02	TE129M	1.33763E-13	SM151	6.59726E 00	PU241	5.16586E-01
ZR 95	2.21676E-04	I129	1.36949E-04	EU152	8.77720E-02	PU242	8.14299E-07
NB 95	4.77957E-04	CS134	1.08678E 01	EU154	2.78851E 00	AM241	2.51814E-01
NB 95M	2.81527E-06	CS135	6.81096E-04	EU155	1.32565E 01	AM242	3.86977E-04
TC 99	6.09465E-02	CS136	5.06264E-40	EU156	2.20425E-33	AM242M	3.88917E-04
RU103	8.00574E-10	CS137	3.98403E 02	GD152	3.74750E-16	AM243	8.07885E-07
RU106	1.13029E 02	BA136M	1.62005E-40	TB160	2.39586E-08	CM242	6.92952E-04
RH103M	1.60272E-09	BA137M	3.76889E 02	TL208	2.46928E-10	CM243	2.52454E-05
RH106	1.13029E 02	BA140	1.35687E-38	PB212	6.87224E-10	CM244	5.28145E-06
PD107	3.74323E-04	LA140	1.56152E-38	BI212	6.87246E-10	CM245	6.40436E-11
AG110	2.98332E-01	CE141	1.06031E-12	PO216	6.87000E-10	CM246	1.07931E-12
CD115M	5.45088E-11	CE142	1.12090E-07	RN220	6.87000E-10	CM247	3.39481E-19
IN115	2.64295E-13	CE144	1.46765E 02	RA224	6.87000E-10	CM248	8.17016E-20
IN115M	4.92650E-15	PR143	4.16427E-36	TH228	6.85149E-10	BK249	1.76396E-20
SN121M	6.92705E-04	PR144	1.46770E 02	U232	3.34202E-10	CF249	2.37513E-21
SN123	1.03297E-02						

TOTAL ACTIVITY 2.43 03 Ci/assy

HEAT GENERATION, watts/assy
Primary 4.83 00
Gamma 1.79 00

TABLE 7.18
ISOTOPIC CONTENT (g/assembly) OF A MARK 31A
ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.09327E-05	RU106	3.54470E-05	TE129M	5.30915E-51	GD152	1.75078E-05
HE 3	3.13933E-05	RH103	8.18332E-02	TE130	1.46087E 00	GD154	1.08908E-02
V 51	1.80039E-03	RH103M	8.43046E-45	I127	2.39626E-01	GD155	5.03856E-02
CR 51	8.51178E-63	RH106	2.32439E-11	I129	7.84609E-01	GD156	1.20455E-01
CO 60	1.20408E-03	PD104	2.51804E-02	XE131	1.19224E-07	GD157	2.50909E-03
NI 60	7.49890E-03	PD105	1.47867E 00	XE132	8.62444E-18	GD158	4.46584E-02
GE 72	9.25505E-05	PD106	1.22333E 00	CS133	5.28151E 00	GD160	4.07892E-03
GE 73	2.18633E-04	PD107	7.27072E-01	CS134	2.89888E-04	TB159	8.36976E-03
GE 74	4.40341E-04	PD108	4.83706E-01	CS135	5.90742E-01	TB160	1.31522E-27
GE 76	2.21161E-03	PD110	1.62057E-01	CS137	3.64780E 00	DY160	5.66308E-05
AS 75	9.33979E-04	AG109	3.07350E-01	BA134	4.54159E-02	DY161	1.95500E-03
SE 77	3.90755E-03	AG110	2.74262E-09	BA136	3.30615E-02	DY162	1.10911E-03
SE 78	1.00851E-02	CD110	1.04201E-02	BA137	1.59823E 00	TL208	5.46195E-19
SE 79	2.51353E-02	CD111	5.83102E-02	BA137M	5.55830E-07	PB208	1.62601E-12
SE 80	5.64404E-02	CD112	6.39183E-02	BA138	5.25281E 00	PB212	3.22193E-16
SE 82	1.12441E-01	CD113	7.02305E-03	LA139	5.11455E 00	BI212	3.05589E-17
BR 81	9.68938E-02	CD114	5.25052E-02	CE140	5.01340E 00	PO216	1.28554E-21
KR 82	9.89891E-42	CD115M	4.75687E-40	CE141	5.90036E-51	RN220	4.65329E-15
RB 85	4.29481E-01	CD116	3.95666E-02	CE142	4.66872E 00	RA224	2.81048E-15
RB 87	1.04173E 00	IN115	4.24447E-02	CE144	6.26217E-06	TH228	5.46153E-13
SR 88	1.50715E 00	IN115M	1.80741E-46	PR141	4.74043E 00	U232	2.08454E-11
SR 89	2.77606E-32	SN116	3.34758E-03	PR144	2.64235E-10	U234	1.42441E-17
SR 90	1.69160E 00	SN117	4.03945E-02	PR144M	1.32115E-12	U235	1.20018E-01
Y 89	2.00451E 00	SN118	4.02414E-02	ND142	2.42106E-03	U236	3.73764E-03
Y 90	4.40170E-04	SN119	4.01159E-02	ND143	6.15452E 00	U238	7.02619E 01
Y 91	1.39260E-28	SN120	4.09295E-02	ND144	4.29713E 00	NP237	1.21204E-02
ZR 90	7.64384E-01	SN121M	1.01893E-05	ND145	3.14643E 00	PU236	7.04564E-13
ZR 91	2.57611E 00	SN122	4.52521E-02	ND146	2.53766E 00	PU238	1.18066E-04
ZR 92	2.71837E 00	SN123	3.76163E-15	ND148	1.55832E 00	PU239	7.95944E-01
ZR 93	3.04385E 00	SN124	6.06533E-02	ND150	7.37665E-01	PU240	4.58023E-02
ZR 94	3.15703E 00	SN126	1.19936E-01	PM147	3.42844E-02	PU241	3.19525E-03
ZR 95	1.72579E-25	SB121	4.25191E-02	PM148	1.58542E-44	PU242	2.13672E-04
ZR 96	3.32827E 00	SB123	5.12000E-02	PM148M	1.76757E-42	AM241	7.41076E-02
NB 95	1.99396E-25	SB124	3.30933E-32	SM147	1.78149E 00	AM242	4.57211E-10
NB 95M	1.20795E-28	SB125	1.88654E-03	SM148	7.53457E-02	AM242M	3.82414E-05
MO 95	3.35309E 00	SB126	5.70456E-10	SM149	1.71816E-01	AM243	4.04428E-06
MO 96	1.41172E-03	SB126M	4.33558E-12	SM150	1.01167E 00	CM242	9.26063E-08
MO 97	3.35843E 00	TE122	2.06319E-04	SM151	2.40236E-01	CM243	3.83560E-07
MO 98	3.44525E 00	TE124	5.87409E-05	SM152	5.74904E-01	CM244	4.45311E-06
MO100	3.83255E 00	TE125	8.41851E-02	SM154	1.38257E-01	CM245	3.71757E-10
TC 99	3.59484E 00	TE125M	2.68032E-05	EU151	2.85236E-02	CM246	3.50866E-12
RU100	9.07126E-03	TE126	2.22595E-03	EU152	2.84211E-04	CM247	3.66001E-15
RU101	3.30128E 00	TE127	5.03573E-20	EU153	2.62127E-01	CM248	1.92581E-17
RU102	3.06317E 00	TE127M	2.58059E-17	EU154	4.60673E-03	BK249	3.32859E-27
RU103	4.28809E-42	TE128	4.66552E-01	EU155	6.49544E-03	CF249	5.79186E-22
RU104	2.09898E 00	TE129	4.90604E-54				

TABLE 7.19
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 31A
ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.02350E-01	SN123	3.09785E-11	PM147	3.18057E 01	U236	2.41763E-07
CO 60	1.36634E 00	SN126	3.40773E-04	PM148	2.60622E-39	U238	2.36140E-05
SE 79	1.75295E-03	SB124	5.79312E-28	PM148M	3.77851E-38	NP237	8.54177E-06
RB 87	9.12344E-08	SB125	1.97828E 00	SM147	4.05413E-08	PU236	3.74291E-10
SR 89	7.84063E-28	SB126	4.77082E-05	SM148	2.27764E-14	PU238	2.02065E-03
SR 90	2.39367E 02	SB126M	3.40773E-04	SM149	4.12754E-14	PU239	4.94632E-02
Y 90	2.39430E 02	TE125M	4.83105E-01	SM151	6.12313E 00	PU240	1.04140E-02
Y 91	3.41345E-24	TE127	2.38642E-13	EU152	5.14758E-02	PU241	3.22372E-01
ZR 93	1.23577E-02	TE127M	2.43637E-13	EU154	1.24458E 00	PU242	8.15457E-07
ZR 95	3.62498E-21	TE129	1.02232E-46	EU155	3.12495E 00	AM241	2.54357E-01
NB 95	7.81586E-21	TE129M	1.61014E-46	GD152	3.74750E-16	AM242	3.69726E-04
NB 95M	4.60370E-23	I129	1.36949E-04	TB160	1.48526E-23	AM242M	3.71580E-04
TC 99	6.09446E-02	CS134	3.75692E-01	TL208	1.60832E-10	AM243	8.07126E-07
RU103	1.37402E-37	CS135	6.81093E-04	PB212	4.47626E-10	CM242	3.06663E-04
RU106	1.18437E-01	CS137	3.16456E 02	BI212	4.47626E-10	CM243	1.97950E-05
RH103M	2.75073E-37	BA137M	2.99367E 02	PO216	4.47626E-10	CM244	3.60186E-06
RH106	1.18437E-01	CE141	1.68081E-46	RN220	4.47626E-10	CM245	6.39912E-11
PD107	3.74322E-04	CE142	1.12090E-07	RA224	4.47626E-10	CM246	1.07773E-12
AG110	1.29301E-05	CE144	1.95782E-02	TH228	4.47628E-10	CM247	3.39481E-19
CD115M	1.21202E-35	PR144	1.59789E-02	U232	4.47943E-10	CM248	8.17000E-20
IN115	2.64295E-13	PR144M	2.39743E-04	U234	8.89544E-20	BK249	5.55729E-24
IN115M	1.09543E-39	ND144	5.08741E-12	U235	2.59380E-07	CF249	2.37113E-21
SN121M	6.02978E-04						

TOTAL ACTIVITY 1.14 03 Ci/assy

HEAT GENERATION, watts/assy
Primary 1.96 00
Gamma 1.10 00

TABLE 7.20
ISOTOPIC CONTENT (g/assembly) OF A MARK 31B
ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	3.09725E-05	RH103M	3.83771E-17	I129	5.60208E-01	EU155	1.86487E-02
HE 3	1.30192E-05	RH106	2.24280E-08	I131	2.55644E-69	EU156	3.32066E-38
V 51	6.10537E-04	PD104	1.40449E-02	XE131	1.08406E-07	GD152	1.05567E-05
CR 51	1.02592E-23	PD105	1.01725E 00	XE132	8.15389E-18	GD154	3.42281E-03
CO 60	1.52633E-03	PD106	6.65952E-01	CS133	3.90628E 00	GD155	1.98195E-02
NI 60	1.42474E-03	PD107	5.11851E-01	CS134	5.01254E-03	GD156	8.58418E-02
GE 72	5.53973E-05	PD108	3.40648E-01	CS135	3.19443E-01	GD157	1.84508E-03
GE 73	1.37713E-04	PD110	1.10862E-01	CS136	5.77570E-45	GD158	3.09479E-02
GE 74	2.88863E-04	AG109	2.15690E-01	CS137	3.39901E 00	GD160	2.80003E-03
GE 76	1.55584E-03	AG110	3.65282E-05	BA134	2.22250E-02	TB159	5.78015E-03
AS 75	6.31582E-04	CD110	5.92384E-03	BA136	2.36872E-02	TB160	1.21225E-12
SE 77	2.79837E-03	CD111	6.49711E-02	BA136M	5.06802E-52	DY160	5.35756E-05
SE 78	7.31296E-03	CD112	4.02728E-02	BA137	4.78556E-01	DY161	1.33534E-03
SE 79	1.83534E-02	CD113	3.82119E-03	BA137M	5.17919E-07	DY162	7.43153E-04
SE 80	4.19684E-02	CD114	5.80008E-02	BA138	3.90447E 00	TL208	9.82037E-15
SE 82	8.28475E-02	CD115M	1.39619E-15	BA140	1.65368E-43	PB208	1.07880E-08
BR 81	7.16440E-02	CD116	2.42721E-02	LA139	3.79213E 00	PB212	5.79272E-12
KR 82	9.27800E-42	IN115	2.59721E-02	LA140	2.49416E-44	BI212	5.49436E-13
RB 85	3.21904E-01	IN115M	5.30491E-22	CE140	3.72176E 00	PO216	2.31050E-17
RB 87	7.83076E-01	SN116	1.69151E-03	CE141	3.03910E-17	RN220	8.72287E-15
SR 88	1.13258E 00	SN117	2.47253E-02	CE142	3.47329E 00	RA224	5.05130E-11
SR 89	3.11481E-11	SN118	2.48050E-02	CE144	3.47225E-02	TH228	9.78957E-09
SR 90	1.63334E 00	SN119	2.46985E-02	PR141	3.51806E 00	U232	1.82129E-07
Y 89	1.50845E 00	SN120	2.52302E-02	PR143	5.49790E-41	U234	9.70505E-18
Y 90	4.25010E-04	SN121M	8.45397E-06	PR144	1.46513E-06	U235	7.94675E-02
Y 91	6.43038E-10	SN122	2.79453E-02	PR144M	7.32552E-09	U236	2.75359E-03
ZR 90	2.18766E-01	SN123	8.05099E-07	ND142	1.57319E-03	U238	4.77112E 01
ZR 91	1.93399E 00	SN124	3.81732E-02	ND143	4.80709E 00	NP237	7.46641E-03
ZR 92	2.03504E 00	SN125	8.85006E-60	ND144	3.16922E 00	PU236	9.38422E-08
ZR 93	2.27691E 00	SN126	7.99308E-02	ND145	2.33085E 00	PU238	6.68281E-05
ZR 94	2.36145E 00	SB121	2.63023E-02	ND146	1.86752E 00	PU239	5.58907E-01
ZR 95	8.27053E-09	SB123	3.18614E-02	ND147	5.27623E-51	PU240	3.41355E-02
ZR 96	2.47302E 00	SB124	3.56239E-14	ND148	1.14059E 00	PU241	3.23854E-03
NB 95	9.55576E-09	SB125	1.54922E-02	ND150	5.30014E-01	PU242	1.49294E-04
NB 95M	5.78891E-12	SB126	3.80179E-10	PM147	3.62878E-01	AM241	4.56437E-02
MO 95	2.49325E 00	SB126M	2.88944E-12	PM148	3.65586E-18	AM242	2.42053E-10
MO 96	8.66615E-04	TE122	1.04059E-04	PM148M	4.07681E-16	AM242M	2.02454E-05
MO 97	2.48665E 00	TE124	5.56248E-05	SM147	9.99870E-01	AM243	2.29283E-06
MO 98	2.54735E 00	TE125	3.98839E-02	SM148	4.16278E-02	CM242	1.08512E-07
MO100	2.83398E 00	TE125M	2.20059E-04	SM149	1.30951E-01	CM243	2.20290E-07
TC 99	2.65499E 00	TE126	1.56421E-03	SM150	7.14533E-01	CM244	3.05940E-08
RU100	6.75974E-03	TE127	7.84919E-10	SM151	1.75855E-01	CM245	1.36912E-10
RU101	2.41715E 00	TE127M	2.24205E-07	SM152	4.27318E-01	CM246	1.41484E-12
RU102	2.22317E 00	TE128	3.28465E-01	SM154	9.79656E-02	CM247	1.14004E-15
RU103	1.95203E-14	TE129	3.19250E-21	EU151	6.72476E-03	CM248	5.02299E-18
RU104	1.49244E 00	TE129M	3.45481E-18	EU152	3.77325E-04	BK249	2.83531E-24
RU106	2.39144E-02	TE130	1.05708E 00	EU153	1.83830E-01	CF249	1.55691E-22
RH103	6.39353E-02	I127	1.65043E-01	EU154	6.83725E-03		

TABLE 7.21
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 31B
ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.99401E-01	SN126	2.27108E-04	PR144M	1.32933E 00	U234	6.06082E-20
CR 51	9.44138E-19	SB124	6.23612E-10	ND144	3.75153E-12	U235	1.71742E-07
CO 60	1.73202E 00	SB125	1.62421E 01	ND147	4.26657E-46	U236	1.78112E-07
SE 79	1.27999E-03	SB126	3.17951E-05	PM147	3.36642E 02	U238	1.60350E-05
RB 87	6.85816E-08	SB126M	2.27108E-04	PM148	6.00576E-13	NP237	5.26192E-06
SR 89	8.79738E-07	TE125M	3.56639E 00	PM148M	8.71390E-12	PU236	4.58525E-05
SR 90	2.31123E 02	TE127	2.07304E-03	SM147	2.27540E-08	PU238	1.14374E-03
Y 90	2.31183E 02	TE127M	2.11643E-03	SM148	1.25849E-14	PU239	3.47329E-02
Y 91	1.57617E-05	TE129	6.65249E-14	SM149	3.14679E-14	PU240	7.76134E-03
ZR 93	9.22889E-03	TE129M	1.04776E-13	SM151	4.48227E 00	PU241	3.26739E-01
ZR 95	1.73721E-04	I129	9.77811E-05	EU152	6.83454E-02	PU242	5.69763E-07
NB 95	3.74562E-04	CS134	6.49620E 00	EU154	1.84780E 00	AM241	1.56660E-01
NB 95M	2.20625E-06	CS135	3.68301E-04	EU155	8.57157E 00	AM242	1.95737E-04
TC 99	4.50109E-02	CS136	4.26853E-40	EU156	1.82949E-33	AM242M	1.96718E-04
RU103	6.25479E-10	CS137	2.94872E 02	GD152	2.25989E-16	AM243	4.57583E-07
RU106	7.99039E 01	BA136M	1.36593E-40	TB160	1.36858E-08	CM242	3.59335E-04
RH103M	1.25219E-09	BA137M	2.78949E 02	TL208	2.89169E-06	CM243	1.13689E-05
RH106	7.99039E 01	BA140	1.20668E-38	PB212	8.04786E-06	CM244	2.47456E-06
PD107	2.63518E-04	LA140	1.38868E-38	BI212	8.04811E-06	CM245	2.35668E-11
AG110	1.72213E-01	CE141	8.65736E-13	PO216	8.04523E-06	CM246	4.34585E-13
CD115M	3.55740E-11	CE142	8.33888E-08	RN220	8.04523E-06	CM247	1.05743E-19
IN115	1.61723E-13	CE144	1.10775E 02	RA224	8.04523E-06	CM248	2.13094E-20
IN115M	3.21518E-15	PR143	3.69909E-36	TH228	8.02355E-06	BK249	4.73372E-21
SN121M	5.00284E-04	PR144	1.10779E 02	U232	3.91374E-06	CF249	6.37384E-22
SN123	6.63031E-03						

TOTAL ACTIVITY 1.80 03 Ci/assy

HEAT GENERATION, watts/assy
Primary 3.58 00
Gamma 1.27 00

TABLE 7.22
ISOTOPIC CONTENT (g/assembly) OF A MARK 31B
ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.75986E-05	RU106	2.50585E-05	TE129M	4.15864E-51	GD152	1.05567E-05
HE 3	2.63931E-05	RH103	6.39353E-02	TE130	1.05708E 00	GD154	7.20791E-03
V 51	6.10537E-04	RH103M	6.58662E-45	I127	1.65043E-01	GD155	3.40721E-02
CR 51	2.88644E-63	RH106	2.35010E-11	I129	5.60208E-01	GD156	8.58418E-02
CO 60	4.08278E-04	PD104	1.40449E-02	XE131	1.08406E-07	GD157	1.84508E-03
NI 60	2.54272E-03	PD105	1.01725E 00	XE132	8.15389E-18	GD158	3.09479E-02
GE 72	5.53973E-05	PD106	8.89840E-01	CS133	3.90628E 00	GD160	2.80003E-03
GE 73	1.37713E-04	PD107	5.11850E-01	CS134	1.73281E-04	TB159	5.78015E-03
GE 74	2.88863E-04	PD108	3.40648E-01	CS135	3.19441E-01	TB160	7.51508E-28
GE 76	1.55584E-03	PD110	1.10862E-01	CS137	2.65587E 00	DY160	5.35756E-05
AS 75	6.31582E-04	AG109	2.15650E-01	BA134	2.70641E-02	DY161	1.33534E-03
SE 77	2.79837E-03	AG110	1.58318E-09	BA136	2.36872E-02	DY162	7.43153E-04
SE 78	7.31296E-03	CD110	5.96025E-03	BA137	1.17769E 00	TL208	6.39632E-15
SE 79	1.83515E-02	CD111	6.49711E-02	BA137M	4.11389E-07	PB208	1.90417E-08
SE 80	4.19684E-02	CD112	4.02728E-02	BA138	3.90447E 00	PB212	3.77310E-12
SE 82	8.28475E-02	CD113	3.82119E-03	LA139	3.79213E 00	BI212	3.57866E-13
BR 81	7.16440E-02	CD114	5.80008E-02	CE140	3.72176E 00	PO216	1.50545E-17
KR 82	9.27800E-42	CD115M	3.10448E-40	CE141	4.81763E-51	RN220	5.68352E-15
RB 85	3.21904E-01	CD116	2.42721E-02	CE142	3.47329E 00	RA224	3.29125E-11
RB 87	7.83076E-01	IN115	2.59721E-02	CE144	4.72655E-06	TH228	6.39581E-09
SR 88	1.13258E 00	IN115M	1.17957E-46	PR141	3.51806E 00	U232	2.44113E-07
SR 89	2.23360E-32	SN116	1.69151E-03	PR144	1.99440E-10	U234	9.70477E-18
SR 90	1.27628E 00	SN117	2.47253E-02	PR144M	5.57179E-13	U235	7.94635E-02
Y 89	1.50845E 00	SN118	2.48050E-02	ND142	1.57319E-03	U236	2.75359E-03
Y 90	3.32102E-04	SN119	2.46585E-02	ND143	4.80709E 00	U238	4.77112E 01
Y 91	1.10985E-28	SN120	2.52302E-02	ND144	3.20393E 00	NP237	7.46638E-03
ZR 90	5.75897E-01	SN121M	7.35891E-06	ND145	2.33085E 00	PU236	8.25091E-09
ZR 91	1.93399E 00	SN122	2.79453E-02	ND146	1.86752E 00	PU238	6.25109E-05
ZR 92	2.03504E 00	SN123	2.41447E-15	ND148	1.14059E 00	PU239	5.58747E-01
ZR 93	2.27689E 00	SN124	3.81732E-02	ND150	5.30014E-01	PU240	3.40993E-02
ZR 94	2.36145E 00	SN126	7.99303E-02	PM147	2.58290E-02	PU241	2.02099E-03
ZR 95	1.35245E-25	SB121	2.63033E-02	PM148	8.71887E-45	PU242	1.49446E-04
ZR 96	2.47302E 00	SB123	3.18622E-02	PM148M	9.72281E-43	AM241	4.61244E-02
NB 95	1.56262E-25	SB124	1.93877E-32	SM147	1.33652E 00	AM242	2.31263E-10
NB 95M	9.46640E-29	SB125	1.22303E-03	SM148	4.16278E-02	AM242M	1.93429E-05
MO 95	2.49325E 00	SB126	3.80176E-10	SM149	1.30951E-01	AM243	2.29067E-06
MO 96	8.66615E-04	SB126M	2.88942E-12	SM150	7.14533E-01	CM242	4.68413E-08
MO 97	2.48665E 00	TE122	1.04059E-04	SM151	1.63219E-01	CM243	1.72730E-07
MO 98	2.54735E 00	TE124	5.56248E-05	SM152	4.27318E-01	CM244	2.08646E-08
MO100	2.83398E 00	TE125	5.43555E-02	SM154	9.79656E-02	CM245	1.36800E-10
TC 99	2.65490E 00	TE125M	1.73727E-05	EU151	1.93634E-02	CM246	1.41276E-12
RU100	6.75979E-03	TE126	1.56477E-03	EU152	2.21307E-04	CM247	1.14004E-19
RU101	2.41715E 00	TE127	6.42065E-20	EU153	1.83830E-01	CM248	5.02288E-16
RU102	2.22317E 00	TE127M	1.83401E-17	EU154	3.05221E-03	BK249	8.93252E-28
RU103	3.35024E-42	TE128	3.28465E-01	EU155	4.39604E-03	CF249	1.55429E-22
RU104	1.49244E 00	TE129	3.84291E-54				

TABLE 7.23
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 31B
ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.70120E-01	SN123	1.58841E-11	PM147	2.39616E 01	U236	1.78112E-07
CO 60	4.63299E-01	SN126	2.27106E-04	PM148	1.43327E-39	U238	1.60350E-05
SE 79	1.27985E-03	SB124	3.39389E-28	PM148M	2.07818E-38	NP237	5.26191E-06
RB 87	6.85916E-08	SB125	1.28224E 00	SM147	3.04242E-08	PU236	4.38320E-06
SR 89	6.30849E-28	SB126	3.17948E-05	SM148	1.25849E-14	PU238	1.06985E-03
SR 90	1.80599E 02	SB126M	2.27106E-04	SM149	3.14679E-14	PU239	3.47229E-02
Y 90	1.80646E 02	TE125M	3.13128E-01	SM151	4.16014E 00	PU240	7.75313E-03
Y 91	2.72037E-24	TE127	1.69576E-13	EU152	4.00859E-02	PU241	2.03900E-01
ZR 93	9.22883E-03	TE127M	1.73125E-13	EU154	8.24863E-01	PU242	5.70345E-07
ZR 95	2.84079E-21	TE129	8.00781E-47	EU155	2.11486E 00	AM241	1.58310E-01
NB 95	6.12507E-21	TE129M	1.26122E-46	GD152	2.25989E-16	AM242	1.87011E-04
NB 95M	3.60780E-23	I129	5.77810E-05	TB160	8.48667E-24	AM242M	1.87949E-04
TC 99	4.50094E-02	CS134	2.24570E-01	TL208	1.88345E-06	AM243	4.57153E-07
RU103	1.07350E-37	CS135	3.68300E-04	PB212	5.24200E-06	CM242	1.55114E-04
RU106	8.37268E-02	CS137	2.34220E 02	BI212	5.24200E-06	CM243	8.91437E-06
RH103M	2.14911E-37	BA137M	2.21572E 02	PO216	5.24201E-06	CM244	1.68761E-06
RH106	8.37268E-02	CE141	1.37238E-46	RN220	5.24201E-06	CM245	2.35476E-11
PD107	2.63518E-04	CE142	6.33888E-08	RA224	5.24200E-06	CM246	4.33948E-13
AG110	7.46393E-06	CE144	1.50792E-02	TH228	5.24203E-06	CM247	1.05743E-19
CD115M	7.91004E-36	PR144	1.50797E-02	U232	5.24572E-06	CM248	2.13089E-20
IN115	1.61723E-13	PR144M	1.80953E-04	U234	6.06065E-20	BK249	1.49134E-24
IN115M	7.14909E-40	ND144	3.79263E-12	U235	1.71742E-07	CF249	6.36311E-22
SN121M	4.35482E-04						

TOTAL ACTIVITY 8.61 02 Ci/assy

HEAT GENERATION, watts/assy
Primary 1.47 00
Gamma 8.02–01

TABLE 7.24
ISOTOPIC CONTENT (g/assembly) OF A MARK 53A
ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.19812E-05	RH103M	1.00569E-17	I129	1.77370E-01	EU155	5.12962E-03
HE 3	5.03626E-06	RH106	1.22713E-08	I131	3.97952E-70	EU156	1.25583E-38
V 51	5.91778E-04	PD104	2.12183E-02	XE131	1.68752E-08	GD152	3.88062E-06
CR 51	9.94399E-24	PD105	4.46303E-01	XE132	1.17664E-18	GD154	3.05178E-03
CO 60	1.49330E-03	PD106	5.07983E-01	CS133	8.43070E-01	GD155	5.44757E-03
NI 60	1.39391E-03	PD107	3.26035E-01	CS134	2.80489E-03	GD156	5.32181E-02
GE 72	8.49971E-06	PD108	2.30050E-01	CS135	5.19165E-02	GD157	3.58964E-04
GE 73	2.40152E-05	PD110	6.66822E-02	CS136	2.07204E-45	GD158	1.83622E-02
GE 74	5.29478E-05	AG109	1.40626E-01	CS137	7.66063E-01	GD160	1.74040E-03
GE 76	2.41330E-04	AG110	6.91632E-05	BA134	1.26462E-02	TB159	3.53148E-03
AS 75	1.10291E-04	CD110	1.17389E-02	BA136	1.61245E-02	TB160	1.62684E-12
SE 77	4.37450E-04	CD111	3.07670E-02	BA136M	1.81816E-52	DY160	8.23055E-05
SE 78	1.63294E-03	CD112	1.33273E-02	BA137	1.12579E-01	DY161	7.36751E-04
SE 79	3.47100E-03	CD113	3.64766E-04	BA137M	1.16728E-07	DY162	4.85029E-04
SE 80	8.17805E-03	CD114	1.54645E-02	BA138	7.58451E-01	TL208	9.26604E-13
SE 82	1.18706E-02	CD115M	1.94211E-16	BA140	2.19057E-44	PB208	3.35550E-07
BR 81	1.25396E-02	CD116	4.52957E-03	LA139	7.44166E-01	PB212	5.46597E-10
KR 82	2.32258E-42	IN115	4.11638E-03	LA140	3.30453E-45	BI212	5.18421E-11
RB 85	3.69314E-02	IN115M	7.37919E-23	CE140	7.38669E-01	PO216	2.18117E-15
RB 87	8.09498E-02	SN116	7.22408E-04	CE141	4.74621E-18	RN220	8.23463E-13
SR 88	1.15962E-01	SN117	4.53824E-03	CE142	6.70878E-01	RA224	4.76854E-05
SR 89	2.55384E-12	SN118	4.57619E-03	CE144	5.59664E-03	TH228	9.27640E-07
SR 90	1.61472E-01	SN119	4.69024E-03	PR141	7.10165E-01	U232	4.24738E-05
Y 89	1.47215E-01	SN120	4.75273E-03	PR143	6.68189E-42	U234	8.79245E-15
Y 90	4.20167E-05	SN121M	5.01360E-06	PR144	2.36162E-07	U235	6.04868E-15
Y 91	6.14652E-11	SN122	5.23823E-03	PR144M	1.18079E-09	U236	1.15815E-14
ZR 90	2.17074E-02	SN123	1.36675E-07	ND142	1.39174E-03	U238	1.07235E-14
ZR 91	2.16888E-01	SN124	7.62041E-03	ND143	7.46828E-01	NP237	8.82936E-01
ZR 92	2.63633E-01	SN125	1.47782E-06	ND144	5.65172E-01	PU236	2.00153E-07
ZR 93	3.41371E-01	SN126	2.41851E-02	ND145	4.13764E-01	PU238	3.59255E-01
ZR 94	3.92160E-01	SB121	4.90158E-03	ND146	3.51365E-01	PU239	7.23507E-02
ZR 95	1.25407E-09	SB123	6.06406E-03	ND147	6.87723E-52	PU240	1.37625E-02
ZR 96	4.59669E-01	SB124	1.58851E-14	ND148	2.39809E-01	PU241	3.07090E-03
NB 95	1.44895E-09	SB125	4.35130E-03	ND150	1.41425E-01	PU242	5.83519E-04
NB 95M	8.77781E-13	SB126	1.15033E-10	PM147	6.58212E-02	AM241	5.28523E-02
MO 95	4.39167E-01	SB126M	8.74272E-13	PM148	6.15125E-19	AM242	1.49999E-23
MO 96	7.48818E-04	TE122	4.50246E-05	PM148M	6.85957E-17	AM242M	1.25460E-18
MO 97	5.07585E-01	TE124	3.01914E-05	SM147	1.84223E-01	AM243	9.89303E-15
MO 98	5.49387E-01	TE125	1.14200E-02	SM148	1.58288E-02	CM242	2.38034E-20
MO100	6.51562E-01	TE125M	6.18084E-05	SM149	1.69362E-02	CM243	5.71077E-15
TC 99	5.68561E-01	TE126	7.52161E-04	SM150	1.77500E-01	CM244	2.91132E-15
RU100	4.18559E-03	TE127	2.49789E-10	SM151	2.58323E-02	CM245	8.01655E-17
RU101	5.67767E-01	TE127M	7.13502E-08	SM152	1.51234E-01	CM246	1.45997E-17
RU102	5.87450E-01	TE128	1.00912E-01	SM154	4.08564E-02	CM247	9.73762E-20
RU103	5.11536E-15	TE129	7.71482E-22	EU151	9.86166E-04	CM248	3.98054E-21
RU104	5.88273E-01	TE129M	8.34869E-19	EU152	1.78697E-05	BK249	2.18224E-27
RU106	1.30846E-02	TE130	3.01252E-01	EU153	6.92987E-02	CF249	1.19829E-25
RH103	1.67546E-02	I127	5.87357E-02	EU154	6.03739E-03		

TABLE 7.25
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 53A
ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	1.15818E-01	SN126	6.87172E-05	PR144M	2.14272E-01	U234	5.49091E-17
CR 51	9.15129E-19	SB124	2.78075E-10	ND144	6.69016E-13	U235	1.30722E-20
CO 60	1.69454E 00	SB125	4.56194E 00	ND147	5.56175E-47	U236	7.49127E-15
SE 79	2.42071E-04	SB126	5.62041E-06	PM147	6.10625E 01	U238	3.60399E-21
RB 87	7.08959E-09	SB126M	6.87172E-05	PM148	1.01119E-13	NP237	6.22247E-04
SR 89	7.21298E-08	TE125M	1.11405E 00	PM148M	1.46618E-12	PU236	1.06329E-04
SR 90	2.28490E 01	TE127	6.59717E-04	SM147	4.19235E-09	PU238	6.14851E 00
Y 90	2.28549E 01	TE127M	6.73524E-04	SM148	4.78533E-15	PU239	4.49618E-03
Y 91	1.50659E-06	TE129	1.60761E-14	SM149	4.06857E-15	PU240	3.12918E-03
ZR 93	1.38366E-03	TE129M	2.53198E-14	SM151	6.58413E-01	PU241	3.09827E-01
ZR 95	2.63415E-05	I129	3.09589E-05	EU152	3.23678E-03	PU242	2.22694E-06
NB 95	5.67952E-05	CS134	3.63512E 00	EU154	1.63161E 00	AM241	1.81402E-01
NB 95M	3.34536E-07	CS135	5.98571E-05	EU155	2.46718E 00	AM242	1.21297E-17
TC 99	9.63900E-03	CS136	1.53135E-40	EU156	6.91889E-34	AM242M	1.21905E-17
RU103	1.63910E-10	CS137	6.64577E 01	GD152	8.30726E-17	AM243	1.97436E-15
RU106	4.37187E 01	BA136M	4.90030E-41	TB160	1.83717E-08	CM242	7.88242E-17
RH103M	3.28142E-10	BA137M	6.28689E 01	TL208	2.72846E-04	CM243	2.94725E-17
RH106	4.37188E 01	BA140	1.59873E-39	PB212	7.59351E-04	CM244	2.35479E-13
PD107	1.67854E-04	LA140	1.83986E-39	BI212	7.59382E-04	CM245	1.37990E-17
AG110	3.26071E-01	CE141	1.35203E-13	PU216	7.59489E-04	CM246	4.48448E-18
CD115M	4.94838E-12	CE142	1.61069E-08	RN220	7.59489E-04	CM247	9.03204E-24
IN115	2.56319E-14	CE144	1.78557E 01	RA224	7.59489E-04	CM248	1.68869E-23
IN115M	4.47234E-16	PR143	4.49571E-37	TH228	7.60292E-04	BK249	3.64338E-24
SN121M	2.96691E-04	PR144	1.78563E 01	U232	9.12713E-04	CF249	4.90573E-25
SN123	1.12557E-03						

TOTAL ACTIVITY 3.82 02 Ci/assy

HEAT GENERATION, watts/assy
Primary 9.88 -01
Gamma 3.64 -01

TABLE 7.26
ISOTOPIC CONTENT (g/assembly) OF A MARK 53A
ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	6.80773E-06	RU106	1.37106E-05	TE129M	1.00456E-51	GD152	3.88062E-06
HE 3	1.02097E-05	RH103	1.67546E-02	TE130	3.01252E-01	GD154	6.39401E-03
V 51	5.91778E-04	RH103M	1.72605E-45	I127	5.87357E-02	GD155	9.36758E-03
CR 51	2.79775E-63	RH106	1.28584E-11	I129	1.77370E-01	GD156	5.32181E-02
CO 60	3.99443E-04	PD104	2.12183E-02	XE131	1.68752E-08	GD157	3.58564E-04
NI 60	2.48769E-03	PD105	4.46303E-01	XE132	1.17664E-18	GD158	1.83622E-02
GE 72	8.49971E-06	PD106	5.21057E-01	CS133	8.43070E-01	GD160	1.74040E-03
GE 73	2.40152E-05	PD107	3.26035E-01	CS134	9.69637E-05	TB159	3.53148E-03
GE 74	5.29478E-05	PD108	2.30050E-01	CS135	5.19165E-02	TB160	1.00852E-27
GE 76	2.41330E-04	PD110	6.66822E-02	CS137	6.08451E-01	DY160	8.23055E-05
AS 75	1.10291E-04	AG109	1.40626E-01	BA134	1.53541E-02	DY161	7.36751E-04
SE 77	4.37450E-04	AG110	2.99762E-09	BA136	1.61245E-02	DY162	4.85029E-04
SE 78	1.63294E-03	CD110	1.18079E-02	BA137	2.70148E-01	TL208	1.03700E-12
SE 79	3.47065E-03	CD111	3.07670E-02	BA137M	9.27161E-08	PB208	1.56387E-06
SE 80	8.17805E-03	CD112	1.33273E-02	BA138	7.58451E-01	PB212	6.11710E-10
SE 82	1.18706E-02	CD113	3.64766E-04	LA139	7.44166E-01	BI212	5.80186E-11
BR 81	1.25396E-02	CD114	1.54645E-02	CE140	7.38669E-01	PO216	2.44066E-15
KR 82	2.32258E-42	CD115M	4.31836E-41	CE141	7.52375E-52	RN220	9.21420E-13
RB 85	3.69314E-02	CD116	4.52957E-03	CE142	6.70878E-01	RA224	5.33584E-09
RB 87	8.09498E-02	IN115	4.11638E-03	CE144	7.61867E-07	TH228	1.03678E-06
SR 88	1.15962E-01	IN115M	1.64079E-47	PR141	7.10165E-01	U232	3.87278E-05
SR 89	1.83132E-33	SN116	7.22408E-04	PR144	3.21473E-11	U234	8.79219E-15
SR 90	1.26174E-01	SN117	4.53824E-03	PR144M	1.60733E-13	U235	6.04866E-15
Y 89	1.47215E-01	SN118	4.57619E-03	ND142	1.39174E-03	U236	1.15815E-14
Y 90	3.28318E-05	SN119	4.69024E-03	ND143	7.46828E-01	U238	1.07235E-14
Y 91	1.06085E-29	SN120	4.75273E-03	ND144	5.70767E-01	NP237	8.82936E-01
ZR 90	5.70135E-02	SN121M	4.36416E-06	ND145	4.13764E-01	PU236	1.75981E-06
ZR 91	2.16888E-01	SN122	5.23823E-03	ND146	3.51365E-01	PU238	3.31968E-01
ZR 92	2.63633E-01	SN123	4.09884E-16	ND148	2.39809E-01	PU239	7.23299E-02
ZR 93	3.41368E-01	SN124	7.62041E-03	ND150	1.41425E-01	PU240	1.37480E-02
ZR 94	3.92160E-01	SN126	2.41850E-02	PM147	4.68503E-03	PU241	1.91638E-03
ZR 95	2.05073E-26	SB121	4.90260E-03	PM148	1.46702E-45	PU242	5.83508E-04
ZR 96	4.59669E-01	SB123	6.06420E-03	PM148M	1.63554E-43	AM241	5.31558E-02
NB 95	2.36941E-26	SB124	8.64515E-33	SM147	2.45359E-01	AM242	1.43313E-23
NB 95M	1.43540E-29	SB125	3.43515E-04	SM148	1.58268E-02	AM242M	1.19867E-16
MO 95	4.39167E-01	SB126	1.15032E-10	SM149	1.69362E-02	AM243	9.88369E-15
MO 96	7.48818E-04	SB126M	8.74268E-13	SM150	1.77500E-01	CM242	2.90273E-21
MO 97	5.07585E-01	TE122	4.50246E-05	SM151	2.39758E-02	CM243	4.47784E-15
MO 98	5.49387E-01	TE124	3.01914E-05	SM152	1.51234E-01	CM244	1.98547E-15
MO100	6.51562E-01	TE125	1.54846E-02	SM154	4.08564E-02	CM245	8.00999E-17
TC 99	5.68543E-01	TE125M	4.87949E-06	EU151	2.84269E-03	CM246	1.45783E-17
RU100	4.18559E-03	TE126	7.52328E-04	EU152	1.04809E-05	CM247	9.73762E-20
RU101	5.67767E-01	TE127	2.04328E-20	EU153	6.52967E-02	CM248	3.98045E-21
RU102	5.87450E-01	TE127M	5.83647E-18	EU154	2.69511E-03	BK249	6.87505E-31
RU103	8.77944E-43	TE128	1.00912E-01	EU155	1.20920E-03	CF249	1.19628E-25
RU104	5.88273E-01	TE129	9.28659E-55				

TABLE 7.27
ISOTOPIC CONTENT (Ci/assembly) OF A MARK 53A
ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	6.58082E-02	SN123	3.37556E-12	PM147	4.34632E 00	U236	7.49127E-15
CO 60	4.53273E-01	SN126	6.87167E-05	PM148	2.41159E-40	U238	3.60399E-21
SE 79	2.42045E-04	SB124	1.51337E-28	PM148M	3.49671E-39	NP237	6.22245E-04
RB 87	7.08959E-09	SB125	3.60144E-01	SM147	5.58363E-09	PU236	9.34877E-06
SR 89	5.17233E-29	SB126	9.62034E-06	SM148	4.78533E-15	PU238	5.68151E 00
SR 90	1.78541E 01	SB126M	6.87167E-05	SM149	4.06857E-15	PU239	4.49489E-03
Y 90	1.78588E 01	TE125M	8.79489E-02	SM151	6.11094E-01	PU240	3.12587E-03
Y 91	2.60028E-25	TE127	5.39651E-14	EU152	1.89843E-03	PU241	1.93346E-01
ZR 93	1.38365E-03	TE127M	5.50945E-14	EU154	7.28355E-01	PU242	2.22690E-06
ZR 95	4.30753E-22	TE129	1.93513E-47	EU155	5.81729E-01	AM241	1.82444E-01
NB 95	9.28751E-22	TE129M	3.04782E-47	GD152	8.30726E-17	AM242	1.15890E-17
NB 95M	5.47054E-24	I129	3.09589E-05	TB160	1.13851E-23	AM242M	1.16471E-17
TC 99	9.63868E-03	CS134	1.25664E-01	TL208	3.05393E-04	AM243	1.97250E-15
RU103	2.81316E-38	CS135	5.98569E-05	PB212	8.49854E-04	CM242	9.61230E-18
RU106	4.58105E-02	CS137	5.27880E 01	BI212	8.49855E-04	CM243	2.31095E-17
RH103M	5.63186E-38	BA137M	4.99375E 01	PO216	8.49843E-04	CM244	1.60593E-13
RH106	4.58105E-02	CE141	2.14327E-47	RN220	8.49843E-04	CM245	1.37877E-17
PD107	1.67854E-04	CE142	1.61069E-08	RA224	8.49843E-04	CM246	4.47791E-18
AG110	1.41323E-05	CE144	2.43059E-03	TH228	8.49751E-04	CM247	9.03204E-24
CD115M	1.10029E-36	PR144	2.43067E-03	U232	8.32217E-04	CM248	1.68865E-23
IN115	2.56319E-14	PR144M	2.91675E-05	U234	5.49075E-17	BK249	1.14783E-27
IN115M	9.94445E-41	ND144	6.75640E-13	U235	1.30722E-20	CF249	4.89747E-25
SN121M	2.58260E-04						

TOTAL ACTIVITY 1.52 02 Ci/assy

HEAT GENERATION, watts/assy
Primary 3.73 -01
Gamma 1.91 -01

TABLE 7.28
ISOTOPIC CONTENT (g/kg U-235) OF AN OFFSITE
FUEL ASSEMBLY – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	4.62499E-04	PD105	3.71585E 00	XE132	3.89105E-68	EU156	8.31210E-49
HE 3	3.89289E-04	PD106	1.94560E 00	CS133	3.17906E 01	GD152	9.37293E-05
AL 0	3.84428E 04	PD107	7.92109E-01	CS134	3.79353E-02	GD154	3.16172E-02
GE 72	1.72764E-04	PD108	3.88417E-01	CS135	4.32189E 00	GD155	8.88420E-02
GE 73	7.14360E-04	PD110	1.38805E-01	CS136	1.55467E-57	GD156	2.44156E-01
GE 74	1.87085E-03	AG109	1.88015E-01	CS137	2.65693E 01	GD157	2.49260E-03
GE 76	1.32370E-02	AG110	1.33637E-05	BA134	3.05785E-01	GD158	6.83328E-02
AS 75	4.42453E-03	CD110	1.01027E-02	BA136	5.42933E-02	GD160	3.35415E-03
SE 77	2.51175E-02	CD111	1.08229E-01	BA136M	1.36419E-64	TB159	6.25619E-03
SE 76	6.17116E-02	CD112	7.94921E-02	BA137	5.90926E 00	TB160	1.57974E-14
SE 79	1.52442E-01	CD113	8.26298E-03	BA137M	4.04845E-26	DY160	1.45579E-04
SE 80	3.66994E-01	CD114	1.40298E-01	BA138	3.37005E 01	DY161	8.96483E-04
SE 82	7.43035E-01	CD115M	5.51056E-19	BA140	1.15296E-55	DY162	4.87975E-04
BR 81	6.25577E-01	CD116	7.14269E-02	LA139	3.23695E 01	TL208	8.53766E-14
RB 85	3.27491E 00	IN115	5.69216E-02	LA140	1.73895E-56	PB208	3.11962E-08
RB 87	7.92213E 00	IN115M	2.09376E-25	CE140	3.17366E 01	PB212	5.03642E-11
SR 88	1.14874E 01	SN116	5.94406E-03	CE141	1.78479E-21	BI212	4.77671E-12
SR 89	1.89763E-13	SN117	6.57471E-02	CE142	3.00082E 01	PO216	2.01023E-16
SR 90	1.61256E 01	SN118	7.80134E-02	CE144	6.04158E-02	RN220	7.58926E-14
Y 89	1.53996E 01	SN119	7.47751E-02	PR141	2.99675E 01	RA224	4.39484E-10
Y 90	4.19606E-03	SN120	7.82402E-02	PR143	2.31798E-52	TH228	8.56597E-08
Y 91	8.78485E-12	SN121M	3.50167E-05	PR144	3.39319E-06	U232	5.13034E-06
ZR 90	2.87438E 00	SN122	8.80096E-02	PR144M	1.69657E-08	U234	4.22710E-02
ZR 91	1.92447E 01	SN123	1.37743E-07	ND142	1.71373E-02	U235	1.49999E 00
ZR 92	1.96477E 01	SN124	1.39222E-01	ND143	3.98881E 01	U236	8.50496E-01
ZR 93	4.23763E 01	SN126	2.39230E-01	ND144	2.88292E 01	U238	3.88085E-01
ZR 94	2.16511E 01	SB121	8.25284E-02	ND145	2.01935E 01	NP237	2.06775E-01
ZR 95	1.99721E-10	SB123	1.06139E-01	ND146	1.56857E 01	PU236	2.68476E-06
ZR 96	2.15590E 01	SB124	2.62986E-16	ND147	2.61183E-65	PU238	1.60467E-01
NB 95	2.30757E-10	SB125	3.46908E-02	ND148	9.12716E 00	PU239	2.57510E 00
NB 95M	1.39794E-10	SB126	1.61345E-09	ND150	3.53604E 00	PU240	1.40564E-01
MO 95	2.20957E 01	SB126M	1.22629E-11	PM147	1.89706E 00	PU241	1.82783E-02
MO 96	7.24410E-03	TE122	5.17799E-04	PM148	5.06584E-21	PU242	6.99531E-04
MO 97	2.08639E 01	TE124	2.50096E-04	PM148M	5.64915E-19	AM241	6.56810E-03
MO 98	2.09321E 01	TE125	1.48658E-01	SM147	8.77620E 00	AM242	3.43946E-12
MO100	2.27251E 01	TE125M	4.92769E-04	SM148	6.02892E-01	AM242M	2.87678E-07
TC 99	2.16175E 01	TE126	6.39495E-03	SM149	8.94427E-01	AM243	2.51188E-08
RU100	5.81652E-02	TE127	1.01230E-10	SM150	6.01607E 00	CM242	7.70226E-10
RU101	1.85493E 01	TE127M	2.89156E-08	SM151	1.11152E 00	CM243	3.22441E-09
RU102	1.57795E 01	TE128	1.91579E 00	SM152	2.47766E 00	CM244	3.94696E-10
RU103	6.45462E-18	TE129	1.75000E-25	SM154	4.29244E-01	CM245	2.54420E-12
RU104	7.17700E 00	TE129M	1.89379E-22	EU151	5.58289E-02	CM246	2.08001E-14
RU106	1.80363E-02	TE130	7.17927E 00	EU152	1.72477E-03	CM247	2.24043E-17
RH103	2.11411E-05	I127	7.51751E-01	EU153	1.10433E 00	CM248	1.05857E-19
RH103M	1.26899E-20	I129	3.37458E 00	EU154	4.53961E-02	BK249	1.92995E-26
RH106	1.69152E-08	XE131	1.30641E-27	EU155	5.66492E-02	CF249	3.60754E-24
PD104	1.48218E-01						

TABLE 7.29
ISOTOPIC CONTENT (Ci/kg U-235) OF AN OFFSITE
FUEL ASSEMBLY – 6 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	4.47083E 03	SN126	9.63853E-04	PM148	8.32758E-16	U236	5.75594E-05
SE 79	1.06314E-02	SB124	4.60372E-12	PM148M	1.20747E-14	U238	1.30430E-07
RB 87	6.93819E-07	SB125	3.63702E 01	SM147	1.99719E-07	NP237	1.45724E-04
SR 89	5.35961E-09	SB126	1.34939E-04	SM148	1.82265E-13	PU236	1.42625E-03
SR 90	2.28184E 03	SB126M	9.63854E-04	SM149	2.14868E-13	PU238	2.74632E 00
Y 90	2.28244E 03	TE125M	8.88175E 00	SM151	2.83305E 01	PU239	1.60028E-01
Y 91	2.15328E-07	TE127	2.67358E-04	EU152	3.12411E-01	PU240	3.19599E-02
ZR 93	1.71762E-01	TE127M	2.72954E-04	EU154	1.22684E 01	PU241	1.84412E 00
ZR 95	4.19510E-06	TE129	3.64664E-18	EU155	2.72539E 01	PU242	2.67121E-06
NB 95	9.04511E-06	TE129M	5.74344E-18	EU156	4.57949E-44	AM241	2.25434E-02
NB 95M	5.32776E-08	I129	5.89013E-04	GD152	2.00647E-15	AM242	2.78133E-06
TC 99	3.66490E-01	CS134	4.91638E 01	TB160	1.78398E-10	AM242M	2.79527E-06
RU103	2.06822E-13	CS135	4.98291E-03	TL208	2.51398E-05	AM243	5.01299E-09
RU106	6.02635E 01	CS137	2.30494E 03	PB212	6.99715E-05	CM242	2.55058E-06
RH103M	4.14051E-12	BA137M	2.18047E 03	BI212	6.99691E-05	CM243	1.66407E-07
RH106	6.02636E 01	CE141	5.08425E-17	PO216	6.99968E-05	CM244	3.19245E-08
PD107	4.07805E-04	CE142	7.20459E-07	RN220	6.99968E-05	CM245	4.37538E-13
AG110	6.30036E-02	CE144	2.56552E 02	RA224	6.99969E-05	CM246	6.38901E-15
CD115M	1.40406E-14	PR143	1.55958E-47	TH228	7.02068E-05	CM247	2.07808E-21
IN115	3.66894E-13	PR144	2.56561E 02	U232	1.10245E-04	CM248	4.49085E-22
IN115M	1.26899E-18	PR144M	3.07868E 00	U234	2.63983E-04	BK249	3.22218E-23
SN121M	2.07220E-03	ND144	3.41263E-11	U235	3.24174E-06	CF249	1.47690E-23
SN123	1.13437E-03	PM147	1.75590E 03				

TOTAL ACTIVITY 1.18 04 Ci/kg U-235

HEAT GENERATION, watts/kg U-235
Primary 2.11 01
Gamma 8.52 00

TABLE 7.30
ISOTOPIC CONTENT (g/kg U-235) OF AN OFFSITE
FUEL ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.62792E-04	RH106	1.77244E-11	I127	7.51748E-01	GD154	5.67480E-02
HE 3	5.88996E-04	PD104	1.48218E-01	I129	2.37458E 00	GD155	1.32138E-01
AL 0	3.84428E 04	PD105	3.71585E 00	XE131	1.30641E-27	GD156	2.44156E-01
GE 72	1.72764E-04	PD106	1.96362E 00	XE132	3.89105E-68	GD157	2.49260E-03
GE 73	7.14361E-04	PD107	7.92108E-01	CS133	3.17906E 01	GD158	6.83329E-02
GE 74	1.87085E-03	PD108	3.88417E-01	CS134	1.31140E-03	GD160	3.35415E-03
GE 76	1.32370E-02	PD110	1.28809E-01	CS135	4.32188E 00	TB159	8.25821E-03
AS 75	4.42455E-03	AG109	1.88015E-01	CS137	2.11042E 01	TB160	9.79306E-30
SE 77	2.51175E-02	AG110	5.75196E-10	BA134	3.42408E-01	DY160	1.45579E-04
SE 78	6.17115E-02	CD110	1.01160E-02	BA136	5.42933E-02	DY161	8.96486E-04
SE 79	1.52426E-01	CD111	1.08229E-01	BA137	1.13742E 01	DY162	4.87975E-04
SE 80	3.66994E-01	CD112	7.94519E-02	BA137M	3.21572E-06	TL208	1.75868E-13
SE 82	7.43034E-01	CD113	8.26300E-03	BA138	3.37005E 01	PB208	2.03182E-07
BR 81	6.25579E-01	CD114	1.40259E-01	LA139	3.23695E 01	PB212	1.03742E-10
RB 85	3.27491E 00	CD115M	1.22525E-43	CE140	3.17367E 01	BI212	9.83959E-12
RB 87	7.92213E 00	CD116	7.14270E-02	CE141	2.82912E-55	PO216	4.13935E-16
SR 88	1.14874E 01	IN115	5.89221E-02	CE142	3.00083E 01	RN220	1.56273E-13
SR 89	1.36072E-34	IN115M	4.65543E-50	CE144	1.09465E-05	RA224	9.04957E-10
SR 90	1.26005E 01	SN116	5.94404E-03	PR141	2.99675E 01	TH228	1.75885E-07
Y 89	1.53996E 01	SN117	6.97469E-02	PR144	4.61893E-10	U232	6.91109E-06
Y 90	3.27879E-03	SN118	7.80131E-02	PR144M	2.30942E-12	U234	4.22698E-02
Y 91	1.51616E-30	SN119	7.47752E-02	ND142	1.71373E-02	U235	1.50000E 00
ZR 90	6.40028E 00	SN120	7.82403E-02	ND143	3.98881E 01	U236	8.90485E-01
ZR 91	1.92446E 01	SN121M	3.04810E-05	ND144	2.89096E 01	U238	3.88085E-01
ZR 92	1.96477E 01	SN122	6.60100E-02	ND145	2.01935E 01	NP237	2.06774E-01
ZR 93	4.23760E 01	SN123	4.13083E-16	ND146	1.56857E 01	PU236	2.36053E-07
ZR 94	2.16511E 01	SN124	1.39223E-01	ND148	9.12715E 00	PU238	1.48278E-01
ZR 95	3.26587E-27	SN126	3.39227E-01	ND150	3.53604E 00	PU239	2.57437E 00
ZR 96	2.15590E 01	SB121	8.25331E-02	PM147	1.35029E-01	PU240	1.40416E-01
NB 95	3.77338E-27	SB123	1.06139E-01	PM148	1.20810E-47	PU241	1.14065E-02
NB 95M	2.28593E-30	SB124	1.43122E-34	PM148M	1.34721E-45	PU242	6.99920E-04
MO 95	2.20957E 01	SB125	2.73868E-03	SM147	1.05382E 01	AM241	1.32765E-02
MO 96	7.24412E-03	SB126	1.61348E-09	SM148	6.02892E-01	AM242	3.28614E-12
MO 97	2.08639E 01	SB126M	1.22628E-11	SM149	8.94428E-01	AM242M	2.74854E-07
MO 98	2.09321E 01	TE122	5.17799E-04	SM150	6.01607E 00	AM243	2.50951E-08
MO100	2.27251E 01	TE124	2.50098E-04	SM151	1.03164E 00	CM242	6.65593E-10
TC 99	2.16168E 01	TE125	1.81063E-01	SM152	2.47766E 00	CM243	2.52827E-09
RU100	5.81650E-02	TE125M	3.65016E-05	SM154	4.29244E-01	CM244	2.69176E-10
RU101	1.85493E 01	TE126	6.39736E-03	EU151	1.35712E-01	CM245	2.54211E-12
RU102	1.57795E 01	TE127	8.28053E-21	EU152	1.01161E-03	CM246	2.07697E-14
RU103	1.13775E-45	TE127M	2.36527E-18	EU153	1.10433E 00	CM247	2.24043E-17
RU104	7.17730E 00	TE128	1.91579E 00	EU154	2.02649E-02	CM248	1.05855E-19
RU106	1.88991E-05	TE129	2.10642E-58	EU155	1.33539E-02	BK249	6.08021E-30
RH103	2.11411E-05	TE129M	2.27949E-55	GD152	9.37297E-05	CF249	3.55588E-24
RH103M	2.17786E-48	TE130	7.17927E 00				

TABLE 7.31
ISOTOPIC CONTENT (Ci/kg U-235) OF AN OFFSITE FUEL ASSEMBLY – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
H 3	2.54034E 00	SN123	3.40190E-12	PM148M	2.87956E-41	U238	1.30430E-07
SE 79	1.06303E-02	SN126	5.63846E-04	SM147	2.39818E-07	NP237	1.45723E-04
RB 87	6.93818E-07	SB124	2.50542E-30	SM148	1.82265E-13	PU236	1.25400E-04
SR 89	3.84317E-30	SB125	2.87125E 00	SM149	2.14868E-13	PU238	2.53773E 00
SR 90	1.78303E 03	SB126	1.34538E-04	SM151	2.62944E 01	PU239	1.59982E-01
Y 90	1.78349E 03	SB126M	5.63846E-04	EU152	1.83235E-01	PU240	3.19262E-02
Y 91	3.71631E-26	TE125M	7.01173E-01	EU154	5.47661E 00	PU241	1.15081E 00
ZR 93	1.71761E-01	TE127	2.16657E-14	EU155	6.42434E 00	PU242	2.67117E-06
ZR 95	6.85990E-23	TE127M	2.23274E-14	GD152	2.00648E-15	AM241	4.55684E-02
NB 95	1.47907E-22	I129	5.89013E-04	TB160	1.10592E-25	AM242	2.65735E-06
NB 95M	8.71204E-25	CS134	1.69556E 00	TL208	5.17859E-05	AM242M	2.67067E-06
TC 99	3.66478E-01	CS135	4.98290E-03	PB212	1.44130E-04	AM243	5.00627E-09
RU103	3.54952E-41	CS137	1.83084E 03	BI212	1.44130E-04	CM242	2.20409E-06
RU106	6.31465E-02	BA137M	1.73196E 03	PO216	1.44133E-04	CM243	1.30480E-07
RH103M	7.10601E-41	CE142	7.20460E-07	RN220	1.44133E-04	CM244	2.17720E-08
RH106	6.31465E-02	CE144	3.49227E-02	RA224	1.44133E-04	CM245	4.37579E-13
PD107	4.07804E-04	PR144	3.49239E-02	TH228	1.44156E-04	CM246	6.37967E-15
AG110	2.73064E-06	PR144M	4.19079E-04	U232	1.48511E-04	CM247	2.07808E-21
CD115M	3.12186E-39	ND144	3.42215E-11	U234	2.63975E-04	CM248	4.49076E-22
IN115	3.66896E-13	PM147	1.25266E 02	U235	3.24175E-06	BK249	1.01513E-26
IN115M	2.82154E-43	PM148	1.56596E-42	U236	5.75994E-05	CF249	1.45575E-23
SN121M	1.80379E-03						

TOTAL ACTIVITY 7.31 03 Ci/kg U-235

HEAT GENERATION, watts/kg U-235
Primary 1.40 01
Gamma 6.18 00

TABLE 7.32
ISOTOPIC CONTENT (g/kg Pu) OF PLUTONIUM-238
SCRAP – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	1.38175E-14	PO216	3.25376E-17	U232	9.14534E-07	PU240	1.18815E-01
PB208	3.06683E-09	RN220	1.22840E-14	PU236	4.79242E-07	PU241	5.38794E-02
PB212	8.15111E-12	RA224	7.11348E-11	PU238	1.12523E 00	PU242	3.04226E-02
BI212	7.73070E-13	TH228	1.38764E-08	PU239	3.22272E-01	AM241	1.27115E-02

TABLE 7.33
ISOTOPIC CONTENT (Ci/kg Pu) OF PLUTONIUM-238
SCRAP – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	4.06867E-06	RN220	1.13297E-05	PU236	2.54551E-04	PU241	5.43554E 00
PB212	1.13244E-05	RA224	1.13297E-05	PU238	1.92578E 01	PU242	1.16104E-04
BI212	1.13239E-05	TH228	1.13731E-05	PU239	2.00274E-02	AM241	4.36290E-02
PO216	1.13297E-05	U232	1.96523E-05	PU240	2.70149E-02		

TOTAL ACTIVITY 2.48 01 Ci/kg Pu

HEAT GENERATION, watts/kg Pu
Primary 6.40 – 01
Gamma 1.86 – 04

TABLE 7.34
ISOTOPIC CONTENT (g/kg Pu) OF PLUTONIUM-238
SCRAP – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	3.13254E-14	PO216	7.37257E-17	U232	1.23252E-06	PU240	1.18690E-01
PB208	3.32856E-08	RN220	2.78351E-14	PU236	4.21366E-08	PU241	3.36229E-02
PB212	1.84785E-11	RA224	1.61190E-10	PU238	1.03577E 00	PU242	3.04221E-02
BI212	1.75261E-12	TH228	3.13287E-08	PU239	3.22180E-01	AM241	3.25917E-02

TABLE 7.35
ISOTOPIC CONTENT (Ci/kg Pu) OF PLUTONIUM-238
SCRAP – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	9.22403E-06	RN220	2.56728E-05	PU236	2.23845E-05	PU241	3.39227E 00
PB212	2.56723E-05	RA224	2.56728E-05	PU238	1.77952E 01	PU242	1.16102E-04
BI212	2.56722E-05	TH228	2.56771E-05	PU239	2.00216E-02	AM241	1.11863E-01
PO216	2.56728E-05	U232	2.64854E-05	PU240	2.69864E-02		

TOTAL ACTIVITY 2.13 01 Ci/kg Pu

HEAT GENERATION, watts/kg Pu
Primary 5.94 – 01
Gamma 1.82 – 04

TABLE 7.36
ISOTOPIC CONTENT (g/kg Pu) OF PLUTONIUM-239
SCRAP – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	1.54597E-20	PO216	3.64048E-23	U232	1.02323E-12	PU240	1.11248E-02
PB208	3.43132E-15	RN220	1.37439E-20	PU236	5.36201E-13	PU241	1.14603E-03
PB212	9.11990E-18	RA224	7.95894E-17	PU238	1.56117E-06	PU242	5.01399E-05
BI212	8.64953E-19	TH228	1.55256E-14	PU239	1.87506E-01	AM241	2.70376E-04

TABLE 7.37
ISOTOPIC CONTENT (Ci/kg Pu) OF PLUTONIUM-239
SCRAP – 5 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	4.55225E-12	RN220	1.26762E-11	PU236	2.64850E-10	PU241	1.15624E-01
PB212	1.26704E-11	RA224	1.26763E-11	PU238	2.67188E-05	PU242	1.91353E-07
BI212	1.26698E-11	TH228	1.27248E-11	PU239	1.16524E-02	AM241	9.28000E-04
PO216	1.26762E-11	U232	2.19880E-11	PU240	2.52944E-03		

STEP 1 EXECUTED AS SPECIFIED

TOTAL ACTIVITY 1.31–01 Ci/kg Pu

HEAT GENERATION, watts/kg Pu
Primary 4.75 –04
Gamma 2.82 –07

TABLE 7.38
ISOTOPIC CONTENT (g/kg Pu) OF PLUTONIUM-239
SCRAP – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	3.50486E-20	PO216	6.24924E-23	U232	1.37901E-12	PU240	1.11131E-02
PB208	3.72418E-14	RN220	3.11435E-20	PU236	4.71446E-14	PU241	7.15169E-04
PB212	2.06747E-17	RA224	1.80347E-16	PU238	1.44259E-06	PU242	5.01389E-05
BI212	1.96092E-18	TH228	3.50523E-14	PU239	1.87452E-01	AM241	6.93233E-04

TABLE 7.39
ISOTOPIC CONTENT (Ci/kg Pu) OF PLUTONIUM-239
SCRAP – 15 YEARS

ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION	ISOTOPE	CONCENTRATION
TL208	1.03203E-11	RN220	2.87241E-11	PU236	2.50449E-11	PU241	7.21543E-02
PB212	2.87235E-11	RA224	2.87241E-11	PU238	2.46854E-05	PU242	1.91350E-07
BI212	2.87235E-11	TH228	2.87289E-11	PU239	1.16491E-02	AM241	2.37936E-03
PO216	2.87241E-11	U232	2.96333E-11	PU240	2.52617E-03		

STEP 1 EXECUTED AS SPECIFIED

TOTAL ACTIVITY 8.87 –02 Ci/kg Pu

HEAT GENERATION, watts/kg Pu
Primary 5.22 –04
Gamma 4.81 –07

8. EFFLUENT CONTROL AND ESTIMATED RELEASES TO THE ENVIRONMENT

8. EFFLUENT CONTROL AND ESTIMATED RELEASES TO THE ENVIRONMENT

(W. L. Marter)

8.1 Effluent Control

8.1.1 General

Defense waste processing must be designed and operated in such a manner that liquid and gaseous effluents meet established standards for releases of radioactivity to the environment. In adapting these standards for a specific aspect of operations, such as waste solidification, it must be recognized that releases of radioactivity will continue from other operational activities at SRP, i.e., the release of radioactive materials must be apportioned to all existing sources on the plant site. These include the normal releases from operating areas as well as migratory losses from existing seepage basins and burial grounds, and possibly the release involved in decommissioning production facilities.

8.1.2 Regulatory Aspects

See Section 11.

8.1.3 SRP Operating Standards

The Savannah River Plant currently operates under a Technical Standard for release of radioactivity from the plant site. This standard does not specify amounts of radioactive nuclides that can be released in gaseous or liquid effluents, but rather, limits releases such that the annual exposure to an offsite individual will not exceed the limits shown in Table 8.1.

Again, these dose limits apply to all releases from all operations at SRP and only a portion of the limits could be assigned to a waste processing facility. No simple formula can be provided that enables the direct calculation of the amounts of individual radionuclides that can be released and yet remain within the technical standard. It is necessary to determine the identity of nuclides to be released, the amount of release, and the mode of release, i.e., gaseous or liquid. From this information, environmental dose commitments can be calculated and a judgment made as to acceptability of the releases. This analysis provides the contribution to environmental dose from each radionuclide by each mode of release and thus would serve as guidance in determining those aspects of effluent control that might require improved performance.

8.1.4 Seepage Basin Criteria

Current DOE policy [2] states that establishment of new seepage basins is to be avoided to avoid accumulation of radioactivity in soil, unless the radioactivity (1) is retrievable, or (2) does not build up above an acceptable level. Fission products in basins currently in use at SRP are not reasonably retrievable because of dispersion through large amounts of soil. The "acceptable level" for buildup of radioactivity in soil has already been exceeded in many basins from the standpoint that basin sites cannot be released for unrestricted use at time of seepage basin decommissioning.

The current criteria for use of seepage basins require that the release of fission products, activation products, uranium, and thorium be limited to the lowest practical level consistent with sound waste management practices. Transuranic release limits are set as low as practicable. At most, releases must be lower than values listed in Reference 3 to avoid buildup of radionuclides in the soil. Except in seepage basins already exceeding the reference values, the intention of the limit in transuranic concentrations in soil is to avoid the need for soil removal upon decommissioning of seepage basins.

The seepage basin criteria were used as the basis for reactivating the P and C Areas seepage basins in 1979. Consequently, the reference process assumes that the activity levels in aqueous effluents will be reduced to the lowest practical level and to levels well below those concentrations prescribed for release to uncontrolled areas [4].

8.2 Estimated Releases to the Environment

The annual discharge of radioactive contaminants to the atmosphere and plant streams was estimated. Tables 8.2 through 8.10 summarize these data for 5- and 15-year-aged feed to the DWPF. Table 8.11 compares these estimated releases to 1978 SRP releases. Offsite dose calculations from the estimated DWPF releases were not completed at the time this document was issued. However, for comparison purposes, the offsite dose from the previously estimated DWPF releases (DPSTD-77-2), which are greater than the current estimate, is compared to the offsite dose from SRP 1978 releases in the following two paragraphs.

Offsite dose from 1978 SRP atmospheric releases was 112 man-rem (calculated with NRC GASPAR code for the 80-km population).* Approximately 92% of this population dose was from tritium. Particulates only accounted for 0.86% of the dose. The offsite dose for the estimated DWPF releases was 0.124 man-rem with approximately 75% from tritium and 25% from particulates. This dose is only 0.11% of the dose from normal SRP releases and is judged acceptable.

Offsite dose from 1978 SRP aqueous releases was 16 man-rem downstream from SRP (calculated with NRC LADTAP code).* Tritium accounted for 78% of this dose. Although DWPF releases would cause a population dose of 4.7 man-rem, a 29% increase of the dose from normal SRP releases, the population dose would still be only 0.02% of the dose from natural sources to the population groups considered. Dose to an individual from consuming 2 liters of river water per day would be 0.13 mrem from DWPF releases and 0.35 mrem from SRP 1978 releases, a total of 0.48 mrem, well within the 4 mrem limit specified by the EPA** for public drinking water supplies. The anticipated DWPF releases to liquid effluents are therefore judged acceptable.

TABLE 8.1

Savannah River Plant Annual Exposure Operating Guides

Type of Exposure	Dose Limit, mrem/yr
Whole Body	10
Gonads	10
Bone Marrow	10
Gastrointestinal Tract	30
Bone	30
Thyroid	30
All Other Organs	30

---

* Doses previously published in PTDS #2 were calculated with SRL computer codes and will differ slightly from these doses calculated with NRC computer codes.

** National Interim Primary Drinking Water Regulations, 40 CFR 141.

TABLE 8.2
ESTIMATED ANNUAL AQUEOUS RELEASES TO THE ENVIRONMENT – 5 YEARS

ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	9.95477E 02	SN123	2.26765E-10	ND144	4.10044E-19	U238	2.40729E-13
CR 51	8.66364E-26	SN126	1.28804E-11	PM147	2.06069E-05	NP236	1.43401E-17
CO 60	1.41706E-07	SB124	6.10498E-17	PM148	5.92861E-20	NP237	7.29210E-12
SE 79	2.31534E-10	SB125	7.21560E-07	PM148M	8.59623E-19	PU236	5.16982E-11
RB 87	1.40492E-14	SB126	1.80325E-12	SM147	1.62850E-15	PU237	3.77283E-21
SR 89	6.51139E-14	SB126M	1.28804E-11	SM148	4.79495E-21	PU238	6.21026E-07
SR 90	3.99130E-05	TE125M	3.37185E-07	SM149	1.48629E-21	PU239	5.84519E-09
Y 90	3.90232E-05	TE127	1.47191E-10	SM151	2.01025E-07	PU240	3.69382E-09
Y 91	1.20169E-12	TE127M	1.50272E-10	EU152	3.14318E-09	PU241	6.94581E-07
ZR 93	1.50273E-09	TE129	3.71905E-21	EU154	5.16316E-07	PU242	4.92170E-12
ZR 95	8.20261E-12	TE129M	5.85747E-21	EU155	4.08720E-07	AM241	8.94853E-09
NB 95	1.76357E-11	I129	1.25223E-09	EU156	4.35761E-41	AM242	1.18103E-11
NB 95M	1.04173E-13	CS134	7.05122E-06	TB160	9.54227E-16	AM242M	1.18695E-11
TC 99	1.09974E-08	CS135	1.21754E-10	TL206	4.42964E-27	AM243	4.76992E-12
RU103	5.96116E-17	CS137	6.50503E-05	TL207	6.57499E-17	CM242	2.89898E-11
RU106	7.78556E-06	BA137M	6.15376E-05	TL208	1.02594E-12	CM243	4.59448E-12
RH103M	5.96703E-17	CE141	3.00156E-20	TL209	4.17939E-21	CM244	1.34731E-10
RH106	7.78557E-06	CE142	8.13477E-15	U232	4.23619E-12	CM245	5.49678E-15
PD107	8.91939E-12	CE144	8.40923E-06	U233	5.02004E-16	CM246	4.38760E-16
AG110	1.23589E-08	PR143	1.02088E-13	U234	1.32305E-11	CM247	5.39371E-22
CD115M	9.94976E-19	PR144	8.40954E-06	U235	4.37027E-14	CM248	5.63252E-22
SN121M	2.79319E-11	PR144M	1.00913E-07	U236	9.47892E-13		

TOTAL ESTIMATED RELEASES (Ci)

Tritium	9.95 02
Fission Products	2.67-04
Uranium	1.87-11
Transuranics	1.34-06

TABLE 8.3
ESTIMATED ANNUAL AQUEOUS RELEASES TO THE ENVIRONMENT — 15 YEARS

ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	5.65630E 02	SN123	6.79870E-19	PM147	1.46676E-06	NP236	1.43393E-17
CU 60	3.79043E-08	SN126	1.28803E-11	SM147	2.09802E-15	NP237	7.32546E-12
SE 79	2.31509E-10	SB124	3.32242E-35	SM148	4.79495E-21	PU236	4.54546E-12
RB 87	1.40492E-14	SB125	5.69638E-08	SM149	1.48629E-21	PU238	5.73860E-07
SR 89	4.66908E-35	SB126	1.80324E-12	SM151	1.86578E-07	PU239	5.84351E-09
SR 90	3.04947E-05	SB126M	1.28803E-11	EU152	1.84352E-09	PU240	3.68991E-09
Y 90	3.04926E-05	TE125M	2.66193E-08	EU154	2.30484E-07	PU241	4.33448E-07
Y 91	2.07398E-31	TE127	1.20401E-20	EU155	9.63472E-08	PU242	4.92164E-12
ZR 93	1.50271E-09	TE127M	1.22921E-20	TB160	5.91537E-31	AM241	1.76225E-08
ZR 95	1.34130E-28	I129	1.25221E-09	TL206	1.48005E-25	AM242	1.12838E-11
NB 95	2.89201E-28	CS134	2.43756E-07	TL207	1.80782E-16	AM242M	1.13404E-11
NB 95M	1.70345E-30	CS135	1.21754E-10	TL208	2.19396E-12	AM243	4.76543E-12
TC 99	1.08970E-08	CS137	5.16701E-05	TL209	1.90320E-20	CM242	9.35914E-12
RU106	8.15304E-09	BA137M	4.88801E-05	U232	5.60292E-12	CM243	3.60254E-12
RH106	8.15304E-09	CE142	8.13477E-15	U233	8.20140E-16	CM244	9.18841E-11
PD107	9.91937E-12	CE144	1.14469E-09	U234	3.01663E-11	CM245	5.49228E-15
AG110	5.35648E-13	PR144	1.14473E-09	U235	4.37027E-14	CM246	4.38118E-16
CD115M	1.98993E-43	PR144M	1.37365E-11	U236	9.48986E-13	CM247	5.39371E-22
SN121M	2.43139E-11	ND144	4.13163E-19	U238	2.40729E-13	CM248	5.63250E-22

TOTAL ESTIMATED RELEASES (Ci)

Tritium	5.66 02
Fission Products	1.64-04
Uranium	3.70-11
Transuranics	1.04-06

TABEL 8.4
ESTIMATED ANNUAL ATMOSPHERIC RELEASES TO THE ENVIRONMENT – 5 YEARS
SOURCE – SAND FILTER STACK

ISOTOPS	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	2.81251E 01	SN126	2.28395E-10	PR144M	1.78939E-06	U236	1.73383E-11
CR 51	1.34427E-24	SB124	1.08254E-15	ND144	7.27093E-18	U238	4.40329E-12
CO 60	2.59202E-06	SB125	1.27948E-05	PM147	3.65404E-04	NP236	2.62302E-16
SE 79	1.03722E-07	SB126	3.19754E-11	PM148	1.05127E-18	NP237	1.33383E-10
RB 87	6.88282E-12	SB126M	2.28396E-10	PM148M	1.52429E-17	PU236	9.47801E-10
SR 89	7.70655E-13	TE125M	1.51052E-04	SM147	2.88767E-14	PU237	6.91689E-20
SR 90	4.61738E-04	TE127	6.59387E-08	SM148	8.50243E-20	PU238	1.13855E-05
Y 90	4.61159E-04	TE127M	6.73186E-08	SM149	2.63551E-20	PU239	1.07162E-07
Y 91	1.42226E-11	TE129	1.66606E-10	SM151	3.56460E-06	PU240	6.77201E-08
ZR 93	2.74971E-08	TE129M	2.62402E-10	EU152	5.74933E-08	PU241	1.27340E-05
ZR 95	1.50038E-10	I129	6.42646E-03	EU154	9.44420E-06	PU242	9.02314E-11
NB 95	3.23499E-10	CS134	9.09847E-05	EU155	7.47609E-06	AM241	1.63682E-07
NB 95M	1.90548E-12	CS135	1.57104E-09	EU156	7.97072E-40	AM242	2.16027E-10
TC 99	1.37724E-06	CS137	8.39377E-04	TB160	1.69204E-14	AM242M	2.17110E-10
RU103	4.12772E-13	BA137M	7.94043E-04	TL206	6.87286E-26	AM243	8.72489E-11
RU106	5.39399E-02	BA140	9.96154E-45	TL207	1.02015E-15	CM242	5.30266E-10
RH103M	4.13177E-13	LA140	6.54150E-45	TL208	1.59180E-11	CM243	8.40397E-11
RH106	5.39100E-02	CE141	5.42877E-19	TL209	6.48456E-20	CM244	2.46443E-09
PD107	1.38390E-10	CE142	1.44246E-13	U232	7.74863E-11	CM245	1.00544E-13
AG110	1.91756E-07	CE144	1.49113E-04	U233	9.18239E-15	CM246	8.02558E-15
CD115M	1.38361E-17	PR143	1.81024E-42	U234	2.42006E-10	CM247	9.86591E-21
SN121M	4.95291E-10	PR144	1.49119E-04	U235	7.99388E-13	CM248	1.03027E-20
SN123	4.01394E-09						

TOTAL ESTIMATED RELEASES (Ci)

Tritium	2.81 01
Fission Products	1.18-01
Uranium	3.41-10
Transuranics	2.45-05

TABLE 8.5
ESTIMATED ANNUAL ATMOSPHERIC RELEASES TO THE ENVIRONMENT – 15 YEARS
SOURCE – SAND FILTER STACK

ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	1.59808E 01	SN123	1.20555E-17	PM148	2.50706E-45	NP236	2.62287E-16
CO 60	6.93336E-07	SN126	2.28394E-10	PM148M	3.63513E-44	NP237	1.33993E-10
SE 79	1.03711E-07	SB124	5.69132E-34	SM147	3.72023E-14	PU236	8.33336E-11
RB 87	6.88282E-12	SB125	1.01009E-06	SM148	8.50243E-20	PU237	5.54201E-44
SR 89	5.52608E-34	SB126	3.19752E-11	SM149	2.63551E-20	PU238	1.05208E-05
SR 90	3.60809E-04	SB126M	2.28395E-10	SM151	3.30841E-06	PU239	1.07131E-07
Y 90	3.60954E-04	TE125M	1.19249E-05	EU152	3.37208E-08	PU240	6.76486E-08
Y 91	2.45466E-30	TE127	5.39371E-18	EU154	4.21591E-06	PU241	7.94656E-06
ZR 93	2.74869E-08	TE127M	5.50659E-18	EU155	1.76233E-06	PU242	9.02304E-11
ZR 95	2.45344E-27	I129	6.42630E-03	TB160	1.04892E-29	AM241	3.22342E-07
NB 95	5.28991E-27	CS134	3.14530E-06	TL206	2.29639E-24	AM242	2.06397E-10
NB 95M	3.11587E-29	CS135	1.57103E-09	TL207	2.80493E-15	AM242M	2.07432E-10
TC 99	1.87718E-06	CS137	6.66725E-04	TL208	3.40407E-11	AM243	8.71669E-11
RU103	7.08402E-41	BA137M	6.30715E-04	TL209	2.95294E-19	CM242	1.71192E-10
RU106	5.64891E-05	CE142	1.44240E-13	U232	1.02486E-10	CM243	6.58957E-11
RH103M	7.09101E-41	CE144	2.02978E-08	U233	1.50016E-14	CM244	1.68069E-09
RH106	5.64891E-05	PR144	2.02984E-08	U234	5.51786E-10	CM245	1.00462E-13
PD107	1.38390E-10	PR144M	2.43577E-10	U235	7.99388E-13	CM246	8.01383E-15
AG110	8.31090E-12	ND144	7.32626E-18	U236	1.73584E-11	CM247	9.86590E-21
CD115M	3.08750E-42	PM147	2.60087E-05	U238	4.40329E-12	CM248	1.03027E-20
SN121M	4.31136E-10						

TOTAL ESTIMATED RELEASES (Ci)

Tritium	1.60 01
Fission Products	8.55-03
Uranium	6.76-10
Transuranics	1.90-05

TABLE 8.6
ESTIMATED ANNUAL ATMOSPHERIC RELEASES TO THE ENVIRONMENT – 5 YEARS
SOURCE – REGULATED FACILITY VESSEL VENT

ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	3.96581E 00	SN123	1.67637E-11	ND144	3.03568E-20	U238	1.83166E-15
CR 51	2.92151E-26	SN126	9.53560E-13	PM147	1.52560E-06	NP236	1.09122E-19
CO 60	1.07233E-09	SB124	4.51974E-18	PM148	4.38913E-21	NP237	5.54897E-14
SE 79	4.47719E-11	SB125	5.34197E-08	PM148M	6.36410E-20	PU236	4.74948E-15
RB 87	1.13697E-16	SB126	1.33501E-13	SM147	1.20564E-16	PU237	3.46608E-25
SR 89	1.06359E-18	SB126M	9.53501E-13	SM148	3.54984E-22	PU238	5.70536E-11
SR 90	6.40193E-10	TE125M	6.52022E-08	SM149	1.10036E-22	PU239	5.36995E-13
Y 90	6.40359E-10	TE127	2.84626E-11	SM151	1.48826E-08	PU240	3.39349E-13
Y 91	1.97194E-17	TE127M	2.90584E-11	EU152	2.39183E-11	PU241	6.38108E-11
ZR 93	1.14352E-11	TE129	7.19156E-22	EU154	3.92896E-09	PU242	4.52153E-16
ZR 95	6.24169E-14	TE129M	1.13266E-21	EU155	3.11019E-09	AM241	6.80950E-11
NB 95	1.34502E-13	I129	4.66615E-11	EU156	3.31596E-43	AM242	8.98718E-14
NB 95M	7.92713E-16	CS134	2.24799E-09	TB160	7.06449E-17	AM242M	9.03225E-14
TC 99	1.53345E-08	CS135	3.88162E-14	TL206	1.49373E-27	AM243	3.62973E-14
RU103	7.12410E-17	CS137	2.07387E-08	TL207	2.21717E-17	CM242	2.20600E-13
RU106	9.30443E-06	BA137M	1.96188E-08	TL208	3.45957E-13	CM243	3.49622E-14
RH103M	7.13113E-17	CE141	2.26659E-21	TL209	1.40934E-21	CM244	1.02525E-12
RH106	9.30444E-06	CE142	6.02243E-16	U232	3.22356E-14	CM245	4.18284E-17
PD107	3.00774E-12	CE144	6.22565E-07	U233	3.82007E-18	CM246	3.33879E-18
AG110	4.16759E-09	PR143	7.55797E-45	U234	1.00679E-13	CM247	4.10439E-24
CD115M	3.01798E-19	PR144	6.22569E-07	U235	3.32560E-16	CM248	4.28611E-24
SN121M	2.06789E-12	PR144M	7.47093E-09	U236	7.21305E-15		

TOTAL ESTIMATED RELEASES (Ci)

Tritium	3.97 00
Fission Products	2.16-05
Uranium	1.42-13
Transuranics	1.92-10

TABLE 8.7
ESTIMATED ANNUAL ATMOSPHERIC RELEASES TO THE ENVIRONMENT – 15 YEARS
SOURCE – REGULATED FACILITY VESSEL VENT

ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	2.25337E 00	SN121M	1.80003E-12	PM147	1.08589E-07	NP236	1.09116E-15
CO 60	2.89441E-10	SN123	5.03530E-20	SM147	1.55324E-16	NP237	5.57436E-14
SE 79	4.47671E-11	SN126	9.53573E-13	SM148	3.54984E-22	PU236	4.17588E-16
RB 87	1.13697E-16	SB124	2.45970E-36	SM149	1.10036E-22	PU238	5.27203E-11
SR 89	7.66182E-40	SB125	4.21722E-09	SM151	1.38130E-08	PU239	5.36840E-13
SR 90	5.00244E-10	SB126	1.33501E-13	EU152	1.40286E-11	PU240	3.38989E-13
Y 90	5.00375E-10	SB126M	9.53574E-13	EU154	1.75389E-09	PU241	3.98207E-11
Y 91	3.40335E-36	TE125M	5.14738E-09	EU155	7.33166E-10	PU242	4.52148E-16
ZR 93	1.14350E-11	TE127	2.32822E-21	TB160	4.37934E-32	AM241	1.34101E-10
ZR 95	1.02068E-30	TE127M	2.37693E-21	TL206	4.99092E-26	AM242	8.58653E-14
NB 95	2.20070E-30	I129	4.66607E-11	TL207	6.09617E-17	AM242M	8.62959E-14
NB 95M	1.29626E-32	CS134	7.77120E-11	TL208	7.39832E-13	AM243	3.62631E-14
TC 99	1.53940E-08	CS135	3.88161E-14	TL209	6.41785E-21	CM242	7.12198E-14
RU103	1.22264E-44	CS137	1.64730E-08	U232	4.26359E-14	CM243	2.74140E-14
RU106	9.74957E-09	BA137M	1.55833E-08	U233	6.24095E-18	CM244	6.99204E-13
RH103M	1.22185E-44	CE142	6.02243E-16	U234	2.29554E-13	CM245	4.17942E-17
RH106	9.74958E-09	CE144	8.47454E-11	U235	3.32560E-16	CM246	3.33389E-18
PD107	3.00774E-12	PR144	9.47467E-11	U236	7.22138E-15	CM247	4.10439E-24
AG110	1.80628E-13	PR144M	1.01697E-12	U238	1.83186E-15	CM248	4.28610E-24
CD115M	6.71033E-44	ND144	3.05678E-20				

TOTAL ESTIMATED RELEASES (Ci)

Tritium	2.25 00
Fission Products	2.00-07
Uranium	2.81-13
Transuranics	2.28-10

TABLE 8.8

ESTIMATED ANNUAL ATMOSPHERIC RELEASES TO THE ENVIRONMENT – 5 YEARS

SOURCE – PRODUCT SALT CONCENTRATION/SOLIDIFICATION VESSEL VENT

ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	7.71420E 00	SN123	3.58975E-11	ND144	6.49283E-20	U238	3.91500E-15
CR 51	6.24706E-26	SN126	2.03955E-12	PM147	3.26301E-06	NP236	2.33214E-19
CO 60	2.30457E-09	SB124	9.00699E-18	PM148	9.38764E-21	NP237	1.18591E-13
SE 79	9.57652E-11	SB125	1.14256E-07	PM148M	1.36118E-19	PU236	9.42956E-15
RB 87	2.43003E-16	SB126	2.65538E-15	SM147	2.57867E-16	PU237	6.88150E-25
SR 89	1.30646E-18	SB126M	2.03956E-12	SM148	7.59253E-22	PU238	1.13273E-10
SR 90	3.18718E-10	TE125M	1.39465E-07	SM149	2.35349E-22	PU239	1.06614E-12
Y 90	3.18930E-10	TE127	6.08803E-11	SM151	3.18316E-08	PU240	6.73737E-13
Y 91	2.52183E-17	TE127M	6.21545E-11	EU152	5.11177E-11	PU241	1.26689E-10
ZR 93	2.44389E-11	TE129	1.53825E-21	EU154	8.39688E-09	PU242	8.97699E-16
ZR 95	1.33400E-13	TE129M	2.42272E-21	EU155	6.64701E-09	AM241	1.45531E-10
NB 95	2.37625E-13	I129	9.97926E-11	EU156	7.08677E-43	AM242	1.92072E-13
NB 95M	1.69416E-15	CS134	4.70675E-09	TB160	1.51098E-16	AM242M	1.93035E-13
TC 99	3.29378E-08	CS135	8.15002E-14	TL206	3.19506E-27	AM243	7.75737E-14
RU103	1.52386E-16	CS137	4.34402E-08	TL207	4.74251E-17	CM242	4.71461E-13
RU106	1.99023E-05	BA137M	4.10943E-08	TL208	7.39996E-13	CM243	7.47205E-14
RH103M	1.52536E-16	CE141	4.84785E-21	TL209	3.01458E-21	CM244	2.19115E-12
RH106	1.99023E-05	CE142	1.28810E-15	U232	6.88931E-14	CM245	8.93944E-17
PD107	6.43352E-12	CE144	1.33157E-06	U233	8.16415E-18	CM246	7.13557E-18
AG110	8.91441E-09	PR143	1.61653E-44	U234	2.15169E-13	CM247	8.77180E-24
CD115M	6.45542E-19	PR144	1.33162E-06	U235	7.10739E-16	CM248	9.16017E-24
SN121M	4.47289E-12	PR144M	1.59791E-08	U236	1.54156E-14		

TOTAL ESTIMATED RELEASES (Ci)	
Tritium	7.71 00
Fission Products	4.62-05
Uranium	3.03-13
Transuranics	3.91-10

TABLE 8.9
ESTIMATED ANNUAL ATMOSPHERIC RELEASES TO THE ENVIRONMENT – 15 YEARS
SOURCE – PRODUCT SALT CONCENTRATION/SOLIDIFICATION VESSEL VENT

ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES	ISOTOPE	CURIES
H 3	4.38321E 00	SN121M	3.84998E-12	PM147	2.32254E-07	NP236	2.33200E-15
CO 60	6.16449E-10	SN123	1.07654E-19	SM147	3.32214E-16	NP237	1.19134E-13
SE 79	9.57549E-11	SN126	2.03954E-12	SM148	7.59253E-22	PU236	8.29073E-16
RB 87	2.43003E-16	SB124	5.26091E-36	SM149	2.35349E-22	PU238	1.04670E-10
SR 89	9.79839E-40	SB125	9.01995E-09	SM151	2.95439E-08	PU239	1.06583E-12
SR 90	6.39742E-10	SB126	2.85536E-13	EU152	2.99815E-11	PU240	6.73024E-13
Y 90	6.39910E-10	SB126M	2.03954E-12	EU154	3.74837E-09	PU241	7.90596E-11
Y 91	4.35241E-36	TE125M	1.10100E-08	EU155	1.56690E-09	PU242	8.97690E-16
ZR 93	2.44387E-11	TE127	4.97995E-21	TB160	9.36669E-32	AM241	2.86597E-10
ZR 95	2.13138E-30	TE127M	5.08414E-21	TL206	1.06755E-25	AM242	1.83510E-13
NB 95	4.70326E-30	I129	9.97909E-11	TL207	1.30396E-16	AM242M	1.84430E-13
NB 95M	2.77033E-32	CS134	1.62779E-10	TL208	1.58249E-12	AM243	7.75008E-14
TC 99	3.29067E-08	CS135	8.13062E-14	TL209	1.37277E-20	CM242	1.52209E-13
RU103	2.61525E-44	CS137	3.45050E-08	U232	9.11203E-14	CM243	5.85884E-14
RU106	2.08545E-08	BA137M	3.26416E-08	U233	1.33380E-17	CM244	1.49432E-12
RH103M	2.61784E-44	CE142	1.28810E-15	U234	4.90598E-13	CM245	8.93215E-17
RH106	2.08545E-08	CE144	1.81257E-10	U235	7.10739E-16	CM246	7.12510E-18
PD107	6.43351E-12	PR144	1.81264E-10	U236	1.54334E-14	CM247	8.77180E-24
AG110	3.86360E-13	PR144M	2.17513E-12	U238	3.91500E-15	CM248	9.16014E-24
CD115M	1.43533E-43	ND144	6.54224E-20				

TOTAL ESTIMATED RELEASES (Ci)	
Tritium	4.38 00
Fission Products	4.31-07
Uranium	6.01-13
Transuranics	4.75-10

TABLE 8.10

Estimated Total Annual Releases (Ci) to the Environment

	Point of Release			
	Atmosphere		Aqueous	
Isotopic Group	5-Yr	15-Yr	5-Yr	15-Yr
Tritium	3.98+01	2.26+01	9.95+02	5.65+02
Fission Products	1.18-01	8.55-03	2.67-04	1.64-04
Uranium	3.41-10	6.77-10	1.87-11	3.70-11
Transuranics	2.45-05	1.90-05	1.34-06	1.04-06

TABLE 8.11

Comparison of Annual Radioactive Releases (Ci) SRP vs. DWPF

	Point of Release					
	Atmosphere			Aqueous		
		DWPF			DWPF	
Isotopic Group	SRP*	5-Yr	15-Yr	SRP*	5-Yr	15-Yr
Tritium	3.8 +05	3.98+01	2.26+01	4.0+04	9.95+02	5.65+02
Fission Products**	1.11+01	1.18-01	8.55-03	7.7-01	2.67-04	1.64-04
Uranium	3.1 -03	3.41-10	6.77-10	5.6-02	1.87-11	3.70-11
Transuranics	8.5 -03	2.45-05	1.90-05	5.8-03	1.34-06	1.04-06

---

* 1978 Releases.

** Does not include noble gases.

8.3 References

1. Deleted.

2. Plan for Management of AEC-Generated Wastes. USAEC Report WASH-1202(73), E. I. du Pont de Nemours & Company (Inc.), Savannah River Laboratory, Aiken, SC (July 1973).

3. Deleted.

4. Standards for Radiation Protection. ERDA Manual, Chapter 0524. U.S. Energy Research and Development Administration, Washington, DC.

9. SAFETY ANALYSIS (M. W. Lee)

9.1 Nuclear and Process Safety

Potential incidents from trivial to major accidents, that could adversely affect the nuclear and process safety of the DWPF and/or could contaminate onsite or offsite populations have been identified. The possible causes of each incident, its consequence, the expected frequency of the occurrence and applicable safety features have been identified [1-6]. These incidents were abstracted from a literature review of related nuclear facilities and from historical records of similar unit operations at the Savannah River Plant. A more detailed analysis of possible causes and consequences using fault tree and cause-consequence techniques will be made during the preparation of the Safety Analysis Report for the DWPF prior to plant startup.

Engineered safety features were selected to either reduce the frequency of the postulated event or to mitigate its consequence. Safety features which reduce the frequency of events include modifications of process equipment, suggested administrative controls, warning alarms, interlock systems, and negative feedback controls. Examples of mitigating safety features are fire suppression system emergency cooling and power systems, explosion limiting devices, and redundant equipment with alarms.

A list of potential incidents, the areas where they may occur, and the identified applicable engineered safety features to mitigate or prevent the incidents are summarized in Tables 9.1 through 9.3.

9.2 Hazards Analysis*

9.2.1 Potential Effects from Normal Operations

9.2.1.1 Occupational Radiation Exposures

Most of the operations necessary to implement the DWPF plans will result in small amounts of radiation exposure to the involved personnel. DOE places restrictions on radiation exposures of workers. The DOE radiation protection standard is 5 rems to the whole body each year and/or 3 rems each calendar quarter [7]. Extensive efforts are made, beyond those required to ensure compliance, with the objective of reducing worker exposure to amounts that are as low as reasonably achievable (ALARA). These efforts include detailed planning of work, which involves radiation exposure potential, to reduce exposure time and to provide adequate shielding. The execution of such work is carried out under written procedures that are approved by health physics specialists. These procedures specify the time limits for the work and the protective clothing and equipment for the work. Depending on the radiation and contamination potential, the work may be continuously monitored by health physicists.

Experience with operation of the Savannah River Plant indicates that actual personnel exposures can be expected to be considerably less than the DOE standards as a result of the ALARA policy. For example, a summary of SRP occupational dose for 1965 to 1975 is shown in Table 9.4. The annual average dose per monitored employee ranged from 2.7 to 3.7 rems, with the exception of a single apparent dose of 24.8 rems to an employee in 1971 that was not substantiated in follow-up investigations.

Work done in the irradiated fuel reprocessing areas at SRP is similar in many important aspects to work that would be done in conjunction with waste processing. Table 9.5 gives exposure experience for workers involved in the reprocessing activities, excluding those whose jobs involve no potential occupational exposure. As can be seen by comparing Tables 9.4 and 9.5, there is little difference in the exposure received by the average plant employee and those involved specifically with processing operations. The radiation exposures of workers in new waste management facilities should be expected to be even lower than workers in present SRP processing buildings because of the greater shielding and improved equipment for handling radioactive material.

---

* This chapter is an excerpt from the Draft Programmatic Environmental Impact Statement for Management of Defense High-Level Radioactive Waste, Savannah River Plant, issued in March 1978.

Table 9.6 gives results of estimating the occupational exposures by two different techniques: the assumption was made that individual doses would be the same as the average SRP experience for 1965 to 1975 and it was assumed that individual doses would be equal to the DOE standards discussed above. The latter is a very conservative assumption because, even if the potential for such exposures existed, it would be impractical, and undesirable, to rotate and schedule all employees so that everyone received exposure up to the DOE limit.

9.2.1.2 Non-Nuclear Occupational Risks

Some non-nuclear risk of injuries, and death exists during construction of new facilities and during the operating campaign. (For minor injuries, only first aid is required and no days are lost from work; major injuries involve one or more lost workdays.) Experience with many construction activities at SRP and from 26 years of operation has shown that these risks can be low in magnitude and below those experienced in many other industrial activities. Tables 9.8 and 9.9 give the results of estimating the number of occupational casualties during construction of new facilities and for the operating phases, respectively.

9.2.1.3 Offsite Radiation Exposures

All facilities will be designed and operated such that radioactive releases from normal operations will be within the overall EPA criteria for such releases and within specific DOE and NRC standards. The current DOE standards for offsite radiation exposures are shown in Table 9.10 [7].

Although the facilities must be operated to fall within the limits discussed above, they will also be operated with the objective of keeping exposures as low as reasonably achievable. In all likelihood, this will result in extremely low, if not zero, exposures from the long-term storage or disposal facilities, and offsite exposures from the handling and processing operations that are comparable to those currently experienced from similar activities at SRP. In 1976, these exposures to a hypothetical maximum individual* were below 1 mrem from all SRP activities and included contributions from the reactors and from isotopes such as H-3, Kr-85, Ar-41, and Xe-133,135 that would not be released in significant quantities in the waste handling and processing operations. Routine releases from SRP are discussed more fully in Reference 8.

---

* Maximum individuals are assumed to be at the site boundary under conditions of maximum probable exposure.

9.2.1.4 Nonradioactive Pollutants

No mechanisms have been identified for chemical releases under normal conditions for the storage or disposal modes and, therefore, the following discussion is concentrated on processing operations.

When the waste is fixed in glass, there will be releases from the processing operations to the atmosphere and to the onsite streams of chemicals such as Hg, NO_x, NH_3, CO_2, NaOH, $NaNO_3$, and heated water. These releases, when combined with those from other activities at SRP, must be within emission standards set by South Carolina and Georgia and the Federal Government [9,10]. Some of the more important standards are shown in Table 9.11. In addition to the limits imposed by the above standards, SRP operates under National Pollutant Discharge Elimination System (NPDES) permits that limit the discharge of pollutants to tributaries of the Savannah River [11].

Waste management policy at SRP is to limit releases of potentially polluting chemicals to levels that are lower than those required by the standards and permits, to the extent that is reasonably achievable. This policy is implemented by operating controls and by appropriate engineered systems. The extent to which these systems are needed and the releases to the environment that are to be expected will be determined as the research and development program proceeds and detailed design studies are made. Operation of similar processes and pollution abatement devices at SRP is described in detail in Reference 8, where it is shown that SRP emissions to the atmosphere have been far below the standards shown in Table 9.11, with the exception of particulates from some of the coal-burning power plants. Electrostatic precipitators have been installed on the largest power plants, and prototype improvements are being tested on other plants to ensure conformity with South Carolina emission standards for particulates.

Water that discharges from the SRP creeks to the Savannah River now meets Federal and South Carolina regulations. However, a project has been submitted to DOE for FY-1978 funding [12] that would bring most discharges from individual operating sites into compliance with NPDES Permit No. SC 0000175 before those discharges enter the creeks. Most of the water covered in the project is runoff from coal piles and ash basins, and is of low pH and has high suspended solids.

In addition to the emissions to water and air described above, there will be low levels of occupational exposure to non-radioactive pollutants of some workers. Such exposures would occur during processing operations, but not during transportation, storage, or disposal. Reference 13 specifies limits and controls required for exposure to chemicals as legislated by the Occupational Health and Safety Act. Concentrations in air of chemicals to which the worker is exposed will normally be maintained by engineering controls such as ventilation at less than the action level values specified in Subpart Z of Reference 13. Potential exposure of the worker is limited because the chemicals are normally introduced into the process within ventilated enclosures designed to contain radioactivity. Exposures may occur in storage areas, during transport of chemicals from the storage areas, and during preparation of the chemicals for the processes. When concentrations are above an action level, routine monitoring is required rather than audit monitoring. When threshold limit values are exceeded, workers will wear personal protective equipment including respiratory protection as prescribed in Subpart I of Reference 13. Engineering controls would be added or modified to reduce transient high concentrations to less than threshold limit values. Records are required for each worker exposed to chemicals at concentrations greater than threshold limit values.

9.2.2 Potential Effects from Abnormal Events

9.2.2.1 General

Details of consequences and probabilities of a wide range of abnormal events will be published in the Safety Analysis Report dealing with all aspects of the DWPF. Such analyses must await detailed system design based on results of the research and development program. One of the primary purposes of the program is to influence the design of various parts of the facility to ensure a high degree of confidence in acceptable safety regarding abnormal events.

Preliminary analyses have, however, been reported in Reference 8 for risks from unusual events that might occur in all operations involved. Events considered were major process incidents, natural events such as tornadoes and earthquakes, sabotage, airplane crash, and abandonment. The magnitudes were chosen to be upper bounds of credible occurrences. This approach provides a sound physical basis to obtain release fractions, to follow environmental pathways, and to calculate radiation exposures. Detailed results from Reference 8 are reviewed in the discussion below. In general, they show that consequences alone, without regard for probabilities, do not pose any disaster potential for the offsite populations. Individual doses that occur are comparable to background doses in most cases. It is expected that when formal analyses are made of all systems, the results will show much lower risks.

Some of the important physical reasons why the hazards associated with the waste are limited include:

- Very large amounts of energy are required to create waste particles small enough to be widely distributed through the airborne pathway. This is true on a per curie basis for the salt cake and sludge currently stored in tanks as well as for the high-integrity forms like glass.
- There are no inherent internal sources of high energy in the waste management systems. Energy required to release radioactive particles would have to be introduced externally and in some abnormal manner.
- There are no radioactive noble gases or significant amounts of easily volatilized radioactive elements in the waste that could contribute to potential doses from the airborne pathway.
- High-integrity waste forms and engineered surface storage facilities can impose major barriers against waste migration.
- Liquid releases from SRP would be absorbed in the soil or diluted many orders of magnitude by the onsite creeks and swamps and by the Savannah River before reaching drinking water users. Even if diversion systems fail and no corrective actions are taken, no large individual doses can occur.
- The SRP waste facilities are within a large exclusion area surrounded by land of low population density.

An added level of accident protection to both workers and offsite population is provided by the design of waste management facilities. The construction methods and materials that meet routine radiation shielding requirements and that ensure adequate resistance to earthquakes and tornadoes also provide resistance and containment for other unlikely incidents.

9.2.2.2 Occupational Radiation Exposures

All the very low probability events that have some potential for releasing radioactive materials offsite also have the potential for exposing working personnel to high radiation exposures. These events include major process incidents, tornadoes and earthquakes of incredible magnitude, sabotage, and airplane crash. The distribution of radiation effects among the personnel at the site is impossible to predict because it would depend upon precise details of location of the personnel and corrective actions relative to the chain of events under way. This is in contrast to the predictability of offsite effects, where the major determinants are amount of activity released and meteorology or water flow patterns. Furthermore, the radiation would probably be a small contributor to the worker casualties in these unlikely events; most of the casualties would be from explosive forces, falling buildings, tornado-driven missiles, fire, saboteur gunfire, etc.

Even though consequences mentioned above are possible, their occurrence is extermely unlikely. This fact is generally illustrated by formal safety analyses of existing and designed nuclear systems, and by the experience of the commercial and defense nuclear enterprises over the past thirty years. When this low probability of occurrence is considered, the resulting occupational risk (the product of consequence times probability) from radiation exposure is negligible.

9.2.2.3 Non-Nuclear Occupational Risks

The non-nuclear risks to onsite workers from abnormal events are in the same category as the risks discussed above for radiation exposures, in the sense that casualties are possible but the likelihood of occurrence is so small that the risks are negligible. The number of casualties possible for each abnormal event is difficult or impossible to estimate because of the mitigating effects of forewarning, corrective action, etc. However, there has been no mechanism identified that would increase the non-nuclear risks above those normally experienced in any large industrial operation. In practice, the unusually heavy construction of the waste management facilities would probably provide greater worker protection against abnormal events than that afforded by most other industrial facilities.

9.2.2.4 Offsite Radiation Exposures

Analyses have previously been reported (Reference 14) which make estimates, using pessimistic assumptions where necessary, of the offsite radiation exposures that might occur for a variety of abnormal events. The events considered were major process incidents; natural occurrences such as tornadoes, earthquakes, floods, and meteorite impact; sabotage, airplane crash; and abandonment. The analyses considered the four major modules: removal from tanks, processing, transportation, and storage. The results are given as consequences (measured by radiation dose commitment)* to maximum offsite individuals and to the offsite population within 150 km. The consequences were then multiplied by an estimate of annual probability of occurrence to obtain annual risk. Finally, the annual risk was integrated for 300 years, accounting for radioactive decay and population growth, to obtain total risk for the period. (After 300 years of decay, individual doses that could occur from any of the events analyzed are negligible.) These data are given in Table 9.12. They show that there is no disaster potential to the offsite population from abnormal events. Although some of the maximum individual doses are of concern, they could occur to only a limited number of people and are calculated assuming no corrective actions are taken. Doses to average individuals in the nearby population would be thousands to tens of thousands of times lower, depending upon pathways, and therefore would be inconsequential compared to even the variation in natural background in the local area.

9.2.2.5 Offsite Land Contamination

Levels of radionuclide deposition that would require evacuation of people and restrictions on farming and milk production are discussed in more detail in Reference 14 and are given below in Table 9.13. The deposition limits were derived from the dose criteria given in Table 9.14 which are also discussed in Reference 14.

Only two operational modules have potential for causing offsite land contamination for any of the abnormal events considered. These two are sabotage during removal of waste from tanks and sabotage during processing waste to glass. The consequences, if each of these events did occur, are given in Tables 9.15 and 9.16, respectively, in terms of land contaminated and people evacuated.

9.2.2.6 Nonradioactive Pollutants

There will be no unusually large stores of chemicals required for implementation of any of the alternative plans. Therefore, there is little potential for pollutant release to the environment for the abnormal events considered. Furthermore, mitigating features such as sand filters and liquid diversion systems would be expected to retain most accidental releases. Operations have been

---

* Table IV-6 in the Draft Programmatic Environmental Impact Statement for Management of Defense High-Level Radioactive Waste, Savannah River Plant, issued March 1978.

conducted over the past 27 years at SRP using large quantities of such chemicals as nitric acid and hydrogen sulfide with no adverse effect on the environment, as discussed in Reference 8. Similar experience for releases attributable to abnormal events is expected to apply to any future waste management operations.

When the high-activity fraction is separated from the waste and subsequently processed to glass, there will remain about 19 million gallons of decontaminated salt cake. This salt could be stored in decontaminated waste tanks existing after processing, and would be subject to occurrence of the abnormal events discussed previously. The worst of these would be abandonment, with subsequent filling of the tanks with rainwater and runoff to the Savannah River. This scenario was analyzed in Reference 14, and the consequences are given in Table 9.17. Not only is this event considered very unlikely, but also the river would not be polluted above drinking water standards even if no corrective actions were taken.

TABLE 9.1

Operational Areas in the DWPF

Operational Area	Incidents
General	1-27
Waste Removal and Blending	28-49
Evaporation and Salt Solidification	50-62
Aluminum Dissolving	63-66
Centrifugation	67-71
Sand Filtration	72-76
Supernate Decontamination (Ion Exchange)	77-83
Elutriant Recovery (NH_3 and CO_2)	84-90
Recycle Concentration	91
Spray Drying	94-105
Glass Melting	106-109
Mechanical Cell	111
Crane Operation	112-119
Electric Power Supply	120-122
Water Supply	123-129
Steam Generation and Distribution	130-132
Sampling	133-139
Ventilation System	140-147
Gang Valve Operation	148-150
Compressed Air and Gas Systems	151-152

TABLE 9.2

Potential Incidents

Incident Number	Incidents	Applicable Engineered Safety Features
	(General)	
1	Earthquake greater than safe shutdown	1, 216
2	Meteorite impact	*
3	Hurricane or tornado	1, 216
4	Flood	2
5	Large aircraft impact	*
6	Sabotage	3
7	Total loss of cooling capability	1, 4
8	Loss of electric power	5, 11, 166, 167, 168, 169
9	Adverse effects of lightning	5, 7, 48
10	Adverse winter operating conditions	6, 8
11	Fire	9, 10, 60
12	Criticality	12, 38
13	Transfer error	13, 14, 15, 16
14	Vessel overflow	17, 18, 19, 20, 21, 52, 200
15	Transfer line pluggage	19, 20, 21, 22, 23, 53, 54, 113, 114, 115, 116, 117, 118
16	Vessel and line leakage	19, 20, 21, 25, 42, 200
17	Suckback	26, 27, 28, 29, 30, 31
18	Siphoning	32
19	Coil failure	17, 33, 34, 35
20	Vessel or piping rupture from impact of dropped equipment	19, 20, 21, 36, 61, 62
21	Chemical addition error	13, 14, 37, 200
22	Uncontrolled chemical reaction	13, 14, 17, 18, 20, 38, 39, 43, 44, 200
23	Instrument line pluggage	41, 42
24	Release during equipment removal	35, 34
25	Loss of instrument or process compressed air	11, 46, 47, 52
26	Temperature excursion in solids (Sludge) settling out of feed streams	40
27	Leakage through cell or canyon wall	20, 21, 25, 49, 50, 51

TABLE 9.2, Contd

Incident Number	Incidents	Applicable Engineered Safety Features
	(Waste Removal and Blending)	
28	Overflow of pump pit	17, 19, 20, 59
29	Overflow of waste tank	17, 18, 35, 55, 59
30	Waste tank explosion	5, 56, 57, 58, 59
31	Overflow of diversion box	19, 20, 35, 59, 63
32	Boiling waste tank	65, 66
33	Activity bypasses waste tank filter	60, 67, 68
34	Failure of seal between waste removal platform and tank	*
35	Increased air activity in waste tanks from slurrying activity	*
36	Overstressing of waste tank components	69
37	Potential for high personnel exposure during installation, removal, and maintenance of sludge pumps	45, 70, 71, 72, 73
38	Loss of tank ventilation	5, 57, 58
39	Underground equipment crushed by heavy vehicles	12, 74, 75, 76
40	Below ground leaks from waste tanks	20
41	Pump tank explosion	5, 56, 59, 64
42	Above ground release from process line	35, 59, 77, 78
43	Release from segregated water	*
44	Airborne release from diversion box	*
45	Contamination spread from localized spill	59
46	Tank damage from vortex formation	*
47	Rapid corrosion of carbon steel tanks	38
48	Failure of support structure for tank sludge pumps	*
49	Opening of self-heated cracks in tank	68, 79, 89

TABLE 9.2, Contd

Incident Number	Incidents	Applicable Engineered Safety Features
	(Evaporation and Salt Solidification)	
50	Overflow of evaporator cell	59
51	Leak through evaporator cell	*
52	Evaporator explosion	38, 40, 52, 82, 83
53	Chemical Oxidation of ruthenium to volatile ruthenium tetraoxide	*
54	Evaporator eructation	17, 52
55	Evaporator leak	19, 20, 21
56	Overflow of CTS pit	20, 59, 63
57	CTS tank explosion	40, 53, 59, 81
58	Spill from CTS cleanout port	*
59	Erronous transfer of evaporator materials	14
60	Collapse of salt cake storage tank	*
61	Release of activity from segregated water	*
62	Major liquid release from waste tank riser	17, 59
	(Aluminum Dissolving)	
63	Explosion in the off-gas system	81
64	Pressurization of the dissolver	52, 84, 85
65	Dissolver pot coils not submerged during shutdown	17, 86
66	High liquid level in dissolver	17, 18
	(Centrifugation)	
67	Severe vibration of centrifuge	87, 88
68	Centrifuge missile	87,88
69	Excessive cake compaction	89
70	Failure of centrifuge suspension system	87, 88
71	Centrifuge plow breaks	89,90

TABLE 9.2, Contd

Incident Number	Incidents	Applicable Engineered Safetv Features
	(Sand Filtration)	
72	Overflow of sand filter	17, 18
73	Fire in or around sand filter	*
74	Hydraulic surge	*
75	Failure of backflush system to operate	18
76	Introduction of nitric acid into caustic and ammonia bearing streams	13, 38
	(Supernate Decontamination)	
77	Cs breaktrhough of Duolite© column	22, 23, 24, 38
78	Precipitation in ion exchange column	18, 35, 91
79	Overheating of zeolite column	39, 40, 92
80	High temperature ion exchange column	39, 40
81	Line and sampler pluggage by resin	42
82	Uncontrolled reaction of resin	19, 40, 93
83	Improper resin level	*
	(Elutriant Recovery)	
84	Farming in elutriant recovery concentrator reboiler	23, 35, 94
85	Pluggage of elutriant recovery condenser	53, 95
86	Contamination of Cs elutriant makeup by Cs	53, 96
87	Ammonia compounds	13
88	Overheat of concentrator reboiler	17, 40, 54, 82
89	Overpressurization of concentrator	52, 97
90	Pluggage of elutriant recovery vent system	40, 98
	(Recycle Concentration)	
91	Accumulation of ion exchange resin in evaporator	*
92	Evaporator leakage	99
93	Explosion in evaporator	38, 40, 52, 82, 83

TABLE 9.2, Contd

Incident Number	Incidents	Applicable Engineered Safety Features
	(Spray Drying)	
94	High temperature breach of the spray dryer	40, 100, 101, 102, 103, 104, 105
95	Spray dryer breach from internal corrosion	40, 106
96	Spray dryer breach from thermal shock	40, 53, 107, 108, 109
97	Spray dryer breach from pressurization	42, 110, 111, 145, 146, 147, 148
98	Spray dryer breach from impact	1
99	Bypass or failure of sintered metal filters	53, 149, 150
100	HEPA filter system breached (not applicable)	151, 152, 153
101	Energetic airborne release	40, 100, 101, 102, 103, 104
102	High ruthenium adsorber bed temperature	154, 155
103	Increased volatilization of RuO_4 and localized RuO_2 depositon	40, 102, 103, 104
104	Excessive solvent oxidation in spray dryer	38
105	Abnormal nitrate and/or water in spray dryer	40, 100, 101, 102, 103, 104
	(Vitrification)	
106	Steam explosion	135, 136, 137, 156, 157
107	Refractory collapse or spalling	123, 138, 139, 140, 141, 142, 143, 144
108	Electrical shorting	124, 125, 126, 127, 128, 141
109	Major glass spill	112, 129, 130, 131, 132, 133 134, 144
110	Release of airborne activity to cell or ventilation system	112, 119, 129, 130, 131, 132, 133, 134, 144
	(Mechanical Cell)	
111	Failure of high level waste canister	99, 120, 121, 122

TABLE 9.2, Contd

Incident Number	Incidents	Applicable Engineered Safety Features
	(Crane Operatins)	
112	Personnel exposure in crane cab	158, 159
113	Contamination of crane external to the cab	160
114	Contamination of work areas by crane mishandling	*
115	Disengagement from crane hook	*
116	Damage to equipment by mishandling of crane	*
117	Crane cable failure	161, 162
118	Failure of crane movement control	163, 164
119	Optical system failure in hot crane	165
	(Electric Power Supply)	
120	Failure to supply power to a motor control center	170, 171
121	Failure to supply power to operating equipment	6, 170, 172, 173, 174, 175, 176, 177, 178, 179
122	Failure of emergency diesel generator system	180, 181, 182, 183, 184, 185, 186, 187, 188, 189
	(Water Supply)	
123	Failure of well pump	190, 191, 192, 193
124	Cooling tower system failure	*
125	Failure of cooling water supply header	52, 194
126	Failure of heat exchanger	*
127	Failure of recirculating cooling water return pump	190
128	Closed-loop cooling water contamination	33, 195, 196
129	Radioactive leakage to the environment through cooling water	38, 197
	(Steam Generation and Distribution)	
130	Leak in steam or cooling coil within process vessel	33, 195, 197, 198
131	High steam pressure in process equipment	82
132	Failure of steam supply	40, 52, 199

TABLE 9.2, Contd

Incident Number	Incidents	Applicable Engineered Safety Features
	(Sampling)	
133	Broken sample vial	201
134	Failure to survey person or material prior to removal from sample aisle	202
135	Air reversal	53, 204, 205, 215
136	Failure to obtain sample or analysis or delayed analysis	*
137	Sample spill	204
138	Sampler pressurization	42, 52, 204
139	Failure of radiation monitoring devices	5, 206
	(Ventilation System)	
140	Loss of stack condensate to environment	68, 207
141	Sand filter depression	208, 209, 210
142	Water accumulation in the sand filter	19, 68
143	Fan failure	5, 211
144	Circuit breaker switch failure in vent system	212
145	Vacuum loss in process vessel vent system	6, 52, 82, 213
146	Damper failure	214, 215
147	HEPA Filter failure (not applicable)	53, 60
	(Gang Valve Operation)	
148	Severe potential radiation exposure to personnel in the gang valve corridors	27, 29
149	Failure of gang valve	203
150	Failure to survey person or material prior to removal from gang valve corridor	202

TABLE 9.2, Contd

Incident Number	Incidents	Applicable Engineered Safety Features
	(Compressed Air and Gas System)	
151	Compressed air system faiure	113, 217, 218
152	Breathing air system failure material	38, 113, 218, 219, 220, 221

---

* Incidents which have no safety feature listed are 2, 5, 34, 35, 43, 44, 46, 48, 51, 53, 58, 60, 61, 73, 74, 83, 91, 114, 115, 116, 124, 126, and 136. Most of these can be prevented by administrative control.

TABLE 9.3

Engineered Safety Features

Number	Safety Features	Applicable Incidents
1	Canyon processing areas to conform to maximum design criteria as defined by Building Specification 7096	1, 3, 7, 98
2	Site selection free from flooding	4
3	Restricted and guarded area for all facilities	6
4	Capability for temporary emergency supply of cooling water to canyon vessels	7
5	Automatically started emergency diesel power for critical equipment	8, 9, 30, 38, 41, 139, 143
6	Lightning protection in electric circuitry	9, 121, 144
7	Lightning rods on elevated equipment	9
8	Steam tracing or thermal insulation on liquid bearing lines exposed to weather	10
9	Fire suppression system	11
10	Temperature sensing fire detectors in cells	11
11	Automatic restarter on critical equipment	8, 25
12	Neutron monitor to detect buildup of fissile materials	12, 39
13	Dedicated piping for nitric acid and ammonia cold feed lines	13, 21, 22, 76, 87
14	All valves clearly labeled and identified	13, 21, 22, 59
15	Key lock transfer switches	13
16	Remotely controlled valves	13
17	Liquid level instrumentation with fault indicate light	14, 19, 22, 28, 29 54, 62, 65, 66, 72, 88
18	High liquid level alarm	14, 22, 29, 66, 72, 75, 78
19	Stainless steel lined sump	14, 15, 16, 20, 28, 31, 55, 82, 142
20	Radiation alarms to detect leaks or spills	14, 15, 16, 20, 22, 27, 28, 31, 40, 55, 56

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
21	Separation of sump alarms from sump pump control circuitry	14, 15, 16, 20, 27, 55
22	Liquid flow meter	15, 77
23	Liquid flow rate control	15, 77, 84
24	Alarm for excessive flow	77
25	Avoidance of expansion joints where possible	16, 27
26	Pneumatic-electric interfaces located in areas normally not occupied by personnel	17
27	Gang valves located as high as possible above vessel level	17, 148
28	Seal pots on cold chemical addition lines	17
29	Automatic air blow of gang valves if steam supply fails	17, 148
30	Double containment of gang valves and lines	17
31	Shielded lines from gang valves to process vessel	17
32	Siphon breaker on discharge piping	18
33	"Cash" coil presure regulator	18, 128, 130
34	Closed loop cooling system on cooling coils only	19
35	Gamma radiation monitor	19, 24, 29, 31, 42, 77, 84
36	Protection of piping from dropped loads	20
37	Color coding of cold chemical systems	21
38	Sampling and analysis capability	12, 22, 47, 52, 76, 77, 93, 104, 129, 152
39	High temperature alarm	22, 79, 80
40	Temperature instrumentation	26, 52, 57, 79, 80, 82, 88, 90, 93, 94, 95, 96, 101, 103, 105, 132
41	Diversity in control instruments	23
42	Blowdown capability for plugged instruments and samplers	16, 23, 81, 136, 138

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
43	Agitator	22
44	Antifoam addition line on reboilers	22
45	Carriers for contaminated vessels and equipment	24, 37
46	Emergency portable air compressor	25
47	Pneumatic valves designed to fail in safe position	25
48	On critical equipment, design electrical controls to be fail safe from the effects of lightning	9
49	Stainless steel lining on lower 18 inches of cell walls and floor	27
50	Leak collection and detection system beneath canyon floor	27
51	Corrosion resistant material	27
52	Pressure instrumentation	14, 25, 52, 54, 64, 89, 93, 97, 125, 132, 138, 145
53	ΔP instrumentation	15, 57, 85, 86, 96, 99, 135, 147
54	Specific gravity instrumentation	15, 88
55	Conductivity probe on end of reel tape	29
56	Purge air system with fault alarm to protect against accumulation of hydrogen	30, 41
57	Spare purge air blower with spark-proof electrical system	30, 38
58	Continuous hydrogen monitors and alarms	30, 38
59	Storm water diversion system with automatic diversion feature activated by redundant monitors. (Monitors should not be subject to pluggage by sand)	28, 29, 30, 31, 41, 42, 45 50, 56, 57, 62
60	Parallel HEPA filters in tank exhaust ventilation	11, 33, 147
61	Self-sealing concrete cover over diversion box	20
62	Safety latch on crane hooks	20

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
63	Stainless steel lined diversion box cell	31, 56
64	Continuous monitoring of purge air flow from pump tank	41
65	Cooling water flow alarms for waste tanks	32
66	Reflux condensers on waste tanks	32
67	Continuous radioactive monitors and alarms of tank ventilation exhaust	33
68	Dehumidifier in tank ventilation exhaust	33, 49, 140, 142
69	Vibration measuring equipment for tanks during sludge slurrying	36
70	Spray ring for decontamination of slurry pumps during removal	37
71	Shielded crane for slurry pump removal	37
72	Streamlined housing and connection design for slurry pumps	37
73	Remote, shielded decontamination and maintenance facility for slurry pumps	37
74	Minimize pipe lines under roadways	39
75	Provide adequate protection for buried lines in immediate area of tanks, diversion boxes, etc. from heavy equipment loads	39
76	Specify and post load bearing capacities near vital equipment	39
77	Flush water system pressure higher than process system pressure	42
78	Double containment of flush water lines from process to control valves	42
79	Availability of pump-out equipment for waste tank and annular space	49
81	Air purge maintained	57, 63
82	Pressure relief valve	52, 88, 93, 131, 145
83	Interlock steam supply with temperature and pressure controls	52, 93

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
84	Interlock operation control with condenser cooling water	64
85	Vent dissolver off-gas condenser to canyon	64
86	Vent dissolver to vessel vent system	65
87	Automatic centrifuge braking if vibration is severe	67, 68, 70
88	Vibration frequency and amplitude readout	67, 68, 70
89	High pressure spray in centrifuge	69, 71
90	Interlock to prevent plowing at high speed in centrifuge	71
91	Conductivity meter on spent regenerated solution on Cs column	78
92	Circulated cooling water through zeolite column	79
93	Keep resin submerged in liquid	82
94	Steam stripper	84
95	Down draft condenser on elutriant recovery	85
96	Demister at vapor stream exit on stripper	86
97	Pressure relief through purge condenser	89
98	Heat tracing	90
99	100% weld inspection	92, 111
100	High temperature shut offs provided	94, 101, 105
101	Temperature monitor for waste input stream of spray dryer	94, 101, 105
102	Current and voltage are monitored for spray dryer heaters	94, 101, 103, 105
103	Coolant flow is monitored for spray dryer heaters	94, 101, 103, 105
104	Automatic system shutdown for spray dryer heaters when malfunction occurs	94, 101, 103, 105

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
105	Sloped surfaces of cone (60° from horizontal) to reduce calcine accumulation on chamber surface	94
106	Corrosive resistant materials ("Incoloy" 800H or "Hastelloy C") for spray dryer construction to minimize corrosion	95
107	Temperature instrumentation and controls on cooling water flow to induction heater coil	96
108	Differential pressure measurement across feed nozzle	96
109	Remotely operated cleanout needle for mix nozzle	96
110	Design resistance to pressurization	97
111	Pressure monitors with shutdown interlocks for high spray dryer pressure	97
112	No uncontained penetration through refractory or containment shell below melt line	109, 110
113	Redundant compressed air with automatic starter	15, 151, 152
114	Molten glass level control devices with backup thermocouple level sensors	15
115	Alarms to indicate power loss, compressed air loss, low vacuum, and instrument faults in the glass melting process	15
116	Use of current control or electrodes to maintain uniform condition	15
117	Aluminum dissolving	15
118	Adequate canyon exhaust filtration	15
119	Cell flush system designed to prevent splashing of water on hot equipment and to prevent accumulation of water on the floor	110
120	Radiation monitors for airborne contamination	111
121	Weld inspection and testing	111
122	Q/A constructed overpack	111

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
123	Cylindrical design minimizes probability of refractory collapse	107
124	Grounding of melter shell and floating electrodes	108
125	Use of insulated power cables rather than bus bars	108
126	Electrical isolation of instruments	108
127	Use of fixed resistance heater in pour spout rather than retractable electrodes	108
128	Monitoring of ground circuit on melter shell for possible detection of arcing	108
129	Top entering electrodes	108, 110
130	External level detection device such as sonic instrument	109, 110
131	Failsafe tilt mechanism such that power loss will result in melter returning to vertical position	109, 110
132	Automatic shutoff of feed should power loss or pressurization occur	109, 110
133	Retrievable catch pan beneath melter and canister	109, 110
134	Dump canisters beneath bottom freeze plug. Combined volume of dump canister should be larger than melter volume	109, 110
135	Two dump canisters with total volume greater than that of the melter and with shroud to protect against entrance of water	106
136	Use of air cooling for electrodes	106
137	Engineered controls for minimizing glass spills, such as level and weight control	106
138	Strategically placed thermocouples on melter outer surface to detect erosion or corrosion of the liner, especially in throat area	107
139	Low glass velocities	106

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
140	Redundancy in power supply to reduce thermal shock from repeated recoveries from loss of power	107
141	Avoidance of startup using liquid sodium hydroxide for normal operation	107, 108
142	Refractory specifications include use of void-free and dense refractory special block finishes involving diamond truing and grinding, joints made as thin as possible, and optimized block size	107
143	Maximum voltage less than 300 to reduce amount of current carried by refractory	107
144	Water cooled steel shell provides secondary jacket for glass containment so that failure of refractory will not result in loss of glass	107, 109, 110
145	Pressure relief device, such as seal pot, provided	97
146	Filter blowback sequenced to avoid pressurizing spray dryer	97
147	Off-gas blower spared	97
148	Interlock to shutdown feed and filter blowback for exhauster failure	97
149	Online particulate analyzer	99
150	Off-gas system designed to handle total filter failure	99
151	Sequential filter units	100
152	Sand filter for calcining filter system	100
153	Fire resistant filter housings	100
154	Temperature instrumentation and alarms	102
155	Gamma monitor with alarm downstream of adsorber	102
156	Sloped flooring to enhance rapid water drainage and removal to remotely located sump	106

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
157	Stainless steel lining on cell floor	106
158	Double filters in series on the crane cab air conditioner	112
159	Install controlled access to the crane cab	112
160	Provide emergency exit on the crane cab	113
161	Crane cable overload devices	117
162	Provide dead man control on the crane	117
163	Redundant design for the crane brake	118
164	Provide spare impact wrench	118
165	Redundant optical system on the crane cab	119
166	Multiple source of electrical generation (onplant as well as offplant)	8
167	Electric power taken from a loop with power coming from either direction on the loop	8
168	Redundant transformers each capable of carrying the entire area electrical load	8
169	Automatic tie-in of double ended area loop	8
170	Redundant, vital equipment automatically supplied power from separate motor control centers	120, 121
171	Uninterruptable instrument power supplies	120
172	Safety related electrical equipment, including conduit switchgear and motor control centers, shall be designed to meet seismic criteria and environmental conditions	121
173	Redundant routings of power and control cables, for safety related circuits, shall be run separately	121
174	Control and power cables shall be run separately	121

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
175	The electrical power systems important to safety shall be designed to include the capability for periodically testing the operability and functional performance of those system components and the operability of the system as a whole	121
176	Concrete that encases buried conduit for power distribution is dyed red to indicate contents	121
177	Cable encasements for safety related functions are maximum resistance construction	121
178	Proximity of liquid-bearing lines above motor control center should be avoided where possible	121
179	Proximity of electrical equipment to thermally hot process equipment should be avoided where possible	121
180	Two separate maximum resistance emergency power system	122
181	Primary oil supply tanks (day tanks) for diesels are maximum resistance construction	122
182	Either diesel is sized to carry full area emergency load with capability for manual switch-over when one fails	122
183	Install emergency generator operating indication	122
184	Autotransfer to emergency power, not responsive to momentary surges, sequential loading, automatic reset	122
185	Provided battery charger	122
186	Diesel generator room is heated to maintain temperatures above freezing	122
187	All emergency electric equipment should be located to protect against steam, water or process fluid leaks which could cause ambient temperatures or humidity to rise to a level causing electrical equipment malfunction	122

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
188	Emergency electrical equipment should be protected from potential accident-generated flooding	122
189	Fire within one electrical enclosure should not spread to redundant electric equipment	122
190	Install redundant backup pump with automatic start	123, 127
191	Install diesel power or steam driven pump backup	123
192	Sufficient inventory of water in cooling tower to achieve safe shutdown	123
193	Design pump for cold weather condition	123
194	Pressure sensor and alarms	125
195	Water diversion to retention basin	128,130
196	Activity monitor for closed-loop cooling water	128
197	Activity monitor and alarms in steam condensate discharge	130
199	Design pressure reducing station for winter conditions	132
200	Dikes or curbing to contain vessel contents	14, 16, 21, 22
201	Redesign of vial retainer of sample vial	133
202	Sensitive monitoring equipment at exits to unregulated areas	134, 150
203	Alternative pumpout equipment in case of gang valve failure	149
204	Use of shielded sample cell	135, 136, 137, 138
205	Pressure differential alarm	135
206	Redundant air monitors powered by separate electrical source	139
207	Stack with acid resistant brick liner	140
208	Depression gauge and alarm for sand filter	141

TABLE 9.3, Contd

Number	Safety Features	Applicable Incidents
209	Stainless steel sand bed support over lateral ducts	141
210	Roof and sides of sand filter sealed to prevent water from leaking into sand	141
211	Parallel for system with automatic start	143
212	Circuit breaker switch in weather proof box	144
213	Redundant vacuum system with bypass valving capability	145
214	Automatic and manual control capability on dampers	146
215	Air reversal warning system	135, 146
216	Stack located far enough from important structures so that it would not cause significant damage if it fell	1, 3
217	Automatic isolation of system if loss of compressed air occurs	151
218	Instrumentation and alarms for system pressure and compressor operability	151, 152
219	Filtration system for removal of oil and other impurities from breathing air	152
220	Redesign of breathing air connections to prevent against accidental connection of other gases	152
221	Kink-resistant breathing air hoses	152

TABLE 9.4

SRP Whole Body Occupational Dose

Year	Number of Employees Monitored	Total Dose, rem	Average Dose per Monitored Employee, rem	Maximum Individual Exposure, rem
1965	4977	2340	0.47	2.9
1966	5032	2074	0.41	3.4
1967	5041	2604	0.52	3.0
1968	4875	2412	0.49	3.3
1969	4705	2758	0.59	3.2
1970	4626	2353	0.51	3.7
1971	4836	2401	0.50	3.3 (24.8)
1972	5210	1711	0.33	3.4
1973	5005	1488	0.30	2.7
1974	5138	1367	0.27	3.1
1975	5263	1161	0.22	2.7
	Average Over Period		0.42	

TABLE 9.5

SRP Reprocessing Area Whole Body Occupational Dose

Year	Number of Employees Monitored	Total Dose, rem	Average Dose per Monitored Employee, rem	Maximum Individual Exposure, rem
1965	1501	916	0.61	2.8
1966	1497	928	0.62	3.1
1967	1489	980	0.66	3.0
1968	1454	829	0.57	2.9
1969	1441	994	0.69	2.9
1970	1378	868	0.63	2.6
1971	1567	815	0.52	2.8
1972	1756	685	0.39	2.9
1973	1613	742	0.46	2.7
1974	1674	720	0.43	2.9
1975	1781	570	0.32	2.7
	Average Over Period		0.54	

TABLE 9.6

Occupational Radiation Exposure

Basis: Process to Glass; Ship to Offsite Geologic Disposal

Operational Module	Rem/Year in Maximum Year	
	SRP Experience	DOE Standards
Removal from tanks	4.2	5.0×10^1
Processing	2.31×10^2	2.75×10^3
Transportation	1.40×10^2	1.40×10^2
Storage	0	0
Total/max.yr (rem)	3.75×10^2	2.94×10^3
Total for campaign (rem)[a]	3.75×10^3	2.94×10^3

---

[a] See Table 9.7 for campaign times.

TABLE 9.7

Manpower and Time Requirements

Operation	No. of Employees[a]	Time Required
Reconstitute, transfer from old to new tank	6	6 months
Decontaminate old tank	6	6 months
Remove 60 million gallons from present tanks, transfer to new processing building	10	10 years
Process 60 million gallons to glass, 10-year time	550	10 years
Transport glass offsite	Use DWD treatment	10 years

---

[a] Includes supervision and overhead.

TABLE 9.8

Non-Nuclear Occupational Casualties During Construction of New Facilities

	Events/Year	
	Major Injuries	Deaths
Construction of Processing Facilities	460	5
Fabrication of Transportation Casks and Vehicles	39	0.5
Construction of Storage Facilities	28	0.4
Total for Campaign	530	5.9

TABLE 9.9

Non-Nuclear Occupational Casualties During the Operational Campaign

	Events/Year		
	Minor Injuries	Major Injuries	Deaths
Removal from Tanks	1.5	0.0013	0.00016
Processing	80.5	0.078	0.0089
Transportation	-	1.6	0.052
Storage	0.58	0.0051	0.00006
Total per Year	83	1.7	0.061
Total for Campaign	990	16	0.63

TABLE 9.10

DOE Radiation Exposure Limits to Offsite Individuals, mrem

Type of Exposure	Maximum Individual Dose[a]	Average Population Dose
Whole Body	500	170
Gonads	500	170
Bone Marrow	500	170
G. I. Tract	1500	500
Bone	1500	500
Thyroid	1500	500
Other Organs	1500	500

---

[a] These individuals are assumed to be at the site boundary under conditions of maximum probable exposure.

TABLE 9.11

Typical State and Federal Air and Water Quality Standards[a] [9,10]

Pollutant	Limiting Concentrations	Comment
SO_2	80 g/m^3	Ambient air, SC
SO_2	43 g/m^3	Ambient air, GA
SO_2	1300 g/m^3	One-hour, air, SC
SO_2	715 g/m^3	One-hour, air, GA
SO_2	3.5 $lb/10^6$ Btu	Air emission, SC
Particulates (Fly Ash)	0.6 $lb/10^6$ Btu	Air emission, SC
NO_x	100 g/m^3	Ambient air, SC and GA
H_2S	10 ppm, 8 hr	Air, detectable effects
Nonmethane Hydrocarbons	130 g/m^3	Three-hour, air, SC
Sulfate	250 ppm	Drinking water standard, Federal
Chloride	250 ppm	Drinking water standard, Federal
Nitrate	10 ppm	Drinking water standard, Federal
Barium	1 ppm	Drinking water standard, Federal
Iron	0.3 ppm	Drinking water standard, Federal
Boron	1 ppm	Drinking water standard, Federal
Zinc	5 ppm	Drinking water standard, Federal
Chromium	0.05	Drinking water standard, Federal
Manganese	0.05 ppm	Drinking water standard, Federal
Arsenic	0.05 ppm	Drinking water standard, Federal
Mercury	0.002 ppm	Drinking water standard, Federal
Copper	1 ppm	Drinking water standard, Federal
Phenob	0.001 ppm	Drinking water standard, Federal

---

a. The above listing is not meant to imply that all the chemicals would be released from the waste management facilities.

TABLE 9.12

Summary of Risks for Processing Waste to Glass (glass stored in offsite geologic storage)

Event	Maximum Individual Dose, rem[a]	Population Dose for Maximum Year, man-rem	Probability Events/Year	Maximum Risk man-rem/Year
Removal from Tanks				
Routine Releases	Negligible	1.4	1.0	1.4
Sludge Spill	5.0×10^{-4}	1.5×10^{1}	5.0×10^{-2}	7.5×10^{-1}
Spill at Inlet	1.2×10^{-3}	3.7×10^{1}	5.0×10^{-2}	1.9
Tornado	2.0×10^{-3}	5.4×10^{1}	6.0×10^{-4}	3.2×10^{2}
Spill	2.0×10^{-2}	1.1×10^{3}	5.0×10^{-3}	5.4
Explosion	7.8	3.0×10^{4}	1.0×10^{-4}	3.0
Sabotage	1.2×10^{2}	3.5×10^{5}	1.0×10^{-5}	3.5
Below-Ground Leaks	1.5×10^{-1}	1.7×10^{5}	1.0×10^{-5}	1.7
Processing				
Routine Releases	2.2×10^{-5}	3.0	1.0	3.0
Process Incidents	$<1.0 \times 10^{-5}$	4.2×10^{-1}	1.0	4.2×10^{-1}
Sabotage	4.2×10^{1}	8.9×10^{4}	1.0×10^{-5}	8.9×10^{-1}
Airplane Crash	1.5×10^{-1}	3.1×10^{2}	7.0×10^{-8}	2.2×10^{-5}
Transportation				
Routine Exposures	5.0×10^{-3}	6.3×10^{1}	1.0	6.3×10^{1}
Accidents	6.9×10^{-1}	1.2×10^{2}	1.3×10^{-4}	1.5×10^{-2}
Storage				
Expected Releases	Negligible	1.3×10^{2}	1.0	1.3×10^{2}
Time-Integrated Risk, man-rem[b]		9.0×10^{2}		

---

a. Equivalent whole body dose, rem.

b. Annual population risk integrated for 300 years, accounting for radioactive decay and population growth by a factor of 5.

TABLE 9.13

Radionuclide Deposition Limits for Evacuation and Restrictions on Farming, Ci/m^2

Isotope	Evacuation Direct Radiation	Inhalation	Restrictions on Farming First Year	Longer
Sr-90	-	2×10^{-4}	4×10^{-5}	2×10^{-4}
Cs-137	3×10^{-5}	1×10^{-3}	2×10^{-6}	8×10^{-5}
Pu-238, 239	-	1×10^{-7}	-	-

TABLE 9.14

Radiation Dose Criteria

Evacuation Limits	
External Irradiation	10 rem to whole body in 30 years
Inhalation	75 rem to critical organ in 50 years
Farming Restrictions (Short Term)	
Sr-90	4 rem to bone marrow in first year[a]
Cs-137	5 rem to whole body in first year[a]
Farming Restrictions (>1 year)	
Sr-90	(5 rem to bone marrow in 50 years)/year
Cs-137	(1 rem to whole body in 50 years)/year

---

a. The 50-year dose commitments due to these exposures in the first year are about 25 rem to the bone marrow from Sr-90 and 5 rem to the whole body from Cs-137. (Almost all the dose from Cs-137 is received in the year in which it is ingested.)

TABLE 9.15

Contamination Effects from Sabotage During Removal of Waste from Tanks

Distance from Release, km	Acres Decontaminated	People Moved
15-20	8.5×10^3	2.2×10^3
20-25	1.1×10^4	3.2×10^2
25-30	1.3×10^4	0
30-35	1.6×10^4	0
35-40	1.8×10^4	0
40-45	2.1×10^4	0
45-50	2.3×10^4	0
50-55	2.5×10^4	0
55-60	0	0
Total Offsite	1.3×10^5	2.5×10^3

Table 9.16

Contamination Effects from Sabotage During Waste Processing

Distance from Release, km	Acres Decontaminated	People Moved
15-20	8.5×10^3	0
20-25	0	0
Total Offsite	8.5×10^3	0

TABLE 9.17

Consequences of Runoff from Abandoned Salt Tanks Reaching the Savannah River

Component	River Water Concentration	EPA Drinking Water Standard
Cs-137	1.1×10^{-3} nCi/L	$<8 \times 10^{-3}$ nCi/L
Sr-90	2.2×10^{-4} nCi/L	8×10^{-3} nCi/L
Pu (total)	6.2×10^{-4} nCi/L	1.5×10^{-2} nCi/L
U	5.8×10^{-6} mg/L	5.0×10^{-1} mg/L
Hg	1.4×10^{-4} mg/L	2.0×10^{-3} mg/L
$NO_3 + NO_2$	2.0×10^{-1} mg/L	>1.0 mg/L

9.3 REFERENCES

1. W. S. Durant. *Potential Incidents Applicable to the Defense Waste Processing Facility - Waste Removal and Blending, Evaporation and Salt Solidification.* Internal Report DPST-78-403, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC 29801 (June 1978).

2. W. S. Durant. *Potential Incidents Applicable to the Defense Waste Processing Facility - Sludge Supernate Separation.* Internal Report DPST-78-445, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC 29801 (November 1978).

3. M. W. Lee. *Potential Incidents Applicable to the Defense Waste Processing Facility - Supernate Treatment.* Internal Report DPST-78-509, Savannah River Laboratory, E. I. Du Pont de Nemours and Company, Aiken, SC 29801 (August 1978).

4. W. S. Durant and E. W. Holtscheiter. *Potential Incidents Applicable to the Defense Waste Processing Facility - Sludge Treatment.* Internal Report DPST-78-510, Savannah River Laboratory, E. I. Du Pont de Nemours and Company, Aiken, SC 29801 (January 1979).

5. W. S. Durant and M. W. Lee. *Potential Incidents Applicable to the Defense Waste Processing Facility - Auxiliaries.* Internal Report DPST-78-550, Savannah River Laboratory, E. I. Du Pont de Nemours and Company, Aiken, SC 29801 (January 1979).

6. M. W. Lee. *Potential Incidents Applicable to the Defense Waste Processing Facility - Iodine Adsorption and Adsorber Recovery Process.* Internal Report DPST-78-510 (addendum), Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC 29801 (1978)

7. DOE Manual Chapter 0524. *Standards for Radiation Protection.* (April 8, 1975).

8. *Final Environmental Statement, Waste Management Operations, Savannah River Plant.* Report DOE-1537 (October 1977).

9. *Air Pollution Control Regulations and Standards for the State of South Carolina.* South Carolina Pollution Control Authority, Columbia, SC (1972).

10. *Public Health Service Drinking Water Standards, 1962.* U.S. Department of Health, Education, and Welfare, Washington, DC (1962).

11. *NPDES Permit SC 0023710,* issued 2-15-75; and *NPDES Permit SC 0000175,* issued 11-19-76.

12. *Project 78-SR-023 (9.2 million).* Submitted by DOE for FY-1978 funding.

13. *U.S. Code of Federal Regulation, Title 29, Part 1910,* "Occupational Safety and Health Standards."

14. *Alternatives for Long-Term Management of Defense High-Level Radioactive Waste - Savannah River Plant.* Report DOE-77-42 (May 1977).

10. MATERIALS OF CONSTRUCTION (G. G. Wicks)

10.1 General Considerations

The basic material of construction that will be used in the DWPF will be 304L stainless steel, which has good corrosion resistance to high-level waste at most of the anticipated working temperatures. In addition, Type 304L stainless steel is a ductile material with good fatigue properties, low sensitization during welding which means good resistance toward stress-corrosion cracking, and is a material of good strength that is cost-effective. Type 304L stainless steel has been used extensively at Savannah River with good experience. Although Type 304L stainless steel, as well as Types 316 or 316L stainless steel, can be used in many areas of the solidification operation, there are certain areas that will require special materials. For example, in areas subjected to halides and their acid solutions, especially at elevated temperatures, nickel-based alloys such as "Hastelloy", "Inconel", or "Incoloy" will be desirable.

Areas of interest include external piping, tanks, separation facilities, salt-handling operations, spray dryer, off-gas system, the ceramic melter, and glass-waste canisters. Materials selection will be determined by material specifications, working experience at Savannah River and Battelle Northwest Laboratories, and in several instances, by current experimental programs.

For solutions containing nitric acid, Types 304L, 321, and 347 stainless steels can be used for processing these solutions over a wide range of temperatures and concentrations. Stainless steels or higher nickel alloys with relatively high chrome content (Types 309, 310, and 20Cr-29Ni) would provide better resistance to corrosion by nitric acid containing chloride ions.

10.2 External Piping

Coaxial pipes will be used to transport the feed streams from the diversion box into the Waste Processing Facility. The inner pipe or pipes, which will be in contact with the waste, should be constructed from Type 304L stainless steel. The outer jacket may be constructed from a mild steel. This coaxial pipe arrangement is currently being used for transferring waste into and out of storage tanks.

10.3 Internal Piping

Piping to be used inside the Waste Processing Facility will be constructed of Type 304L stainless steel.

10.4 Separation Facilities

Piping, valves, and joints will be made primarily of Type 304L stainless steel. Equipment, such as commercially available parts of the centrifuge and other components, can also be constructed of either Types 316 or 316L stainless steel. These alloys offer better corrosion resistance as well as being less susceptible to pitting, compared to Type 304L stainless steel.

10.5 Spray Dryer

The leading materials candidates for constructing the spray dryer are the nickel-based alloys "Hastelloy" C-4* and "Incoloy" 800H ("Incoloy" 800H has been selected by Wilmington Engineering for constructing the TNX calciner).

The present conditions for materials of construction of the SRP spray dryer are: (1) a maximum wall temperature of 950°C, (2) internal working temperatures in the range of 250-600°C, and (3) compatibility with chlorides and fluorides. An additional limitation is that the spray dryer material should also be compatible with nitric acid.

In general, superalloys which exhibit good to excellent corrosion resistance toward chlorides, fluorides, and nitric acid include "Hastelloy" C-276, "Hastelloy" C-4, "Hastelloy" X, "Inconel" 617, "Inconel" 625, "Incoloy" 800H, and "Incoloy" 825. The "Hastelloy" alloys are especially suited to HCl and HF environments.

A recent analysis at SRL indicates that significant quantities of chlorides and fluorides along with water vapor will be present in drying and melting operations. In addition, small amounts of

---

* "Hastelloy" C-4 is no longer a candidate alloy because tests have demonstrated that this alloy has very low resistance to penetration by molten glass and possibly vapors from glass melt [1].

HCl and HF acids could also form from chemical reactions within the dryer and condense from temperature changes during shutdown and startup. However, since operating temperatures will be above the dew point, large quantities of the acids would not be anticipated and their effects should be minimal. Assessments of "Incoloy" 800H and the benefits of using higher corrosion-resistant but more expensive alloys for plant use, such as "Hastelloy" C-4, will continue to be investigated.

"Hastelloy" C-4 is a nickel-chromium-molybdenum alloy that is characterized by outstanding high-temperature stability, corrosion resistance, ductility, and resistance to stress-corrosion cracking. In addition, this alloy has good resistance to HCl and HF acids, although it is more expensive than some nickel-based alloys.

"Incoloy" 800H is a nickel-iron-chromium alloy with good corrosion, oxidation, and strength properties at elevated temperatures. In addition, it also has good resistance against scaling, stress-corrosion cracking and has been used within Du Pont for many years. It is not as resistant to HCl and HF as "Hastelloy" C-4. "Incoloy" 800H is one of the less expensive nickel-based alloys and is readily available.

Spray dryers have been constructed and operated successfully at other sites. In general, these materials of construction were subjected to significantly lower processing temperatures and different environments than those considered for drying of SRP waste. For example, at Battelle-Pacific Northwest Laboratory, a spray dryer was constructed from Type 310 stainless steel (25Cr-20Ni) for use with simulated glass-waste compositions that were chlorine deficient. No detectable corrosion of the 3/8-in.-thick wall was observed after 552 hours of feed calcining with six associated heating and cooling cycles. The calciner vessel used at the Idaho Chemical Processing Plant in the high-level Waste Calcining Facility (WCF) was constructed of Type 347 stainless steel. This material was used in conjunction with a fluidized bed and showed no severe corrosion after 13 years of operation. Baffle plates were made from Type 310 stainless steel. In the new WCF, Type 347 stainless steel (18Cr-10Ni) has been selected for the vessel, baffle plates, and other internal parts.

10.6 Off-Gas System

Equipment at the beginning of the off-gas system could experience significant corrosion, so the leading materials of construction are high corrosion-resistant alloys, such as the nickel-based materials

"Incoloy" 800H, "Inconel" 625, "Hastelloy" B and C-4. These alloys generally provide good protection against halides at temperatures lower than those in the spray dryer and would be used in the wet scrubber system, including the ejector venturi, deep-bed washable filters, pumps, heat exchanger, and off-gas condensate collection tank.

"Incoloy" 800H or "Hastelloy" C-4 could be used in the first parts of the off-gas system where moderate temperatures and halogens are potentially anticipated. For areas near the ejector venturi where HCl or HF can form (temperatures below the dew point), "Hastelloy" B or "Inconel" 625 are recommended. Due to fabrication considerations, "Inconel" 600 is the reference material for the sintered filters.

Beyond wet scrubbing, 304L stainless steel can be used if relatively low temperatures and halide content are produced. However, if the Cl^- content is greater than 250 ppm, 300 series stainless steel should not be used (Engineering Department Standard No. 5992) due to possible stress-corrosion cracking. In this case, either the high-nickel alloys used earlier should be employed or the pH of the solution should be increased. For example, for a molar ratio of $NO_3^-/Cl^- > 1$, no cracking is observed at 260°C if the pH is over 10 [2].

In the Idaho Chemical Processing Plant solidification process, Type 304L stainless steel is used extensively in the off-gas system. For equipment exposed to the highest erosion and corrosion effects, such as the quench tower and related pumps, higher-integrity materials of Type 347 stainless steel and Carpenter®20 (trademark of Carpenter Technology Corp.) are used. A nickel-chromium alloy, ARMCO Nitronic®50 (trademark of Armco Steel Corp.), is being considered for future scrubber pump construction at the facility.

10.7 Melter System

10.7.1 Joule-Heated Ceramic Melter

The corrosion/erosion resistance of electrode and refractory materials to be used in the ceramic melter are currently being evaluated at SRL. These components comprise the principal elements of a Joule-heated continuous ceramic melter, the reference melting concept for incorporation and solidification of waste into a glass matrix. This selection will depend on corrosion/erosion resistance and the associated lifetime of the materials, as well as electrical resistivity, thermal shock resistance, thermal expansion and conductivity, and cost and availability of the material. The wear of electrode and refractory materials will most likely determine the lifetime of the melters. The leading refractory candidate is "Monofrax" K-3 and the leading electrode candidate is "Inconel" 690.

10.7.2 Melter Materials Experimental Program

The corrosion/erosion resistance of electrode and refractory materials will be studied by two basic techniques. First, a crucible or finger test is being used that is a modification of a standard ASTM test for "Static Corrosion of Refractories by Molten Glass" [3]. These tests provide a good relative comparison of the corrosion resistance for materials of interest over the temperature range of concern.

A second experimental technique will evaluate the attack of molten glass under simulated service conditions for the leading refractory and electrode materials determined from the previous finger tests. This is accomplished by constructing a mini-melter which will subject the refractory to molten glass only on one side while maintaining a temperature gradient through the refractory. These experiments are a modification of the ASTM "Simulated Service Test for Corrosion Resistance of Refractories to Molten Glass" [4].

Additional erosion studies will be made by suspending refractory and electrode samples on rods and rotating them in the molten glass.

10.8 Canister Materials Experimental Program

Long-term materials compatibility tests between candidate canister metals and simulated glass-waste compositions have been in progress since 1974. Canister metals in this study included 304L stainless steel, Cor-Ten® A (trademark of U.S. Steel), "Inconel" 600, and AISI 1020 low carbon steel. Supplementary studies will use simulated wastes of average, high iron and high aluminum content with Type 21 frit, and additional canister candidate materials. The leading material for canisters to be used in the ceramic melting process is Type 304L stainless steel.

10.9 Mechanical Cells A and B

The etch tank and associated piping in each cell will be exposed to 3.5M HNO_3 - 0.4M NaF solutions (or vapors) at nominally 50°C. Several candidate materials of construction to adequately resist attack from these solutions and vapors have been identified. In decreasing order of preference they are "Inconel"* 671, 690, "Haynes"** 25, "Ferralium"***, and "Inconel" 625.

10.10 References

1. W. N. Rankin. Attack of High-Strength, Oxidation-Resistant Alloys During In-Can Melting of Simulated Waste Glasses. Internal Report DP-MS-79-39 (Rev.), proposed for presentation at Corrosion/80 NACE Meeting, Chicago, Illinois, March 6-10, 1980.
2. J. H. Phillips and W. J. Singley. "Evaluation of Performance of Screening Tests of Inhibitors to Prevent Chloride Stress Corrosion." Corrosion 15, 450t (1959).
3. ASTM-0621-68. American Society for Testing and Materials Part 17, revised 1973.
4. ASTM-0622-68. American Society for Testing and Materials Part 17, revised 1973.
5. Deleted.

---

* Trademark of International Nickel Co.

** Trademark of Union Carbide Corporation.

*** Trademark of Cabot Corporation.

11. REGULATORY REQUIREMENTS (E. J. Hennelly)

11.1 General

The regulatory aspects of the DWPF are complex because the completed facility must comply with the pertinent regulations at the time of startup, which is still about a decade away, and because many of the regulations that will be in effect then are yet to be issued. Therefore, a key requirement of the regulatory effort associated with the solidification program will be to anticipate and prepare for the regulatory situation at startup. A successful regulatory effort will reduce the delays and costs that would result from retrofitting to meet unanticipated controls.

Regulations pertaining to nonradioactive releases can be forecast with some confidence because Congress has established long lead times for implementation. For example, limits for discharges to streams in the mid-1980s are now being proposed by EPA. In addition, criteria and regulations for long-term disposal of radioactive waste being formulated by EPA and NRC (e.g., 10 CFR 60), and many of these regulations will be applicable when the DWPF operations begin.

A major uncertainty involves the future licensing authority of NRC for DOE solidification facilities. NRC does not now have this authority. NRC-DOE-Du Pont information exchanges will mitigate the impact of this possible extension of NRC jurisdiction.

11.2 Current Regulations

11.2.1 Nonradioactive Releases

The major environmental laws pertaining to nonradioactive releases from a waste processing facility are the Federal Water Pollution Control Act and Clean Air Act. These Acts established the bases for the EPA water regulations and the South Carolina air quality standards. The Acts established national long-term goals for air and water release.

In addition, EPA and SC DHEC are giving increased attention to the effects on ground-water quality of solid waste disposal practices because of the provisions of the Resource Conservation and Recovery Act (RCRA) of 1976. Use of seepage basins and landfills for disposal of nonradioactive liquid and solid wastes may be restricted by future SC DHEC regulations, to be published in

1980, that will implement RCRA. Incorporation of ion exchange effluent into concrete with subsequent disposal on the Savannah River Plant will also be conducted in accordance with these regulations as well as with regulations covering disposal of radioactive waste, if applicable.

11.2.2 Radioactive Releases

Limits on radioactive releases are now controlled primarily by DOE Manual Chapter 0524. The EPA regulations (40 CFR 190) that pertain only to releases from commercial nuclear cycle facilities provide recent guidance on acceptable limits for public exposure. The EPA guidelines represent the future trend, and should be carefully considered in establishing release guides for the waste processing facility. The offsite dose from SRP operations is substantially below the EPA limit. The contribution from the waste processing operations should result in minimal offsite dose to allow the SRP total to continue to remain well within the EPA limits.

11.2.3 Occupational Radiation Exposure

Exposure guides for plant wastes are given in DOE Manual Chapter 0524. A more restrictive limit (1 rem/yr for planned exposures) is included in the DOE criteria for new plutonium facilities. The limit of 1 rem/yr for planned exposures, although not now required for a waste processing facility, represents the most current DOE position on personnel exposure and a likely requirement for the future.

11.2.4 Product and Shipping Container Specifications

The only current regulatory requirement for the product is that it be a solid. EPA is now preparing criteria and NRC is in the process of preparing regulations that will give more specific guidance for acceptable commercial waste forms. Preliminary guidance from these agencies indicates the following properties may be important for all solidified high-level waste:

- uniformity of solid
- heat output limit
- radiation level limit
- chemical composition of solid
- fissile content accountability
- leachability limit

Each property may require some means of verifying that it is within prescribed limits.

The recent NRC Regulation 10 CFR 71 requires an NRC license for shipment of DOE waste. To obtain a license, DOE will need an NRC-approved quality assurance plan for manufacture of shipping containers.

NRC Regulation 10 CFR 71.42, "Special Requirements for Plutonium Shipments After June 17, 1978," requires a double barrier to accidental release of radioactivity. Both barriers must meet requirements of Regulatory Guide 7.6, "Stress Allowables for the Design of Shipping Cask Containment Vessels."

11.3 Future Related Regulations

Recently NRC and EPA have become very active in the preparation of Federal regulations regarding the permanent disposal of high-level radioactive waste. NRC is expected to issue for comment a draft Regulation 10 CFR 60, "Disposal of High-Level Radioactive Waste," in February 1980. The draft has already received some preliminary review by DOE and their subcontractors. The final regulation (probably due in 1981) will prescribe all of the Federal regulations for licensing a high-level waste repository. EPA recently (November 1979) presented their latest draft criteria for high-level waste disposal. The NRC regulations must be compatible with the EPA criteria. Each of these two documents would apply to a defense waste repository. Currently it is believed that the glass waste form that is proposed to be made in the DWPF will be acceptable in a licensed repository and that a salt repository will also, in combination with appropriate overpack material, meet any of the proposed EPA criteria and NRC regulations. It is for these reasons that the DWPF construction and operations are currently believed to be decoupled from the proposed NRC and EPA mandated regulatory requirements. It will be necessary to follow the development of these criteria and regulations during 1980 and 1981 to reaffirm the decoupling and to adjust, as necessary, any current or proposed SRP-DWPF operations to meet future regulatory requirements. Frequent DOE-NRC information exchanges would be helpful in planning for the future regulatory situations.

12. SOLID WASTE HANDLING (H. E. Hootman)

12.1 General

Solid wastes will arise from normal process operations and from the repair, replacement, or retirement of process equipment. Processing of these wastes will be determined primarily by the composition of the material, its size, and the degree and type of radioactive contamination associated with the waste. Facilities for "hot" and "warm" canyon maintenance as well as decontamination will be integrated into the DWPF design and will serve the same function as that of similar operations in present SRP fuel reprocessing canyons (e.g. repair or decontamination of process vessels and equipment).

Process waste will be primarily contaminated with fission product β-γ emitters. TRU contamination will be present in some of the waste; however, an assay of the TRU contamination will be hindered by the extremely high β-γ fission product emitter background radiation. A continuation of present waste management practices is proposed for these wastes (e.g. encapsulation and storage in a monitored burial ground facility).

12.2 Solid Waste Description

Normal contaminated operating solid wastes generated in the DWPF will include such materials as maintenance, job control and decontamination resides as cellulosic wipes, plastic sheets, gloves, protective clothing, and contaminated small tools. On a less regular basis, failed process tanks, jumpers, filters, and adsorbent beds will have to be removed from the process and prepared for storage. The most infrequent types of waste to be considered might result from process upsets where a process vessel such as a glass melter would fail containing a full charge of vitrified HLW. The treatment of such waste will require provision for the separation of the contaminated process equipment from the vitrified HLW waste and separate disposition of the residues.

A more detailed breakdown of anticipated solid waste arisings is shown in Table 12.1.

12.3 Waste Treatment Processes

Processing contaminated DWPF wastes consists mainly of containerizing the wastes for shipment to an onsite storage (burial ground area). The amount of mechanical disassembly or decontamination employed on the noncombustible wastes will vary with the type of material involved.

12.3.1 Process Equipment

Failed tools and process equipment are usually decontaminated to remove as much of the surface contamination as possible before the equipment leaves the building. Decontamination involves the removal of radioactive contamination by either mechanical or chemical means. This can be accomplished with high pressure sprays, detergent and acid or alkaline washes applied both internally and externally.

12.3.2 Contained Process Wastes

Absorber columns and resin beds, if they cannot be regenerated, should be simply sealed in their containers, decontaminated on the container surfaces and shipped to a burial ground.

12.3.3 Job Control Wastes

Both combustible and noncombustible job control wastes are shipped untreated in standard cardboard radioactive waste cartons to the burial ground for trench burial. Contaminated scrap, welding slag, fluxes and rod tips and other process created wastes are shipped in appropriate containers to a burial ground in a shielded cask car.

12.3.4 Process Upset Wastes

During the course of normal operation very little residue of the HLW will be associated with materials removed from the DWPF and present SRP reprocessing canyon techniques can be employed. However, because of the vitrification process used in the DWPF, it is possible that occasions may arise where the molten glass and HLW mixture solidifies in the glass melter, is dumped from the melter to an emergency receiver or spills outside of a glass canister. In these cases, the equipment will be packaged and shipped to a repository under specified regulations.

12.4 Waste Treatment Facilities

The solid waste handling facilities are to be closely coupled with the process functions of the DWPF. Design of process equipment, cranes, hot and warm maintenance cells, and decontamination facilities should provide the dual function of process maintenance and waste management operations. Provisions should be made for shipping the largest process equipment (i.e. 12 ft x 12 ft x 20 ft spray dryer) and the heaviest (30-ton glass melter) process equipment to the burial ground by railroad car. Smaller equipment may be transported in a shielded cask car. Much of the job control waste may be shipped by regulated truck because of its relatively low level of radioactivity.

TABLE 12.1

DWPF Solid Waste Generation

	Volumes, ft^3	
Waste Type	Unit	Annual[a]
A. Normal Process		
1. Combustible		20,000
2. Noncombustible		
a. Job control		5,000
b. Miscellaneous		5,000
3. Resin beds		488
4. Adsorber columns		
a. Silica gel		1
b. Zeolite		40
5. Filters		
a. Deep Bed Washable Filter	4	16
b. Sintered metal	34	68
B. Process Equipment		
1. Spray Dryer	2880	576
2. Glass melter	138	69
3. Centrifuge	75	38
4. Pumps		20
5. Valves		5
6. Jumpers	0.5	25
7. Vessels	100	20
8. Vessel vents	960	144

---

a. Assumes 20-year DWPF operation.

13. APPENDICES

APPENDIX 13.1

13.1 BUILDINGS 221-F AND 221-H WASTE VOLUMES AND COMPOSITIONS

Waste volumes and compositions for 221-F and H canyon operations were requested for predicting waste produced during the late 1980's. These volume and composition data were primarily required for computing the radionuclide inventory of the reference feed to the DWPF. However, the data also allow determination of the range in chemical composition of DWPF feed in the event that feed is not blended or if a decision is made to process either F- or H-Area waste separately. Sections 13.1.1 and 13.1.2 are essentially reproductions of reports prepared by the Separations Technology Department [1,2].

13.1.1 Building 221-F Waste Volumes and Compositions

13.1.1.1 Summary

High-heat and low-heat wastes transferred from Building 221-F to Building 241-F were assayed and the volumes and compositions tabulated. Compositions are tabulated on the basis of processing one metric ton of uranium (MTU). Purex wastes from HAW and LAW evaporator concentrates were tabulated in an earlier letter [3]. This appendix discusses those wastes and also all others going into high-heat waste and low-heat waste storage in Building 241-F from Buildings 221-F, 211-F, and A-Line.

13.1.1.2 Discussion

Figures 13.1-1 through 13.1-4 show the flowsheets for high-heat and low-heat waste transferred to Building 241-F. The compositions of some of the individual streams vary widely, especially those of low-heat waste streams. For this reason, compositions of some minor streams are now shown. However, typical compositions for the major streams are shown in Tables 13.1-1 and 13.1-2. The total waste coming directly from Purex is also included in the tables. The total volume of high-heat waste is 249 L/MTU at a density of 1.25 g/mL. The total volume of low-heat waste is 1696 L/MTU at a density of 1.22 g/mL. Typical uranium throughput was 100 MTU/month.

Tables 13.1-1 and 13.1-2 are based on using Mark 31A targets. For Mark 31B targets, only the coating waste is different from that of Mark 31A. Coating waste composition for Mark 31B targets is shown in Table 13.1-2.

The larger quantity of coating waste from Mark 31B targets causes the total low-heat waste to be greater than Mark 31A low-heat waste by a factor of 1.15.

Table 13.1-3 shows the percentage of high- and low-heat waste generated directly from Purex operation. HAW evaporator concentrate was 72.9% of total high-heat waste. LAW evaporator concentrate was 15.4% of the total low-heat waste transferred to Building 241-F.

13.1.2 Building 221-H Waste Volumes and Compositions

13.1.2.1 Summary

Waste volumes and composition data for H-Area canyon operations have been requested for predicting waste generation during the late 1980's. Current HM and frame waste generation rates are expected to be applicable to future operations when properly adjusted for changes in fuel or target designs and flowsheet improvements. Aluminum is the waste-controlling constituent in the HM process where 61 L of waste per kilogram of aluminum is calculated as compared with 59 L/kg Al received for waste storage (Table 13.1-4).

The flowsheet for processing Pu-238 shows 8020 L of low-heat waste for each kilogram of Pu-238 as compared with receipts of 9300 L/kg Pu-238 for waste storage (Table 13.1-4).

Composition and the streams contributing to the wastes for HM and Pu-238 processing are presented in Tables 13.1-5 through 13.1-8.

13.1.2.2 Discussion

HM waste calculations are based on current solvent extraction flowsheets [1] for Mark 16B and Mark 22 fuels. Since HM processing is aluminum-limited, forecasts can be adjusted for changes in fuel types on the basis of aluminum ratio. This study used 10.5 kg aluminum per Mark 16B or Mark 22 fuel tube.

The 1AW stream carries the aluminum and nitric acid and is the main contributor to the high-heat waste (Table 13.1-5). When that stream is concentrated, the next largest contributor is the caustic required to neutralize excess acid, convert aluminum to the soluble aluminate ion, and provide 1.2M NaOH excess for corrosion protection of the waste tanks. Since 4 moles of caustic are required for each mole of aluminum, any factor influencing aluminum has a corresponding effect on the volume and concentration of high-heat waste.

The principal contributor to low-heat waste is the 2AW stream, but spent solvent washes and waste from decontamination make significant contributions (Table 13.1-6). Low-activity waste feeds contain less salts than do high-activity waste feeds and hence, permit greater volume reduction - 4.12 vs. 1.83 - prior to discharge to waste storage.

Another contributor to low-heat waste is frame operations to recover Pu-238 and Np-237. Actual waste generation by the frame process is about 9300 L/kg Pu-238 recovered as compared to the flowsheet amount of 8020 L/kg Pu-238. The flowsheet volume does not include dissolver heel or sump material processing, extra decontamination washes, or product recycles which occur occasionally. The waste generated relates best to resin column runs. Plutonium recovery per column run depends primarily upon target design, the amount of plutonium scrap processed, and the amount of plutonium recycled from waste recovery. Recent experience shows 280 grams of Pu-238 recovered per Column RC-1 run (initial resin column for decontamination) and is the basis for the frame waste flowsheet (Figure 13.1-5 and Table 13.1-7). Current operation processes Mark 53A targets, and waste volume should remain unchanged if new targets contain similar amounts of actinides and aluminum.

The ratio of neptunium to Pu-238 in process feed has varied widely, averaging 3.45 in the past three years. If that ratio applies, low-heat wastes generated from frame processing total 2700 L/kg neptunium recovered.

Frame waste composition, Table 13.1-8, was developed from the flowsheet (Table 13.1-7) and is currently the best estimate of the actual wastes. Components present in the low-heat waste were converted to the ionic state and the metallic cations were balanced with hydroxyl anions. The major component in frame waste is sodium nitrate, resulting from neutralization of large amounts of nitric acid.

13.1.3 References

1. T. G. Campbell and D. F. Chostner. *Building 221-F Waste Volumes and Compositions.* Internal Memorandum to J. L. Womack, DPSPU-78-272-198. E. I. du Pont de Nemours & Co., Aiken, SC (November 30, 1978).

2. C. J. Thomas and T. M. Thompson. *HM Waste Volumes and Composition.* Internal Memorandum to J. L. Womack, DPSPU-78-272-178. E. I. du Pont de Nemours & Co., Aiken, SC (October 23, 1978).

3. D. F. Chostner. *Purex Waste Volumes and Compositions.* Internal Memorandum DPSPU-77-272-268, E. I. du Pont de Nemours & Co., Aiken, SC (October 21, 1977).

4. J. H. Hershey and G. M. Johnson. *Waste Management Revised Waste Generation Factors.* Internal Memorandum to J. A. Porter, E. I. du Pont de Nemours & Co., Aiken, SC (December 7, 1977).

TABLE 13.1-1

High-Heat Waste Flowsheet[a]

Stream Description	Stream Composition, lb HNO_3	$Al(NO_3)_3$	$NaNO_3$	$Fe(SO_3NH_2)_2$	NaOH	$Fe(OH)_3$	$NaAlO_2$	Na_2SO_4	H_2O	Total
1st Cycle Waste (1AW)	1317	40	21						11,514	12,892
2nd U Cycle Waste (1DW)	522			15					7,103	7,640
Miscellaneous Purex HHW[b]	59	5	5	6	73				686	834
Neutralized HAWC (Figure 13.1-1)			107		14	10	17	20	332	500
Miscellaneous HHW from Tank 15.4			19						100	119
Head End-Cake Wash			0.5						66	66.5
Total High-Heat Waste			126.5		14	10	17	20	498	685.5

---

a. Basis: 1 MTU.

b. Includes: Frame Waste Recycle (6.6), Hot-Canyon Sumps 820 and 805, ferrous sulfamate adjustment for plutonium recovery column feed, 50% Caustic.

TABLE 13.1-2

Low-Heat Waste Flowsheet[a]

Stream Description	Stream Composition, lb HNO_3	Na_2SO_4	$Fe_2(SO_4)_3$	$NaNO_3$	NaOH	$Fe(OH)_3$	$NaAlO_2$	$NaNO_2$	$Al(NO_3)_3$	HAS	H_2O	Total
2nd Pu Cycle Waste (2AW)	1566	43	40	7							6542	8198
Miscellaneous Purex LHW[b]	31				38						2864	2933
Neutralized LAWC (Figure 13.1-3)		86		78	8	32					499	703
B-Line Waste				75	33				16		310	434
Coating Waste[c]				182	59		170	41			756	1208
Decontamination Solution	37									45	800	882
Waste from Tank 5.2				307	68		170	41	16	45	1877	2524
Lab Waste Evaporator (18.6E)				146							328	474
General-Purpose Evaporator (710)				257							603	860
Total Low-Heat Waste		86		788	63	32	170	41	16	45	3307	4561

---

a. Basis: 1 MTU.

b. Includes: B-Line Waste, Acid Solvent Washes, Alkaline Solvent Washes, 50% Caustic.

c. For Mark 31A targets; Mark 31B target coating waste contains:

	lb/MTU
$NaNO_3$	388
NaOH	125
$NaAlO_2$	370
$NaNO_2$	87
H_2O	1614
Total	2584

TABLE 13.1-3

Purex Waste vs. Total Waste

High-Heat Waste	
Purex Waste (HAWC)	500 lb/MTU
Total High-Heat Waste (Table 13.1-1)	685.5 lb/MTU
Contribution of Purex Waste to Total High-Heat Waste	72.9%
Low-Heat Waste	
Purex Waste (LAWC)	703 lb/MTU
Total Low-Heat Waste (Table 13.1-2)	4561 lb/MTU
Contribution of Purex Waste to Total Low-Heat Waste	15.4%

TABLE 13.1-4

Waste Volumes

	L/kg Aluminum	
	Flowsheet	Plant Experience
High-Heat Waste		
HM Process		
1AW	33.5	-
Head End	0.1	-
	33.6	39.6[a]
Low-Heat Waste		
HM Process		
Low-Activity Waste	22.2	-
Solvent Washes	4.3	-
Decontamination Waste	1.1	-
General-Purpose Evaporator	-	3.7[b]
	27.6	20.52

	L/kg Pu-238	
	Flowsheet	Plant Experience
Frames		
Frame Waste Recovery	6150	7050
Resin Digestion	1870	2250
	8020	9300[c]

---

a. See Reference 4.

b. 11/77 to 10/78.

c. 1975 to 10/78; volume adjusted to same salt content.

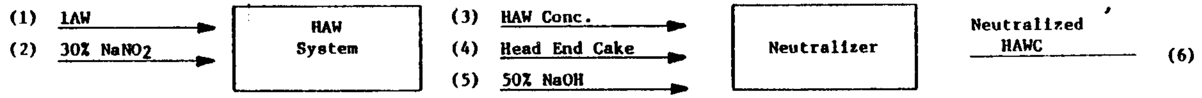
TABLE 13.1-5

HM High-Heat Waste[a]

	Composition, kg																		
Stream[b]	Volume, liters	Sp Gr	Total Mass	H_2O	HNO_3	$Al(NO_3)_3$	$HgNO_3$	$NaNO_2$	$Fe(NO_3)_3$	$Fe_2(SO_4)_3$	$NaNO_3$	Gelatin	MnO_2	NaOH	HgO	$Fe(OH)_3$	FS[c]	$NaAlO_2$	Na_2SO_4
1	30.42	1.237	37.6	26.72	2.69	7.89	0.174										0.152		
2	0.25	1.206	0.297	0.21				0.089											
3	19.05	1.384	26.36	15.55	2.61	7.89	0.174		0.049	0.082	0.005								0.087
4	0.133	1.05	0.14	0.125	0.001							0.0006	0.013						
5	12.26	1.52	18.642	9.32										9.32					
6	33.64	1.344	45.23	26.09							13.119	0.0006	0.013	1.62	0.116	0.065		3.04	0.174

---

a. Basis: 1 kg Al fed to 1st cycle. Streams are indicated here:



b. Evolved gaseous products not shown.

c. FS is ferrous sulfamate, $Fe(NH_2 \cdot SO_3)_2$.

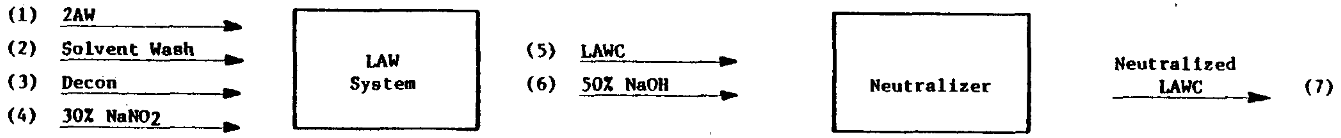
TABLE 13.1-6

HM Low-Heat Waste[a]

	Composition, kg[b]																	
Stream	Volume, liters	Sp Gr	Total Mass	H_2O	HNO_3	$NaNO_2$	$Fe(NO_3)_2$	$Fe_2(SO_4)_3$	$NaNO_3$	NaOH	$Fe(OH)_3$	FS[c]	Na_2SO_4	Na_2CO_3	$KMnO_4$	HAS	$NaHSO_4$	MnO_2
1	76.17	1.112	84.74	59.18	16.35							0.648						
2	15.80	1.038	16.4	15.74										0.656				
3	4.1	1.05	4.305	4.04	0.082					0.031					0.04	0.117		
4	2.0	1.206	2.4	1.68		0.72												
5	23.40	1.24	23.4	15.98	6.18		0.211	0.348	1.282				0.371				0.005	0.022
6	7.34	1.52	11.15	5.58						5.58								
7	27.67	1.248	34.56	20.79					11.42	1.34	0.279		0.742				0.005	0.022

---

a. Basis: 1 kg Al fed to 1st cycle. Streams are indicated here.



b. Evolved gaseous products not shown.

c. FS is ferrous sulfamate, $Fe(NH_2.SO_3)_2$.

TABLE 13.1-7

Frame Waste Flowsheet[a]

Stream No. and Description	Composition, kg													
	Actinide	Al	HNO_3	$Hg(NO_3)_2$	KF	H_2O	FS[b]	N_2H_4[c]	Ascorbic, Oxalic Acid	$NaNO_2$	NaOH	Resin	$KMnO_4$	Total
1 Waste	0.5	65	3254	1.9	5.7	4089	42	13	-	-	-	-	-	7471
2 Waste	0.2	-	2171	-	1.9	3825	41	7	-	-	-	-	-	6046
3 Waste	-	-	964	-	-	2764	31	-	-	-	-	-	-	3759
4 Waste	0.04	-	11	-	-	243	-	-	1.6	-	-	-	-	256
5 Waste	-	-	321	-	-	461	-	-	-	-	-	-	-	782
6 Cold Feed	-	-	3607	-	-	3675	115	63	-	-	-	-	-	7460
7 Column Feed	0.94	65	10328	1.9	7.6	15057	229	83	1.6	-	-	-	-	25775
8 Cold Feed	-	-	604	-	-	1275	-	-	-	-	-	-	-	1879
9 Product	0.94	-	32	-	-	214	-	-	-	-	-	-	-	247
10 Waste	-	65	10900	1.9	7.6	16118	229	83	1.6	-	-	-	-	27407
11 Adjustment	-	-	-	-	-	938	-	-	-	404	-	-	-	1343
12 Evaporator Feed	0	65	10900	1.9	7.6	17057	229	83	1.6	404	-	-	-	28750
13 Overheads	-	-	8720	-	-	14535	-	-	-	-	-	-	-	23255
14 Bottom	0	65	2180	1.9	7.6	2522	229	83	1.6	404	-	-	-	5495
15 Caustic	-	-	-	-	-	1679	-	-	-	-	1679	-	-	3358
16 Neutralized Waste	0	65	2180	1.9	7.6	3788	229	83	1.6	404	1679	-	-	8440[d,e]
17 Resin	0	-	349	-	-	509	-	-	-	-	-	59	-	917
18 Cold Feed	-	-	-	-	-	1009	-	-	-	-	335	-	43	1380
19 Digested Resin	0	-	349	-	-	1511	-	-	-	-	335	59	43	2297[f]
20 Low-Heat Waste	0	65	2529	1.9	7.6	5299	229	83	1.6	404	2014	59	43	10737[e]
														(Volume, 8020 L)

---

a. Basis: 1 kg Pu-238 recovered; one column RC-1 yields 280 grams of Pu-238 and 965 grams of neptunium.

b. FS is ferrous sulfamate.

c. N_2H_4 is hydrazine mononitrate.

d. Neutralized evaporator bottoms Sp Gr ∿1.35.

e. Includes 137 kg of gaseous products.

f. Digested resin solution Sp Gr ∿1.23.

TABLE 13.1-8

Frame Waste Composition (Low-Heat Waste)[a]

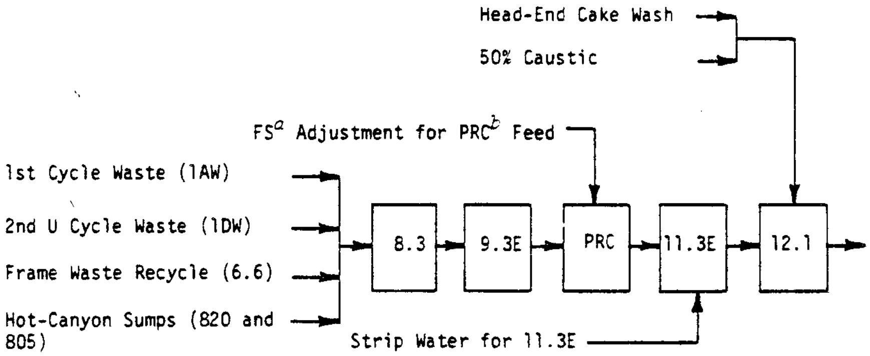
	Moles	kg	Wt %
NO_3^-	40,158	2,490	23.5
Na^+	56,205	1,293	12.2
OH^- [b]	20.759	353	3.3
SO_4^{2-}	1,850	178	1.7
Al^{3+}	2,401	65	0.6
Fe^{3+}	925	52	0.5
MnO_2	270	23.5	0.2
K^+	403	15.8	0.2
F^-	131	2.5	0.02
Hg^{2+}	5.9	1.2	0.01
H_2O [c]	340,333	6,126	57.8
		10,600 (Volume, 8020 L)	100

---

a. Basis: 1 kg Pu-238 recovered.

b. Moles required to balance ionic charges.

c. Weight by difference.



---

a. Ferrous Sulfamate

b. Plutonium Recovery Column

FIGURE 13.1-1. Purex High-Heat Waste

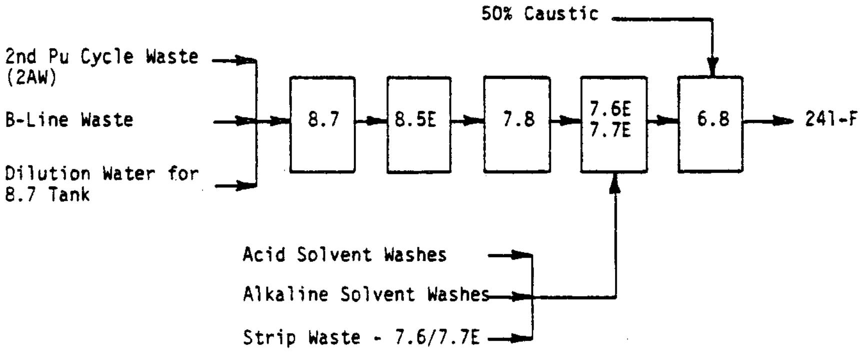
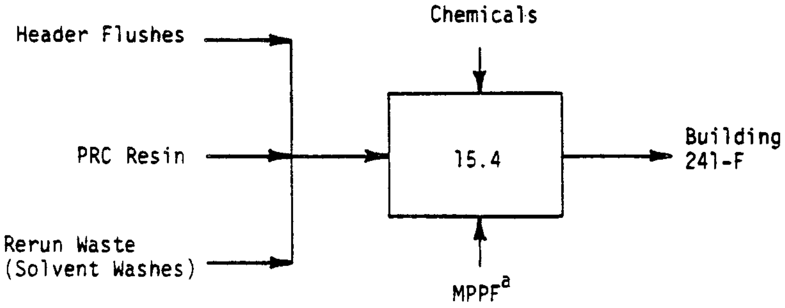


FIGURE 13.1-2. Miscellaneous High-Heat Waste



---

a. Multi-Purpose Processing Facility

FIGURE 13.1-3. Purex Low-Heat Waste

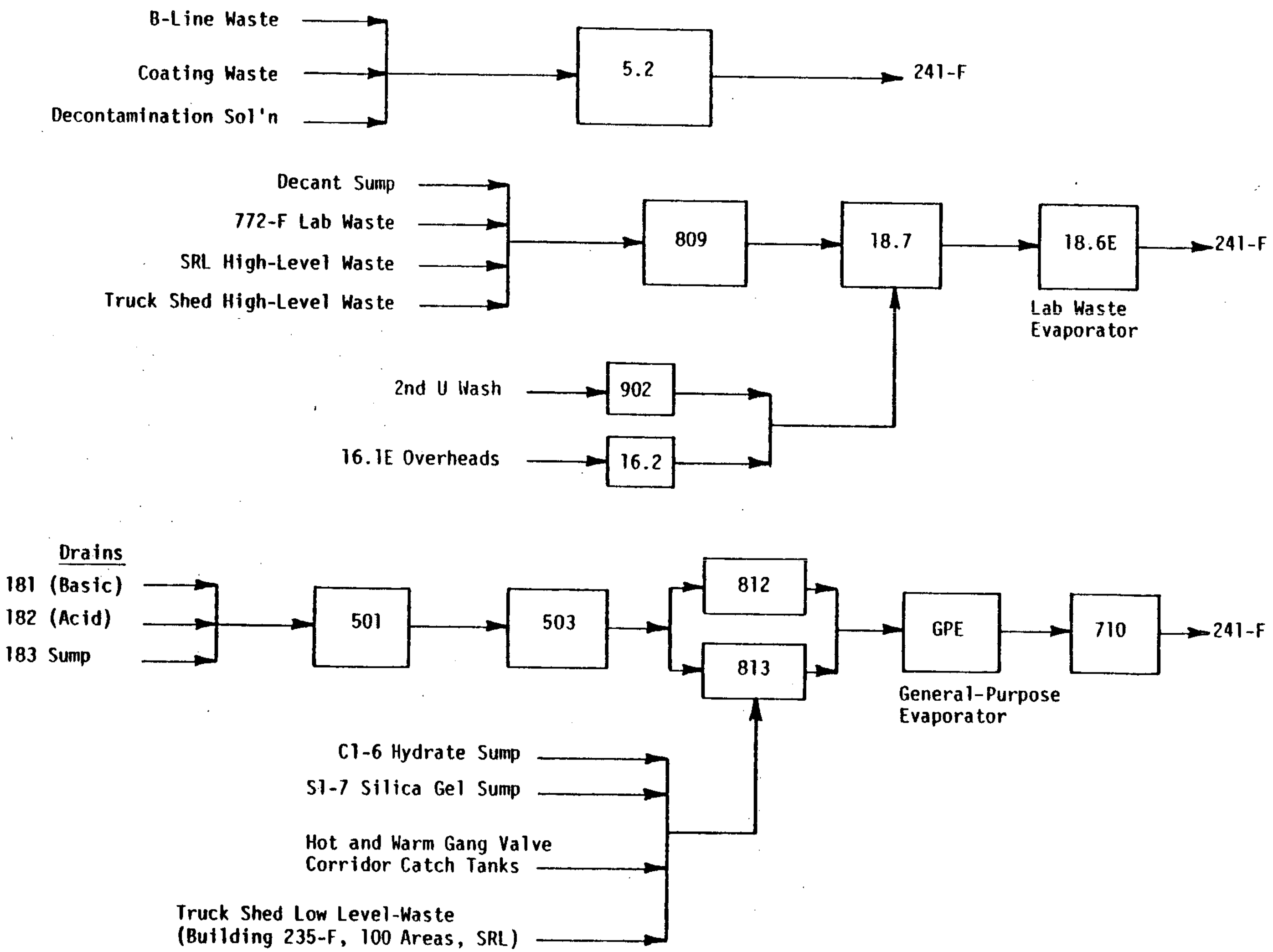


FIGURE 13.1-4. Miscellaneous Low-Heat Waste

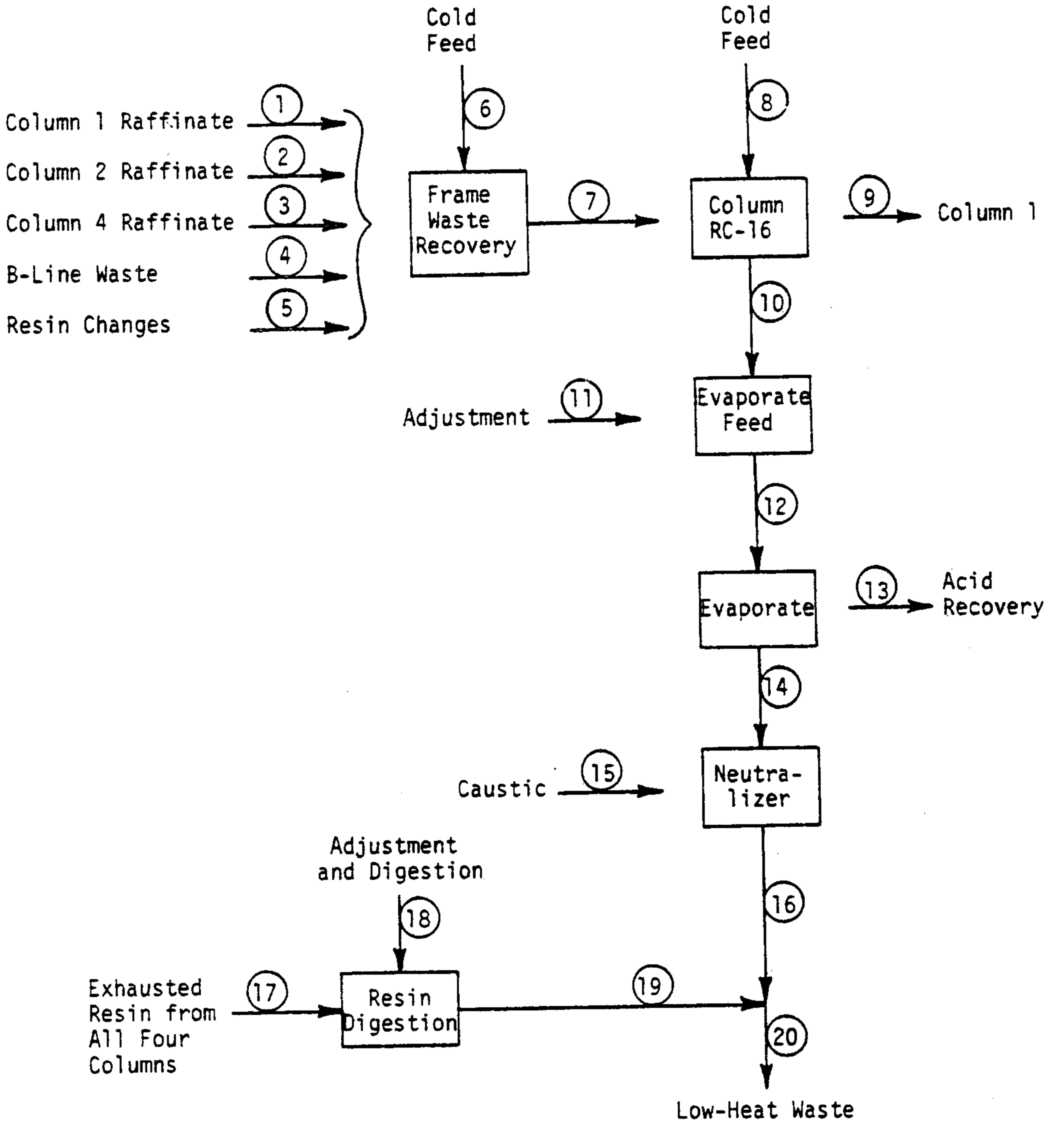


FIGURE 13.1-5. Frame Waste Flowsheet

APPENDIX 13.2

BASES FOR DETERMINING DWPF FEED STREAM COMPOSITION

13.2 BASES FOR DETERMINING DWPF FEED STREAM COMPOSITION

13.2.1 General

This appendix summarizes the bases used to prepare the DWPF reference feed compositions.

13.2.2 Tank Cleaning

Tank cleaning was assumed to use 120 kgal of 4 wt % oxalic acid for dissolving/slurrying residual sludge left in tanks after hydraulic cleaning. Tank 16H oxalic acid was assumed to be neutralized with 10% excess NaOH, clarified, evaporated, and stored with salt cake. Prior to DWPF startup, oxalic acid from 23 tanks was assumed to be digested (described below), neutralized, clarified, evaporated, and stored with salt cake. After startup, oxalic acid from 15 tanks was assumed to be digested, neutralized, clarified, and used to help dissolve salt cake for DWPF supernate feed preparation.

Digestion consists of adding 50 wt % HNO_3 with $Mn(NO_3)_2$ to make up a 1M HNO_3 and 0.01M Mn^{2+} solution. It was assumed 95% of the oxalic acid was digested by the reaction

$$3H_2C_2O_4 + 2HNO_3 \xrightarrow{x} 6CO_{2(g)} + 4H_2O + 2NO \qquad x = 95\%$$

Neutralization was assumed to be accomplished by adding 10 wt % excess NaOH in a 50 wt % solution. The following reactions were assumed to occur

$$H_2C_2O_4 + 2\ NaOH \rightarrow Na_2C_2O_4 \rightarrow 2\ H_2O$$

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$$

$$2\ NaOH + Mn(NO_3)_2 + 1/4\ O_{2(g)} \rightarrow MnO{\cdot}OH_{(s)} + 1/2\ H_2O + 2\ NaNO_3$$

The following quantities were incorporated in the feed description of salt cake and salt cake diluent.

	Prior to DWPF, in Salt Cake, klb	During DWPF, as Diluent, klb
$NaNO_3$	2,215	1,490
$Na_2C_2O_4$	129	45
NaOH	112	71
H_2O	-	16,821
Total	2,456	18,427

A total of 23.2 klb of Mn from tank cleaning was accounted for in the composite sludge composition estimation.

13.2.3 Forecast Quantities

The following series of bases and assumptions were used to develop quantities used in preparing DWPF feed.

- 4.730 Mgal of reconstituted waste are to be processed each year.

- Forecast volumes for waste quantities on hand at startup are,

Equivalent Sludge	4.314 Mgal
Equivalent Salt Cake	13.622 Mgal

  The forecast production rate for fresh waste is 1.473 Mgal/yr.

- Salt cake density is 1.8 g/cm^3 and contains 78 wt % salt on a dry basis. Four gallons of supernate makes one gallon of salt cake.

- Fresh waste and reconstituted waste contain 0.145 lb of solids per gal. Supernate and redissolved salt cake contain 1000 ppm of volume of sludge.

- The wt % of salts in fresh waste supernate, reconstituted supernate, and in the interstitial supernate of settled sludge are all identical.

- The density of the solids is 3 g/cm^3 and the density of supernate is given by the following equations:

13.2.4 Compositions

Salt compositions are based on liquid waste having the same relative compositions as reference supernate.

Reference Supernate Molarities

$NaNO_3$	2.2	Na_2SO_4	0.3
$NaNO_2$	1.1	NaCl	0.022
$NaAlO_2$	0.5	NaF	0.002
NaOH	0.75	Na[HgO(OH)]	0.001
Na_2CO_3	0.3		

Solids compositions were based upon the following elemental analysis which was derived from analyses of actual waste tank sludge samples.

Element	Wt %	Element	Wt %
Fe	20.1	Hg	0.994
U[a]	2.28	Cl	0.900
Ca	1.53	F	0.070[d]
Ni	2.80	C	1.58[d]
Na	3.00[b]	Al	11.9
NO_3^-	1.00[b]	Si	0.316
SO_4^{2-}	0.50[b]	HgI_2	0.376[e]
Mn	5.00[c]	Other	Balance

---

a. Low-heat sludge assumed to contain no significant uranium.

b. Estimated average value, A. J. Hill, Jr., private communication, October 12, 1978.

c. Includes contribution forecast from waste tank decontamination.

d. E. J. Lukosius, private communication, March 6, 1978.

e. Based on 23,180 lb of I-127 released to waste from B-Line operations.

$$\rho_1(x,t) = \rho_w(t) \div [1 - (1-\rho_w(t) \div 2)x] \qquad x<x^*$$

$$\rho_2(x,t) = 0.9757 + 0.9813x - 0.0007\, t \qquad x>x^*$$

Where x = wt fraction of salt in supernate

t = temperature, °C

$\rho_w(t)$ = water's density at temperature t, g/cm^3

x^* = wt fraction when $\rho_1(x^*,t) = \rho_2(x^*,t)$

On the basis of the assumptions listed above, the quantities of sludge, salt cake, and liquid waste on hand at startup are

	Volume, Mgal	Density, g/cm^3	Salt, Mlb	Solids, Mlb	Water, Mlb	Total Mlb
Sludge	4.314	1.369	11.77	8.42	29.11	49.30
Salt Cake	13.622	1.8	159.49	0.1064	45.02	204.62

The time period required to process the waste inventory is 12.43 yr. The quantities of salt cake and sludge that will be consumed at the 12-gpm reconstituted basis and the 12.88-gpm DWPF feed basis instantaneous rates are given below assuming 75% attainment on all tank farm operations.

	Instantaneous Rates	
	DWPF Feed Basis, gal/hr	Reconstituted Basis, gal/hr
Sludge	52.8	52.8
Slurry H_2O	51.8	
Total	105.6	52.8
Salt Cake	166.8	166.8
Water	494.4	494.4
Tank Cleaning Liquid	26.1	26.1
Total Supernate	667.2	667.2
Total Feed	772.8 (12.88 gpm)	720.0 (12.00 gpm)

APPENDIX 13.3

DETAILED SLUDGE ANALYSES 13.3.1

13.3 DETAILED SLUDGE ANALYSES

13.3.1 General

Development of a process to convert Savannah River Plant waste to a high-integrity solid required chemical and radiometric characterization of the insoluble fraction of the waste. For the past several years, sludges have been sampled and analyzed at the Savannah River Laboratory. This appendix summarizes the chemical and radiometric analyses that have been performed to date.

13.3.2 Sludge Analyses

13.3.2.1 Initial Sampling Program (J. A. Stone)

In 1975, twelve 3-liter samples (essentially a surface-type of sample) were collected from four Savannah River Plant waste tanks with a hydraulically operated sampler. Each sludge sample was washed and dried to yield a powdered product that was subsequently characterized by chemical and radiometric analyses [1]. Tables 13.3-1 through 13.3-4 list the chemical composition of sludge from each waste tank sampled. Tables 13.3-5 and 13.3-6 list the residual leachable components and the concentration of radionuclides, respectively, for each sludge sample.

13.3.2.2 Sludge/Supernate Separation Studies (J. A. Stone)

Approximately one year following the initial sludge sampling program, additional sludge samples were obtained from the same four tanks plus four additional tanks. These samples were obtained to prepare a reference waste composition for demonstration of the initial conceptual process for separating the sludge fraction from the supernate fraction [2]. Table 13.3-7 lists the principal components in the washed, dried sludge. The principal radionuclides are tabulated in Table 13.3-8.

13.3.2.3 Chemical Dissolving of Sludge from a High-Level Waste Tank

(A. J. Hill)

A research and development effort has been under way at the Savannah River Laboratory to develop a method to chemically dissolve the sludge not anticipated to be removed during hydraulic slurrying and removal of Tank 16H sludge [3,4]. Tables 13.3-9 and 13.3-10 list, respectively, the principal chemical constituents and radionuclide constituents of washed, dried Tank 16H sludge.

13.3.2.4 Future Analyses (J. R. Fowler)

In January 1979, an extensive sludge sampling program was initiated to obtain large (25-liter) subsurface sludge samples from Waste Tanks 4, 7, 8, 18, 11, 12, 13, 15, and 32. These samples will be used in sludge washing and vitrification studies using bench-scale equipment in the SRL High-Level Caves [5]. As of this writing, Tank 15H has been sampled. Each sample will be thoroughly characterized both chemically and radiometrically [6,7]. As analytical results become available, this section will be updated and ultimately the reference feed composition to the DWPF will be altered as required.

TABLE 13.3-1

Chemical Composition of Washed, Dried Tank 5 Sludge

Element	Wt %	Mole %[a]	Element	Wt %	Mole %[a]
Fe	27.5	39.6	P[b]	0.07	0.2
U	15.4	5.2	Zn[b]	0.07	0.09
Mn	10.8	15.9	Th	0.07	0.02
Na	6.1	21.6	Mg	0.06	0.21
Ni	5.1	7.1	Cu[b]	0.06	0.07
Al	1.5	4.6	Nb[b]	0.05	0.05
Ca	0.6	1.3	Y[b]	0.04	0.03
Nd[b]	0.5	0.3	Ag[b]	0.04	0.03
Si	<0.4	<1.2	Pm[b]	0.04	0.02
Zr[b]	0.4	0.4	Pb[b]	0.04	0.02
Cr[b]	0.3	0.5	Ti[b]	0.04	0.06
Ru[b]	0.3	0.2	Sm[b]	<0.04	<0.02
Ba	0.25	0.15	Eu[b]	0.02	0.01
Ce[b]	0.2	0.1	V[b]	0.01	0.02
K	0.14	0.3	Rh[b]	0.01	0.01
Cl[b]	0.1	0.2	Mo[b]	<0.01	<0.01
Sr[b]	0.1	0.09	Pu[b]	<0.01	<0.005
Hg	0.1	0.04	Np[b]	<0.008	<0.002
La[b]	0.09	0.05	F[b]	0.007	0.03
Pr[b]	0.09	0.05	B[b]	<0.003	<0.02
S[b]	0.08	0.2			

---

a. Calculated from sum of the elements shown, without O, N, or C.

b. From spark-source mass spectrometry (factor of 2 uncertainty); all other values from elemental analyses.

TABLE 13.3-2

Chemical Composition of Washed, Dried Tank 7 Sludge

Element	Wt %	Mole %[a]	Element	Wt %	Mole %[a]
C	16.8	65.3	Cu[b]	0.15	0.11
Fe	8.9	7.4	Sr[b]	0.15	0.08
U	3.3	0.7	La[b]	0.15	0.05
Si	3.2	5.3	Pr[b]	0.15	0.05
Na	2.8	5.7	Ba	0.13	0.04
Al	2.5	4.3	Nb[b]	<0.1	<0.05
Mn	2.2	1.9	Mg	0.08	0.15
Ni	2.1	1.6	Cs[b]	0.06	0.02
Cl[b]	2.0	2.6	Hg[b]	0.06	0.01
Nd[b]	1.0	0.3	Y[b]	0.05	0.03
Ca	0.83	1.0	Sm[b]	0.05	0.02
S[b]	0.5	0.7	Rh[b]	0.05	0.02
Zn[b]	0.5	0.4	B[b]	<0.05	<0.21
Zr[b]	0.5	0.3	Cd[b]	<0.05	<0.02
Ru[b]	0.5	0.2	P[b]	0.03	0.05
Cr[b]	0.45	0.4	Pd[b]	0.03	0.01
K[b]	0.3	0.4	Mo[b]	<0.014	<0.007
Ag[b]	0.3	0.1	Eu[b]	0.013	0.004
Ce[b]	0.25	0.08	Co[b]	<0.013	<0.010
Pb[b]	0.25	0.06	Th	0.007	0.001
F[b]	0.15	0.37	V[b]	<0.005	<0.005

---

a. Calculated from sum of the elements shown, without O or N.

b. From spark-source mass spectrometry (factor of 2 uncertainty); all other values from elemental analyses.

TABLE 13.3-3

Chemical Composition of Washed, Dried Tank 13 Sludge

Element	Wt %	Mole %[a]	Element	Wt %	Mole %[a]
Fe	27.9	39.9	Zn[b]	<0.2	<0.3
Mn	8.8	12.8	Pr[b]	0.2	0.1
Al	7.1	21.0	Ba	0.15	0.09
U	4.0	1.3	Th	0.11	0.04
Na	3.1	10.7	Ti[b]	<0.1	<0.2
Ca	2.3	4.7	Nb[b]	<0.1	<0.09
Hg	2.1	0.8	Ag[b]	<0.1	<0.07
Cl[b]	1.0	2.3	Cr	0.09	0.13
Ce[b]	1.0	0.6	K[b]	0.08	0.2
Nd	<0.6	<0.3	Cs[b]	<0.06	<0.04
Ni	0.5	0.7	Y[b]	0.05	0.05
Pb[b]	0.5	0.2	S[b]	<0.04	<0.1
Si	<0.4	<1.1	Cu[b]	0.03	0.04
Zr[b]	0.4	0.4	V[b]	<0.007	<0.01
Mg[b]	0.3	1.0	B[b]	0.005	0.04
P[b]	0.3	0.8	F[b]	<0.005	<0.02
La[b]	0.3	0.2			

---

a. Calculated from sum of elements shown, without O, N, or C.

b. From spark-source mass spectrometry (factor of 3 uncertainty); all other values from elemental analyses.

TABLE 13.3-4

Chemical Composition of Washed, Dried Tank 15 Sludge

Element	Wt %	Mole %[a]	Element	Wt %	Mole %[a]
Al	33.5	86.2	Pr[b]	0.04	0.02
Fe	3.1	3.9	La[b]	0.04	0.02
Mn	2.3	2.9	B[b]	0.03	0.20
Na[b]	1.2	3.6	P[b]	0.03	0.07
Hg	0.92	0.32	Ru[b]	0.03	0.02
U	0.91	0.26	Ti[b]	<0.02	<0.03
Ni	0.51	0.60	Nb[b]	<0.02	<0.01
Nd[b]	0.30	0.15	S[b]	<0.02	<0.05
Si[b]	0.22	0.55	K	0.015	0.03
Ca	0.21	0.38	Cr[b]	0.01	0.02
Th	0.18	0.06	Y[b]	0.01	0.01
Mg	0.14	0.39	Sm[b]	0.01	0.007
Zr[b]	0.11	0.08	Pb[b]	0.01	0.005
Ba	0.10	0.05	Rh[b]	0.007	0.005
Ce[b]	0.05	0.02	Pu[b]	<0.005	<0.001
Cu[b]	0.04	0.05	F[b]	0.002	0.009
Sr[b]	0.04	0.03	V[b]	<0.0007	<0.0007
Zn[b]	<0.04	<0.04			

---

a. Calculated from sum of elements shown, without O, N, or C.

b. From spark-source mass spectrometry (factor of 3 uncertainty); all other values from elemental analyses.

TABLE 13.3-5

Residual Leachable Components

Component	Tank 5		Tank 7		Tank 13		Tank 15	
	Total, wt %	Leachable, wt %	Total, wt %	Leachable, wt %	Total, wt %	Leachable, wt %	Total, wt %	Leachable, wt %
Na^+	6.1	0.8	2.8	1.9	3.1	1.0	1.2	0.4
NO_3^-	3.0	0.6	1.2	1.2	0.5	0.3	5.0	0.3
NO_2^-	0.06	0.004	0.09	0.03	0.03	0.02	0.04	0.04
SO_4^{2-}	5.5[a]	0.8	19.5[a]	3.7	2.7[a]	0.8	5.7[a]	0.9

---

a. Total sulfate values may be high by a factor of 5 to 10; results of analyses by three different methods gave poor agreement.

TABLE 13.3-6

Specific Activity of Radionuclides

Isotope	Specific Activity, mCi/g			
	Tank 5	Tank 7	Tank 13	Tank 15
Co-60	-	-	0.01	-
Sr-90	74.68	27.03	15.49	25.61
Zr-95	<0.03	<0.01	<0.01	<0.01
Nb-95	<0.03	<0.01	0.02	<0.02
Ru-103	<0.02	<0.01	<0.01	<0.01
Ru-106	2.73	1.41	0.40	1.74
Sb-125	0.43	-	0.12	1.27
Cs-134	<0.02	0.01	<0.01	0.03
Cs-137	1.29	1.30	0.30	0.07
Ce-144	4.77	0.21	2.01	16.89
Eu-154	0.47	<0.01	0.30	1.18
Gross α	0.10	0.06	0.28	0.14

TABLE 13.3-7

Principal Components of Washed, Dried Sludge

	Tanks 4F,6F	Tank 5F	Tank 12H	Tank 13H	Tank 15H	Tank 16H
Principal Metal Cations, wt %						
Fe	32.77	28.90	4.49	25.57	5.29	13.91
Al	2.28	1.57	30.16	8.70	18.75	16.61
Mn	1.99	5.83	1.69	7.85	2.45	2.59
U	9.22	10.81	a	4.18	3.77	4.49
Na	2.95	5.66	1.03	2.58	2.45	2.19
Sr	1.70[b]	1.29[b]	c	3.50[b]	1.80[b]	c
Ca	2.28	0.90	2.13	1.76	0.52	2.87
Hg	0.65	0.12	1.12	2.32	2.51	2.80
Ni	6.29	6.34	0.46	0.45	0.73	0.30
Principal Anions, wt %						
NO_3^-	0.12	1.16	0.42	0.31	0.19	0.32
NO_2^-	0.02	0.12	0.17	0.01	0.16	0.15
SO_4^{2-}	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
PO_4^{3-}	0.69[b]	0.32[b]	c	2.15[b]	2.87[b]	c

---

a. Not detectable.

b. $Sr_3(PO_4)_2$ carrier added.

c. Not determined.

TABLE 13.3-8

Principal Radionuclides in Washed, Dried Sludge, mCi/g

Isotope	Tanks 4F,6F	Tank 5F	Tank 12H	Tank 13H	Tank 15H	Tank 16H
Sr-90	123.0	177.5	41.4	30.1	55.0	53.6
Ce-144	30.5	1.5	17.4	0.3	5.4	0.6
Ru-106	11.4	1.3	1.7	0.08	1.0	0.2
Cs-137	0.7	0.9	0.05	0.3	0.1	0.2
Eu-154	0.7	0.6	0.5	0.08	0.4	0.1
Sb-125	1.4	0.9	0.3	0.06	0.3	0.04
Co-60	1.1	1.1	<0.01	0.01	0.06	0.02
Gross α	0.4	0.1	0.7	0.2	0.1	0.15

TABLE 13.3-9

Calculated Principal Constituents of Washed and Dried Tank 16 Sludge

Constituent	Wt %
AlO_2^-	16
Fe^{3+}	40
MnO_2	16
Na^+	20
SO_4^{2-}	1.1
Si^{4+}	2.0
Ba^{2+}	1.0
Ca^{2+}	1.0
Ce^{4+}	1.0
Hg^{2+}	2.5
UO_2^{2+}	0.4

---

a. Calculated from data for washed and unwashed dried sludge. Estimated relative precision within ±30 to 40%.

TABLE 13.3-10

Major Radionuclides in Tank 16H Sludge

Nuclide	Residual Activity in Centrifuged, Washed, Dried Sludge, mCi/g	Removed by Two Washes, %
Co-60	50.0	Nil
Sr-90	8.6	Nil
Y-90	8.6	Nil
Nb-95	0.55	Nil
Ru-106	13.6	Nil
Rh-106	13.6	Nil
Cs-134	0.40	94
Cs-137	7.3	90
Ba-137	7.3	90
Ce-144	45.5	Nil
Pr-144	45.5	Nil
Pm-147	a	a
Eu-154	17.3	Nil
Pu[b]	0.42	Nil

---

a. Not determined.

b. Total plutonium alpha activity.

13.3.3 References

1. J. A. Stone, J. A. Kelley, and T. S. McMillan. *Sampling and Analyses of SRP High-Level Waste Sludges.* USERDA Report DP-1399, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1976).

2. J. A. Stone. *Separation of SRP Waste Sludge and Supernate.* USERDA Report DP-1441, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1976).

3. R. F. Bradley and A. J. Hill, Jr. *Chemical Dissolving of Sludge from a High-Level Waste Tank at the Savannah River Plant.* USDOE Report DP-1471, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1977).

4. Memorandum, A. J. Hill, Jr. to M. L. Hyder. *Chemical Dissolving of Tank 16H Sludge.* DPST-78-208, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (January 9, 1978).

5. Memorandum, G. W. Wilds to W. J. Mottel. *Sludge Sampling.* DPST-78-619, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (December 4, 1978).

6. Memorandum, J. R. Fowler to D. L. McIntosh. *Information Meeting - 4/27/79, Waste Processing and Analytical Needs.* (May 8, 1979).

7. Memorandum, J. R. Wiley to J. A. Kelley (May 23, 1979).

APPENDIX 13.4

13.4 DETAILED SUPERNATE ANALYSES (R. S. Ondrejcin)

13.4.1 General

Since 1972, a program has been conducted at SRL to characterize the soluble fraction (supernate) of the waste in storage in the 200-Area Waste Tank Farms. Supernate samples were analyzed for the major cations, anions, and radionuclides [1].

13.4.2 Supernate Analyses

Tables 13.4-1 and 13.4-2 summarize the results from chemical and radiometric analyses of supernate samples from selected waste tanks in F Area. Similarly, the results on samples from H-Area tanks are summarized in Tables 13.4-3 and 13.4-4.

13.4.3 References

1. R. S. Ondrejcin. *Chemical Compositions of Supernate Stored in SRP High-Level Waste Tanks.* USAEC Report DP-1347, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (August 1974).

TABLE 13.4-1

F-Area Waste Tank Supernate Analyses

Tank No.	Date Sampled	Ion Concentration, M[a] Na^+	NO_3^-	NO_2^-	$Al(OH)_4^-$	OH^-	CO_3^{2-}	SO_4^{2-}	PO_4^{3-}	Cl^-
1	2/21/73	10.1	1.6	2.4	0.8	6.3	<0.1	0.02	0.08	0.06
1	8/5/74	11.7	1.9	3.4	0.8	7.6	0.13	0.007	0.06	-
1	3/12/75	13.7	1.5	2.7	0.6	9.1	0.11	0.007	0.08	-
2	2/20/73	9.3	2.4	2.9	0.7	4.5	<0.1	0.02	0.04	0.06
2	8/27/74	13	1.5	2.6	0.9	9.4	0.09	0.008	0.07	-
4	6/23/72	-	2.4	3.1	0.5	2.8	0.2	0.03	0.04	0.03
5	3/1/73	9.4	2.4	3.1	0.7	4.4	<0.1	0.02	0.04	0.06
6	3/1/73	5.0	1.6	1.1	0.4	1.7	0.1	0.14	0.02	0.04
8	3/8/73	4.0	1.7	0.5	0.4	1.1	<0.1	0.18	0.02	0.03
18	9/7/72	12.5	2.5	2.6	0.7	3.4	0.3	0.02	0.03	0.11
34	1/12/76	11.4	2.4	2.6	0.4	5.9	$\sim$0	0.008	0.04	-

---

a. Dash indicates "not requested."

TABLE 13.4-2

F-Area Waste Tank Supernate Radionuclide Analyses

Tank No.	Date Sampled	Activity, dis/min/ml[a] Cs-137 x 10^{-9}	Sr-90 x 10^{-5}	Ru-106 x 10^{-6}	Total Pu x 10^{-4}	Gross α x 10^{-4}
1	2/21/73	14	5	140	0.04	<0.05
1	8/5/74	10	20	70	-	8.0
1	3/12/75	15	30	-	2	140
2	2/20/73	8	1	140	<0.01	<0.05
2	8/24/74	13	1.8	20	-	0.4
4	6/23/72	11	-	-	0.5	-
5	3/1/73	23	9	25	0.02	1
6	3/1/73	4	7	200	0.03	1
8	3/8/73	26	12	670	0.02	0.9
18	9/7/72	11	-	30	0.4	-
34	1/12/76	8	4.4	10	4.7	280

---

a. Dash indicates "not requested."

TABLE 13.4-3

H-Area Waste Tank Supernate Analyses

Tank No.	Date Sampled	Ion Concentration, M[a]								
		Na^+	NO_3^-	NO_2^-	$Al(OH)_4^-$	OH^-	CO_3^{2-}	SO_4^{2-}	PO_4^{3-}	Cl^-
9	1/11/73	12.5	1.9	3.2	1.6	3.8	0.1	0.02	0.05	0.029
10	1/5/73	9.1	4.5	1.8	1.0	1.9	<0.1	0.08	0.02	0.020
10	8/27/74	8.9	3.1	2.1	1.2	3.6	0.18	0.02	<0.01	-
11	7/11/72	-	3.7	0.6	0.9	0.8	0.1	0.03	0.009	0.005
12	7/11/72	-	3.3	1.1	0.7	1.0	0.2	0.03	0.009	0.005
13	12/19/72	5.7	3.6	0.5	0.4	1.1	0.1	0.08	0.02	0.018
14	1/3/72	8.9	2.8	2.0	1.1	2.5	<0.1	0.04	0.01	0.019
15	12/19/72	6.2	3.6	1.1	1.0	1.0	0.1	0.05	<0.01	0.016
15	10/9/75	7.1	3.4	1.2	0.53	1.4	0.1	0.04	-	-
15	12/18/75	7.1	3.3	1.2	0.54	1.6	0.04	0.04	-	-
21	5/4/72	-	6.4	0.2	1.2	2.6	0.3	0.06	0.009	0.015
21	6/19/72	-	5.3	1.5	1.0	2.6	0.1	0.05	0.009	0.020
24	2/6/73	9.4	2.6	1.7	0.9	4.3	<0.1	0.02	<0.02	0.040
24	8/27/74	4.1	1.5	0.5	0.2	2.6	0.13	0.01	0.02	-

---

a. Dash indicates "not requested."

TABLE 13.4-4

H-Area Waste Supernate Radionuclide Analyses

Tank No.	Date Sampled	Activity, dis/min/ml[a]				
		Cs-137 $\times 10^{-9}$	Sr-90 $\times 10^{-5}$	Ru-106 $\times 10^{-6}$	Total Pu $\times 10^{-4}$	Gross α $\times 10^{-4}$
9	1/11/73	4	3	4	3	40
10	1/5/73	8	0.4	4	14	25
10	8/27/74	4.5	0.9	10	-	20
11	7/11/72	-	-	-	0.2	-
12	7/11/72	-	-	-	0.001	-
13	12/19/72	1	0.2	3	0.8	3
14	1/3/73	2	18	0.9	6	8
15	12/19/72	5	21	2	0.2	0.5
15	10/9/75	2	30	0.3	0.6	0.8
15	12/18/75	2	26	-	1	65
21	5/4/72	-	-	-	0.5	-
21	6/19/72	-	-	-	0.5	-
24	2/6/73	-	23	-	-	1
24	8/27/74	0.7	0.6	0.1	-	5

---

a. Dash indicates "not requested."

APPENDIX 13.7

13.7 ISOTOPIC CONTENT OF DWPF PROCESS STREAMS (J. R. Chandler)

13.7.1 General

This appendix provides detailed technical information about the radionuclide composition of the DWPF reference feed, process streams, and waste products. Because the data from the radionuclide balance is quite lengthy, data are recorded on the microfiche cards found at the end of this appendix.

13.7.2 Radionuclide Composition of Spent Fuel Assemblies, Assembly Wastes and Reference Waste Blend

The calculational bases for computing the radionuclide composition of the reference waste feed to the DWPF is described in Chapter 7 of this document.

Radionuclide concentrations for irradiated assemblies are calculated in two steps. First, a GLASS computer calculation provides neutron fluxes and spectrum-averaged cross sections at various times during the irradiation. Second, the fluxes and cross sections from GLASS are used by the FPCALCG module of the SHIELD system to compute the isotopic inventory [1]. The first step is necessary since actinide isotopic inventories are sensitive to detailed neutron flux spectrum effects.

The GLASS-FPCALCG calculation computes most of the radionuclides within each assembly at the end of irradiation. The major exceptions are H-3, Eu-154, Cr-51, and Co-60.

Tritium is produced in ternary fission. The tritium content is computed from the equation

$$^{3}\text{H/assembly} = \frac{\text{Exposure/assembly}}{\text{Energy/fission}} \times {}^{3}\text{H/fission.}$$

The following assumptions are made:

- One ^{3}H atom produced per 10^{4} fissions
- 195 MeV per fission
- Assembly exposures listed in Table 7.1.

^{152}Eu is produced by neutron capture in stable ^{151}Eu, the daughter of ^{151}Sm. The ^{151}Eu concentration in an irradiated assembly was determined using the equation

$$\text{Conc } (^{152}\text{Eu}) = \sigma \int_0^T \phi(\bar{t}) \int_0^{\bar{t}} S_m(t)\, \lambda_{Sm}\, dt\, d\bar{t}$$

where $S_m(t)$ is the time-dependent concentration of ^{151}Sm, λ_{Sm} is the decay constant for ^{151}Sm (decaying to ^{151}Eu), $\phi(\bar{t})$ is the neutron flux, σ is the neutron capture cross section for ^{151}Eu, and T is the period of irradiation.

^{51}Cr and ^{60}Co are produced from the activation of impurities in the fuel assemblies. The activation of a given isotope, J, after a period of irradiation and decay can be calculated by the formula

$$A_B = \phi\sigma_{J\rightarrow B} N_J \left(1 - e^{-\lambda_B t_I}\right) e^{-\lambda_B t_D}$$

ϕ = neutron flux, neut/cm^2-sec,

$\sigma_{J\rightarrow B}$ = cross section (barns) for a neutron reaction with isotope J leading to an activated nucleus, B,

N_J = atom density in atoms/b-cm of isotope J,

λ_b = decay constant for the activated nucleus, B, ($\lambda_B = 0.693/T_{\frac{1}{2}}$, where $T_{\frac{1}{2}}$ is the half-life of the activated nucleus),

t_I = irradiation period.

t_D = decay time after the irradiation was ended, and

A_B = number of disintegrations per second of isotope B per cubic centimeter.

This formula accounts for the buildup and decay of isotope B from neutron capture in isotope J and assumes that the loss of isotope B to neutron reactions is negligible.

The Cr impurity was assumed to be 0.2% of aluminum. The ^{50}Cr isotope is 4.35% of natural chromium and has a neutron capture cross section of 15.9 barns to produce the metastable isotope, ^{51}Cr.

The ^{60}Co activity is due to neutron activation of ^{59}Co and ^{60}Ni impurities in the aluminum of the assemblies. The Co impurity was assumed to be 0.001% of aluminum. The ^{59}Co isotope is 100% of natural cobalt and has a neutron capture cross section of 37 barns to produce ^{60}Co. The Ni impurity of aluminum was assumed to be 1%. ^{60}Ni is 26% of natural nickel and has an (n,p) cross section of 9.25 barns to produce ^{60}Co.

Radionuclide concentrations for each assembly are listed at 0 and 180 days following reactor irradiation. Following the 180-day cooling period, separation factors (Table 7.2) are applied and concentrations are tabulated for ages up to 100 years. The reference waste blend is computed from the assembly concentrations and volume proportions of Table 7.3. The radionuclide concentrations in the reference blend are tabulated for ages 0.5 to 100 years.

13.7.3 Radionuclide Composition of Process Streams

A computer model of the DWPF reference flowsheet has been developed with the PROCESS module of the SHIELD system. The radionuclides are separated into soluble and insoluble radionuclides (Appendix 13.9). The components of each group are tabulated in Table 4.18. The steady state solutions from the soluble and insoluble cases are combined for final results. Results are listed for processing waste feed that is 5 years old and waste feed that is 15 years old.

13.7.4 Radionuclide Concentrations in Glass and Saltcrete

The radionuclide composition of glass and saltcrete has been computed for the solidification of wastes of ages 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 years. For the 5 and 15-year cases, the glass and saltcrete components are listed for decay periods up to 1000 years.

13.7.5 Use of Microfiche

The results of the radionuclide calculations are listed on the microfiche. Concentrations are listed in units of curies, grams, watts, and photons/second per volume. The table have headings with the form:

Shield. DWPF. ___?___. Composit. ___?___.

The first variable name refers to the flowsheet which contains this stream. The last name is the stream name. Reference flowsheet stream names have the form FS-i-j, where i is the flowsheet number and j is the stream number.

The times listed in each table are the times since reactor shutdown. Five and fifteen years are listed for the reference DWPF flowsheet.

13.7.6 Cases on Microfiche

Radionuclide concentrations in DWPF process streams have been calculated for three cases. The first case assumes sludge and supernate are 5 years old when vitrified. The second case assumes sludge and supernate are 15 years old when processed. In the third case, the sludge feed is 5 years old and the supernate is 15 years old.

13.7.7 References

1. D. R. Finch, J. R. Chandler and J. P. Church, The SHIELD System, Transactions of the American Nuclear Society, Volume 32, American Nuclear Society, Lagrange Park, IL (November 1979).

APPENDIX 13.9

BASIS FOR DETERMINING RADIONUCLIDES IN SLUDGE AND SUPERNATE FEEDS

13.9 BASIS FOR DETERMINING RADIONUCLIDES IN SLUDGE AND SUPERNATE FEEDS

13.9.1 General

This appendix summarizes the basis used to determine the proportionment of radionuclides between the sludge and supernate feeds.

13.9.2 Tank Farm Inventories

The quantities of solids and salt at startup are (see Appendix 13.2).

	Salt, Mlb	Solids, Mlb
Sludge	11.77	8.42
Salt Cake	159.49	0.1064
Tank Cleaning	1.606	

The time required to process this waste inventory is 12.43 years.

13.9.3 Feed Distribution

Feed rates for the quantities in Section 13.9.2 are

	Salt, lb/hr	Solids, lb/hr
Sludge-Slurry	144.2	103.1
Supernate	1975	1.302
Totals	2119.2	104.4

These feed rates assume 75% attainment on all tank farm operations.

Radionuclides in the waste blend are assumed to have the following solubilities.

Percent of Radionuclides that are Soluble in the Waste Blend

Group Ident.	Radionuclides	% Soluble
I	Cs-Ba	100
II	Tc, Ru-Rh	50.0
III	Ag, Cd, I, Cr, Se, Pd, Te, Tl	5.0
IV	La, Ce-Pr, Pm, Nd, Sm, Tb, Sn-Sb	1.0
V	Sr-Y, Rb, Mo	0.2
VI	Co, Zr-Nb, Eu, Np, U, Pu, Am, Cm	0.1

The radionuclide distributions can be described by:

% of radionuclide in salt of supernate =

$$\frac{(\text{lb/hr salt in supernate})\ (\text{solubility fraction})}{(\text{lb/hr salt in feed})}$$

% of radionuclide in solids of supernate =

$$\frac{(\text{lb/hr solids in supernate})\ (\text{1-solubility fraction})}{(\text{lb/hr solids in feed})}$$

% of radionuclide in salt of sludge =

$$\frac{(\text{lb/hr salt in sludge})\ (\text{solubility fraction})}{(\text{lb/hr salt in feed})}$$

% of radionuclide in solids of sludge =

$$\frac{(\text{lb/hr solids in sludge})\ (\text{1-solubility fraction})}{(\text{lb/hr solids in feed})}$$

Results for each of the radionuclides are listed below.

Group	Percent Distribution Supernate Soluble	 Insoluble	 Sludge-Slurry Soluble	 Insoluble
I	93.20	0	6.80	0
II	46.60	0.63	3.40	49.37
III	4.66	1.19	0.34	93.81
IV	0.93	1.24	0.07	97.76
V	0.19	1.25	0.01	98.55
VI	0.09	1.25	0.01	98.65