

Economic Considerations for Hanford Tank Waste Disposition

By

John Huntley Curtis

B.S., Nuclear Engineering  
Kansas State University, 1993

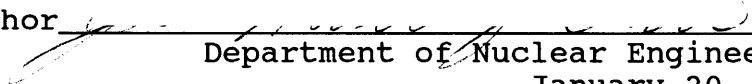
Submitted to the Department of  
Nuclear Engineering in Partial Fulfillment  
of the Requirements for the degree of

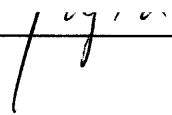
MASTER OF SCIENCE  
in Nuclear Engineering  
at the

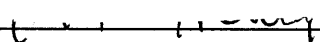
Massachusetts Institute of Technology

February 1995

© Massachusetts Institute of Technology 1995  
All rights reserved

Signature of Author   
Department of Nuclear Engineering  
January 20, 1995

Certified by   
Mujid S. Kazimi  
Department Head and Professor  
Thesis Supervisor

Accepted by   
Allan F. Henry  
Departmental Committee on Graduate Studies

1995

FEB 2 1995

# ECONOMIC CONSIDERATIONS FOR HANFORD TANK WASTE DISPOSITION

by

JOHN HUNTLEY CURTIS

Submitted to the Department of Nuclear Engineering on  
January 20, 1995 in partial fulfillment of the  
requirements for the Degree of Masters of Science in  
Nuclear Engineering

## ABSTRACT

This thesis examines the economic impact that each of the Hanford waste partitioning options, the mission duration, and the High Level Waste (HLW) repository fee has on the eventual cost of disposal of vitrified Hanford Tank Waste. The model utilized here is a highly simplified one, and can only yield the relative economic order of the various options. It is concluded that the most economical way to process the waste is by vitrifying all of the waste and disposing of it on site. This conclusion does have severe political and possibly regulatory repercussions. The next least expensive option is shown to be TRUEX-A, in which most of the radionuclides are sent to the HLW repository. TRUEX-A also is the least sensitive to fluctuations with regards to repository fees and mission duration. Although interest rates and inflation over time were not included in the model, it stands to reason that the least expensive option would be least effected by these additions. The cost of vitrifying all of the waste and sending it to the HLW repository is shown to be extremely large, irrespective of the magnitude of the repository fee.

A description of the partitioning processes is given and graphical presentations are given for each partitioning process cost and a breakdown of these costs into the basic parameters used to calculate the total cost. Figures are also used to demonstrate how the limiting element for HLW glass loading was determined.

Thesis Supervisor: Mujid S. Kazimi  
Title: Professor of Nuclear Engineering

# Economic Considerations for Hanford Tank Waste Disposition

<b>TITLE PAGE</b> .....	<b>1</b>
<b>ABSTRACT</b> .....	<b>2</b>
<b>TABLE OF CONTENTS</b> .....	<b>3</b>
<b>LIST OF TABLES</b> .....	<b>4</b>
<b>LIST OF FIGURES</b> .....	<b>5</b>
<b>1. INTRODUCTION</b> .....	<b>7</b>
1.1 HANFORD PAST .....	7
1.1.1 Single Shell Tanks .....	8
1.1.2 Double Shell Tanks .....	9
1.2 HANFORD WASTE CONTENT .....	9
1.3 WASTE DISPOSITION .....	13
<b>2. VITRIFIED WASTE PERFORMANCE</b> .....	<b>17</b>
2.1 CHEMICAL PROPERTIES IN GLASS .....	19
<b>3. EFFECTS OF PROCESSING OPTIONS ON SODIUM CONTENT</b> .....	<b>21</b>
3.1 SLUDGE WASH-A .....	21
3.2 SLUDGE WASH-B .....	22
3.3 SLUDGE WASH-C .....	22
3.4 TRUEX-A .....	24
3.5 TRUEX-B .....	24
3.6 TRUEX-C .....	25
3.7 NO PARTITIONING .....	25
3.8 CONCLUSION .....	25
<b>4. SIMPLIFIED ECONOMIC MODEL</b> .....	<b>28</b>
<b>5. EFFECTS OF PROCESSING OPTIONS ON COST AND RESULTS</b> ....	<b>34</b>
<b>6. CONCLUSIONS AND FUTURE WORK</b> .....	<b>42</b>
<b>7. REFERENCES</b> .....	<b>44</b>
<b>Appendix A - HLW and LLW limiting elements</b> .....	<b>46</b>
<b>Appendix B - Graphical Breakdown of Results</b> .....	<b>52</b>
<b>Appendix C - Volume Calculation Code and Results.</b> .....	<b>77</b>
C.1 Input .....	82
C.2 Results .....	84
<b>Appendix D Code for Cost Calculations.</b> .....	<b>86</b>
D.1 Input .....	94
D.2 Results .....	94

# List of Tables

<b>TABLE 1-1</b>	MASS OF NA, AL, CR, NI, AND P IN HANFORD TANK WASTE. . .	11
<b>TABLE 1-2</b>	WEIGHT PERCENT OF CHEMICALS IN HANFORD WASTE TANKS . . . . .	11
<b>TABLE 1-3</b>	MAJOR RADIONUCLIDES IN HANFORD WASTE (CI) . . . . .	12
<b>TABLE 1-4</b>	RADIONUCLIDES AND THEIR CLASS A LLW VOLUMES IN HANFORD WASTE. . . . .	14
<b>TABLE 1-5</b>	RADIONUCLIDES AND THEIR CLASS C LLW VOLUMES IN HANFORD WASTE. . . . .	16
<b>TABLE 2-1</b>	SELECTED LOADING LIMITS FOR CONTAINERIZED AND BOROSILICATE GLASS <sup>17</sup> . . . . .	18
<b>TABLE 2-2</b>	SELECTED METALS AND THEIR EFFECTS IN GLASS <sup>8</sup> . . . . .	19
<b>TABLE 3-1</b>	PERCENTAGE OF RADIONUCLIDES SENT TO LLW DISPOSAL. . . . .	26
<b>TABLE 3-2</b>	PERCENT OF ELEMENTS SENT TO HLW AND LLW. . . . .	27
<b>TABLE 4-1</b>	COST, LABOR, AND THROUGHPUT ESTIMATES FOR PARTITIONING PROCESSES <sup>17</sup> . . . . .	30
<b>TABLE 4-2</b>	BASELINE COST ESTIMATES FOR HLW AND LLW VITRIFICATION FACILITIES <sup>17</sup> . . . . .	31
<b>TABLE 4-3</b>	HLW AND LLW DISPOSAL COST ESTIMATES <sup>17</sup> . . . . .	31
<b>TABLE A-1</b>	ELEMENTS, THEIR GLASS LOADING LIMITS, AND THE RESULTING NUMBER OF HLW AND LLW CANISTERS. . . . .	47

# LIST OF FIGURES

FIGURE 2-1 (A) THE $\text{SiO}_2$ GLASS NETWORK, AND (B) THE EFFECT OF SODIUM(A MODIFIER) ON THE GLASS NETWORK. ....	20
FIGURE 3-1 STEPS THAT SOME OR ALL OF THE HANFORD TANK WASTE WILL GO THROUGH FOR EACH PROCESSING OPTION. ....	23
FIGURE 5-1 TOTAL COST AND THE EFFECTS OF MISSION DURATION AND HLW DISPOSAL COST ON THE TOTAL. ....	37
FIGURE 5-2 IMPACT OF HLW DISPOSAL FEES ON TOTAL COST FOR A TEN(10) YEAR MISSION. ....	38
FIGURE 5-3 IMPACT OF HLW DISPOSAL FEES ON TOTAL COST FOR A TWENTY(20) YEAR MISSION. ....	39
FIGURE 5-4 IMPACT OF HLW DISPOSAL FEES ON TOTAL COST FOR A THIRTY(30) YEAR MISSION. ....	40
FIGURE 5-5 TOTAL HLW DISPOSAL COST AND THE IMPACT OF A REDUCED HLW DISPOSAL FEES, BY PARTITIONING PROCESS. ....	40
FIGURE 5-6 TOTAL COST FOR A 10, 20, 30, AND 40 YEAR MISSION DURATIONS WITH A \$200,000/CAN HLW DISPOSAL FEE. ....	41
FIGURE A-1 HLW CANISTERS RESULTING FROM SW-A PARTITIONING. ....	48
FIGURE A-2 HLW CANISTERS RESULTING FROM SW-B PARTITIONING. ....	48
FIGURE A-3 HLW CANISTERS RESULTING FROM SW-C PARTITIONING. ....	49
FIGURE A-4 HLW CANISTERS RESULTING FROM TRUEX-A PARTITIONING. ....	49
FIGURE A-5 HLW CANISTERS RESULTING FROM TRUEX-B PARTITIONING. ....	50
FIGURE A-6 HLW CANISTERS RESULTING FROM TRUEX-C PARTITIONING. ....	50
FIGURE A-7 HLW CANISTERS IF ALL WASTE WENT DIRECTLY TO HWVP WITH NO PARTITIONING. ....	51
FIGURE B-1 COST BREAKDOWN FOR THE SLUDGE WASH-A PARTITIONING PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	53
FIGURE B-2 COST BREAKDOWN FOR THE SLUDGE WASH-B PARTITIONING PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	54
FIGURE B-3 COST BREAKDOWN FOR THE SLUDGE WASH-C PARTITIONING PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	55
FIGURE B-4 COST BREAKDOWN FOR THE TRUEX-A PARTITIONING PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	56
FIGURE B-5 COST BREAKDOWN FOR THE TRUEX-B PARTITIONING PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE HLW VOLUME. ....	57
FIGURE B-6 COST BREAKDOWN FOR THE TRUEX-C PARTITIONING PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	58
FIGURE B-7 COST BREAKDOWN FOR THE NO PARTITIONING ON-SITE DISPOSAL PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE WASTE VOLUME. ....	59
FIGURE B-8 COST BREAKDOWN FOR THE NO PARTITIONING OFF-SITE DISPOSAL PROCESS FOR A TEN(10) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	60

FIGURE B-9	COST BREAKDOWN FOR THE SLUDGE WASH-A PARTITIONING PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	61
FIGURE B-10	COST BREAKDOWN FOR THE SLUDGE WASH-B PARTITIONING PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	62
FIGURE B-11	COST BREAKDOWN FOR THE SLUDGE WASH-C PARTITIONING PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	63
FIGURE B-12	COST BREAKDOWN FOR THE TRUEX-A PARTITIONING PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	64
FIGURE B-13	COST BREAKDOWN FOR THE TRUEX-B PARTITIONING PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE HLW VOLUME. ....	65
FIGURE B-14	COST BREAKDOWN FOR THE TRUEX-C PARTITIONING PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	66
FIGURE B-15	COST BREAKDOWN FOR THE NO PARTITIONING ON-SITE DISPOSAL PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE WASTE VOLUME. ....	67
FIGURE B-16	COST BREAKDOWN FOR THE NO PARTITIONING OFF-SITE DISPOSAL PROCESS FOR A TWENTY(20) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE WASTE VOLUME. ....	68
FIGURE B-17	COST BREAKDOWN FOR THE SLUDGE WASH-A PARTITIONING PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	69
FIGURE B-18	COST BREAKDOWN FOR THE SLUDGE WASH-B PARTITIONING PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	70
FIGURE B-19	COST BREAKDOWN FOR THE SLUDGE WASH-C PARTITIONING PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	71
FIGURE B-20	COST BREAKDOWN FOR THE TRUEX-A PARTITIONING PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	72
FIGURE B-21	COST BREAKDOWN FOR THE TRUEX-B PARTITIONING PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE HLW VOLUME. ....	73
FIGURE B-22	COST BREAKDOWN FOR THE TRUEX-C PARTITIONING PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH AL CONTENT DECIDING THE HLW VOLUME. ....	74
FIGURE B-23	COST BREAKDOWN FOR THE NO PARTITIONING ON-SITE DISPOSAL PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE WASTE VOLUME. ....	75
FIGURE B-24	COST BREAKDOWN FOR THE NO PARTITIONING OFF-SITE DISPOSAL PROCESS FOR A THIRTY(30) YEAR MISSION DURATION WITH NA CONTENT DECIDING THE WASTE VOLUME. ....	76

# 1. Introduction

This thesis will examine the economic implications of the partitioning options for the disposal of Hanford High Level Waste. The storage and remediation activities of the high level waste stored currently at Hanford are consuming about \$500 million per year and are estimated to require such expenditure for the next thirty to forty years. Thus, it is important to examine the sensitivity of the cost to the degree to which the volume containing plutonium will be separated from the other waste. This will be done by first, explaining the High Level Waste situation at Hanford. Second, the performance of vitrified waste will be examined. Third, the effects of processing options on the eventual waste volume will be ascertained. Fourth, a simplified economic model will be constructed and explained. Finally, the effects of processing on the final cost of Hanford waste treatment will be examined.

## *1.1 Hanford Past*

Hanford is a U.S. Department of Energy (DOE) Site and has been generating radioactive waste since 1944. Located near the Southeastern corner of Washington state and performing national defense activities, Hanford has been

storing liquid and chemical radioactive waste resulting from reprocessing of research and weapons material production reactors in underground storage tanks known as Single-Shell Tanks(SST) and Double-Shell Tanks(DST)<sup>1</sup>. Because the waste was produced from processing of reactor fuels, it contains actinides and it is classified as high level waste.

The waste in these tanks are the result of processing nuclear fuel for plutonium extraction. From 1944 to 1980 waste was transferred into SST's. The SST's hold waste from several processing techniques and the content of each tank is approximately known but the exact chemical makeup is still being determined. From the late 1960's to the present, the waste has been routed to storage in DST's<sup>2</sup>. While the contents of several SST's has leaked into the ground, the DST's are less prone to leaking, and indeed have not leaked. Also, the tracking of the DST's waste was improved so that the content of each DST is well known.

#### **1.1.1 Single Shell Tanks**

There are 149 Single-shell tanks. SST's have a single carbon steel wall that is surrounded by reinforced concrete and range in size from 55,000 gallons to one million gallons. These tanks are buried, covered with six to ten feet of soil, and contain waste as old as 1944 and as recent as 1980<sup>3</sup>. Most of the strontium and cesium were removed

from the old waste and converted to solid form. The resulting strontium fluoride and cesium chloride capsules are in storage and will not be considered in this paper. The SST's contain 136,634 m<sup>3</sup> (36,095,000 gal) of waste mostly in the form of sludge and salt cake<sup>4</sup>.

### **1.1.2 Double Shell Tanks**

There are 28 double shell tanks. Since 1980 all of the new waste generated at Hanford has been sent to DST's<sup>5</sup>. The DST's contain 97,145 m<sup>3</sup> (25,663,000 gal) of waste mostly in a pumpable or drainable liquid form<sup>6</sup>. Also, the activity of this waste is higher than the SST's waste due to its age and process advancements.

## **1.2 Hanford Waste Content**

Since several processes generated the Hanford Tank Waste and different methods have been used to prepare the waste for storage, a precise characterization, for processing purposes, of Hanford waste is difficult. However, in an actuarial sense, the waste remaining in storage consists of 41% water(H<sub>2</sub>O) and 34% sodium nitrate(NaNO<sub>3</sub>). On an elemental basis, 21.6 wt% of the waste consists of sodium and 2.1 wt% of aluminum. **Table 1-1** shows the masses of Na, Al, Cr, Ni, and P in the waste. These masses were calculated using the information presented in **Table 1-1**. As will be shown later, the sodium content of

the waste will be the determining factor when LLW glass volume is calculated where as the aluminum or sodium content will determine the HLW glass volume. Table 1-2 shows the major chemicals in the waste and their relative abundance. Table 1-3 shows the representative radionuclide composition of Hanford waste. If all the waste is to be disposed of as class A low level waste, dilution will be needed to meet the radionuclide limits (see Table 1-4 for class A limits). However, the waste can be concentrated up to 6.8 times and still meet the class C limits for LLW (see Table 1-5 for class C limits). This is because the 2.6E+5 m<sup>3</sup> of waste in the tanks, excluding capsules and assuming no pretreatment, would result in 1.6E+9 m<sup>3</sup> of class A waste (see Table 1-4) or 3.8E+4 m<sup>3</sup> of class C waste(see Table 1-5). These volumes were calculated by determining the volume that would be required to accommodate each radionuclide in the waste and allow for class A or C ranking. For most of the radionuclides the limits are based on Ci/m<sup>3</sup> and Equation 1 was used to calculate the volume. When the TRU waste volumes were calculated a similar equation was used based on pCi/g.

$$V_i = \frac{\text{Total\_Curies\_of\_Radionuclide\_i\_in\_the\_Waste}}{\text{Loading\_Limit\_for\_Radionuclide\_i}}$$

Equation 1

**Table 1-1** Content of Na, Al, Cr, Ni, and P in Hanford tank waste.

Element	Na	Al	Cr	Ni	P
Mass (g)	8.03E10	7.76E9	2.75E8	2.44E8	3.98E7

**Table 1-2** Weight percent of chemicals in Hanford Waste Tanks .

WASTE TYPE	LIQUID	SLUDGE	SALT CAKE	SLURRY	TOTAL
VOLUME (1000 m <sup>3</sup> )	25.1	46.0	93.0	94.7	258.8
Composition wt%					
CHEMICAL COMPOSITION	LIQUID	SLUDGE	SALT CAKE	SLURRY	% of Total
NaNO <sub>3</sub>	20.80	25.30	81.50	14.80	41.02
NaNO <sub>2</sub>	15.80	3.80	1.70	5.60	4.96
Na <sub>2</sub> CO <sub>3</sub>	0.60	2.20	0.50	1.90	1.33
NaOH	6.20	5.30	1.50	7.00	4.63
NaAlO <sub>2</sub>	12.50	1.20	1.40	6.00	4.08
NaF				0.04	0.01
Na <sub>2</sub> SO <sub>4</sub>		1.00	1.30	0.30	0.77
Na <sub>3</sub> PO <sub>4</sub>	2.30	15.80	1.60	0.80	4.40
KF				0.40	0.13
FeO(OH)		1.30		0.20	0.34
Organic carbon	0.17			1.20	0.42
NH <sub>4</sub> <sup>+</sup>				0.08	0.03
Al(OH) <sub>3</sub>		2.90		4.90	2.23
SrO*H <sub>2</sub> O		0.10			0.02
Na <sub>2</sub> CrO <sub>4</sub>	1.30				0.14
Cr(OH) <sub>3</sub>		0.20		0.02	0.05
Cd(OH) <sub>2</sub>		0.10			0.02
Ni(OH) <sub>2</sub>				<0.1	
BiPO <sub>4</sub>		0.50			0.11
Cl <sup>-</sup>		0.10			0.02
Ni <sub>2</sub> Fe(CN) <sub>6</sub>		0.60			0.13
P <sub>2</sub> O <sub>5</sub> *24WO <sub>2</sub> *44H <sub>2</sub> O		<.1			
ZrO <sub>2</sub> *2H <sub>2</sub> O		0.50		0.20	0.17
fission products				<.01	
H <sub>2</sub> O	40.20	33.60	10.50	56.20	33.71
other	<0.1	5.50		<.01	
Hg <sup>+</sup>		.12 ppm			
Total (%)	99.87	100	100	99.64	
Density (g/ml)	1.6	1.7	1.4	1.3	1.4
Density (g/m <sup>3</sup> )	1.6E+6	1.7E+6	1.4E+6	1.3E+6	1.4E+06

\* Ref. DOE/RW-0006, REV. 9, Integrated Data Base for 1993: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics' Table 2.15 & 2.16, 1992

**Table 1-3 Major Radionuclides in Hanford Waste (Ci).**

Radio-nuclide	Liquid	Sludge	Salt Cake	Slurry	Capsules	Total
Co-60		3.22E+3		1.03E+4		1.35E+4
Ni-63		3.08E+5		1.05E+3		3.09E+5
Sr-90	4.13E+5	5.10E+7	2.20E+6	1.09E+7	2.45E+7	8.90E+7
Y-90	4.13E+5	5.10E+7	2.20E+6	1.09E+7	2.45E+7	8.90E+7
Tc-99	1.79E+4			1.43E+4		3.22E+4
Cs-137	9.80E+6	3.61E+6	3.65E+6	1.62E+7	5.55E+7	8.88E+7
Ba-137m	9.27E+6	3.41E+6	3.46E+6	1.53E+7	5.25E+7	8.39E+7
Sm-151		8.33E+5		2.03E+5		1.04E+6
Pu-239		2.20E+4		3.28E+3		2.53E+4
Pu-240		5.29E+3		8.85E+2		6.18E+3
Pu-241		5.25E+4		3.35E+4		8.60E+4
Am-241	7.36E+2	4.53E+4		5.24E+4		9.77E+4

Ref. DOE/RW-0006, Rev. 9

After the volumes were calculated for all relevant radionuclides, the volumes were summed to get the total volume necessary to accommodate all of the waste. The class A waste volume is 97.9% due to Strontium-90, and the class C waste volume is 24% Sr-90, 19% Cs-137, and 28% Tc-99. These volumes are definitely in favor of class C waste since production and storage of class A waste would be far too expensive.

### *1.3 Waste Disposition*

The waste form for permanent disposal of the Hanford tank waste is a matter being debated constantly. However, it has been decided for many years now that the High Level Waste(HLW) will be immobilized in borosilicate glass which has been extensively studied and determined to be very durable. The Low Level Waste(LLW) was earlier going to be immobilized in grout, a cement like material, but since 1993 is planned to be immobilized in some "vitrified" waste form like borosilicate or containerized glass. For this report the loading limits for Borosilicate glass and Containerized glass will be the basis for high level and low level waste volumes respectively resulting from the partitioning processes.

**Table 1-4 Radionuclides and their class A LLW volumes in Hanford waste.**

Glass density 2.5E6 g/m <sup>3</sup>		Class A Volume (m <sup>3</sup> )		Percent of Total
RADIONUCLIDE**	Class A limit (Ci/m <sup>3</sup> )	Class A Volume From Tanks	Class A Volume from Capsules	Class A from Tank Volume
C-14	8.000E-01	6.296E+03		0.00%
Fe-55	7.000E+02	6.786E+00		0.00%
Ni-59	2.200E+01	4.118E-01		0.00%
Co-60	7.000E+02	1.931E+01		0.00%
Ni-63	3.500E+00	8.830E+04		0.00%
Sr-89	7.000E+02	1.293E-08		0.00%
Sr-90	4.000E-02	1.613E+09	6.125E+08	97.92%
Y-90	7.000E+03	9.216E+04	3.500E+04	0.00%
Y-91	7.000E+03	9.543E-07		0.00%
Zr-95	7.000E+03	1.014E-05		0.00%
Nb-95	7.000E+03	2.243E-05		0.00%
Tc-99	3.000E-01	1.073E+05		0.00%
Ru-103	7.000E+02	2.343E-12		0.00%
Rh-103m	7.000E+02	2.100E-12		0.00%
Ru-106	7.000E+02	4.343E+02		0.00%
Rh-106	7.000E+02	4.343E+02		0.00%
Ag-110m	7.000E+02	2.343E-02		0.00%
Ag-110	7.000E+02	3.100E-04		0.00%
Sn-113	7.000E+02	1.131E-04		0.00%
Cd-115m	7.000E+02	2.914E-13		0.00%
Sn-119m	7.000E+02	4.171E-01		0.00%
Sn-123	7.000E+02	2.514E-03		0.00%
Te-123m	7.000E+02	8.557E-09		0.00%
Sb-124	7.000E+02	6.400E-11		0.00%
Sb-125	7.000E+02	4.229E+02		0.00%
Te-125m	7.000E+02	1.031E+02		0.00%
Sb-126	7.000E+02	2.086E-02		0.00%
Sb-126m	7.000E+02	1.643E-01		0.00%
Te-127m	7.000E+02	9.543E-04		0.00%
Te-127	7.000E+02	9.343E-04		0.00%
Te-129m	7.000E+02	1.171E-16		0.00%
I-129	8.000E-03	3.313E+01		0.00%
Cs-134	7.000E+02	2.000E+02		0.00%
Cs-137	1.000E+00	3.326E+07	5.550E+07	2.02%
Ba-137m	7.000E+02	4.491E+04	7.500E+04	0.00%
Ce-141	7.000E+02	1.184E-15		0.00%
Ce-144	7.000E+02	6.614E+02		0.00%
Pr-144	7.000E+02	6.586E+02		0.00%
Pr-144m	7.000E+02	7.914E+00		0.00%

**Table 1-4** continued

Glass density 2.5E6 g/m <sup>3</sup>		Class A Volume (m <sup>3</sup> )		Percent of Total
RADIONUCLIDE**	Class A limit (Ci/m <sup>3</sup> )	Class A Volume From Tanks	Class A Volume from Capsules	Class A from Tank Volume
Pm-147	7.000E+02	8.829E+03		0.00%
Pm-148	7.000E+02	7.114E-15		0.00%
Pm-148m	7.000E+02	1.263E-13		0.00%
Gd-153	7.000E+02	1.529E-04		0.00%
Eu-155	7.000E+02	1.414E+02		0.00%
Tb-160	7.000E+02	1.387E-09		0.00%
U-234	2.500E-01	4.920E+00		0.00%
U-235	2.500E-01	2.072E-01		0.00%
U-236	2.500E-01	4.320E-01		0.00%
U-238	2.500E-01	3.784E+00		0.00%
Np-237	2.500E-01	1.804E+02		0.00%
Np-238	2.500E-01	8.680E-01		0.00%
Pu-238	2.500E-01	1.468E+03		0.00%
Pu-239	2.500E-01	1.011E+05		0.00%
Pu-240	2.500E-01	2.470E+04		0.00%
Pu-241	8.750E-01	9.829E+04		0.00%
Pu-242	2.500E-01	3.472E-01		0.00%
Am-241	2.500E-01	3.937E+05		0.02%
Am-242	1.750E+09	2.463E-08		0.00%
Am-242m	2.500E-01	1.732E+02		0.00%
Am-243	2.500E-01	2.864E+01		0.00%
Cm-242	5.000E+00	7.300E+00		0.00%
Cm-244	2.500E-01	5.788E+03		0.00%
Total Class A Volume (m <sup>3</sup> )		1.647E+09	6.681E+08	100.00%

**Table 1-5 Radionuclides and their class C LLW volumes in Hanford waste.**

Glass density 2.5E6 g/m <sup>3</sup>		Class C Volume (m <sup>3</sup> )		Percent of Total
RADIONUCLIDE**	Class C limit (Ci/m <sup>3</sup> )	Class C Volume From Tanks	Class C Volume from Capsules	Class C from Tank Volume
C-14	8.000E+00	6.296E+02	0.000E+00	1.65%
Ni-59	2.200E+02	4.118E-02	0.000E+00	0.00%
Ni-63	7.000E+02	4.415E+02	0.000E+00	1.16%
Sr-90	7.000E+03	9.216E+03	3.500E+03	24.20%
Tc-99	3.000E+00	1.073E+04	0.000E+00	28.18%
I-129	8.000E-02	3.313E+00	0.000E+00	0.00%
Cs-137	4.600E+03	7.230E+03	1.207E+04	18.99%
Pu-241	8.750E+00	9.829E+03	0.000E+00	25.81%
Cm-242	5.000E+01	7.300E-01	0.000E+00	0.00%
Total Class C Volume (m <sup>3</sup> )		3.808E+04	1.557E+04	100.00%

## 2. Vitrified Waste Performance

Vitrified waste performance is evaluated based on four basic parameters. First, the physical parameters of the waste form are considered. These parameters include: density, thermal conductivity, thermal diffusivity, thermal expansion coefficient, specific heat, flexural strength, tensile strength, compressive strength, Young's modulus (flexural and compressive), bulk modulus, shear modulus, Poison's ratio, fracture toughness, and transverse rupture strength. Second, it is important to study radiation effects on the waste form. Third, the status of the technology required to produce the waste form should be investigated. Finally, the chemical durability of the waste form should be determined<sup>7</sup>.

The first of the three parameter groups for evaluation does not vary greatly with the chemical composition of a particular waste form. Chemical durability, however, can vary by orders of magnitude depending on the chemicals added. The affect each element has on the durability of glass is experimentally determined along with a maximum desirable weight fraction of the element that may be tolerated in glass. When this weight fraction is exceeded the glass matrix will not sufficiently immobilize the waste

and therefore is a loading limit for the element. This loading limit can be used to calculate the glass volume that will result from the processing of Hanford waste using Equation 2.

$$V_i = \frac{C_i}{LL_i * \rho}$$

Equation 2

Here,  $V_i$  = the volume of glass ( $m^3$ ) that would result if C grams of chemical or element i were incorporated into a glass of density  $\rho$  ( $g/m^3$ ) and a loading limit LL (grams chemical/grams glass). The loading limits for containerized and borosilicate glass are listed in Table 2-1.

**Table 2-1** Selected loading limits for containerized and borosilicate glass<sup>17</sup>.

Element	Na	Al	Cr	Ni	P
Loading Limit (wt%)	11.13	7.94	0.34	1.57	0.31
Oxide	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	Cr <sub>2</sub> O <sub>3</sub>	NiO	P <sub>2</sub> O <sub>5</sub>
Loading Limit (wt%)	15.0	15.0	0.5	2.0	3.0

Using Equation 2 and the loading limits in Table 2-1 sodium will determine the LLW glass volume, and sodium or aluminum will determine the HLW glass volume (see Appendix A).

## 2.1 Chemical Properties in Glass

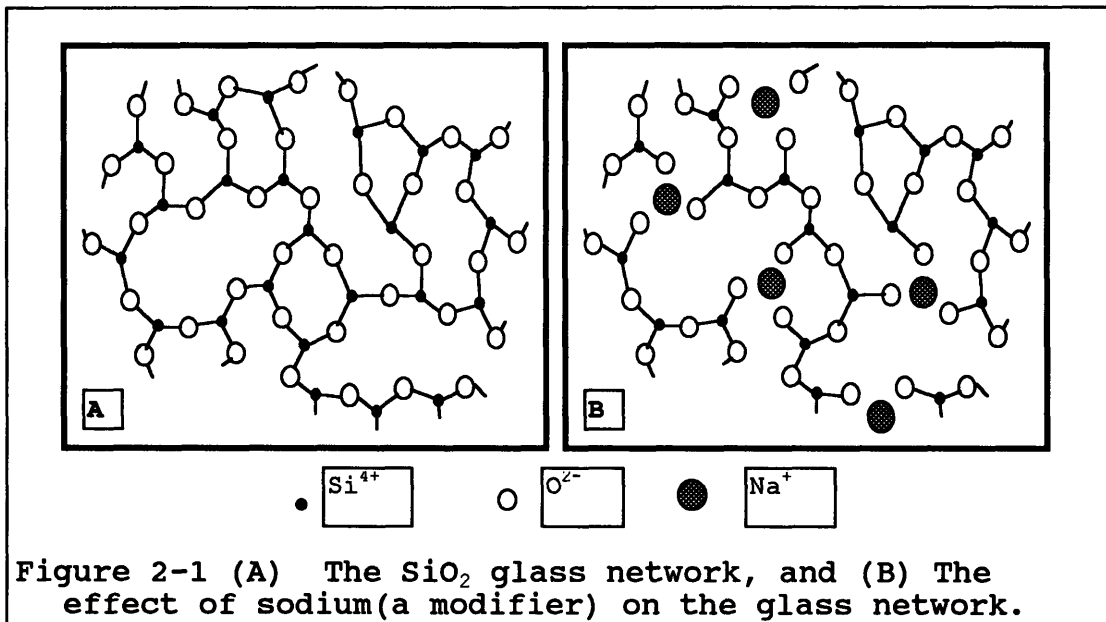
Pure silica has a high melting point(1713°C). To reduce this melting temperature, additional oxides are added. These additional oxides act as glass formers, intermediates or modifiers.(See Table 2-2)<sup>8</sup>. Boron oxide is commonly added to the silicate melt. Boron forms BO<sub>4</sub> groups that stabilize the glass structure at low temperatures(500-600°C). At higher temperatures boron ``assumes a trigonal plane coordination with three oxygens and becomes a network modifier, thereby lowering the melt's viscosity''<sup>9</sup>. Therefore, boron is very useful in lowering the melting temperature and the viscosity of the silica glass system.

**Table 2-2 Selected metals and their effects in glass<sup>8</sup>.**

Metal in Oxide	Designation	Metal in Oxide	Designation	Metal in Oxide	Designation
B	glass former	Pb	intermediate	Ca	modifier
Si	former	Al	intermediate	Sr	modifier
P	former	Cd	intermediate	Na	modifier
Zr	former	Ca	modifier	K	modifier
Zn	intermediate	Mg	modifier	Cs	modifier

The durability of silicate glass, and its ability to incorporate a variety of different elements, makes it a very good waste form. The dominant chemical in the silicate glass system is SiO<sub>2</sub>. Silicon dioxide(SiO<sub>2</sub>) forms a matrix in which waste can be readily trapped. Sodium, however, is a modifier and breaks down the SiO<sub>2</sub> matrix, reduces the durability, and increases the solubility of the glass (see Figure 2-1).

When the oxygen to silicone ratio increases, modifiers break up the silica network. As more modifiers are added to the glass matrix the metals enter holes within the network instead of becoming part of the network. This results in extra oxygen in the melt and not enough silicone to connect with them to form a matrix<sup>8</sup>. And, without a strong matrix the glass is a poor waste form.



# 3. Effects of Processing Options on Sodium Content

At present, there are seven different processes being considered for waste partitioning. These processes are: Sludge Wash-A, Sludge Wash-B, Sludge Wash-C, TRUEX-A, TRUEX-B, TRUEX-C, and No Partitioning. Each of these processes either adds or diverts chemicals to the HLW or the LLW streams. Most of the chemicals are simply routed to one of the waste streams. Sodium, however, is added in all of the processes except for the Sludge Wash-A partitioning process and the No Partitioning processes. Figure 3-1 shows the steps that some or all of the waste will go through for each partitioning process. This is a general diagram, since the order of the steps vary from process to process and the solids and the liquids may be routed differently.

## 3.1 Sludge Wash-A

Sludge Wash-A separates the retrieved waste into a soluble fraction and a solid fraction. The soluble fraction will consist of supernatant, dissolved salt cake, and water washes of the insoluble solids or sludge and will all be sent to LLW treatment. The remaining solids and sludge will be sent to HLW treatment. This process will add a

negligible amount of sodium into the waste stream with 98.6% of the sodium going to LLW and 1.3% to HLW<sup>10</sup>.

### *3.2 Sludge Wash-B*

Sludge Wash-B separates the retrieved waste into a soluble fraction and a solid fraction in the same manner as Sludge Wash-A. After washing, the supernatant is run through a cesium cation exchange process where 99% of the cesium is removed. Sodium is added in this process when NaOH is used to regenerate the cesium ion exchange resin. Thus, 107.6% of the initial amount of sodium is sent to LLW and 2.8% of sodium is sent to HLW.

### *3.3 Sludge Wash-C*

Sludge Wash-C separates the retrieved waste into a soluble fraction and a solid fraction in the same manner as Sludge Wash-A. After washing, the supernatant goes through Organic Destruction, strontium, americium, and plutonium removal (Sodium Titanate Sorption), cesium removal (Cesium Ion-Exchange), and technetium removal (Technetium Ion-Exchange). Sodium is added during the Sludge Wash-C process when the pH is adjusted, when the cesium ion exchangers are regenerated, and when the technetium ion exchangers are regenerated. This results in 115% of the original sodium being sent to LLW and 3.6% to HLW.

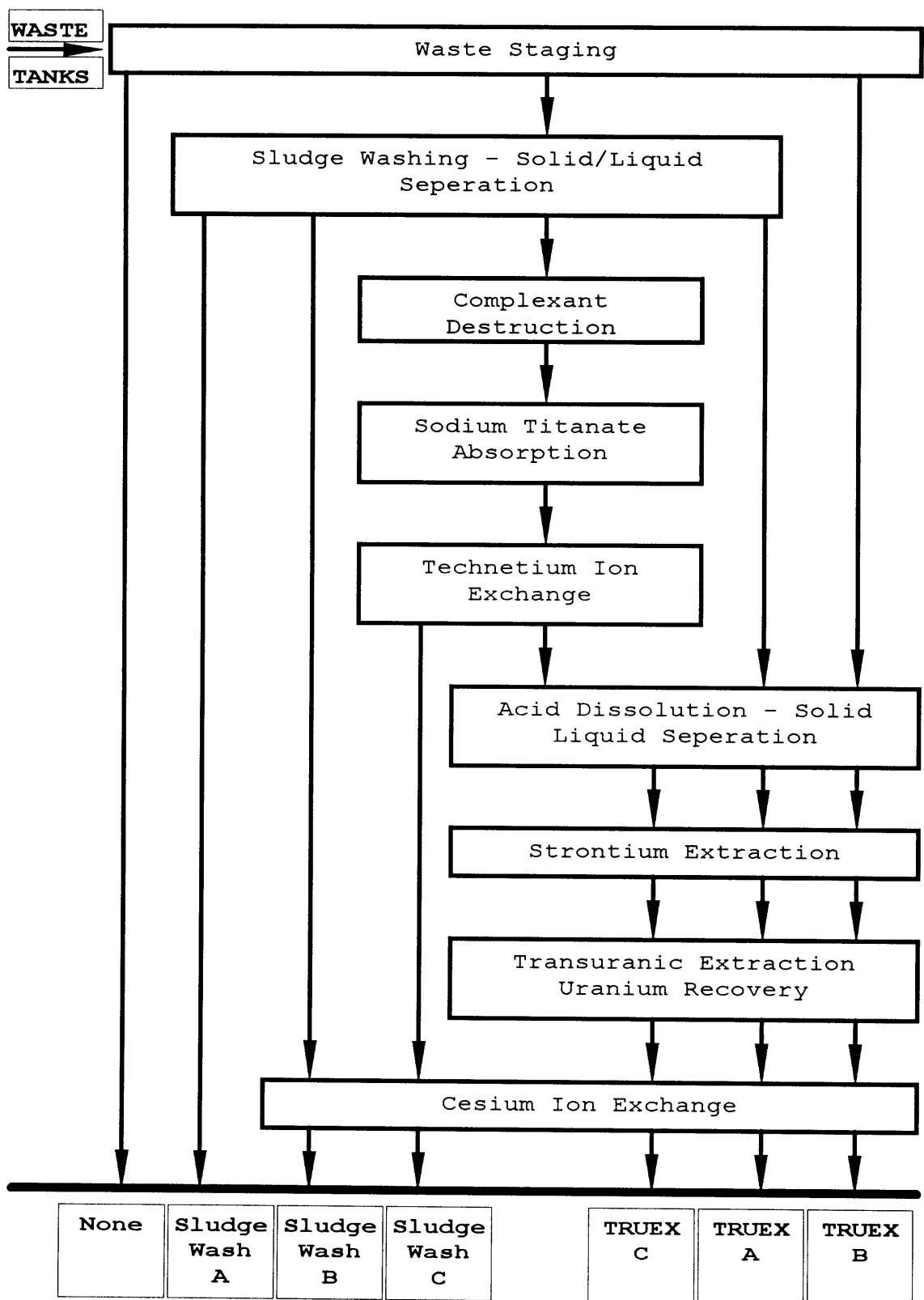


Figure 3-1 Steps that some or all of the Hanford tank waste will go through for each processing option<sup>11</sup>.

### 3.4 *TRUEX-A*

TRUEX-A separates the retrieved waste into a soluble fraction and a solid fraction in the same manner as Sludge Wash-A. After washing, the supernatant is processed through the Cesium Ion-Exchanger then sent to LLW. The solids are dissolved in nitric and oxalic acid, transferred to the TRUEX process for actinide and lanthanide recovery, and then sent through technetium and uranium recovery. The actinide and lanthanide recovery extracts elements with +3, +4, and +6 oxidation states<sup>12</sup>. This includes uranium, plutonium, americium, and thorium. The output stream from TRUEX containing uranium and technetium is purified through PUREX and then the uranium is sent to the uranium stockpile and the technetium is sent to HLW. The TRU's separated in TRUEX are sent to HLW and the remaining waste stream is sent through strontium exchange, then cesium exchange, with the remaining liquids sent to LLW and the radionuclides sent to HLW. This process results in 165% of the initial sodium going to LLW, and 2.5% to HLW.

### 3.5 *TRUEX-B*

TRUEX-B is the same as TRUEX-A except both the solid waste and the supernatant go through TRUEX, Tc and U recovery, Sr ion exchange, and Cs Ion-Exchange. This process sends 219.5% of sodium to LLW and 3.6% to HLW.

### 3.6 TRUEX-C

TRUEX-C sends all of the retrieved waste to sludge wash. The supernatant is then sent to organic destruction.

The liquids from organic destruction are then sent to Cs ion exchange, Tc ion exchange and then to LLW. The solids go to TRUEX and the liquids from TRUEX go to TcIX, SREX sending the recovered radioactive elements to HLW and the rest to LLW. This process sends 185% of sodium to LLW and 2.6 % to HLW.

### 3.7 No Partitioning

The no Partitioning option sends 100% of the waste to either LLW or HLW.

### 3.8 Conclusion

As can be seen in **Table 3-1** sludge wash-A removes the least amount of radionuclides from the LLW stream, sludge wash-B and TRUEX-A remove more, and sludge wash-C removes the most, sending one percent or less of the radioactive material to LLW. In addition to the difference between the cost of on site and off site disposal, the removal of radionuclides has a hidden cost. This cost can be seen by looking at the sodium added to the LLW stream as the partitioning becomes more complex. **Table 3-2** shows this increase. The amount of sodium sent to HLW does not

necessarily increase proportionally with the total amount of sodium in the waste. This is because most of the sodium added is from reloading the ion exchange resins, which uses NaOH, and this goes directly to the LLW stream.

**Table 3-1** Percentage of Radionuclides Sent to LLW Disposal<sup>13</sup>.

Radio-nuclide	No Partitioning On Site Disposal	Sludge Wash A	Sludge Wash B	Sludge Wash C	Truex A	Truex B	Truex C	No Partitioning Off Site Disposal
<b>Sr</b>	100	1	1	0.1	2	1	1	0
<b>Tc</b>	100	50	50	1	50	1	1	0
<b>Cs</b>	100	75	1	1	1	1	1	0
<b>U</b>	100	5	5	1	5	1	1	0
<b>Pu</b>	100	2	2	0.5	3	1	1	0
<b>Am</b>	100	10	10	1	10	1	1	0

**Table 3-2 Percent of Elements Sent to HLW and LLW<sup>14</sup>.**

Waste-Stream	No Partitioning On Site Disposal	Sludge Wash A	Sludge Wash B	Sludge Wash C	Truex A	Truex B	Truex C	No Partitioning Off Site Disposal
<b>HLW</b>								
Na	0	1.30	2.77	3.55	2.47	3.57	2.58	100
Al	0	79	79	79	23	20	23	100
Cr	0	90	90	90	9	9	9	100
Ni	0	90	90	90	90	90	90	100
P	0	50	50	50	5	5	5	100
<b>LLW</b>								
Na	100	98.6	108	115	165	220	185	0
Al	100	21	21	21	77	80	77	0
Cr	100	10	10	10	91	91	91	0
Ni	100	10	10	10	10	10	10	0
P	100	50	50	50	95	95	95	0

## 4. Simplified Economic Model

The simplified economic model used in this report assumes that sodium is the determining factor related to LLW volume. Depending on the process chosen, aluminum, chromium, or sodium content will determine the HLW volume. These volumes are then used to calculate the capital, operating, and disposal cost for the HLW and LLW. The capital cost is calculated using Equation 3 (from the Oak Ridge National Laboratories CONCEPT-5 computer code for engineering projects cost analysis<sup>15</sup>) based on the annual processing capacity and using the engineering scaling factor of 0.7 (marked as **S** in Equation 3).

$$SC = BC \left[ \frac{T}{BT} \right]^S .$$

Equation 3

Where,

SC = the scaled cost.

BC = the base cost.

T = the throughput of the scaled facility.

BT = the base throughput of the facility.

and

S = the engineering scaling factor.

The same equation is used for labor and operating cost calculations with SC = scaled labor or operating cost requirements, and BC = the base labor or operating cost requirements for the facility.

An engineering scaling factor of 0.7 assumes there will be approximately thirty percent savings in the construction of the processing facility when it is scaled up, and will be thirty percent more expensive to construct if it is scaled down. The scaling factor 0.7 is conservatively extrapolated from data used to calculate nuclear power plant construction costs as stated in the Nuclear Energy Cost Data Base<sup>16</sup>. The disposal cost is generally assumed to be two hundred thousand dollars per canister<sup>18</sup>. Since this number is based on the cost of assessing and operating the HLW repository and is not truly known, one hundred, two hundred, and three hundred thousand dollars per canister of HLW glass is considered. The operating costs are scaled at 0.8 to allow for savings in labor and bulk handling of materials. Here 0.8 is the most conservative scaling factor utilized in the Nuclear Energy Cost Data Base<sup>16</sup>.

The baseline capital costs were calculated using the KAISER ENGINEERING INTERACTIVE ESTIMATING program and includes a 50% contingency<sup>17</sup>. The operating costs, capital costs, estimated labor requirements, and the baseline production after a 60% capacity factor is assumed are listed in Table 4-1 for each of the partitioning processes. Keeping in mind that each year of partitioning plant operation results in a labor cost of approximately \$40.5 million, the 60% capacity factor for the partitioning processes is an area that deserves further study.

The LLW and the HLW vitrification and disposal cost assumptions are listed in Table 4-2 and Table 4-3 respectively using the containerized glass facility, operating with a 60% capacity factor, for LLW vitrification and the HWVP, operating with a 70% capacity factor, for HLW vitrification. All of the HLW produced is assumed to be stored on site until it can be shipped to the HLW repository for permanent disposal. The canister costs are assumed to remain constant, as is the on-site storage costs.

**Table 4-1** Cost, Labor, and Throughput estimates for partitioning processes<sup>17</sup>.

Partitioning process	Operating cost(\$/yr)	Capital cost(\$)	Labor Estimate (man-yr)	Baseline Production (m <sup>3</sup> /yr)
SW-A	50,000,000	900,000,000	511	13,663
SW-B	70,000,000	1,250,000,000	619	13,663
SW-C	90,000,000	1,725,000,000	793	13,663
TRUEX-A	90,000,000	1,700,000,000	970	13,663
TRUEX-B	120,000,000	2,340,000,000	1149	4,555
TRUEX-C	105,000,000	2,525,000,000	1070	13,663
NP-1&2	0	0	0	0

**Table 4-2** Baseline cost estimates for HLW and LLW vitrification facilities<sup>17</sup>.

Facility	Capital Cost (\$M)	Labor Estimate (man-yr)	Frit Cost (\$/can)	Energy (\$/can)	Baseline Production (cans/yr)
LLW	1,170	1010	128,775	5,500	1,192
HLW	1,060	912	4,751	570	433.3

**Table 4-3** HLW and LLW Disposal cost estimates<sup>17</sup>.

Waste	Storage cost (\$/can)	Canister cost (\$/can)	Repository fee (\$/can)
LLW	2,521	16,000	0
HLW	18,846	6,000	100,000 200,000 300,000

The final cost is then calculated using Equation 4.

$$TOT = X(DHC + XHFCE) + XHCCI + XHT * XHLCI + Y(DLC + XLFCE) + XLOCI + XLT * XLLCI + XPCCI + XPT(XPCI + XPLCI)$$

Equation 4

Here,

TOT = the total cost due to disposal, frit, energy, and capital expenses.

X = the number of HLW canisters.

Y = the number of LLW canisters.

DHC = the cost of on site storage, canister costs, and the repository fee per canister.  
DLC = the cost of on site storage and the canister costs per canister.  
XHFCE = the frit and energy cost for the HLW facility per canister.  
XLFCE = the frit and energy cost for the LLW facility per canister.  
XHCC1 = the scaled HLW vitrification plant capital cost.  
XLCC1 = the scaled LLW vitrification plant capital cost.  
XPCC1 = the scaled partitioning facility capital cost.  
XHT = the operating duration for HLW vitrification in years.  
XLT = the operating duration for LLW vitrification in years.  
XPT = the operating duration for waste partitioning in years.  
XPC1 = the operating cost for the partitioning facility per year.  
XHLC1 = the scaled labor cost for HLW vitrification per year.  
XLLC1 = the scaled labor cost for LLW vitrification per year.  
XPLC1 = the scaled labor cost for waste partitioning per year.

The LLW glass volumes are calculated using the containerized glass loading limit for sodium. The HLW glass volumes are calculated using the sodium or aluminum loading limits, denoted by -Al or -Na after the partitioning process name for Borosilicate glass. The assumption that sodium is limiting is evident for LLW glass(see Appendix A). However, the HLW volumes are more dependent on the waste feed to the HLW vitrification plant. This is namely due to the chromium content in the waste. The chromium and the aluminum contents in the HLW feed are both close to being limiting for sludge washing. Therefore, small fluctuations in the feed may change the HLW glass volume(always upward). These fluctuations are not as important for the TRUEX processes

since aluminum or sodium are increasingly more defining. Furthermore, sodium is the obvious limit for the no partitioning-2 option(see Appendix A).

Labor costs were calculated with the assumption that the average annual wage will be \$45,000 per year including benefits for each worker<sup>18</sup>. The number of workers was calculated for each processing step, with the help of WHC-EP-0405-A(System Engineering Study for the Closure of Single Shell Tanks), then the number of workers was scaled using an engineering scaling factor of 0.8 to account for increased or decreased demand on personnel as the plant size increases or decreases respectively.

Energy costs were calculated assuming that a 400 l/hr melter consumes 2.0 (kW-hr)/l of feed<sup>19</sup>. The energy consumption was then scaled to the baseline HLW and LLW melters with a scaling factor of 0.8 and an electricity cost of \$0.10/(kW-hr) was also assumed. These energy costs are noted in Table 4-2.

The above assumptions were then incorporated into HANFOR10.FOR and the total costs were calculated. The computer code is listed in Appendix D.

## 5. Effects of Processing Options on Cost and Results

The effects of processing options on total cost are very significant. There is only a relatively small difference between the three sludge wash options. Sludge Wash A, B, and C result in a total cost between 26 and 31 Billion dollars. TRUEX A and C costs 17.6 and 19.9 Billion dollars respectively. TRUEX-B will cost 25.5 billion dollars. The no partitioning options are the least expensive, \$4.5 Billion for the on site disposal, and the most expensive, \$138 Billion for the off site disposal

It should be noted that these cost estimates do not include factors that will remain relatively constant regardless of the partitioning process. Namely, characterization costs (~\$650M), evaporator replacement costs (~\$250M), tank farm upgrades (~\$1,000M), tank waste safety upgrade program (~\$500M), special purpose oxidation facility capital and operating costs (~\$250 & 308M), liquid effluent treatment facility (~\$380M), or the DST and SST retrieval equipment (~\$200 & 3,200M) are not considered in the costs. These exclusions add about \$6.7 Billion dollars that do not depend on the partitioning process.

The effects of the HLW disposal fee on the total cost are shown in Figure 5-2, Figure 5-3, and Figure 5-4 for the

10, 20, and 30 year mission durations respectively. It is clear from these figures and Figure 5-5 that the HLW disposal fee has a linear impact on the total cost of each processing option. This impact is the same for the sludge washing options since the amount of aluminum in the waste is constant and is the limiting element for HLW volume. The impact is much smaller for the TRUEX processes with much of the Al, Na, Cr, and Ni sent to LLW.

Longer mission durations tend to reduce the total cost of processing Hanford tank waste(see Figure 5-6). This trend is most evident when the mission duration is changed from ten to twenty years. A longer mission allows for a smaller capital investment into each facility. However, this savings is eventually lost to the increases in labor costs, as shown. Furthermore, it is reasonable to assume that equipment replacements will make the forty year and greater missions even more expensive in the long run. Our simple model did not quantify this effect.

The chief cost for the sludge washing options is HLW disposal when the HLW disposal cost is \$200 and \$300,000/can regardless of the mission duration. The capital cost of the HLW vitrification facility and the partitioning facility followed the disposal cost as the largest contributor to the total cost for a 10 year mission duration(see Figure B-1, Figure B-2, and Figure B-3), and labor costs for the HLW vitrification facility became a major contributor in the

sludge wash-A 20 (Figure B-9) and 30 year (Figure B-17) scenario and the sludge wash-B 30 year (Figure B-18) option. The HLW frit and energy cost, the LLW disposal cost, the pretreatment labor cost, and the LLW vitrification facility labor cost were not large contributors to the sludge washing options total cost for all three mission durations (see Figure B-1 and Figure B-3 for ten year duration, see Figure B-9 and Figure B-11 for twenty year duration, and see Figure B-17 and Figure B-19 for thirty year duration).

TRUEX-A has the lowest total cost of all the partitioning options examined. Also, TRUEX-A shows the smallest fluctuations when mission duration and HLW disposal costs are varied(see Figure 5-1). LLW frit and energy cost was the largest contributor to the total cost followed by the pretreatment capital cost, for the 10 year (Figure B-4) mission, or the HLW disposal cost, for the 20 (Figure B-12) and 30 year (Figure B-20) missions.

The total cost for TRUEX B and C is mostly due to the pretreatment capital cost, for the 10 year mission(see Figure B-5 and Figure B-6), or the LLW frit and energy cost, and the pretreatment facility operating cost, for the 20 (see Figure B-13 and Figure B-14) and 30 year missions (see Figure B-21 and Figure B-22).

The no partitioning on-site disposal cost is the least expensive option available. This option is also the most politically unfavorable option. This aside, the on-site

disposal option total cost is mostly due to the frit and energy cost of the LLW vitrification facility and is weakly dependent upon the mission duration (see Figure 5-6). This weak dependence is because the labor costs tend to offset the savings when capital costs are reduced (see Figure B-7, Figure B-15, and Figure B-23).

The no partitioning off-site disposal option is by far the most expensive option and is dominated by the HLW disposal fees (see Figure B-8, Figure B-16, and Figure B-24). However, even without the HLW disposal fees this is still the most expensive option.

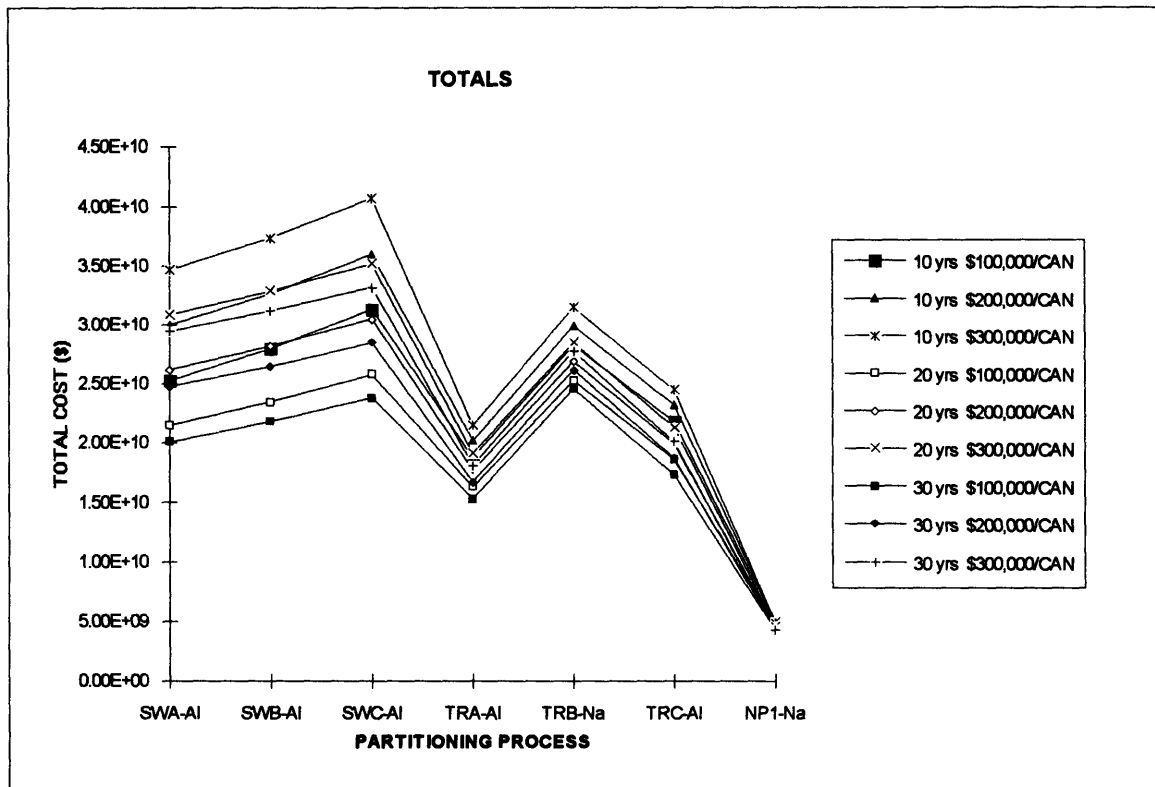


Figure 5-1 Total cost and the effects of mission duration and HLW disposal cost on the total.

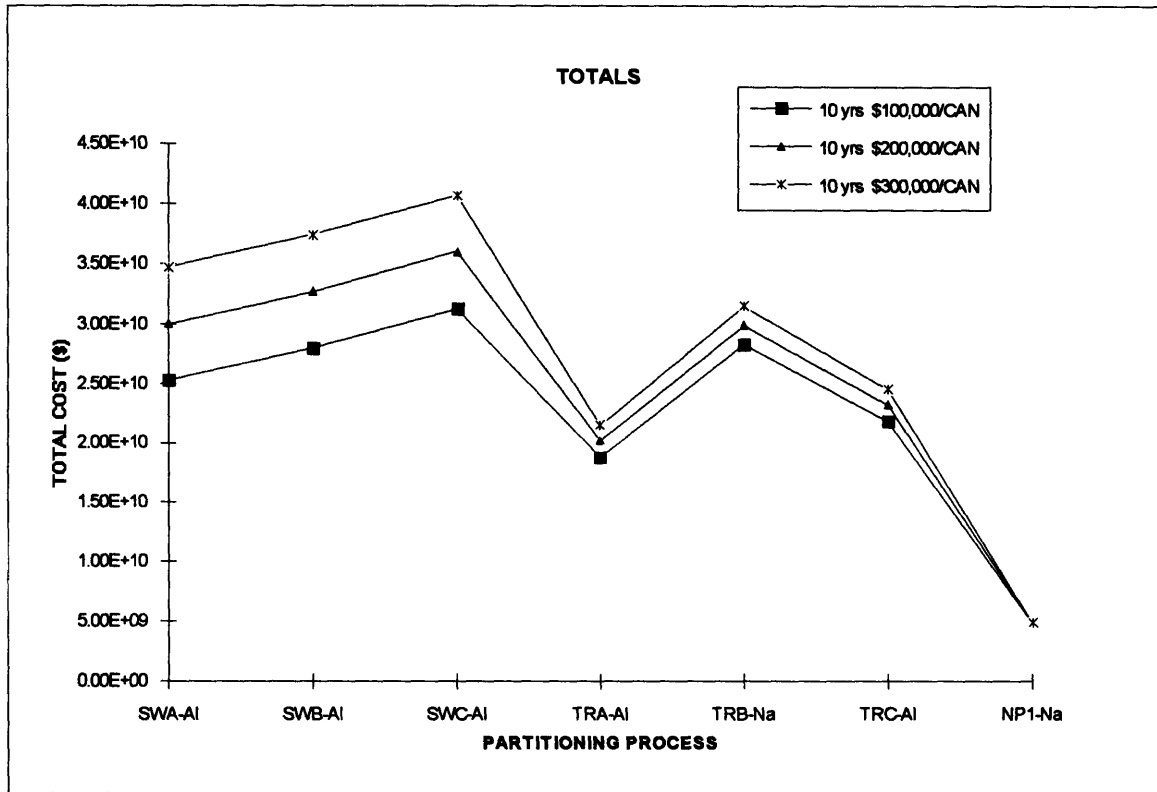


Figure 5-2 Impact of HLW disposal fees on total cost for a ten(10) year mission.

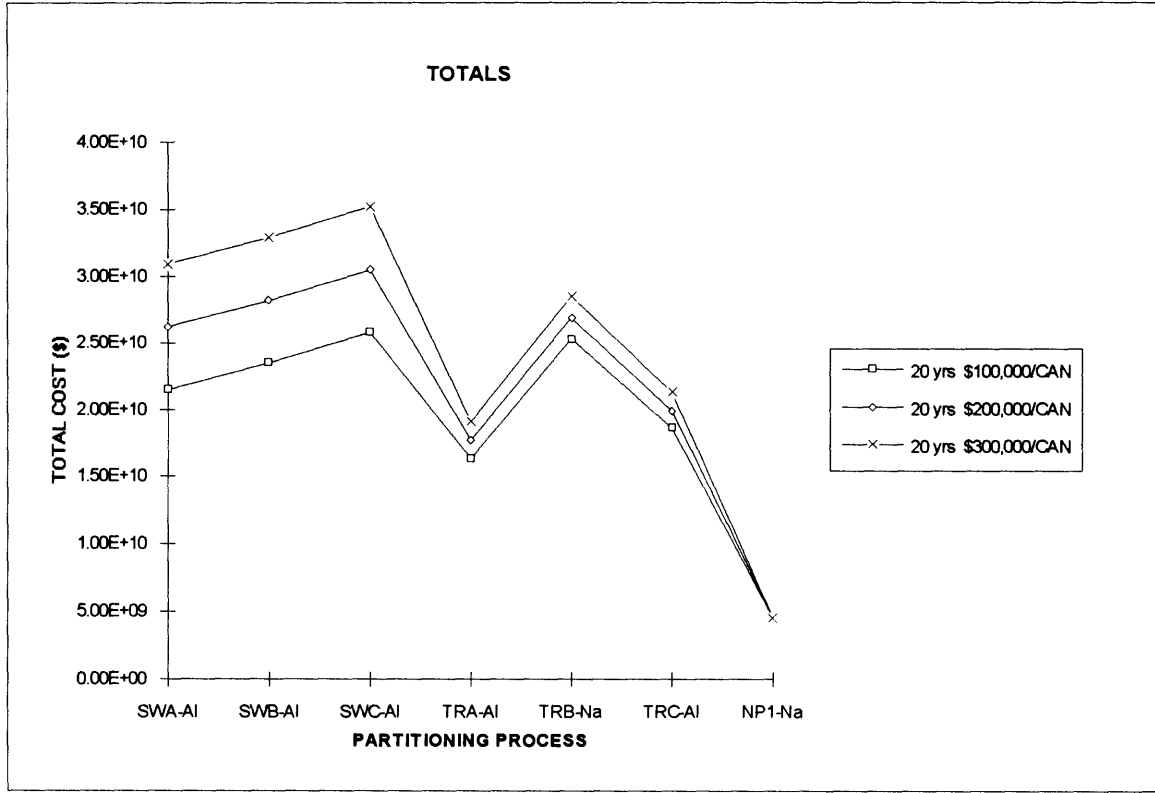


Figure 5-3 Impact of HLW disposal fees on total cost for a twenty(20) year mission.

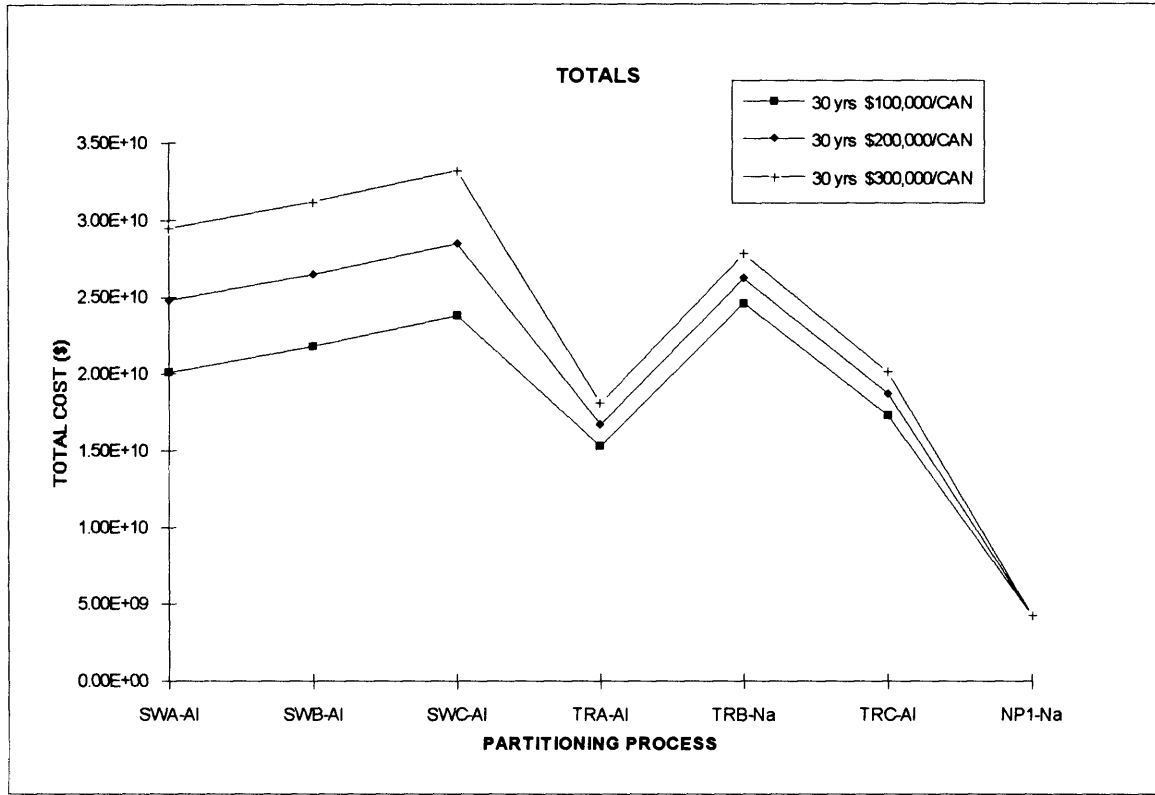


Figure 5-4 Impact of HLW disposal fees on total cost for a thirty(30) year mission.

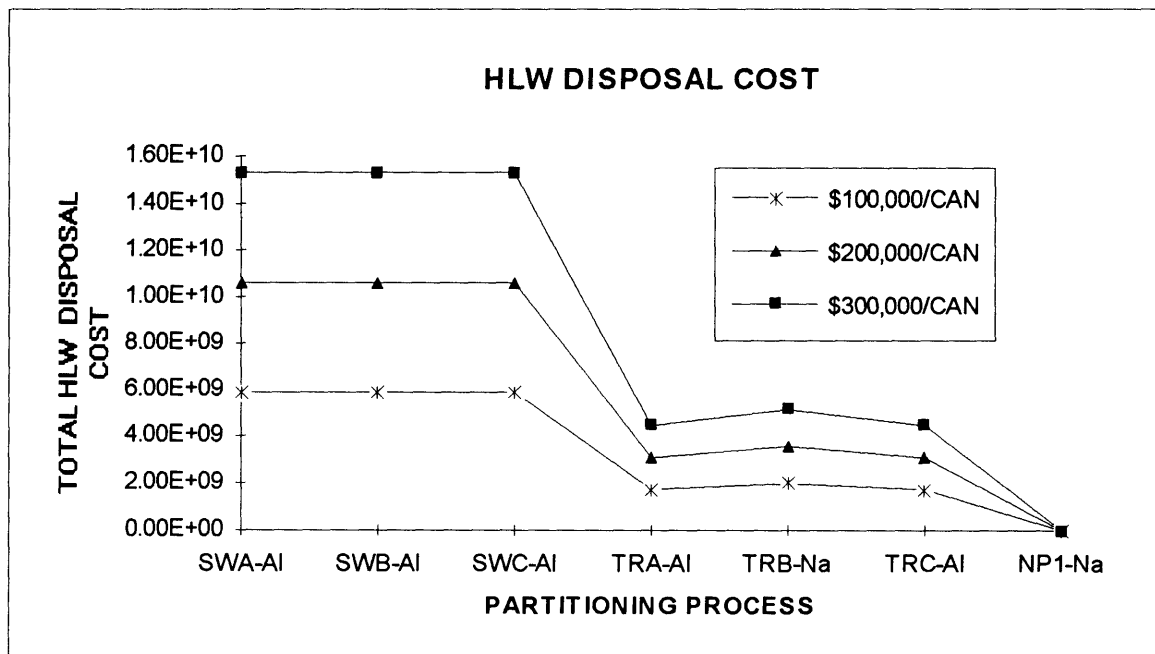


Figure 5-5 Total HLW disposal cost and the impact of a reduced HLW disposal fees, by partitioning process.

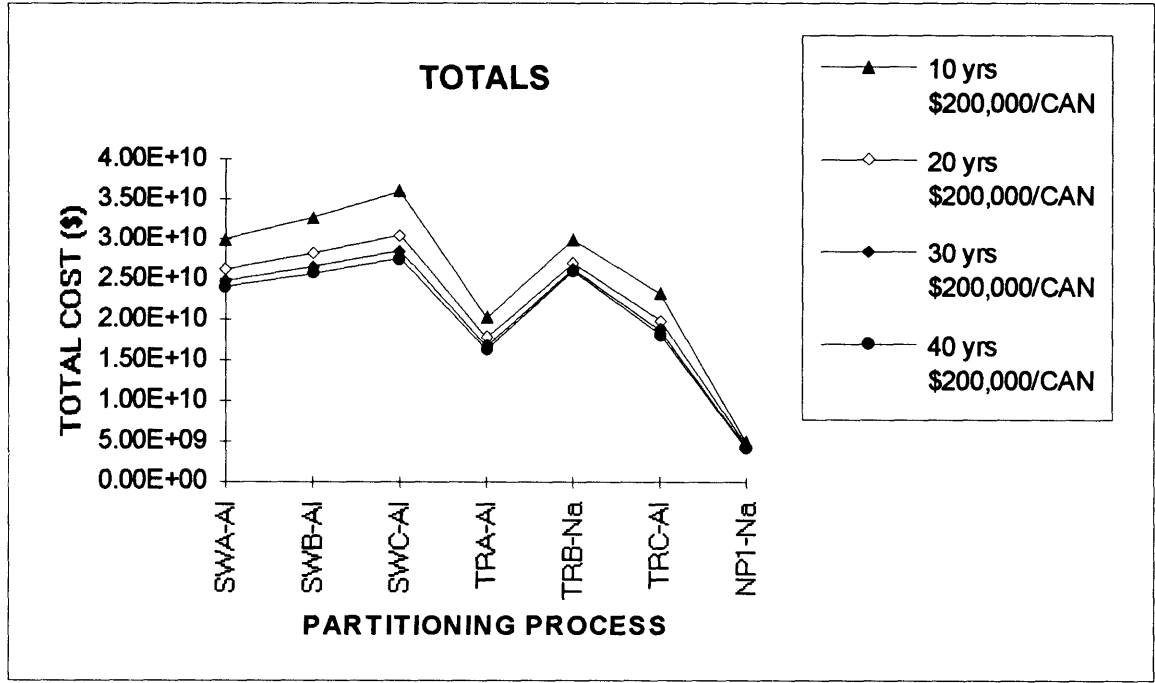


Figure 5-6 Total cost for a 10, 20, 30, and 40 year mission durations with a \$200,000/can HLW disposal fee.

## 6. Conclusions and Future Work

In conclusion, from an economic view the no partitioning option for on site disposal of the tank waste as low level waste looks very appealing. This option does, however, pose several regulatory concerns and political concerns. The next least expensive option is TRUEX-A. This option removes a majority of the radionuclides except Technetium, of which only 50% is removed. The price difference from the least costly option is around \$10 Billion, however, most of the safety concerns will be addressed. TRUEX-A is also the most resilient option with respect to cleanup mission duration and HLW canister fees, next to no partitioning, varying between 15 billion dollars, for a 30 year mission duration and \$100,000 disposal fee, and 22 billion dollars, for a 10 year mission duration and a \$300,000 disposal fee.

Future research into this problem should include determining the extra engineering and capital cost required to increase the capacity factors of all facilities, and determining the feasibility of removing Na, Al, Cr, and Ni from the waste to reduce the total waste volume. Also, with a complete history and content of each tank it should be determined which tank waste can currently be considered low

level waste and what minimum processing is required to allow for the LLW on site disposal of the remaining waste.

# 7. References

<sup>1</sup> WHC-EP-0405 Draft A, 'Systems Engineering Study for the Closure of Single-Shell Tanks', Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management by Westinghouse Hanford Company Richland Washington. 1991, Pg. 1-1

<sup>2</sup> Overview of the Hanford Cleanup Five Year Plan, United States Department of Energy Richland, WA Sept. 1991 pg. 4.

<sup>3</sup> Overview of the Hanford Cleanup Five Year Plan, United States Department of Energy Richland, WA Sept. 1991 pg. 12.

<sup>4</sup> WHC-EP-0182-70, "Tank Farm Surveillance and Waste Status Summary Report for January 1994", Prepared for DOE by WHC Richland Washington. pg. 44 & E-8

<sup>5</sup> WHC-EP-0405 Draft A, 'Systems Engineering Study for the Closure of Single-Shell Tanks', Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management by Westinghouse Hanford Company Richland Washington. 1991 Pg. 1-1,2

<sup>6</sup> WHC-EP-0182-70, "Tank Farm Surveillance and Waste Status Summary Report for January 1994", Prepared for DOE by WHC Richland Washington. pg. E-18

<sup>7</sup> "Radioactive Waste forms for the future", Edited by Werner Lutze and Rodney C. Ewing. Elsevier Science Publishers B.V., 1988, Pg. 701-3

<sup>8</sup> "The Science and Engineering of Materials", Second edition, Donald R. Askeland, University of Missouri-Rolla, PWS-Kent Publishing Company, Boston, 1989

<sup>9</sup> "Radioactive Waste forms for the future", Edited by Werner Lutze and Rodney C. Ewing. Elsevier Science Publishers B.V., 1988, pg. 22

<sup>10</sup> WHC-EP-0405 Draft A, 'Systems Engineering Study for the Closure of Single-Shell Tanks', Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management by Westinghouse Hanford Company Richland Washington. 1991 Pg. F-1

<sup>11</sup> DOE-0230-VA, K.W. Bracken, 'Hanford Site Single-Shell Tank Characterization and Assessment Program Update Meeting No. 12 for National Academy of Sciences', U.S. Department of Energy Field Office, Richland, Washington. October 31 - November 1, . pg. 15.

<sup>12</sup> WHC-EP-0405 Draft A, 'Systems Engineering Study for the Closure of Single-Shell Tanks', Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management by Westinghouse Hanford Company Richland Washington. 1991, pg. F-147.

- <sup>13</sup> WHC-EP-0405 Draft A, 'Systems Engineering Study for the Closure of Single-Shell Tanks', Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management by Westinghouse Hanford Company Richland Washington. 1991, Table 6-2.
- <sup>14</sup> WHC-EP-0405 Draft A, 'Systems Engineering Study for the Closure of Single-Shell Tanks', Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management by Westinghouse Hanford Company Richland Washington. 1991, Table 6-3 and Volume 4.
- <sup>15</sup> C. R. Hudson, II, *CONCEPT-5 Users Manual*, ORNL-5470, January 1979.
- <sup>16</sup> DOE/NE-0044/3 'Nuclear Energy Cost Data Base A Reference Data Base for Nuclear and Coal-fired Powerplant Power Generation Cost Analysis', June 1985.
- <sup>17</sup> WHC-EP-0405 Draft A, 'Systems Engineering Study for the Closure of Single-Shell Tanks', Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management by Westinghouse Hanford Company Richland Washington. 1991.
- <sup>18</sup> Memo from K.T. Thomas to members of the STATS Committee, National Research Council, June 29, 1993
- <sup>19</sup> A.S. Polyakov, A.P. Suslov, V.I. Osnovin, et al. 'Industrial Operation of Joule Heated Ceramic Melters Type EP-500 and Pamela for Vitrification of High Radioactive Waste', *PROCEEDINGS OF THE THIRD ANNUAL SCIENTIFIC CONFERENCE NUCLEAR SOCIETY INTERNATIONAL, MOSCOW*, September 14-18 1992, St. Petersburg, Russia, Supplement number 1 to Vol. 67. 1993. pg. 318.

# ***Appendix A - HLW and LLW limiting elements***

Appendix C shows the output from FILMK6.FOR and plots the HLW volumes that would result if each element were used to determine the final HLW volume. Table A-1 shows the output file. Where the captions are: CHEM = the chemical name. XHGL and XLGL = the wt fraction of CHEM that can be loaded into the HLW and LLW glass respectively. SEPHLW and SEPLLW = the fraction of the initial chemical that will be sent to the HLW or LLW vitrification facility. TOTCHM = the total grams of CHEM that are present in the initial waste. HLW and LLW = the number of canisters that will be produced if  $TOTCHM * SEPH(L)LW$  grams of CHEM is incorporated into the glass with loading  $XH(L)GL$ . The limiting element is fairly evident for LLW since the number of containers that are needed to incorporate the sodium are a factor of ten larger than the number of containers needed to incorporate any of the other elements. The limiting elements for HLW are not as evident and Figure A-1 through Figure A-2 displays the partitioning process and the number of HLW canisters that will be required based on each element.

**Table A-1 Elements, their glass loading limits, and the resulting number of HLW and LLW canisters.**

CHEM	XHGL	XLGL	SEPHLW	SEPLLW	TOTCHM	HLW (0.631 m <sup>3</sup> )	LLW (15.1 m <sup>3</sup> )
name	wt frac	wt frac	frac of init	frac of init	(g)	Containers of glass	Containers of glass
SWA-Na	0.1113	0.1113	0.013	0.986	8.03E+10	5.72E+03	1.75E+04
SWA-Al	0.0794	0.0794	0.79	0.21	7.76E+09	4.71E+04	5.03E+02
SWA-Cr	0.0034	0.0034	0.9	0.1	2.75E+08	4.43E+04	1.98E+02
SWA-Ni	0.0157	0.0157	0.9	0.1	2.44E+08	8.51E+03	3.81E+01
SWA--P	0.0031	0.0031	0.5	0.5	3.98E+07	3.92E+03	1.58E+02
SWB-Na	0.1113	0.1113	0.028	1.076	8.03E+10	1.23E+04	1.90E+04
SWB-Al	0.0794	0.0794	0.79	0.21	7.76E+09	4.71E+04	5.03E+02
SWB-Cr	0.0034	0.0034	0.9	0.1	2.75E+08	4.43E+04	1.98E+02
SWB-Ni	0.0157	0.0157	0.9	0.1	2.44E+08	8.51E+03	3.81E+01
SWB--P	0.0031	0.0031	0.5	0.5	3.98E+07	3.92E+03	1.58E+02
SWC-Na	0.1113	0.1113	0.036	1.15	8.03E+10	1.58E+04	2.04E+04
SWC-Al	0.0794	0.0794	0.79	0.21	7.76E+09	4.71E+04	5.03E+02
SWC-Cr	0.0034	0.0034	0.9	0.1	2.75E+08	4.43E+04	1.98E+02
SWC-Ni	0.0157	0.0157	0.9	0.1	2.44E+08	8.51E+03	3.81E+01
SWC--P	0.0031	0.0031	0.5	0.5	3.98E+07	3.92E+03	1.58E+02
TRA-Na	0.1113	0.1113	0.025	1.65	8.03E+10	1.10E+04	2.92E+04
TRA-Al	0.0794	0.0794	0.23	0.77	7.76E+09	1.37E+04	1.85E+03
TRA-Cr	0.0034	0.0034	0.09	0.91	2.75E+08	4.43E+03	1.80E+03
TRA-Ni	0.0157	0.0157	0.9	0.1	2.44E+08	8.51E+03	3.81E+01
TRA--P	0.0031	0.0031	0.05	0.95	3.98E+07	3.92E+02	3.00E+02
TRB-Na	0.1113	0.1113	0.036	2.2	8.03E+10	1.58E+04	3.89E+04
TRB-Al	0.0794	0.0794	0.2	0.8	7.76E+09	1.19E+04	1.92E+03
TRB-Cr	0.0034	0.0034	0.09	0.91	2.75E+08	4.43E+03	1.80E+03
TRB-Ni	0.0157	0.0157	0.9	0.1	2.44E+08	8.51E+03	3.81E+01
TRB--P	0.0031	0.0031	0.05	0.95	3.98E+07	3.92E+02	3.00E+02
TRC-Na	0.1113	0.1113	0.026	1.85	8.03E+10	1.14E+04	3.27E+04
TRC-Al	0.0794	0.0794	0.23	0.77	7.76E+09	1.37E+04	1.85E+03
TRC-Cr	0.0034	0.0034	0.09	0.91	2.75E+08	4.43E+03	1.80E+03
TRC-Ni	0.0157	0.0157	0.9	0.1	2.44E+08	8.51E+03	3.81E+01
TRC--P	0.0031	0.0031	0.05	0.95	3.98E+07	3.92E+02	3.00E+02
NP1-Na	0.1113	0.1113	0	1	8.03E+10	0.00E+00	1.77E+04
NP1-Al	0.0794	0.0794	0	1	7.76E+09	0.00E+00	2.40E+03
NP1-Cr	0.0034	0.0034	0	1	2.75E+08	0.00E+00	1.98E+03
NP1-Ni	0.0157	0.0157	0	1	2.44E+08	0.00E+00	3.81E+02
NP1--P	0.0031	0.0031	0	1	3.98E+07	0.00E+00	3.15E+02
NP2-Na	0.1113	0.1113	1	0	8.03E+10	4.40E+05	0.00E+00
NP2-Al	0.0794	0.0794	1	0	7.76E+09	5.96E+04	0.00E+00
NP2-Cr	0.0034	0.0034	1	0	2.75E+08	4.92E+04	0.00E+00
NP2-Ni	0.0157	0.0157	1	0	2.44E+08	9.46E+03	0.00E+00
NP2--P	0.0031	0.0031	1	0	3.98E+07	7.83E+03	0.00E+00

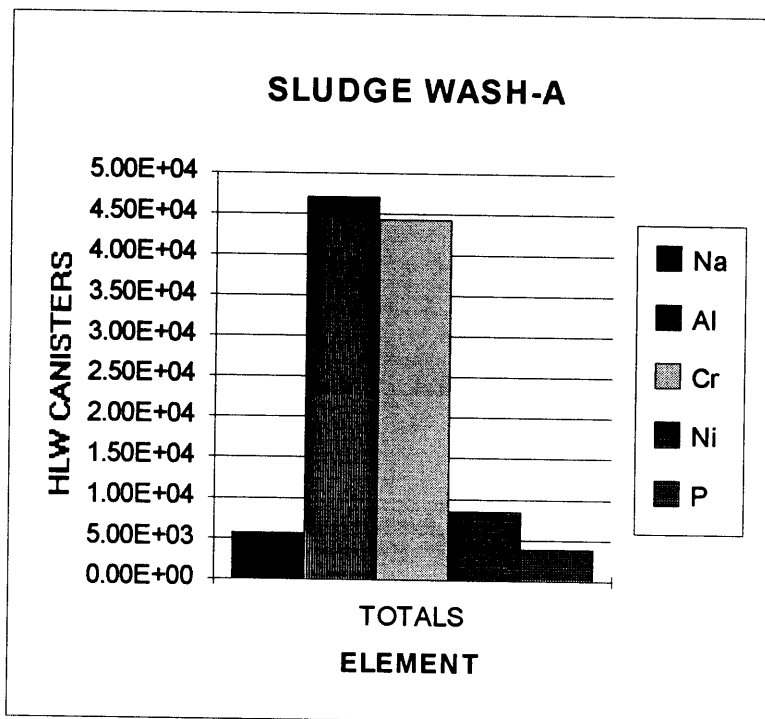


Figure A-1 HLW canisters resulting from SW-A partitioning.

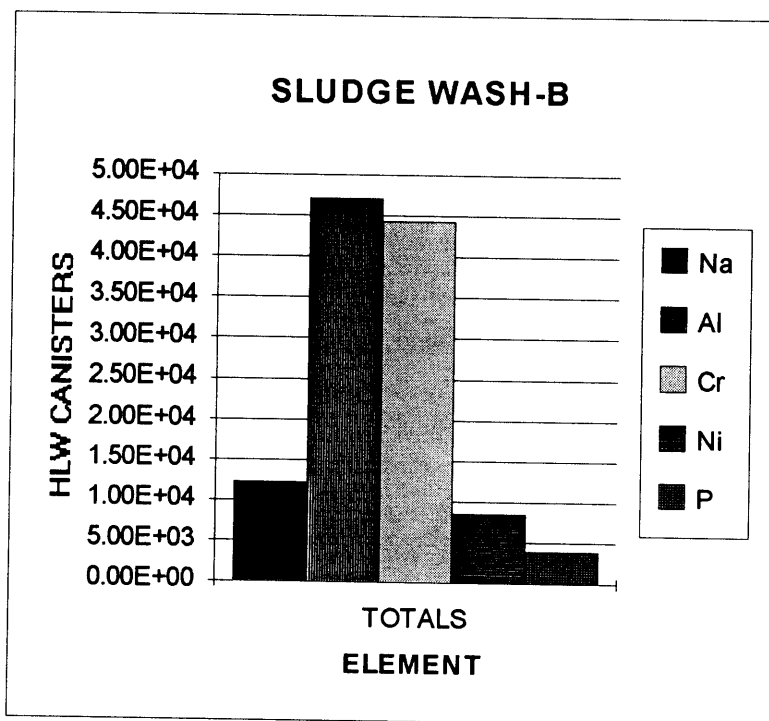


Figure A-2 HLW canisters resulting from SW-B partitioning.

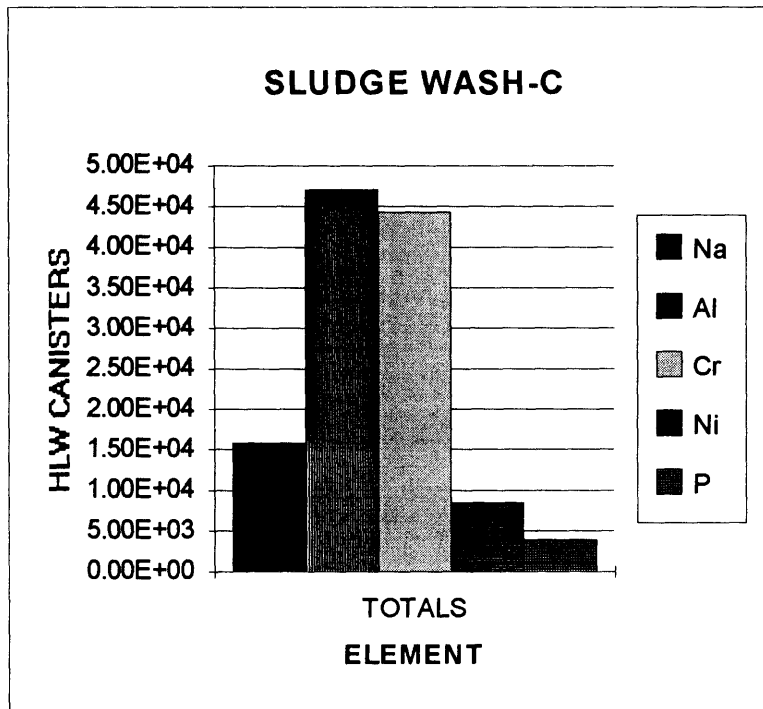


Figure A-3 HLW canisters resulting from SW-C partitioning.

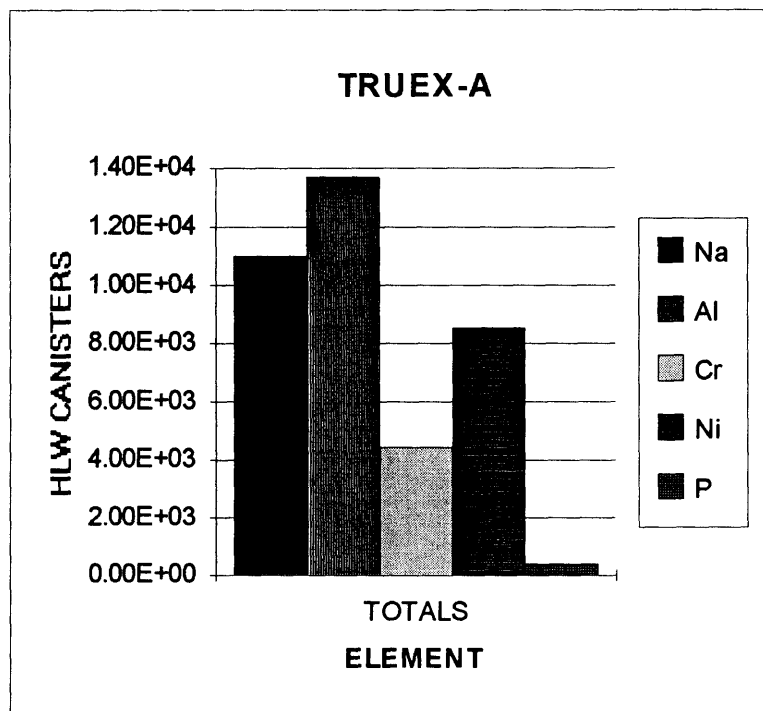


Figure A-4 HLW canisters resulting from TRUEX-A partitioning.

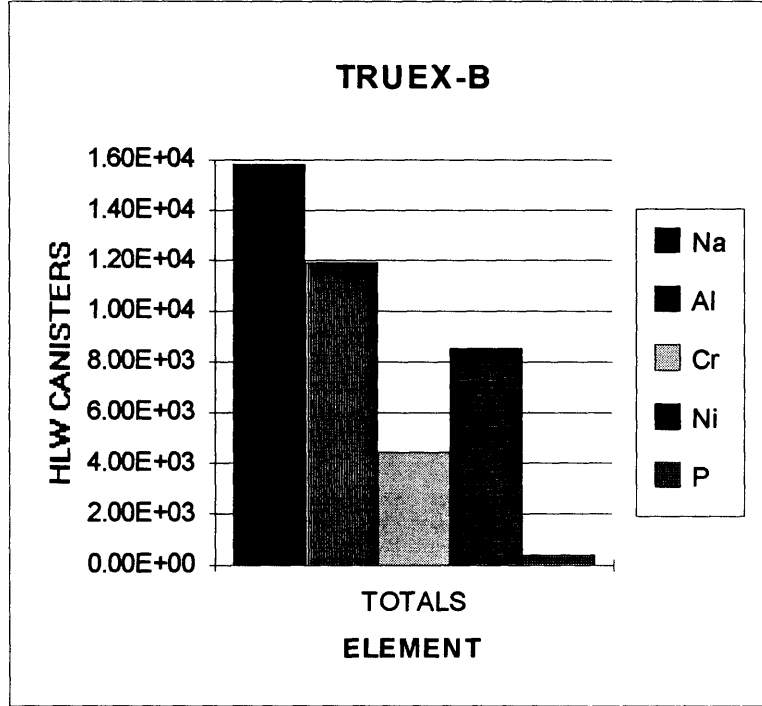


Figure A-5 HLW canisters resulting from TRUEX-B partitioning.

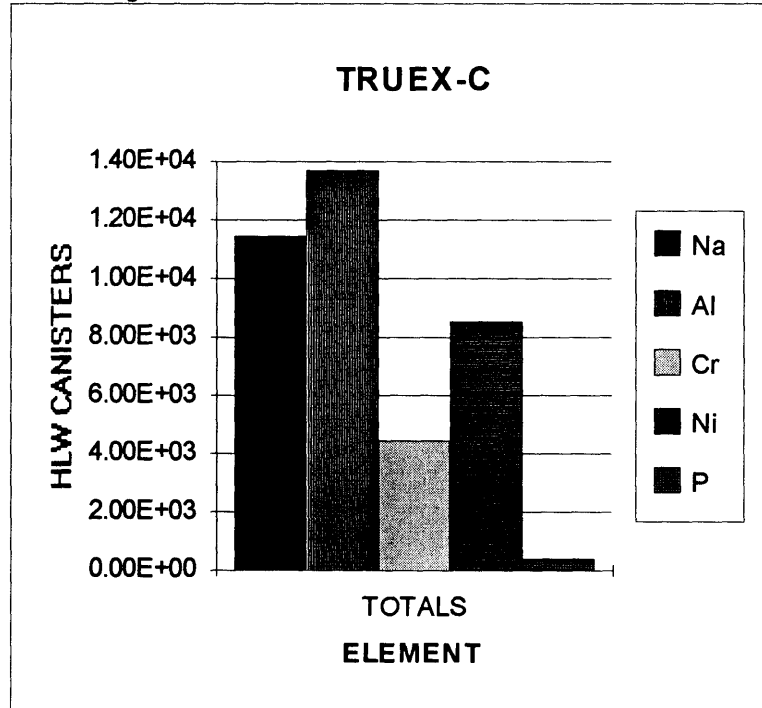


Figure A-6 HLW canisters resulting from TRUEX-C partitioning.

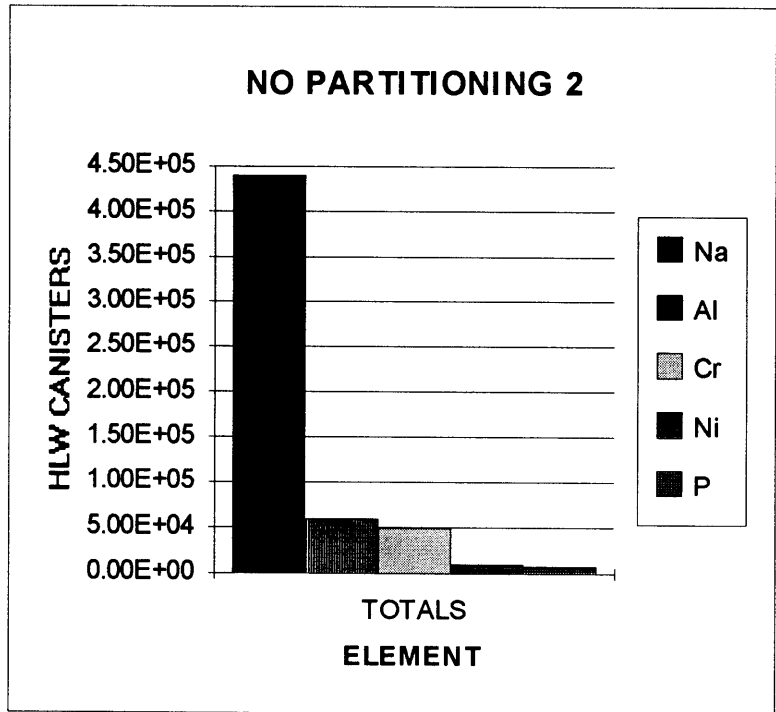


Figure A-7 HLW canisters if all waste went directly to HWVP with no partitioning.

# **Appendix B - Graphical Breakdown of Results**

Appendix B shows the graphical breakdown of the total cost associated with the results. The bar charts are for 10, 20, and 30 year mission duration with a HLW disposal cost of \$200,000/canister. Figure 5-5 shows how the disposal cost varies with the HLW disposal fee.

The acronyms used in the following tables are shown below.

TOT = the total cost due to disposal, frit, energy, and capital expenses.

DHC = the cost of on site storage, canister costs, and the repository fee per canister.

DLC = the cost of on site storage and the canister costs per canister.

XHCC1 = the scaled HLW vitrification plant capital cost.

XLCC1 = the scaled LLW vitrification plant capital cost.

XPCC1 = the scaled partitioning facility capital cost.

XHFCE = the frit and energy cost for the HLW facility per canister.

XLFCFCE = the frit and energy cost for the LLW facility per canister.

XPC = the operating cost for the partitioning facility per year.

XHLC1 = the scaled labor cost for HLW vitrification per year.

XLCC1 = the scaled labor cost for LLW vitrification per year.

XPLC1 = the scaled labor cost for waste partitioning per year.

The first eight graphs are for a 10 year mission duration and \$200,000/can HLW disposal cost.

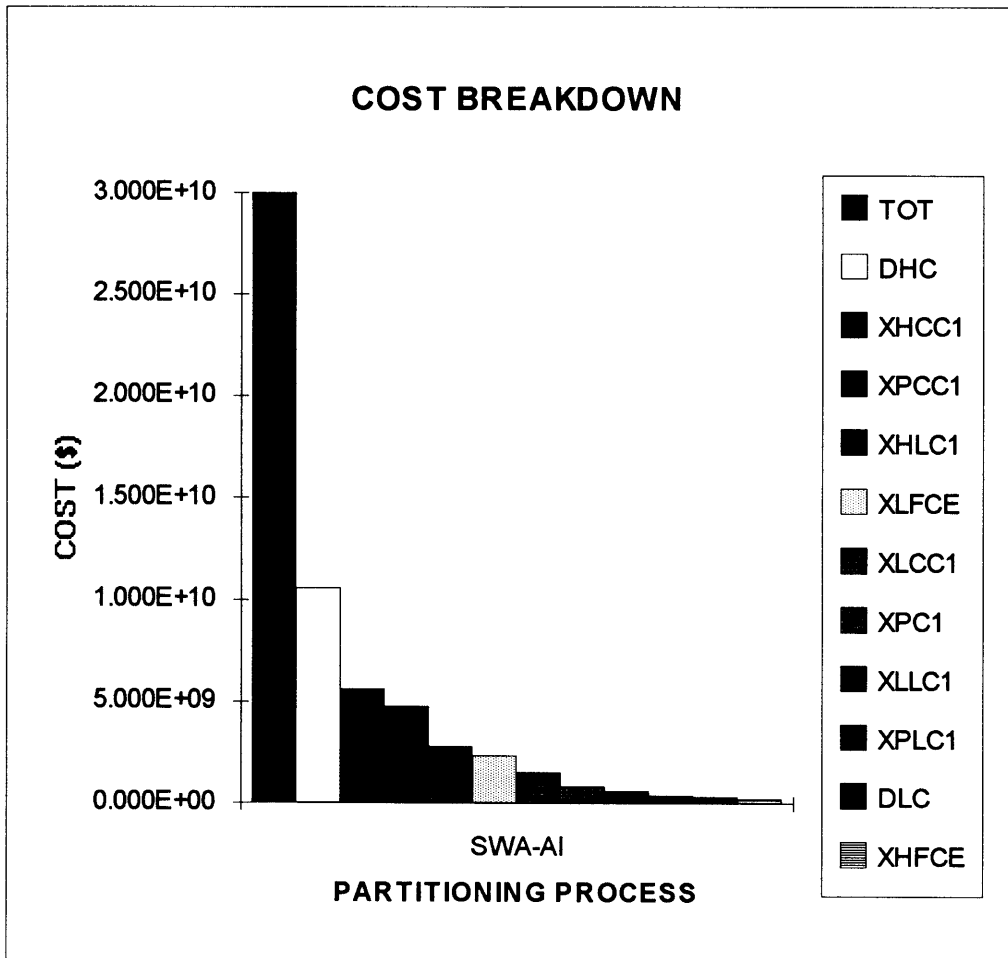


Figure B-1 Cost breakdown for the sludge wash-A partitioning process for a ten(10) year mission duration with Al content deciding the HLW volume.

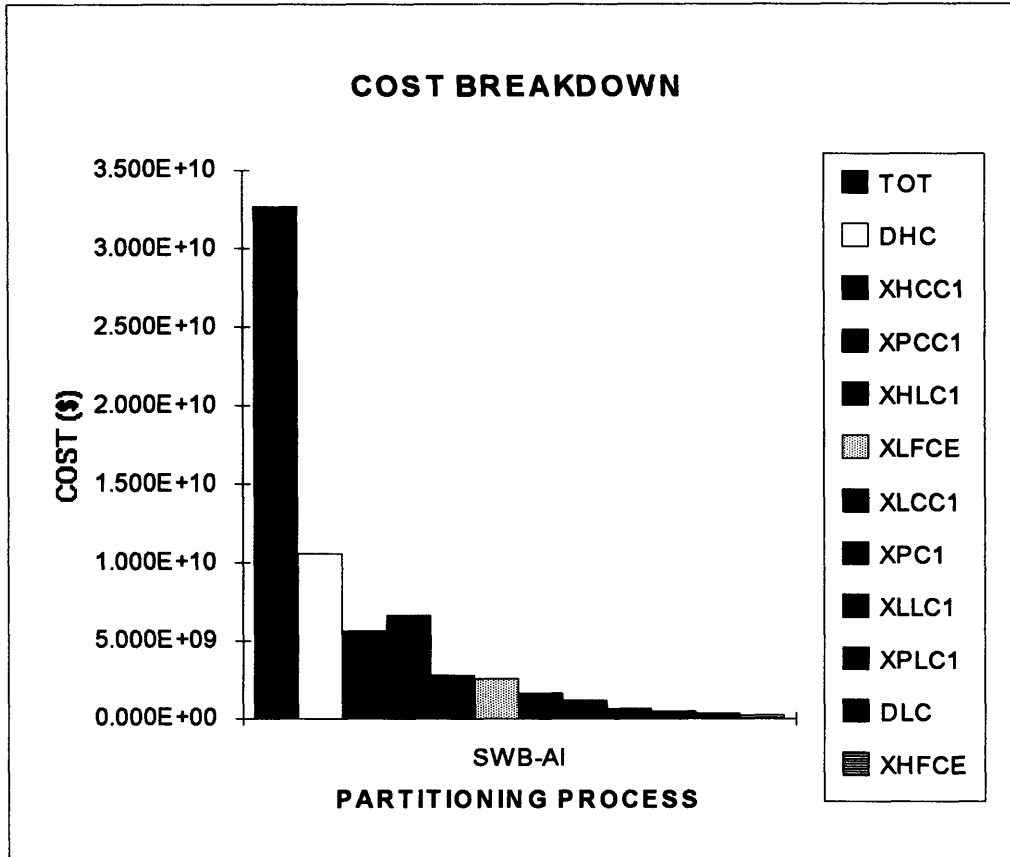


Figure B-2 Cost breakdown for the sludge wash-B partitioning process for a ten(10) year mission duration with Al content deciding the HLW volume.

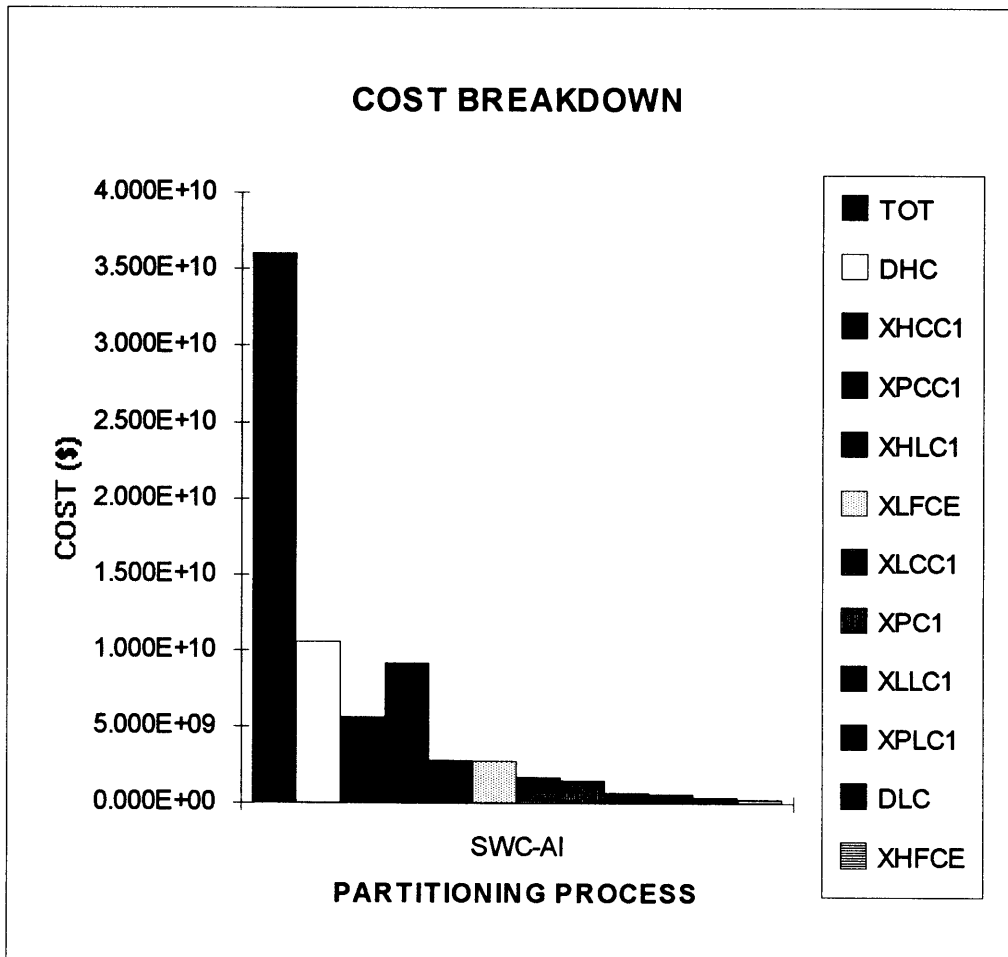


Figure B-3 Cost breakdown for the sludge wash-C partitioning process for a ten(10) year mission duration with Al content deciding the HLW volume.

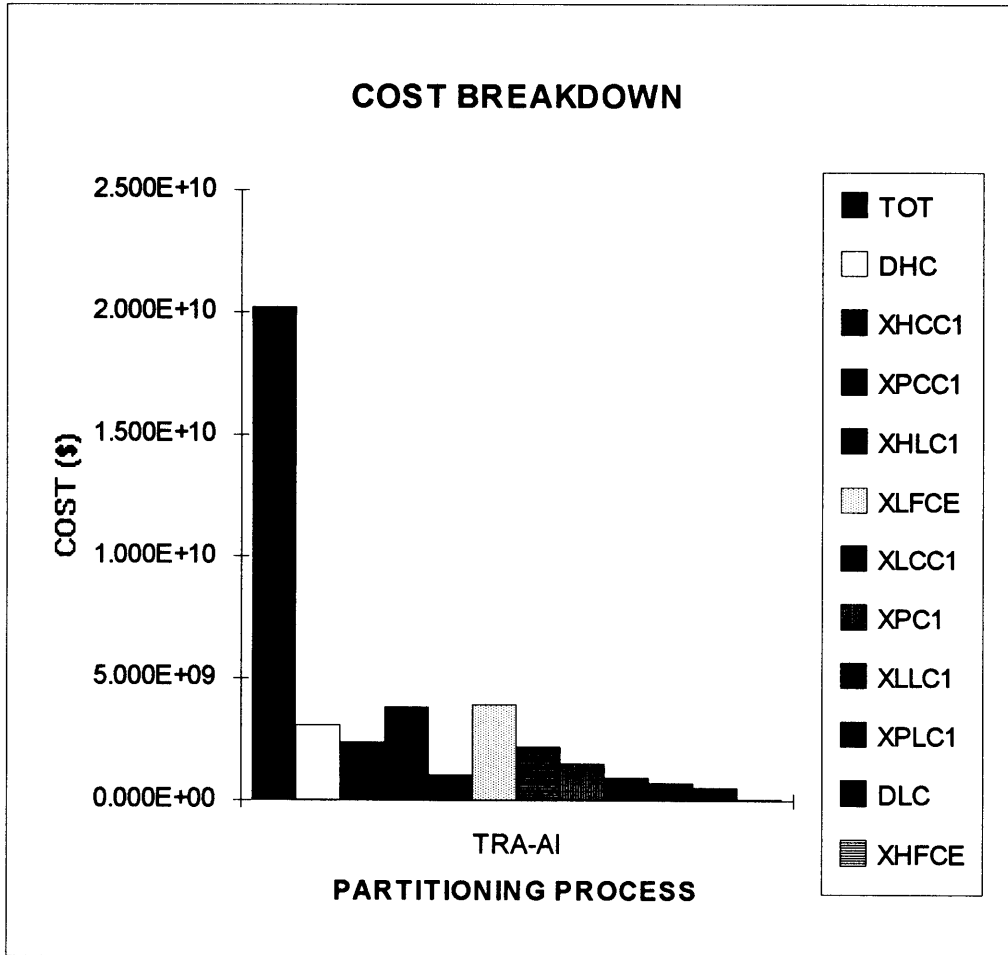


Figure B-4 Cost breakdown for the TRUEX-A partitioning process for a ten(10) year mission duration with Al content deciding the HLW volume.

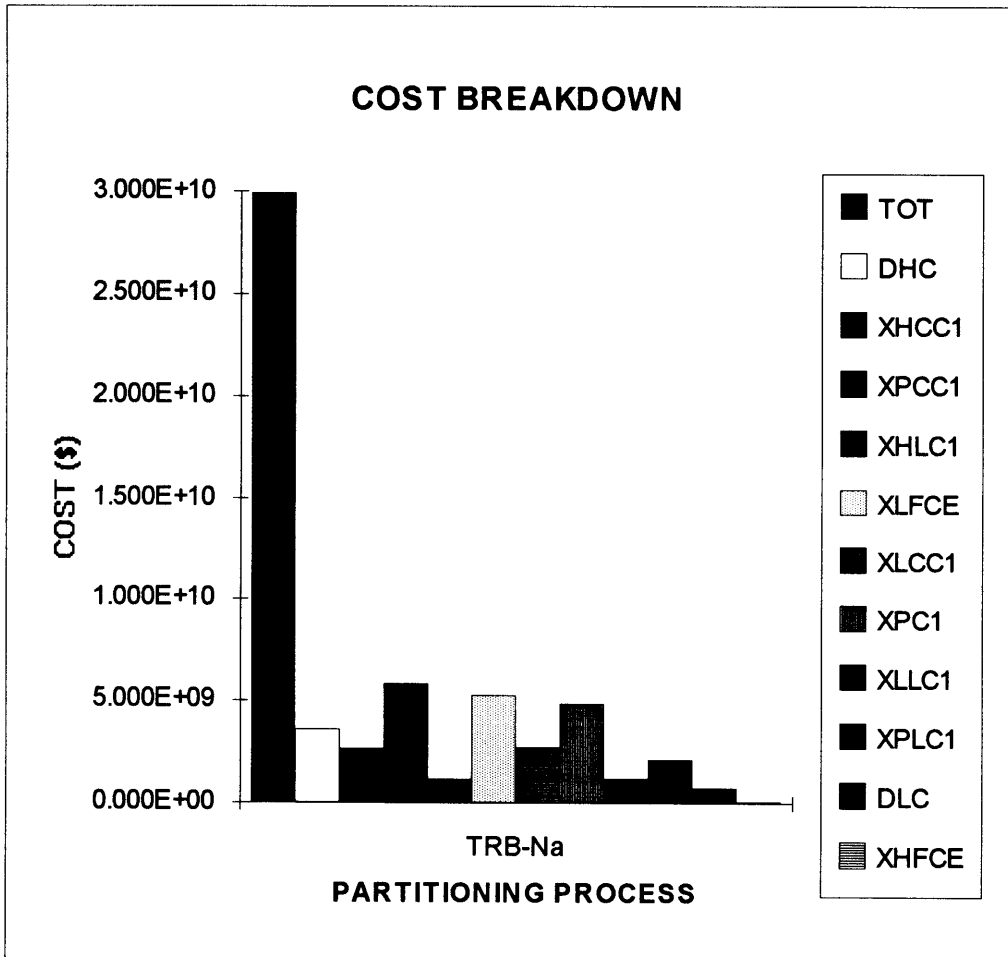


Figure B-5 Cost breakdown for the TRUEx-B partitioning process for a ten(10) year mission duration with Na content deciding the HLW volume.

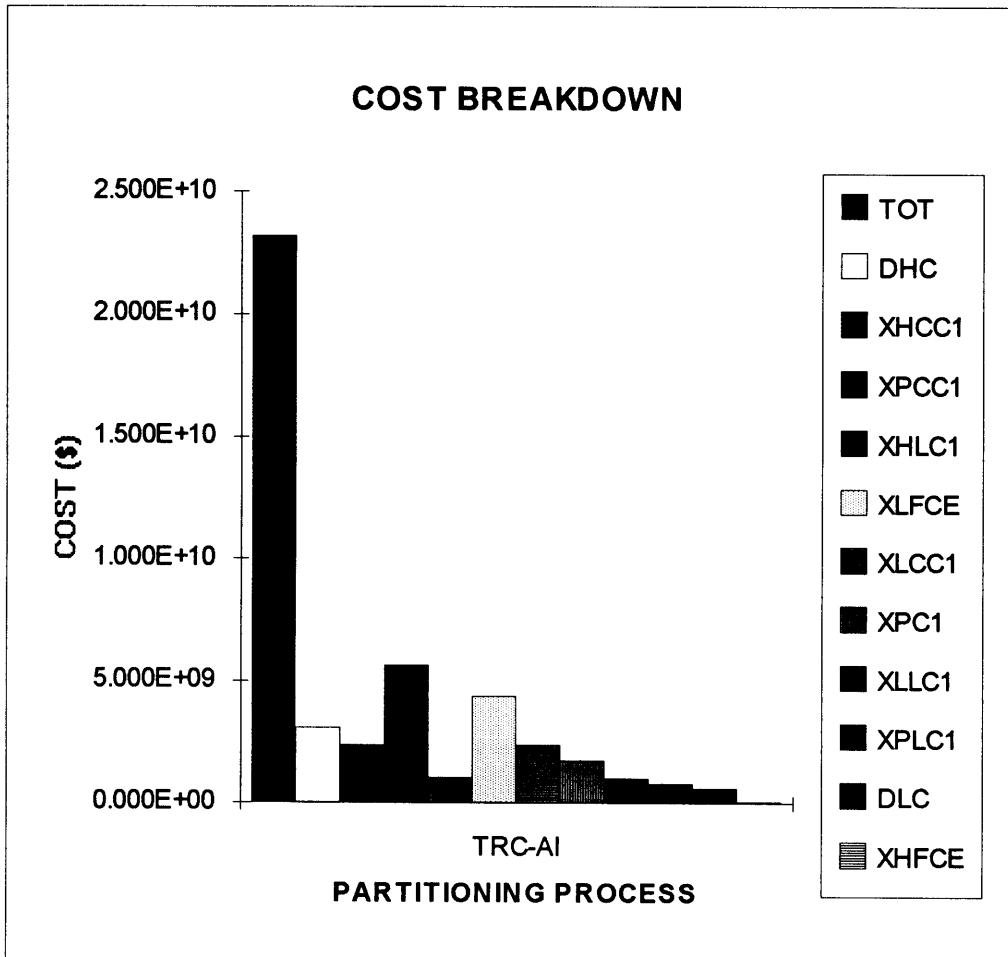


Figure B-6 Cost breakdown for the TRUEX-C partitioning process for a ten(10) year mission duration with AI content deciding the HLW volume.

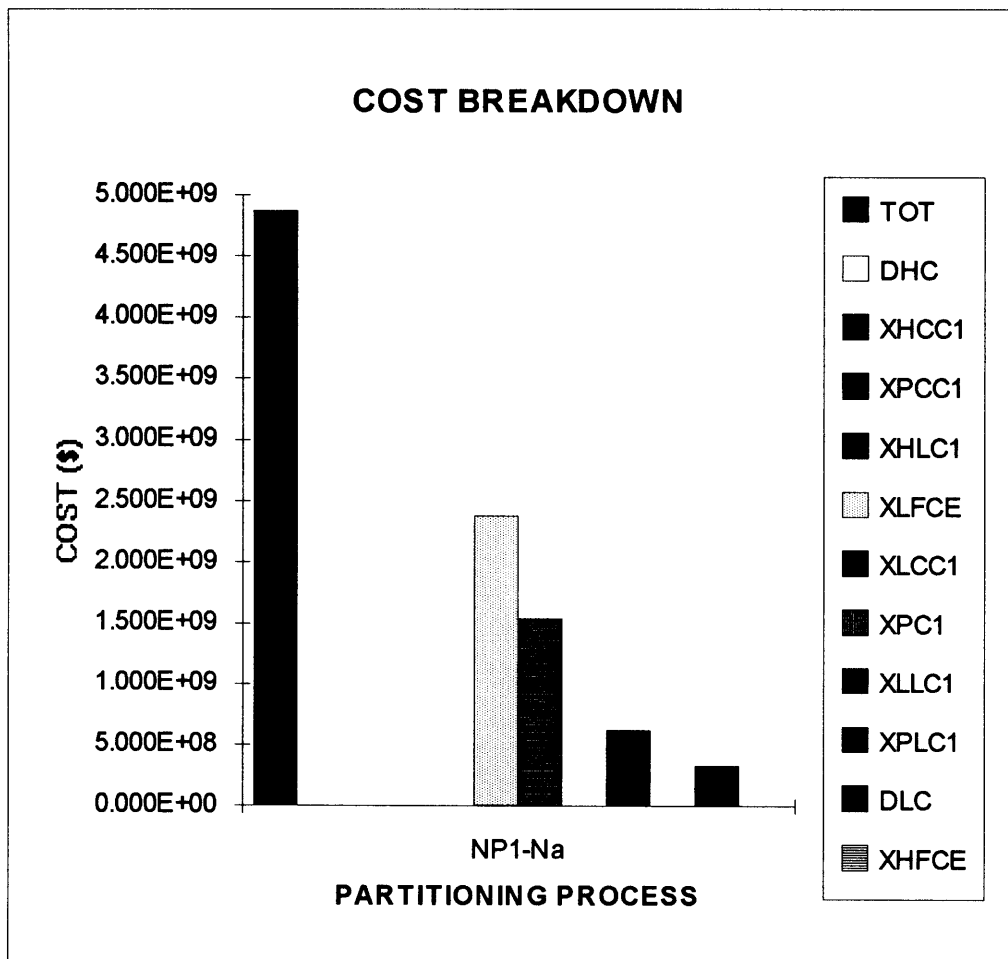


Figure B-7 Cost breakdown for the no partitioning on-site disposal process for a ten(10) year mission duration with Na content deciding the waste volume.

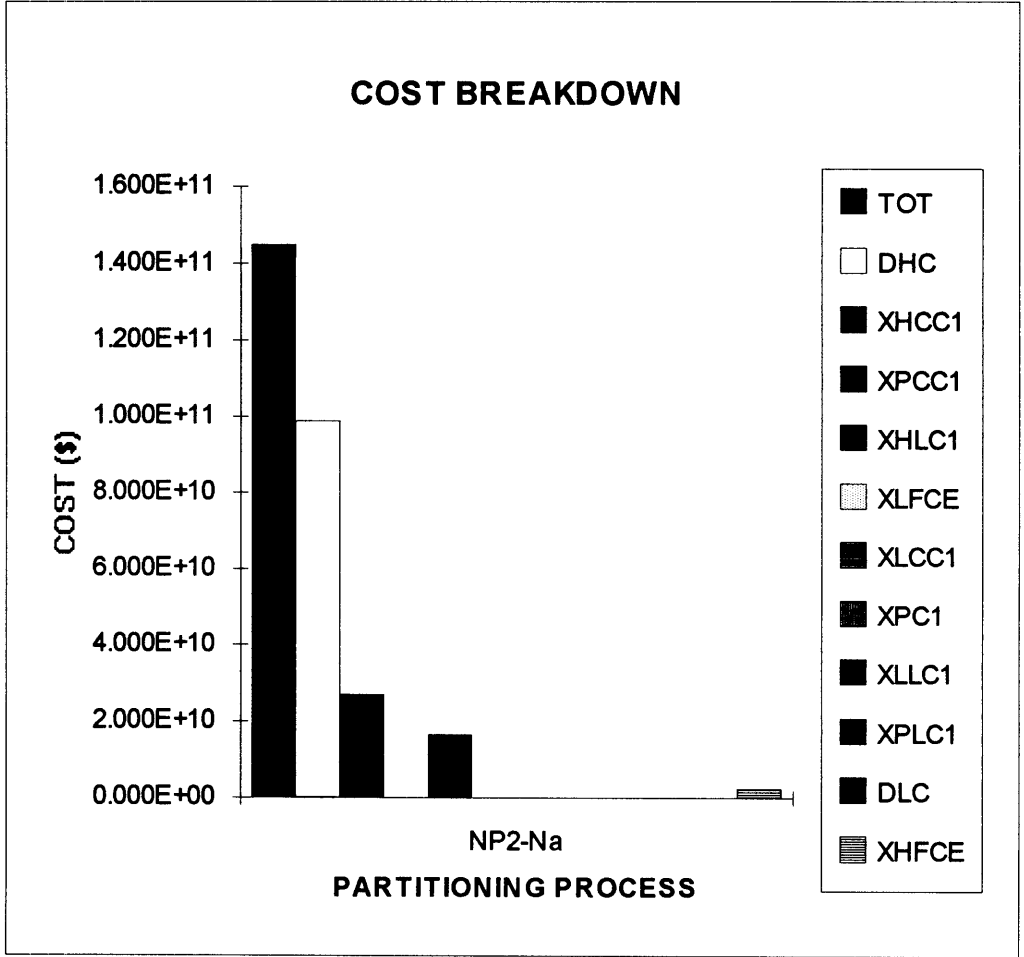


Figure B-8 Cost breakdown for the no partitioning off-site disposal process for a ten(10) year mission duration with Al content deciding the HLW volume.

The next eight graphs are for a 20 year mission duration and \$200,000/can HLW disposal cost.

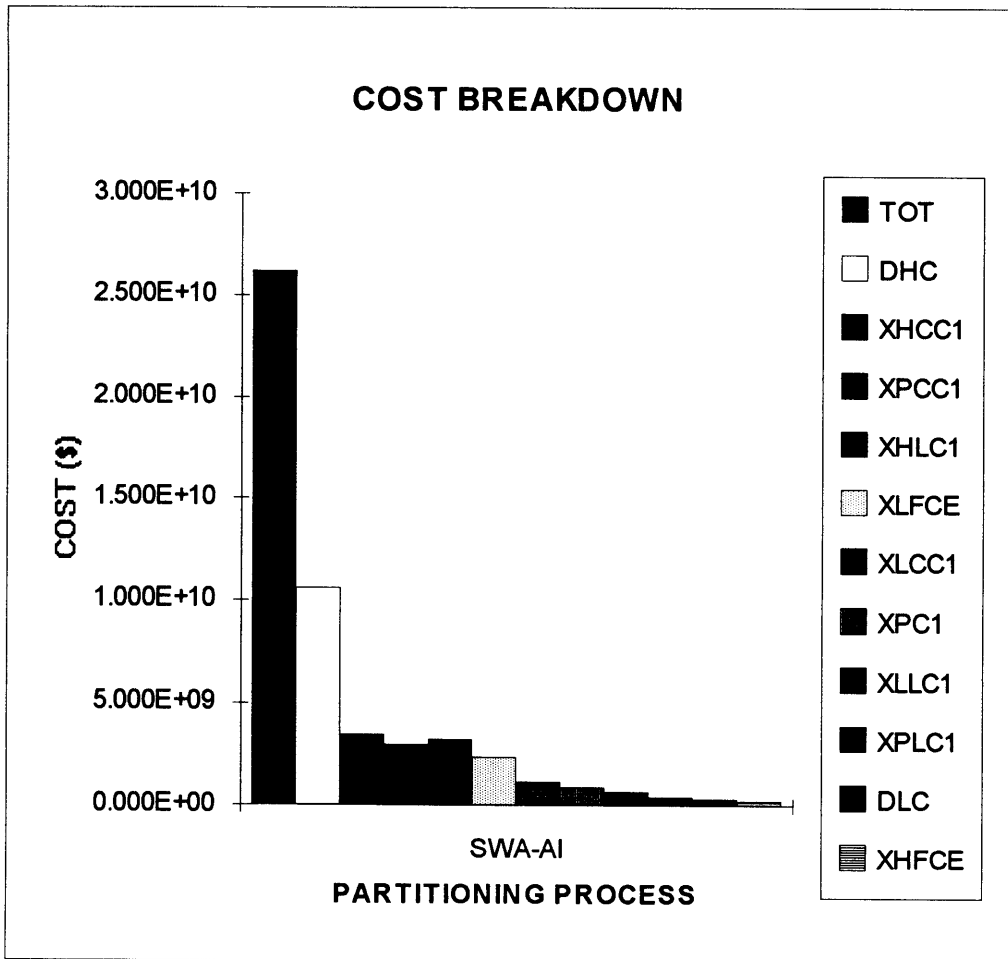


Figure B-9 Cost breakdown for the sludge wash-A partitioning process for a twenty(20) year mission duration with Al content deciding the HLW volume.

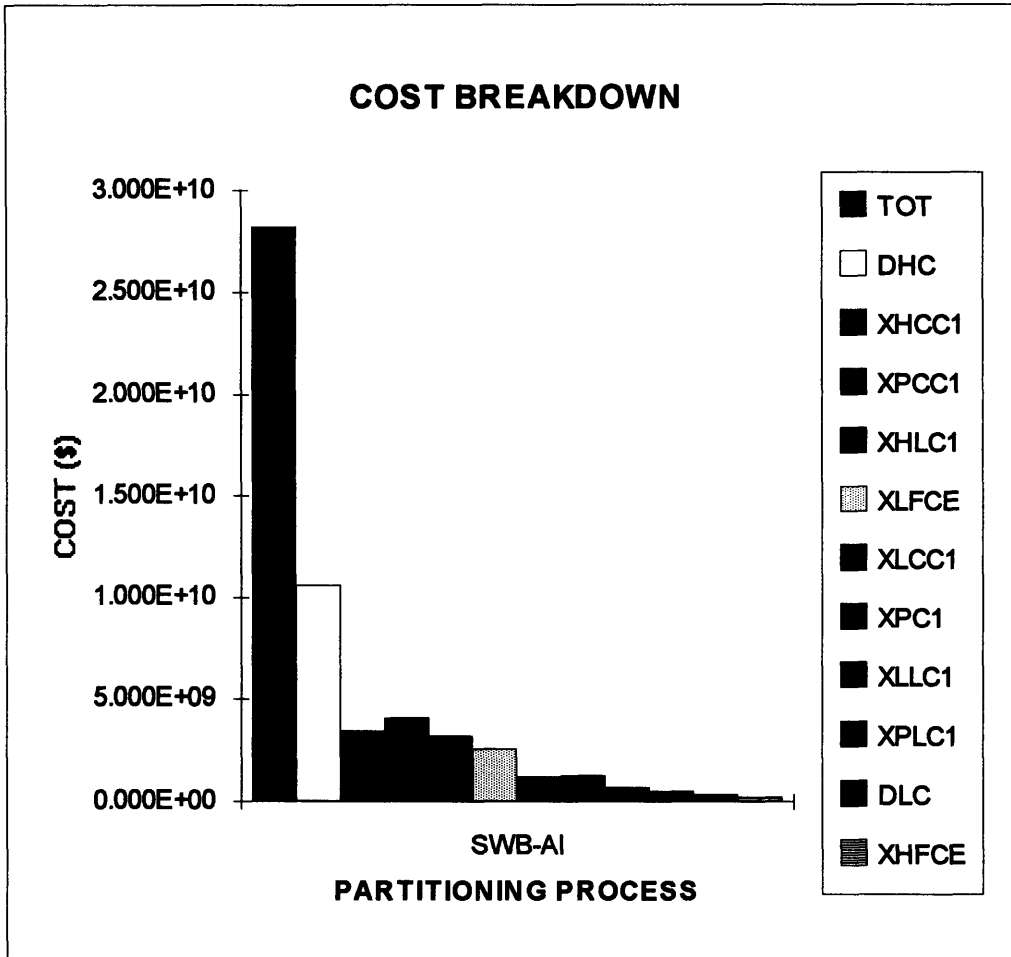


Figure B-10 Cost breakdown for the sludge wash-B partitioning process for a twenty(20) year mission duration with Al content deciding the HLW volume.

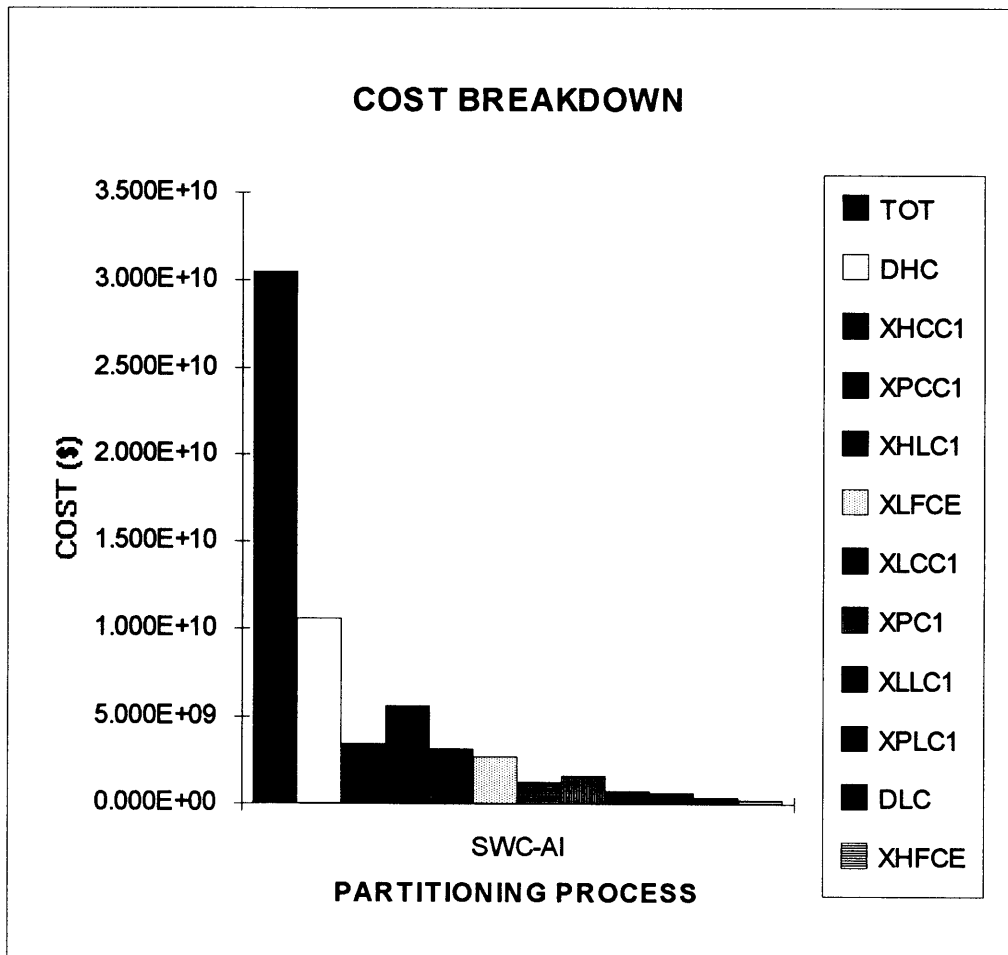


Figure B-11 Cost breakdown for the sludge wash-C partitioning process for a twenty(20) year mission duration with Al content deciding the HLW volume.

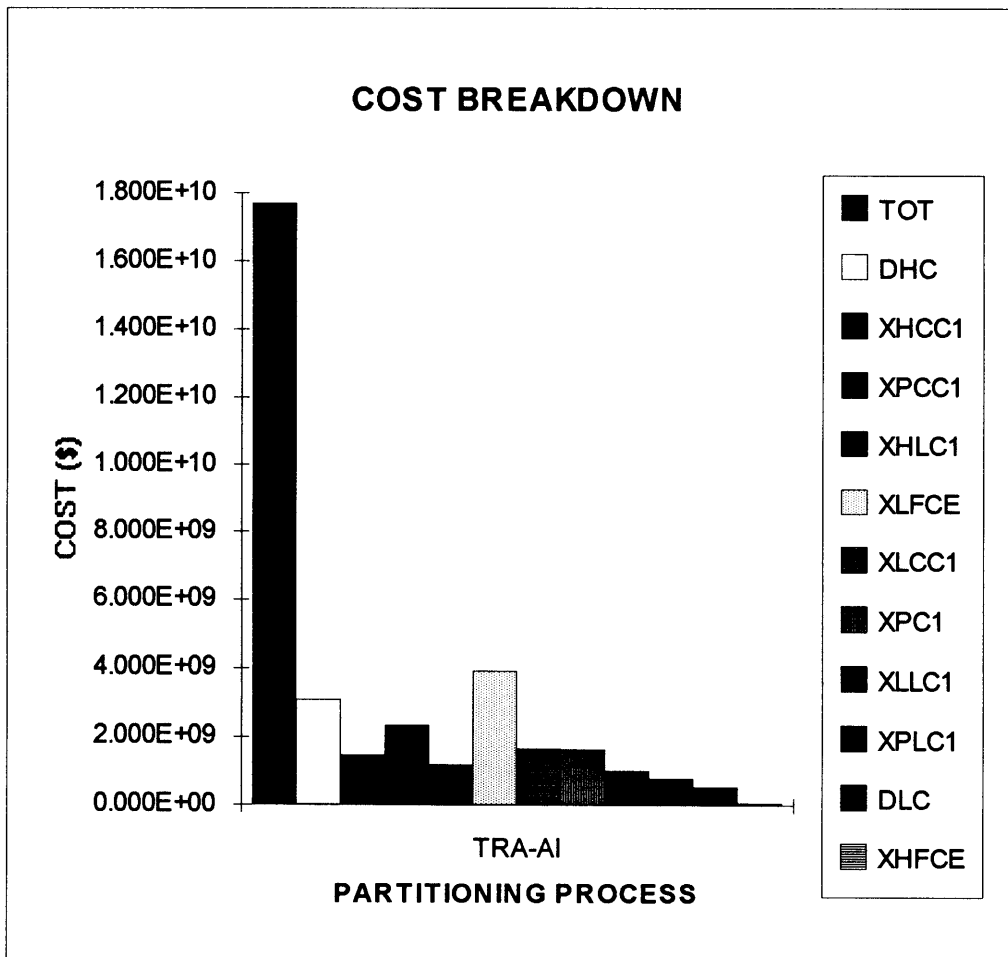


Figure B-12 Cost breakdown for the TRUEX-A partitioning process for a twenty(20) year mission duration with Al content deciding the HLW volume.

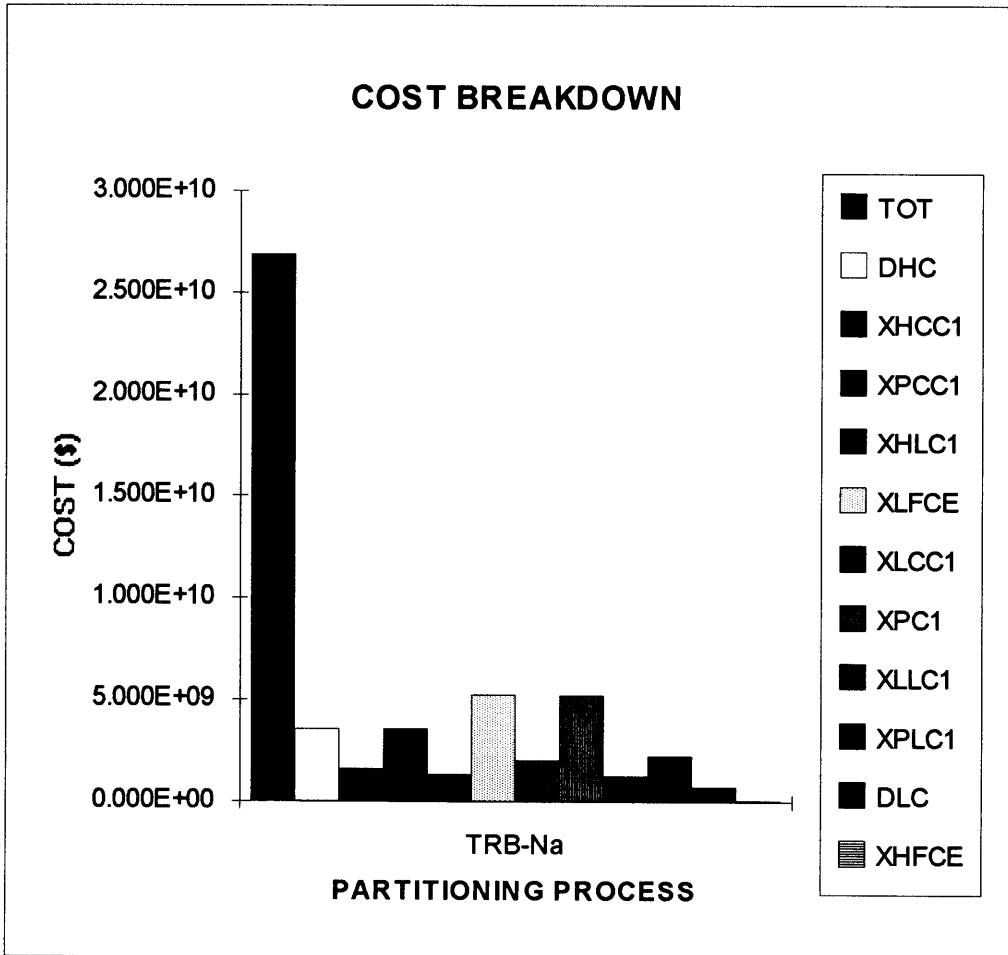


Figure B-13 Cost breakdown for the TRUEX-B partitioning process for a twenty(20) year mission duration with Na content deciding the HLW volume.

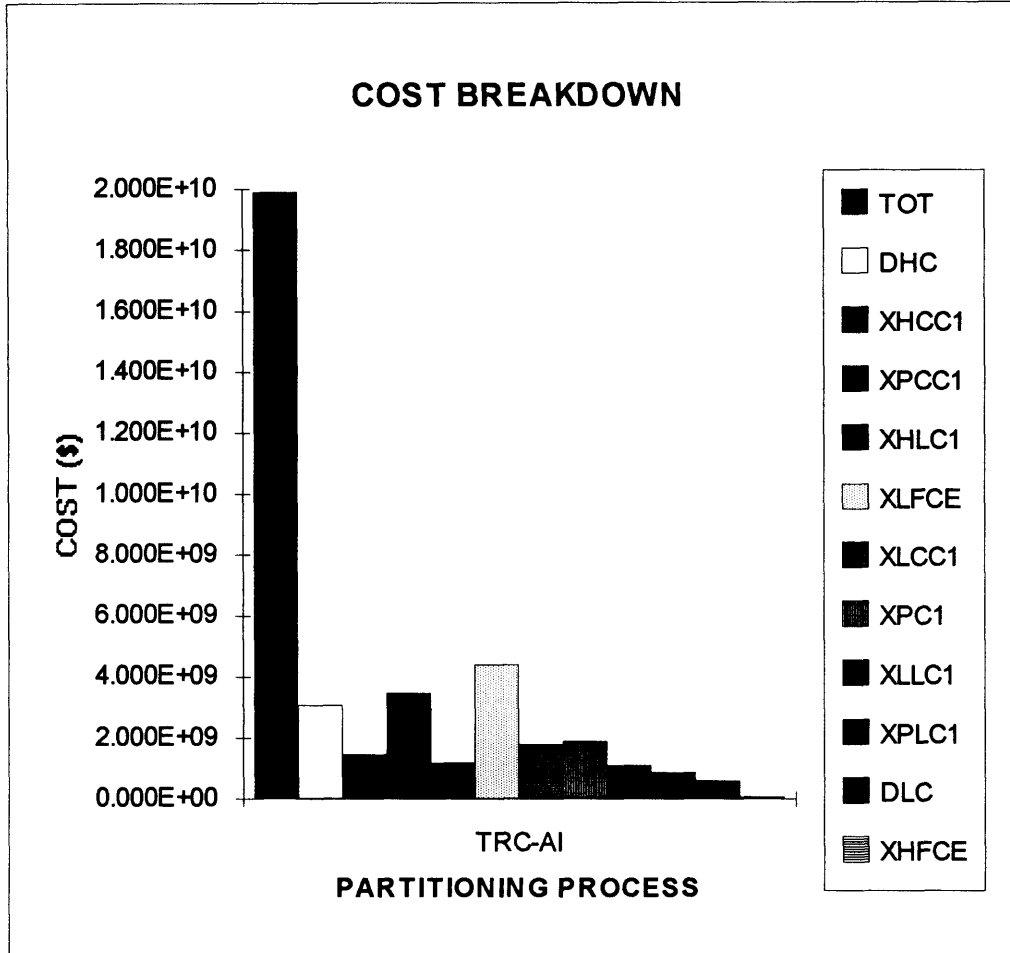


Figure B-14 Cost breakdown for the TRUEX-C partitioning process for a twenty(20) year mission duration with Al content deciding the HLW volume.

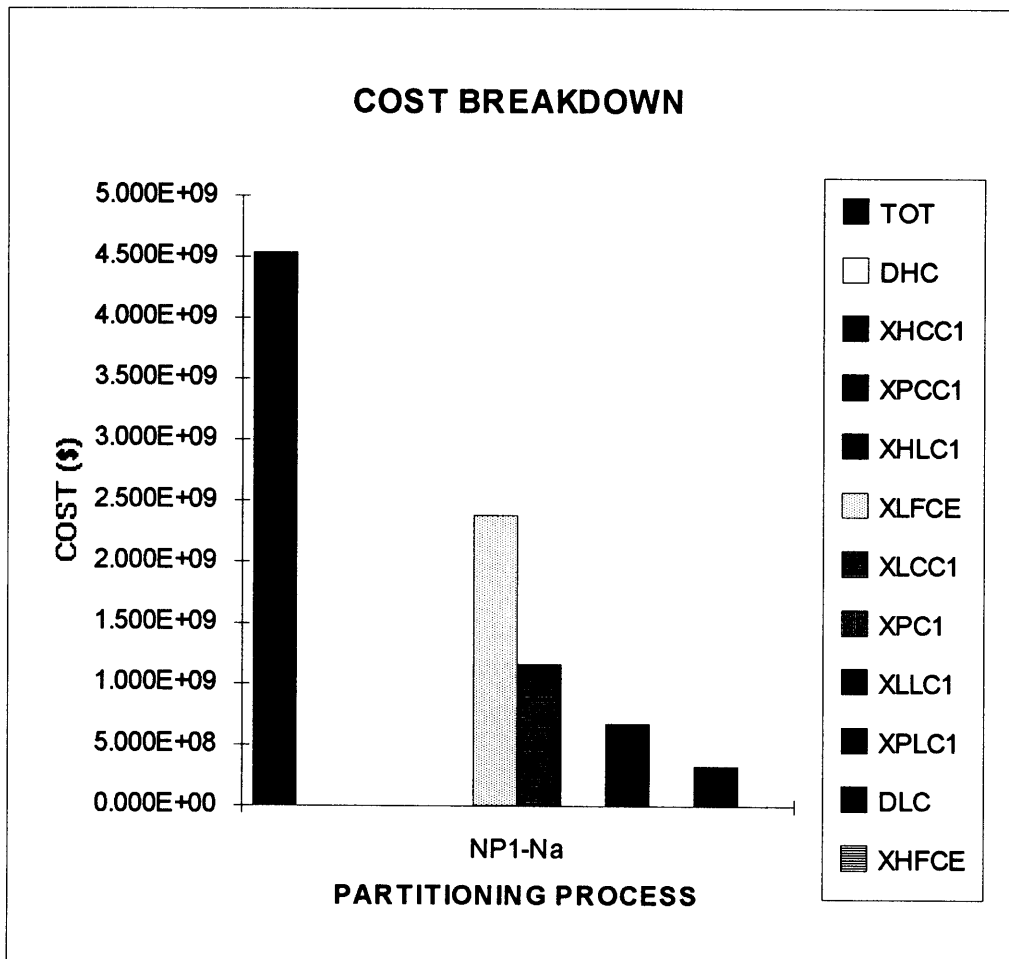


Figure B-15 Cost breakdown for the no partitioning on-site disposal process for a twenty(20) year mission duration with Na content deciding the waste volume.

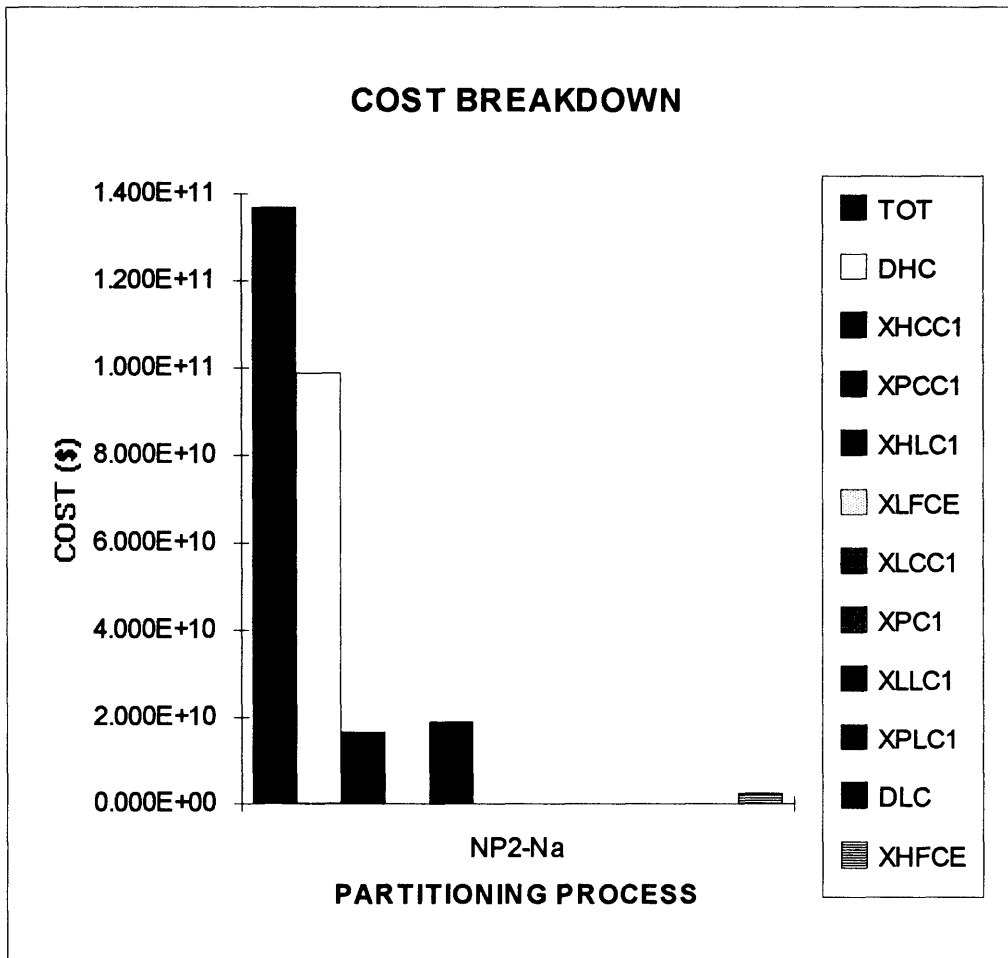


Figure B-16 Cost breakdown for the no partitioning off-site disposal process for a twenty(20) year mission duration with Na content deciding the waste volume.

The next eight graphs are for a 30 year mission duration and \$200,000/can HLW disposal cost.

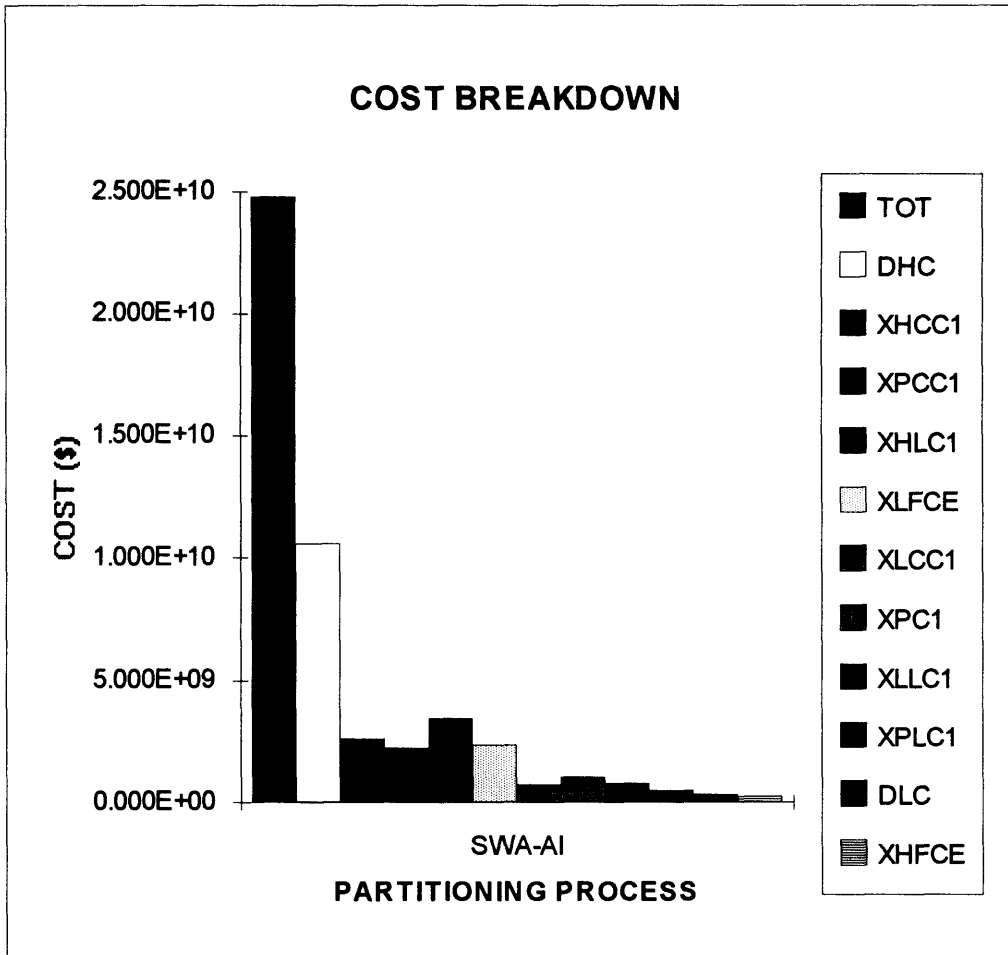


Figure B-17 Cost breakdown for the sludge wash-A partitioning process for a thirty(30) year mission duration with Al content deciding the HLW volume.

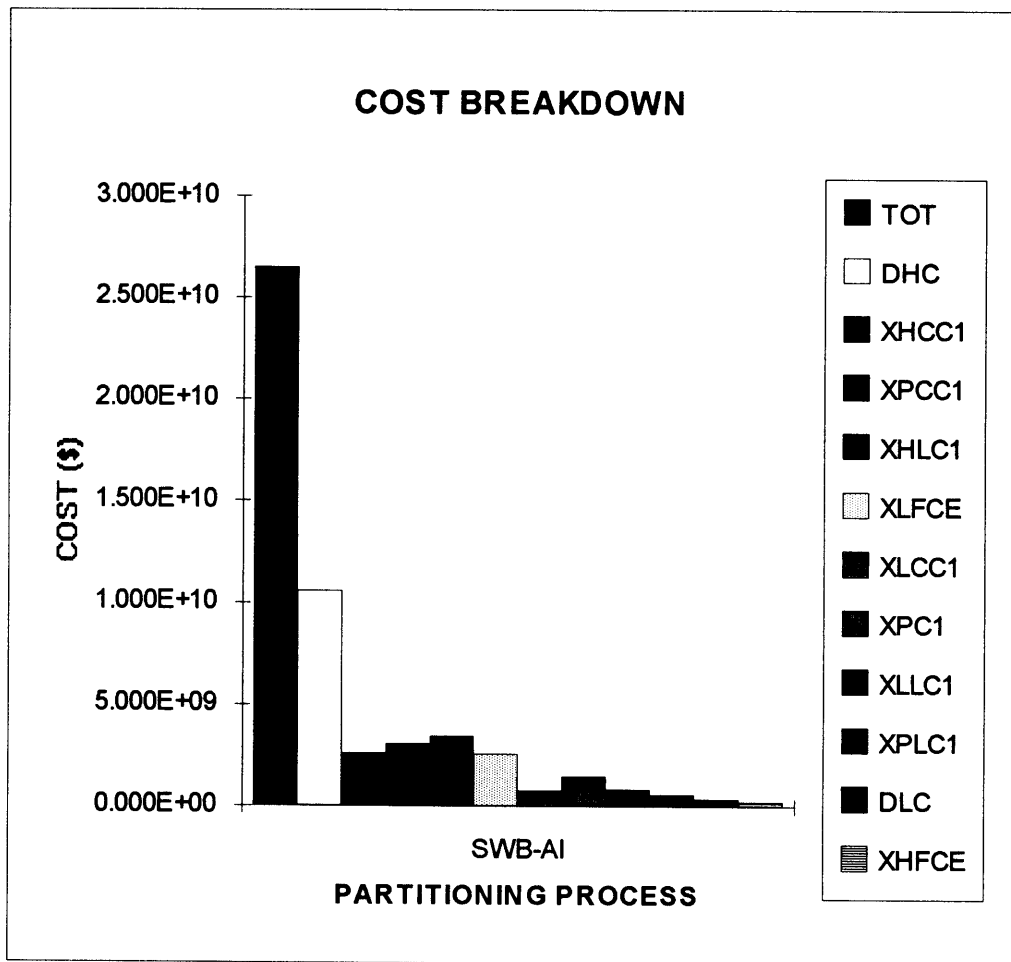


Figure B-18 Cost breakdown for the sludge wash-B partitioning process for a thirty(30) year mission duration with Al content deciding the HLW volume.

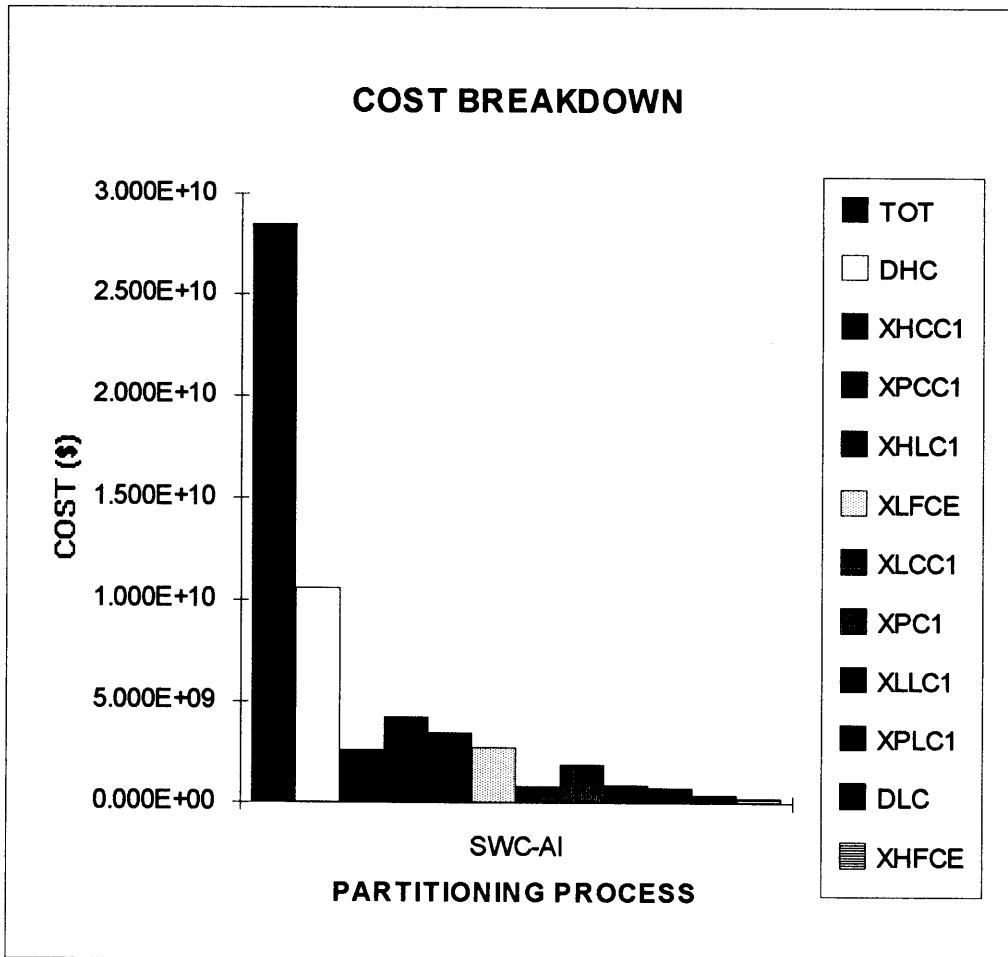


Figure B-19 Cost breakdown for the sludge wash-C partitioning process for a thirty(30) year mission duration with Al content deciding the HLW volume.

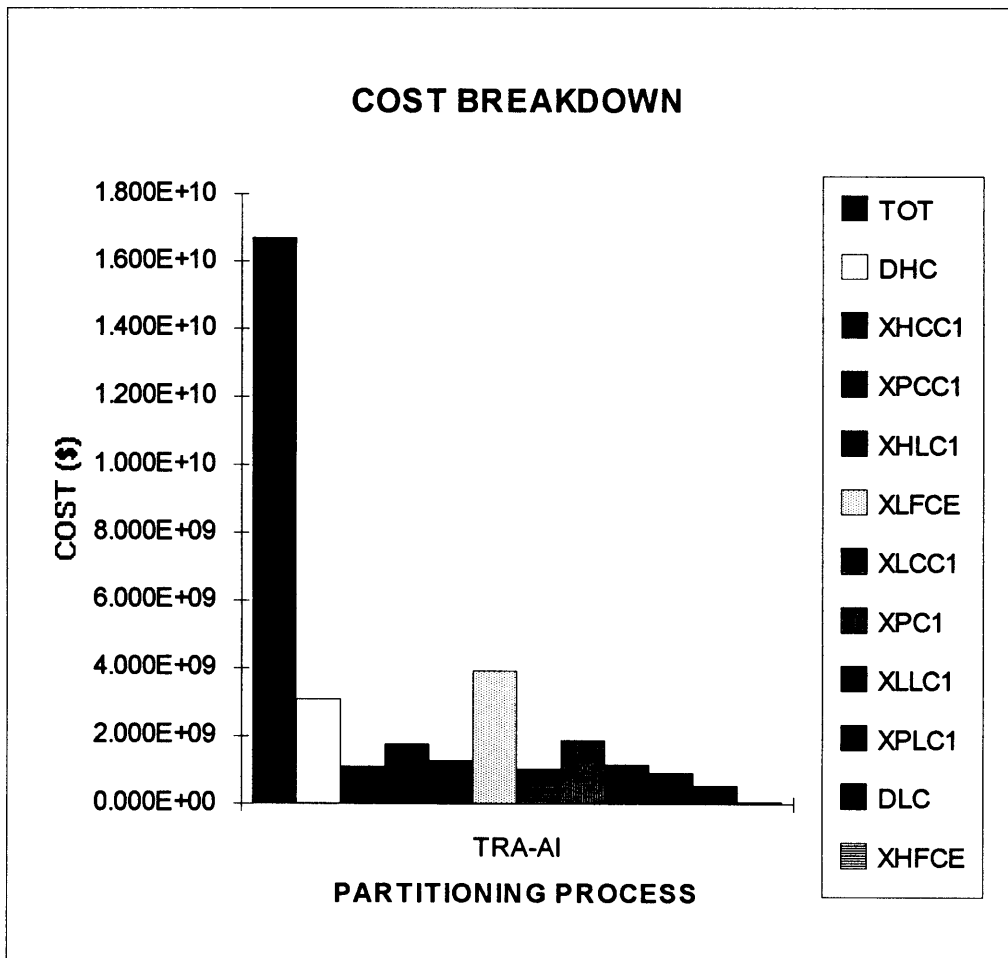


Figure B-20 Cost breakdown for the TRUEX-A partitioning process for a thirty(30) year mission duration with Al content deciding the HLW volume.

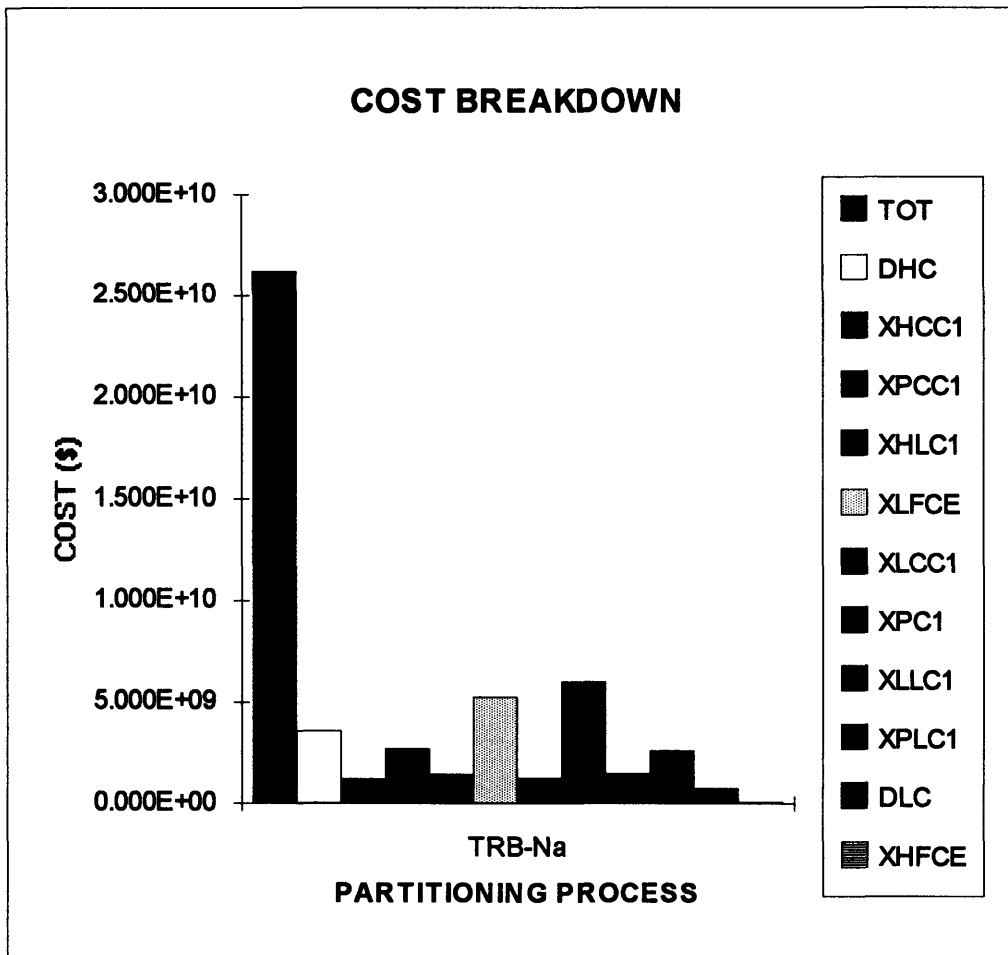


Figure B-21 Cost breakdown for the TRUEx-B partitioning process for a thirty(30) year mission duration with Na content deciding the HLW volume.

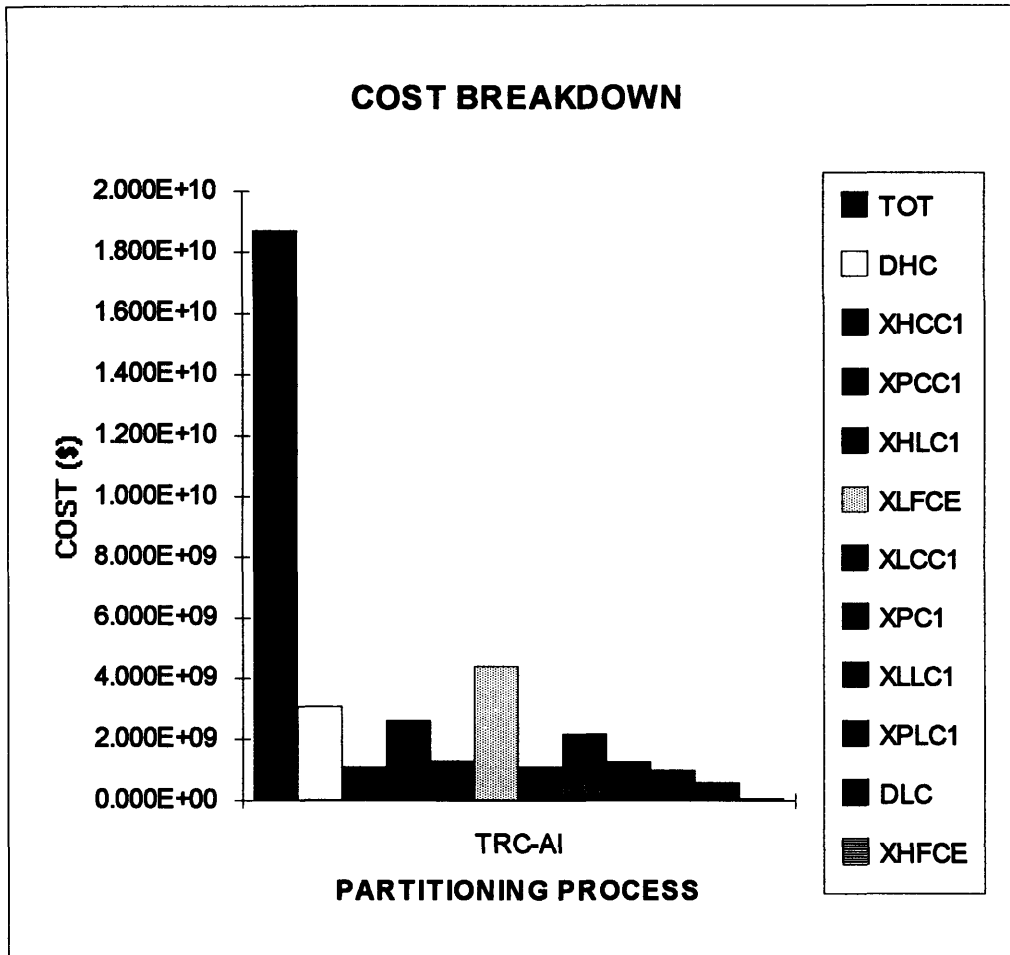


Figure B-22 Cost breakdown for the TRUEX-C partitioning process for a thirty(30) year mission duration with Al content deciding the HLW volume.

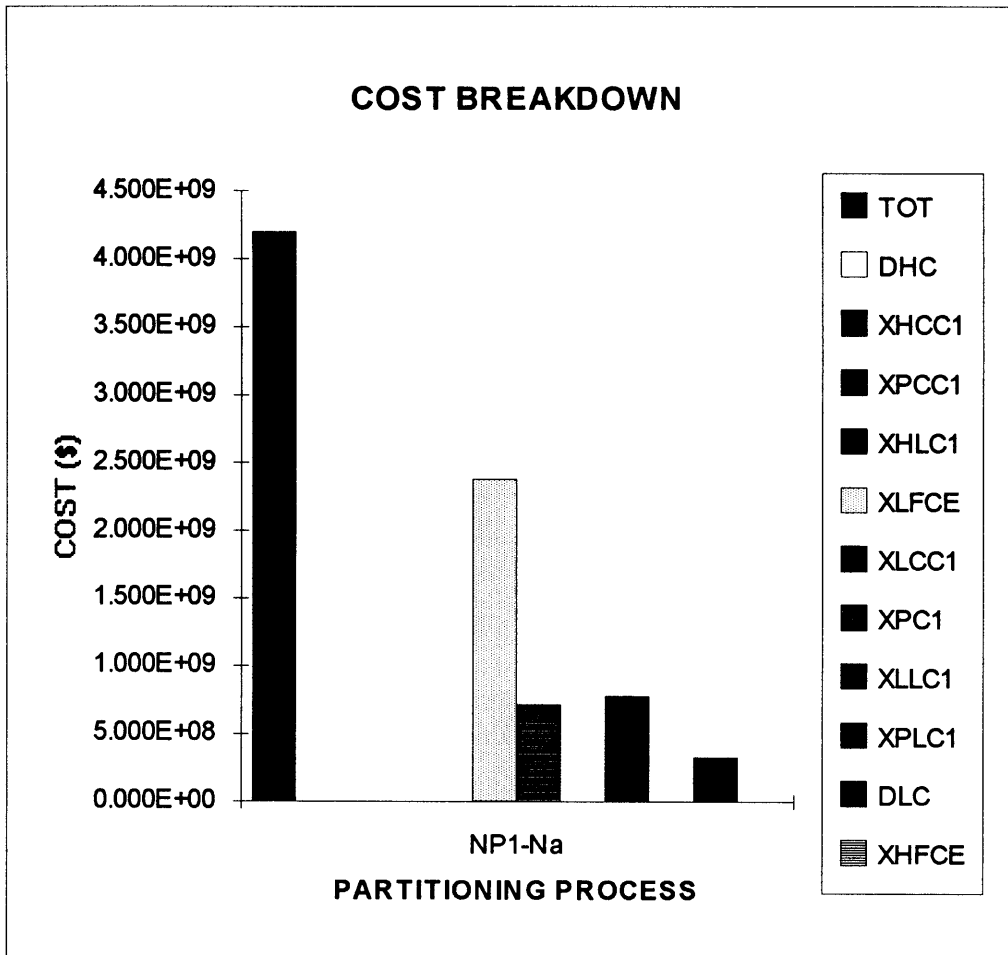


Figure B-23 Cost breakdown for the no partitioning on-site disposal process for a thirty(30) year mission duration with Na content deciding the waste volume.

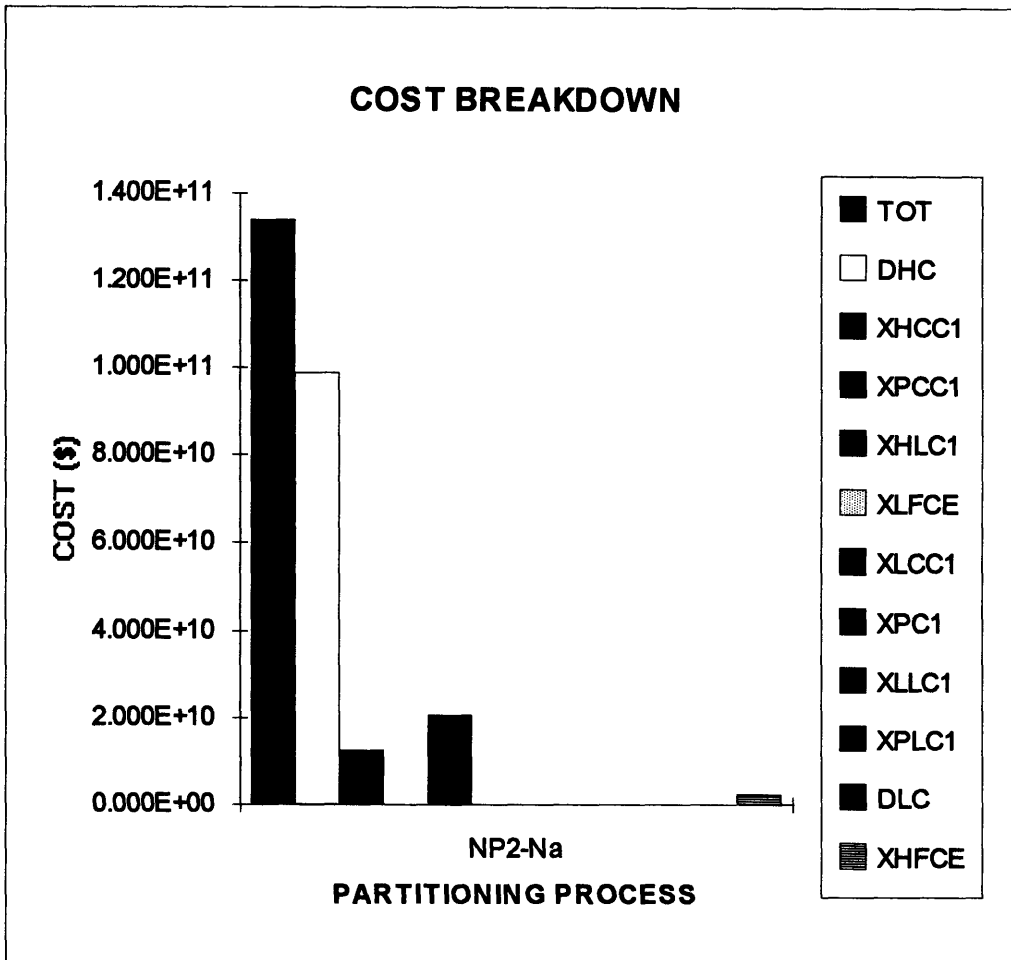


Figure B-24 Cost breakdown for the no partitioning off-site disposal process for a thirty(30) year mission duration with Na content deciding the waste volume.

# Appendix C - Volume Calculation Code and Results.

```

C      FILMK6.FOR IS A PROGRAM DESIGNED TO TAKE USER OR
FILE INPUT
C      AND CREATE AN INPUT FILE FOR HANFOR20.FOR. THE
INPUT FILE FOR
C      FILMK6.FOR CAN BE CREATED INTERNALLY FOR A SINGLE
ELEMENT AND
C      THEN MODIFIED EXTERNALLY TO ENCOMPASS ALL THE
ELEMENTS OF
C      INTEREST. BEFORE CREATING A FILE THE USER NEEDS TO
KNOW
C      THE HIGH LEVEL AND LOW LEVEL WASTE GLASS LOADING WT%
FOR THE
C      ELEMENT OF INTEREST. THIS CAN BE DONE USING THE WT%
OF THE OXIDE
C      AND THE TOTAL GRAMS OF OXIDE THAT WILL BE IN THE
GLASS, OR
C      USING THE WT% OF THE ELEMENT AND THE TOTAL GRAMS OF
THE ELEMENT
C      THAT WILL BE INCORPORATED INTO THE GLASS.
C      NEXT, THE PERCENTAGE OF THE ELEMENT THAT WILL GO TO
HLW AND LLW
C      SHOULD BE KNOWN. FINALLY, THE NUMBER OF ELEMENTS
THAT WILL BE
C      USED SHOULD BE KNOWN.
C      NOTE: TO CHANGE THE CANISTER VOLUMES XHCV AND XLCV
SHOULD BE
C      ALTERED. THIS IS THE VOLUME OF GLASS IN EACH
CANISTER
C      NOT THE CANISTER VOLUME.
C.....
      CHARACTER FILNM*12,FLNM1*12,CHEM(50)*6
      DIMENSION
X(50),Y(50),XHGL(50),XLGL(50),SEPHLW(50),SEPLW(50),
*      TOTCHM(50),J(50)
C      FLG=0
      CALL CLEAR
      XHCV =                0.631
C                        m^3
C      XLCV =                15.1
C                        m^3
C.....
      FHGL=0
      FLGL=0

```

```

      FHSF=0
      FLGWT=0
      CALL DATAIN(22,J,FLGWT,CHEM,XHGL,XLGL,TOTCHM,DENSH,
+           DENSL,SEPHLW,SEPLLW,NUMNI,FILNM)
      IM = NUMNI
      DO 300 I=1,IM
          CALL HLWCAN(I,TOTCHM,SEPHLW,XHGL,XHCV,DENSH,X)
          CALL LLWCAN(I,TOTCHM,SEPLLW,XLGL,XLCV,DENSL,Y)
300      CONTINUE
          CALL
PRNT(6,J,IM,CHEM,XHGL,XLGL,SEPHLW,SEPLLW,X,Y,
+           DENSH,DENSL,FLNM1)
          CALL
PRNT(33,J,IM,CHEM,XHGL,XLGL,SEPHLW,SEPLLW,X,Y,
+           DENSH,DENSL,FLNM1)
      END
C.....
      SUBROUTINE CLEAR
          DO 10 I=1,30
              WRITE(*,*)
10          CONTINUE
          RETURN
      END
C.....
      SUBROUTINE HLWCAN(I,TOTCHM,SEPHLW,XHGL,XHCV,DENSH,X)
          DIMENSION X(*),XHGL(*),SEPHLW(*),TOTCHM(*)
          X(I)=TOTCHM(I)*SEPHLW(I)/(XHGL(I)*XHCV*(DENSH*1E6))
          RETURN
      END
C.....
      SUBROUTINE LLWCAN(I,TOTCHM,SEPLLW,XLGL,XLCV,DENSL,Y)
          DIMENSION Y(*),XLGL(*),SEPLLW(*),TOTCHM(*)
          Y(I)=TOTCHM(I)*SEPLLW(I)/(XLGL(I)*XLCV*(DENSL*1E6))
          RETURN
      END
C.....
      SUBROUTINE
PRNT(IO,J,IM,CHEM,XHGL,XLGL,SEPHLW,SEPLLW,X,Y,
+           DENSH,DENSL,FLNM1)
          CHARACTER FLNM1*12,CHEM(*)*6
          DIMENSION
X(*),Y(*),XHGL(*),XLGL(*),SEPHLW(*),SEPLLW(*),
*           J(*)
          IF(IO.GE.10) THEN
              WRITE(*,12) 'ENTER THE OUTPUT FILE NAME (e.g.
WASTE.OUT) '
              READ(6,13) FLNM1
              OPEN(UNIT=IO,FILE=FLNM1,STATUS='UNKNOWN')
          ENDIF
          WRITE(IO,8) IM
          WRITE(IO,9)
C           DO 600 I=1,IM

```

```

        WRITE(IO,10)
CHEM(I),J(I),XHGL(I),XLGL(I),SEPHLW(I),
*          SEPLLW(I),DENSH
        WRITE(IO,11)  DENSL,X(I),Y(I)
600      CONTINUE
        RETURN
8        FORMAT(2X,I2)
9        FORMAT('  CHEM  XHGL  XLGL  SEPHLW  SEPLLW  DENSH
',
+          'DENSL HLm^3  LLm^3  ')
10      FORMAT(2X,A6,2X,I2,2X,F6.4,2X,F6.4,2X,F6.4,2X,F6.4,2X,
+          F6.4)
11      FORMAT(2X,F6.4,2X,E12.4,2X,E12.4)
12      FORMAT( A )
13      FORMAT(A12)
        END
C.....
        SUBROUTINE
DATAIN(IO,J,FLGWT,CHEM,XHGL,XLGL,TOTCHM,DENSH,
+          DENSL,SEPHLW,SEPLLW,NUMNI,FILNM)
        CHARACTER  FILNM*12,CHEM(*)*6
        DIMENSION
XHGL(*),XLGL(*),SEPHLW(*),SEPLLW(*),TOTCHM(*),J(*)
        FLGWT=0
10      FORMAT( A )
11      FORMAT(A6)
        WRITE(*,10) 'WOULD YOU LIKE DATA FROM A FILE?
1=Y,2=N .. '
        READ(6,*) ANS1
        IF (ANS1.EQ.1) THEN
            WRITE(*,10) 'ENTER FILE TO BE RETRIEVED .. '
            WRITE(*,10) 'e.g. WASTE.IN '
            READ(6,130) FILNM
            OPEN(UNIT=10,FILE= FILNM ,STATUS='UNKNOWN')
            READ (10,139) NUMNI
            DO 12 NI=1,NUMNI
                READ (10,140)
CHEM(NI),J(NI),XHGL(NI),XLGL(NI),SEPHLW(NI),
+          SEPLLW(NI),TOTCHM(NI),DENSH,DENSL
12      CONTINUE

            GOTO 172
        ELSE
            GOTO 20
        END IF
20      WRITE(*,10) 'ENTER NUMBER OF CHEMICAL ELEMENTS'
        WRITE(*,10) 'TO BE CONSIDERED(<50) '
        READ(6,*) NUMNI
        DO 21 NI=1,NUMNI
            WRITE(*,10) 'ENTER THE PARTITIONING PROCESS # (I2)

```

```

      READ(6,*) J(NI)
      WRITE(*,22) NI
      READ(6,11) CHEM(NI)
      WRITE(*,10) 'ENTER THE WEIGHT PERCENT LOADING FOR
,
      WRITE(*,10) 'CHEMICAL ',CHEM(NI),'IN THE HLW GLASS
,
      WRITE(*,10) '(F6.4 i.e. 0.1234).. '
      READ(6,*) XHGL(NI)
      WRITE(*,10) 'ENTER THE WEIGHT PERCENT LOADING FOR
,
      WRITE(*,10) 'CHEMICAL ',CHEM(NI),'IN THE LLW GLASS
,
      WRITE(*,10) '(F6.4 i.e. 0.1234 = 12.34%)..'
      READ(6,*) XLGL(NI)
      WRITE(*,10) 'ENTER THE SEPARATION EFFICIENCY FOR
THE HLW'
      READ(6,*) SEPHLW(NI)
      WRITE(*,10) 'ENTER THE SEPARATION EFFICIENCY FOR
THE LLW'
      READ(6,*) SEPLLW(NI)
      WRITE(*,10) 'ENTER TOTAL GRAMS OF
CHEMICAL',CHEM(NI), 'IN THE'
      WRITE(*,10) 'WASTE (E12.4 i.e. 1.123456E+10) .. '
      READ(6,*) TOTCHM(NI)
21      CONTINUE
22      FORMAT('ENTER THE NAME OF CHEMICAL NUMBER ',I2,
*          ' (<6 CHAR i.e. NO3) ..')

      WRITE(*,10) 'ENTER THE DENSITY OF THE HLW GLASS
(g/cc) .. '
      READ(6,*) DENSH
      WRITE(*,10) 'ENTER THE DENSITY OF THE LLW GLASS
(g/cc) .. '
      READ(6,*) DENSL
120      WRITE(*,10) 'DO YOU WISH TO SAVE THIS INPUT DATA
TO A FILE '
      WRITE(*,10) '1=YES, 2=NO '
      READ(6,*) ANS
      IF (ANS.EQ.1) THEN
130      FORMAT(A12)
      WRITE(*,10) 'ENTER FILE NAME .. '
      READ(6,130) FILNM
      OPEN(UNIT=IO,FILE= FILNM ,STATUS='UNKNOWN')
139      FORMAT(2X,I2)
C          CHEM(I) WTCHEM(I) TOTCHM(I)
140
      FORMAT(A6,2X,I2,2X,F6.4,2X,F6.4,2X,F6.3,2X,F6.3,2X,E12.5,
+          2X,F6.4,2X,F6.4)
      WRITE (IO,139) NUMNI
      DO 171 I=1,NUMNI

```

```
                WRITE(IO,140)
CHEM(I),J(I),XHGL(I),XLGL(I),SEPHLW(I),
*           SEPLLW(I),TOTCHM(I),DENSH,DENSL
171         CONTINUE
           END IF
172         RETURN
        END
C.....
*
```

## C.1 Input

40

SWA-Na	1	0.1113	0.1113	0.013	0.986	0.80300E+11
2.6000	2.7000					
SWA-Al	1	0.0794	0.0794	0.790	0.210	7.75800E+09
2.6000	2.7000					
SWA-Cr	1	0.0034	0.0034	0.900	0.100	2.74600E+08
2.6000	2.7000					
SWA-Ni	1	0.0157	0.0157	0.900	0.100	2.43600E+08
2.6000	2.7000					
SWA--P	1	0.0031	0.0031	0.500	0.500	3.98400E+07
2.6000	2.7000					
SWB-Na	2	0.1113	0.1113	0.028	1.076	0.80300E+11
2.6000	2.7000					
SWB-Al	2	0.0794	0.0794	0.790	0.210	7.75800E+09
2.6000	2.7000					
SWB-Cr	2	0.0034	0.0034	0.900	0.100	2.74600E+08
2.6000	2.7000					
SWB-Ni	2	0.0157	0.0157	0.900	0.100	2.43600E+08
2.6000	2.7000					
SWB--P	2	0.0031	0.0031	0.500	0.500	3.98400E+07
2.6000	2.7000					
SWC-Na	3	0.1113	0.1113	0.036	1.150	0.80300E+11
2.6000	2.7000					
SWC-Al	3	0.0794	0.0794	0.790	0.210	7.75800E+09
2.6000	2.7000					
SWC-Cr	3	0.0034	0.0034	0.900	0.100	2.74600E+08
2.6000	2.7000					
SWC-Ni	3	0.0157	0.0157	0.900	0.100	2.43600E+08
2.6000	2.7000					
SWC--P	3	0.0031	0.0031	0.500	0.500	3.98400E+07
2.6000	2.7000					
TRA-Na	4	0.1113	0.1113	0.025	1.650	0.80300E+11
2.6000	2.7000					
TRA-Al	4	0.0794	0.0794	0.230	0.770	7.75800E+09
2.6000	2.7000					
TRA-Cr	4	0.0034	0.0034	0.090	0.910	2.74600E+08
2.6000	2.7000					
TRA-Ni	4	0.0157	0.0157	0.900	0.100	2.43600E+08
2.6000	2.7000					
TRA--P	4	0.0031	0.0031	0.050	0.950	3.98400E+07
2.6000	2.7000					
TRB-Na	5	0.1113	0.1113	0.036	2.200	0.80300E+11
2.6000	2.7000					
TRB-Al	5	0.0794	0.0794	0.200	0.800	7.75800E+09
2.6000	2.7000					
TRB-Cr	5	0.0034	0.0034	0.090	0.910	2.74600E+08
2.6000	2.7000					
TRB-Ni	5	0.0157	0.0157	0.900	0.100	2.43600E+08
2.6000	2.7000					

TRB--P	5	0.0031	0.0031	0.050	0.950	3.98400E+07
2.6000	2.7000					
TRC-Na	6	0.1113	0.1113	0.026	1.850	0.80300E+11
2.6000	2.7000					
TRC-Al	6	0.0794	0.0794	0.230	0.770	7.75800E+09
2.6000	2.7000					
TRC-Cr	6	0.0034	0.0034	0.090	0.910	2.74600E+08
2.6000	2.7000					
TRC-Ni	6	0.0157	0.0157	0.900	0.100	2.43600E+08
2.6000	2.7000					
TRC--P	6	0.0031	0.0031	0.050	0.950	3.98400E+07
2.6000	2.7000					
NP1-Na	7	0.1113	0.1113	0.000	1.000	0.80300E+11
2.6000	2.7000					
NP1-Al	7	0.0794	0.0794	0.000	1.000	7.75800E+09
2.6000	2.7000					
NP1-Cr	7	0.0034	0.0034	0.000	1.000	2.74600E+08
2.6000	2.7000					
NP1-Ni	7	0.0157	0.0157	0.000	1.000	2.43600E+08
2.6000	2.7000					
NP1--P	7	0.0031	0.0031	0.000	1.000	3.98400E+07
2.6000	2.7000					
NP2-Na	8	0.1113	0.1113	1.000	0.000	0.80300E+11
2.6000	2.7000					
NP2-Al	8	0.0794	0.0794	1.000	0.000	7.75800E+09
2.6000	2.7000					
NP2-Cr	8	0.0034	0.0034	1.000	0.000	2.74600E+08
2.6000	2.7000					
NP2-Ni	8	0.0157	0.0157	1.000	0.000	2.43600E+08
2.6000	2.7000					
NP2--P	8	0.0031	0.0031	1.000	0.000	3.98400E+07
2.6000	2.7000					

※

## C.2 Results

40

SWA-Na	1	0.1113	0.1113	0.0130	0.9860	2.6000
2.7000		0.5717E+04		0.1745E+05		
SWA-Al	1	0.0794	0.0794	0.7900	0.2100	2.6000
2.7000		0.4705E+05		0.5033E+03		
SWA-Cr	1	0.0034	0.0034	0.9000	0.1000	2.6000
2.7000		0.4431E+05		0.1981E+03		
SWA-Ni	1	0.0157	0.0157	0.9000	0.1000	2.6000
2.7000		0.8512E+04		0.3806E+02		
SWA--P	1	0.0031	0.0031	0.5000	0.5000	2.6000
2.7000		0.3917E+04		0.1576E+03		
SWB-Na	2	0.1113	0.1113	0.0280	1.0760	2.6000
2.7000		0.1231E+05		0.1904E+05		
SWB-Al	2	0.0794	0.0794	0.7900	0.2100	2.6000
2.7000		0.4705E+05		0.5033E+03		
SWB-Cr	2	0.0034	0.0034	0.9000	0.1000	2.6000
2.7000		0.4431E+05		0.1981E+03		
SWB-Ni	2	0.0157	0.0157	0.9000	0.1000	2.6000
2.7000		0.8512E+04		0.3806E+02		
SWB--P	2	0.0031	0.0031	0.5000	0.5000	2.6000
2.7000		0.3917E+04		0.1576E+03		
SWC-Na	3	0.1113	0.1113	0.0360	1.1500	2.6000
2.7000		0.1583E+05		0.2035E+05		
SWC-Al	3	0.0794	0.0794	0.7900	0.2100	2.6000
2.7000		0.4705E+05		0.5033E+03		
SWC-Cr	3	0.0034	0.0034	0.9000	0.1000	2.6000
2.7000		0.4431E+05		0.1981E+03		
SWC-Ni	3	0.0157	0.0157	0.9000	0.1000	2.6000
2.7000		0.8512E+04		0.3806E+02		
SWC--P	3	0.0031	0.0031	0.5000	0.5000	2.6000
2.7000		0.3917E+04		0.1576E+03		
TRA-Na	4	0.1113	0.1113	0.0250	1.6500	2.6000
2.7000		0.1099E+05		0.2920E+05		
TRA-Al	4	0.0794	0.0794	0.2300	0.7700	2.6000
2.7000		0.1370E+05		0.1845E+04		
TRA-Cr	4	0.0034	0.0034	0.0900	0.9100	2.6000
2.7000		0.4431E+04		0.1803E+04		
TRA-Ni	4	0.0157	0.0157	0.9000	0.1000	2.6000
2.7000		0.8512E+04		0.3806E+02		
TRA--P	4	0.0031	0.0031	0.0500	0.9500	2.6000
2.7000		0.3917E+03		0.2995E+03		
TRB-Na	5	0.1113	0.1113	0.0360	2.2000	2.6000
2.7000		0.1583E+05		0.3893E+05		
TRB-Al	5	0.0794	0.0794	0.2000	0.8000	2.6000
2.7000		0.1191E+05		0.1917E+04		
TRB-Cr	5	0.0034	0.0034	0.0900	0.9100	2.6000

2.7000	0.4431E+04	0.1803E+04			
TRB-Ni	5 0.0157	0.0157	0.9000	0.1000	2.6000
2.7000	0.8512E+04	0.3806E+02			
TRB--P	5 0.0031	0.0031	0.0500	0.9500	2.6000
2.7000	0.3917E+03	0.2995E+03			
TRC-Na	6 0.1113	0.1113	0.0260	1.8500	2.6000
2.7000	0.1143E+05	0.3274E+05			
TRC-Al	6 0.0794	0.0794	0.2300	0.7700	2.6000
2.7000	0.1370E+05	0.1845E+04			
TRC-Cr	6 0.0034	0.0034	0.0900	0.9100	2.6000
2.7000	0.4431E+04	0.1803E+04			
TRC-Ni	6 0.0157	0.0157	0.9000	0.1000	2.6000
2.7000	0.8512E+04	0.3806E+02			
TRC--P	6 0.0031	0.0031	0.0500	0.9500	2.6000
2.7000	0.3917E+03	0.2995E+03			
NP1-Na	7 0.1113	0.1113	0.0000	1.0000	2.6000
2.7000	0.0000E+00	0.1770E+05			
NP1-Al	7 0.0794	0.0794	0.0000	1.0000	2.6000
2.7000	0.0000E+00	0.2397E+04			
NP1-Cr	7 0.0034	0.0034	0.0000	1.0000	2.6000
2.7000	0.0000E+00	0.1981E+04			
NP1-Ni	7 0.0157	0.0157	0.0000	1.0000	2.6000
2.7000	0.0000E+00	0.3806E+03			
NP1--P	7 0.0031	0.0031	0.0000	1.0000	2.6000
2.7000	0.0000E+00	0.3152E+03			
NP2-Na	8 0.1113	0.1113	1.0000	0.0000	2.6000
2.7000	0.4398E+06	0.0000E+00			
NP2-Al	8 0.0794	0.0794	1.0000	0.0000	2.6000
2.7000	0.5956E+05	0.0000E+00			
NP2-Cr	8 0.0034	0.0034	1.0000	0.0000	2.6000
2.7000	0.4923E+05	0.0000E+00			
NP2-Ni	8 0.0157	0.0157	1.0000	0.0000	2.6000
2.7000	0.9457E+04	0.0000E+00			
NP2--P	8 0.0031	0.0031	1.0000	0.0000	2.6000
2.7000	0.7833E+04	0.0000E+00			

# Appendix D Code for Cost Calculations.

## Computer Code Economic and Results

```
C..... HANFOR20.FOR IS AN ITERATIVE PROGRAM DESIGNED TO
DETERMINE
C      THE MOST COST EFFECTIVE WAY TO PROCESS THE HANFORD
WASTE.
C      THIS PROGRAM INPUTS DATA FROM A FILE AND CALCULATES
THE LABOR,
C      CAPITAL, OPERATING, AND DISPOSAL COSTS FOR HLW AND
LLW. THEN
C      CALCULATES THE TOTAL COST USING THE ABOVE NUMBERS.
C.....
C      TWV = TOTAL WASTE VOLUME          2.588E5
C      TOT = TOTAL COST FUNCTION
C      XPC = PRETREATMENT COST/yr
C
C      XPCC = PRETREATMENT CAPITAL COST          SCALED^0.8
C
C      X=XHC = # OF HLW CONTAINERS          SCALED^0.7
C      DHC = HLW DISPOSAL COST =
C      (HLW CONTAINER COST + HLW STORAGE COST + REPOSITORY
FEE)/HCAN
C      XHLC = HLW LABOR COST/yr
C
C      XHPE = HLW PLANT EFFICIENCY          SCALED^0.8
C      XHT = HLW MISSION DURATION yrs
C
C      BHCOPY = BASELINE HLW CONTAINERS PER YEAR
C      XHFC = HLW FRIT COST
C      XHE = HLW ENERGY COST
C      XHFCE =          XHFC+XHE = /HCAN
C      XHCC = HLW CAPITAL COST
C
C      XHLP = LIFETIME PRODUCTION OF BASELINE HLW PLANT =
BHCOPY*XHT
C      SEPHLW = FRACTION OF ORIGINAL WASTE GOING TO HLW
FACILITY
C
C      XHGL = HLW GLASS LOADING          (INPUT FROM FILE)
C      XHCV = HLW CONTAINER VOLUME      (INPUT FROM FILE)
C
C      XLCC = LLW CAPITAL COST
C
C      XLPE = LOW LEVEL WASTE PLANT EFFICIENCY          SCALED^0.7
```

```

C      XLT = LLW MISSION DURATION  yrs
C      XLLC = LLW LABOR COST/yr
C
C
C      XLFCE = LLW FRIT COST/LCAN
C      XLE = LLW ENERGY COST/LCAN
C      BLCPY = BASELINE LLW CONTAINERS PER YEAR
C      XLFCE =          XLFCE+XLE          /LCAN
C      DLC = LLW DISPOSAL COST = (CLOSURE BARRIERS &
CONTAINER COST)/LCAN
C      Y=XLC = # OF LLW CONTAINERS
C      SEPLW = FRACTION OF ORIGINAL WASTE GOING TO LLW
FACILITY
C
C
C      XLGL = LLW GLASS LOADING          (INPUT FROM FILE)
C      XLCV = LLW CONTAINER VOLUME      (INPUT FROM FILE)
C
C
C
C.....
      CHARACTER CHEM(50)*6,FILNM*12
      DIMENSION X(50),Y(50),TOT(50),XHLC1(50),
*          XHCC1(50),XLLC1(50),XLCC1(50),XPCC1(50),
*          XPC1(50),XHGL(50),XLGL(50),XPLC1(50),
*          SEPHLW(50),SEPLW(50),J(50)
      FLG=0
      CALL CLEAR
      FHGL=0
      FLGL=0
      FHSF=0
      FLGWT=0
      CALL DATIN2(23,J,CORV,FLGWT,CHEM,XHGL,XLGL,DENSH,
+          DENSL,SEPHLW,SEPLW,NUMNI,FILNM,X,Y)
      IM=NUMNI

      DO 300 I=1,IM
      TWV = 258800.
      XPPE = 0.6
      XPT = 15.
      BPPY1 = 136634./(10.)
      BPPY2 = 136634./(30.)
C
C.....
C      IF (J(I).EQ.1) THEN
C >      SW-A 0405A(pg F-24)
C          XPLC = 45000.*511.
C          BPPY = BPPY1
C          XPC =          50000000.
C          XPCC =         900000000.
C      ELSE IF (J(I).EQ.2) THEN
C >      SW-B 0405A(pg F-27)
C          XPLC = 45000.*619.
C          BPPY = BPPY1

```

```

      XPC =          70000000.
      XPCC =         1250000000.
C > ELSE IF (J(I).EQ.3) THEN
      SW-C 0405A(pg F-67)
      XPLC = 45000.*793.
      BPPY = BPPY1
      XPC =          90000000.
      XPCC =         1725000000.
C > ELSE IF (J(I).EQ.4) THEN
      TRUEX-A 0405A(F-124)
      XPLC = 45000.*970.
      BPPY = BPPY1
      XPC =          90000000.
      XPCC =         1700000000.
C > ELSE IF (J(I).EQ.5) THEN
      TRUEX-B 0405A(pg F-215)
      XPLC = 45000.*1149.
      BPPY = BPPY2
      XPC =         120000000.
      XPCC =         2340000000.
C > ELSE IF (J(I).EQ.6) THEN
      TRUEX-C 0405A(pg F-2)
      XPLC = 45000.*1070.
      BPPY = BPPY1
      XPC =         105000000.
      XPCC =         2525000000.
C > ELSE
      NO PARTITIONING
      XPLC = 0
      BPPY = 1
      XPC = 0
      XPCC = 0
      ENDIF
C.....
C > CONTAINERIZED GLASS OPTION > WHC-EP-0405A(PG G-80)
220t/day
C > 15wt% LIMIT Na2O > LLW ON SITE DISPOSAL 15.1 m^3 > C
      XLCV =         15.1
      XLT =          15.
      XLPE =          0.60
C          STORE CANS
      DLC =         2521.+16000.
      XLCC =         1170000000.
      BLCPY =        18000./XLCV
      XLLP =         BLCPY*XLT
      XLLC =         45000.*1010.
      XLFCE =        (1532420000./11900.)+5500.
C          FRIT          ENERGY
C > HWVP GLASS OPTION > WHC-EP-0405A(pg H-1)
C > 25 wt% LIMIT ON OXIDES > HLW OFF SITE DISPOSAL 0.631 m^3
> C
C          STORE CANS REPOSITORY FEE

```

```

DHC =      18846.+6000.+200000.
XHT =      20.
XHCV =     0.631
XHPE =     0.70
XHLC =     45000.*912.
BHCPY =    433.33
XHFCE =    (61760000./13000.)+570.
C          FRIT          ENERGY
XHLP =     BHCPY*XHT
XHCC =     1060000000.

C.....
C.....
C          SEPHLW = INPUT FROM FILE
C          SEPLLW = INPUT FROM FILE
C          XHGL = INPUT FROM FILE
C          XLGL = INPUT FROM FILE
C.....

          CALL HLWCAP(X,I,XHCC,XHLP,XHCC1)
          CALL HLWLBR(X,I,XHLC,XHLP,XHLC1)
          CALL LLWLBR(Y,I,XLLC,XLLP,XLLC1)
          CALL LLWCAP(Y,I,XLCC,XLLP,XLCC1)
          CALL PRECAP(X,I,XPCC,XHLP,XPCC1)
          CALL PRELBR(I,TWV,BPPY,XPT,XPLC,XPLC1)
          CALL PREOP(I,TWV,XPT,BPPY,XPC,XPC1)
          CALL TOTAL(X,Y,DHC,XHFCE,XHLC1,XHT,XPT,XHCC1,DLC,
*
XLFCE,XLLC1,XLT,XLCC1,XPCC1,XPLC1,XPC1,I,TOT)
          CALL CALC(I,TOT,IN,TMIN)
300      CONTINUE
CC          CALL PRNT(
6,IM,IN,CHEM,XHGL,XLGL,SEPHLW,SEPLLW,TOT)
          CALL PRNT(31,IM,IN,CHEM,XHGL,XLGL,SEPHLW,SEPLLW,TOT)
          CALL
PRINT2(32,X,Y,CHEM,DHC,XHFCE,XHLC1,XHT,XPT,XHCC1,DLC,XLFCE,
*
XHGL,XLGL,SEPHLW,SEPLLW,XLLC1,XLT,XLCC1,XPCC1,XPLC1,XPC1,IM,
TOT)
          END
C.....
SUBROUTINE CLEAR
DO 10 I=1,30
WRITE(*,*)
10      CONTINUE
RETURN
END
C.....
SUBROUTINE HLWCAP(X,I,XHCC,XHLP,XHCC1)
DIMENSION X(*),XHCC1(*)
XHCC1(I)=XHCC*(X(I)/XHLP)**0.7
RETURN
END
C.....

```

```

SUBROUTINE HLWLBR(X, I, XHLC, XHLP, XHLC1)
  DIMENSION X(*), XHLC1(*)
  XHLC1(I) = XHLC * (X(I) / XHLP) ** 0.8
  RETURN
END
C.....
SUBROUTINE LLWCAP(Y, I, XLCC, XLLP, XLCC1)
  DIMENSION Y(*), XLCC1(*)
  XLCC1(I) = XLCC * (Y(I) / XLLP) ** 0.7
  RETURN
END
C.....
SUBROUTINE LLWLBR(Y, I, XLLC, XLLP, XLLC1)
  DIMENSION Y(*), XLLC1(*)
  XLLC1(I) = XLLC * (Y(I) / XLLP) ** 0.8
  RETURN
END
C.....
SUBROUTINE PRECAP(X, I, XPCC, XHLP, XPCC1)
  DIMENSION X(*), XPCC1(*)
  XPCC1(I) = XPCC * (X(I) / XHLP) ** 0.7
  RETURN
END
C.....
SUBROUTINE PRELBR(I, TWV, BPPY, XPT, XPLC, XPLC1)
  DIMENSION XPLC1(*)
  XPLC1(I) = XPLC * (TWV / (BPPY * XPT)) ** 0.8
  RETURN
END
C.....
SUBROUTINE PREOP(I, TWV, XPT, BPPY, XPC, XPC1)
  DIMENSION XPC1(*)
  XPC1(I) = XPC * (TWV / (BPPY * XPT)) ** 0.8
  RETURN
END
C.....
SUBROUTINE
TOTAL(X, Y, DHC, XHFCE, XHLC1, XHT, XPT, XHCC1, DLC, XLFCE,
*
XLLC1, XLT, XLCC1, XPCC1, XPLC1, XPC1, I, TOT)
  DIMENSION
X(*), Y(*), TOT(*), XHLC1(*), XHCC1(*), XLLC1(*),
*
  XLCC1(*), XPCC1(*), XPC1(*), XPLC1(*)

TOT(I) = X(I) * (DHC + XHFCE) + XPCC1(I) + (XPC1(I) + XPLC1(I)) * XPT +
*
XHLC1(I) * XHT + XHCC1(I) + Y(I) * (DLC + XLFCE) + XLLC1(I) * XLT + XLCC1(I)
  RETURN
END
C.....
SUBROUTINE CALC(I, TOT, IN, TMIN)
  DIMENSION TOT(*)

```

```

        IF (I.EQ.1) THEN
            TMIN=TOT(1)
        ELSE IF (TOT(I).LT.TMIN) THEN
            TMIN=TOT(I)
            IN=I
        ENDIF
        RETURN
    END
C.....
    SUBROUTINE
    PRNT (IO, IM, IN, CHEM, XHGL, XLGL, SEPHLW, SEPLLW, TOT)
        CHARACTER CHEM(*)*6
        DIMENSION
    TOT(*), XHGL(*), XLGL(*), SEPHLW(*), SEPLLW(*)
        IF (IO.GE.10) THEN
            OPEN (UNIT=IO, FILE='HAN1520.OUT', STATUS='UNKNOWN')
            WRITE (IO, 10)
    CHEM (IN), XHGL (IN), XLGL (IN), SEPHLW (IN),
        *           SEPLLW (IN), TOT (IN)
            WRITE (IO, 5)
        ENDIF
        WRITE (6, 5)
        WRITE (6, 10) CHEM (IN), XHGL (IN), XLGL (IN), SEPHLW (IN),
        *           SEPLLW (IN), TOT (IN)
        DO 600 I=1, IM
            WRITE (IO, 10) CHEM (I), XHGL (I), XLGL (I), SEPHLW (I),
        *           SEPLLW (I), TOT (I)
    600    CONTINUE
    5    FORMAT (1X, ' XHGL    XLGL    SEPHLW    SEPLLW
TOTAL COST ')
    10
    FORMAT (2X, A6, 2X, F6.4, 2X, F6.4, 2X, F6.4, 2X, F6.4, 2X, E12.4)
        RETURN
    END
C.....
    SUBROUTINE
    PRINT2 (IO, X, Y, CHEM, DHC, XHFCE, XHLC1, XHT, XPT, XHCC1, DLC,
        *
    XLFCE, XHGL, XLGL, SEPHLW, SEPLLW, XLLC1, XLT, XLCC1, XPCC1, XPLC1,
        *   XPC1, IM, TOT)
        CHARACTER CHEM(*)*6
        DIMENSION
    X(*), Y(*), TOT(*), XHLC1(*), XHCC1(*), XLLC1(*), XLCC1(*),
        *
    XPLC1(*), XPCC1(*), XHGL(*), XLGL(*), SEPHLW(*), SEPLLW(*), XPC1(*)
    )
        IF (IO.GE.10) THEN

    OPEN (UNIT=IO, FILE='HANALL15.OUT', STATUS='UNKNOWN')
        ENDIF
        WRITE (IO, 15)
        WRITE (IO, 16)

```

```

        WRITE(IO,17)
        WRITE(IO,18)
        DO 600 I=1,IM
            WRITE(IO,10)
CHEM(I),XHGL(I),XLGL(I),SEPHLW(I),SEPLLW(I),
*          TOT(I),X(I)
            WRITE(IO,11)
Y(I),DHC*X(I),XHFCE*X(I),XHLCL(I)*XHT,XHT
            WRITE(IO,11)
XHCC1(I),DLC*Y(I),XLFCE*Y(I),XLLC1(I)*XLT,XLT
            WRITE(IO,11)
XLCC1(I),XPCC1(I),XPLC1(I)*XPT,XPC1(I)*XPT,XPT
600      CONTINUE
        RETURN
15      FORMAT(2X,'CHEM  XHGL  XLGL  SEPHLW  SEPLLW  TOT  X
')
16      FORMAT(2X,'Y  DHC  XHFCE  XHLCL  XHT  ')
17      FORMAT(2X,'XHCC1  DLC  XLFCE  XLLC1  XLT  ')
18      FORMAT(2X,'XLCC1  XPCC1  XPLC1  XPC1  XPT  ')
10
FORMAT(1X,A6,2X,F5.3,2X,F5.3,2X,F5.3,2X,F5.3,2X,E12.4,2X,E12
.4)
11      FORMAT(1X,E12.4,2X,E12.4,2X,E12.4,2X,E12.4,2X,F5.1)
C12
FORMAT(2X,E12.4,2X,E12.4,2X,E12.4,2X,E12.4,2X,F5.1)
C13      FORMAT(2X,E12.4,2X,E12.4,2X,E12.4)
C42
C14      FORMAT(2X,E12.4,2X,E12.4)
        END
C.....
        SUBROUTINE
DATIN2(IO,J,CORV,FLGWT,CHEM,XHGL,XLGL,DENSH,
+          DENSL,SEPHLW,SEPLLW,NUMNI,FILNM,X,Y)
        CHARACTER  FILNM*12,CHEM(*)*6
        DIMENSION XHGL(*),XLGL(*),SEPHLW(*),SEPLLW(*),
+          X(*),Y(*),J(*)
        CORV=0
        FLGWT=0
10      FORMAT( A )
11      FORMAT(A6)
        WRITE(*,10) 'ENTER FILE TO BE RETRIEVED .. '
        WRITE(*,10) 'e.g. WASTE.IN '
        READ(6,130) FILNM
        OPEN(UNIT=IO,FILE= FILNM ,STATUS='UNKNOWN')
        READ (IO,139) NUMNI
        DO 12 NI=1,NUMNI
            READ(IO,140)
CHEM(NI),J(NI),XHGL(NI),XLGL(NI),SEPHLW(NI),
+          SEPLLW(NI),DENSH
            READ(IO,141) DENSL,X(NI),Y(NI)
12      CONTINUE
130     FORMAT(A12)

```

```
139     FORMAT(2X,I2)
140     FORMAT(2X,A6,2X,I2,2X,F6.4,2X,F6.4,2X,F6.4,2X,F6.4,
+       2X,F6.4)
141     FORMAT(2X,F6.4,2X,E12.4,2X,E12.4)
      RETURN
      END
C.....
*
```

## D.1 Input

8						
SWA-A1	1	0.0794	0.1113	0.7900	0.9860	2.6000
2.7000		0.4705E+05		0.1745E+05		
SWB-A1	2	0.0794	0.1113	0.7900	1.0760	2.6000
2.7000		0.4705E+05		0.1904E+05		
SWC-A1	3	0.0794	0.1113	0.7900	1.1500	2.6000
2.7000		0.4705E+05		0.2035E+05		
TRA-A1	4	0.0794	0.1113	0.2300	1.6500	2.6000
2.7000		0.1370E+05		0.2920E+05		
TRB-Na	5	0.1113	0.1113	0.0360	2.2000	2.6000
2.7000		0.1583E+05		0.3893E+05		
TRC-A1	6	0.0794	0.1113	0.2300	1.8500	2.6000
2.7000		0.1370E+05		0.3274E+05		
NP1-Na	7	0.1113	0.1113	0.0000	1.0000	2.6000
2.7000		0.0000E+00		0.1770E+05		
NP2-Na	8	0.1113	0.1113	1.0000	0.0000	2.6000
2.7000		0.4398E+06		0.0000E+00		

※

## D.2 Results

CHEM	XHGL	XLGL	SEPHLW	SEPLLW	TOT	X
Y	DHC	XHFCE	XHLC1	XHT		
XHCC1	DLC	XLFCF	XLLC1	XLT		
XLCC1	XPCC1	XPLC1	XPC1	XPT		
SWA-A1	0.079	0.111	0.790	0.986		0.2622E+11
0.4705E+05						
	0.1745E+05		0.1058E+11	0.2503E+09		0.3177E+10
20.0						
	0.3464E+10		0.3232E+09	0.2343E+10		0.6686E+09
15.0						
	0.1150E+10		0.2941E+10	0.4157E+09		0.9039E+09
15.0						
SWB-A1	0.079	0.111	0.790	1.076		0.2817E+11
0.4705E+05						
	0.1904E+05		0.1058E+11	0.2503E+09		0.3177E+10
20.0						
	0.3464E+10		0.3526E+09	0.2557E+10		0.7169E+09
15.0						
	0.1223E+10		0.4085E+10	0.5036E+09		0.1265E+10
15.0						
SWC-A1	0.079	0.111	0.790	1.150		0.3053E+11
0.4705E+05						
	0.2035E+05		0.1058E+11	0.2503E+09		0.3177E+10
20.0						
	0.3464E+10		0.3769E+09	0.2732E+10		0.7561E+09
15.0						

0.1281E+10	0.5638E+10	0.6451E+09	0.1627E+10
15.0			
TRA-A1 0.079	0.111 0.230	1.650	0.1768E+11
0.1370E+05			
0.2920E+05	0.3080E+10	0.7289E+08	0.1184E+10
20.0			
0.1461E+10	0.5408E+09	0.3921E+10	0.1009E+10
15.0			
0.1649E+10	0.2342E+10	0.7891E+09	0.1627E+10
15.0			
TRB-Na 0.111	0.111 0.036	1.850	0.2687E+11
0.1583E+05			
0.3893E+05	0.3559E+10	0.8423E+08	0.1329E+10
20.0			
0.1616E+10	0.7210E+09	0.5227E+10	0.1270E+10
15.0			
0.2017E+10	0.3567E+10	0.2251E+10	0.5224E+10
15.0			
TRC-A1 0.079	0.111 0.230	1.850	0.1994E+11
0.1370E+05			
0.3274E+05	0.3080E+10	0.7289E+08	0.1184E+10
20.0			
0.1461E+10	0.6064E+09	0.4396E+10	0.1106E+10
15.0			
0.1787E+10	0.3479E+10	0.8704E+09	0.1898E+10
15.0			
NP1-Na 0.111	0.111 0.000	1.000	0.4542E+10
0.0000E+00			
0.1770E+05	0.0000E+00	0.0000E+00	0.0000E+00
20.0			
0.0000E+00	0.3278E+09	0.2377E+10	0.6762E+09
15.0			
0.1162E+10	0.0000E+00	0.0000E+00	0.0000E+00
15.0			
NP2-Na 0.111	0.111 1.000	0.000	0.1368E+12
0.4398E+06			
0.0000E+00	0.9889E+11	0.2340E+10	0.1899E+11
20.0			
0.1656E+11	0.0000E+00	0.0000E+00	0.0000E+00
15.0			
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15.0			