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Project Technical Information

Conceptual Study of In-Tank Cesium Removal Using an Inorganic Ion Exchange Material

R. S. Goheen
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Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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SUMMARY

This conceptual study investigates a generic in-tank cesium removal flowsheet using two inorganic ion exchange materials: crystalline silicotitanates (CST) and IE-96 zeolites. The mathematical model derived for the study assumed a batch process where the ion exchange material and waste are brought into contact in a storage tank with optimal mixing. The focus of this study was on the impact of each ion exchanger on the number of high-level waste (HLW) glass canisters produced compared to a reference pretreatment strategy involving sludge wash with additional supernatant decontamination using an elutable ion exchange. The number of contacts between the waste and ion exchange material was varied between one and five. Two waste streams were chosen for analysis: Neutralized Current Acid Waste (NCAW) waste, and a theoretical blending of all tank wastes. The resulting low-level waste (LLW) stream was assumed to meet specific limits for cesium: Class A (1 Ci/m^3), Class C (4600 Ci/m^3), or 1/10th of Class A (40.1 Ci/m^3). The number of HLW glass canisters were estimated using two separate methods: the High Level Waste Vitrification Plant (HWVP) Reference Feed limits, and the Optimal Waste Loading (OWL) software.

Based on existing data and the assumptions used here, the use of CST as an in-tank cesium removal technology would result in a very large increase in the number of HLW glass produced compared to the reference pretreatment strategy if the Class A limit on cesium was imposed. In the optimal situation investigated (5 contacts between waste and ion exchange material), using CST would result in a total of 140,000 canisters for the total waste blend and 3200 canisters for NCAW. These high canister estimates are due to a titania (TiO_2) limit of 1 wt% in the present glass formulation. Using IE-96 for in-tank cesium removal (5 contacts) results in 320,000 canisters for the total waste blend and 34,000 canisters for NCAW. If Class C limits on are assumed, no treatment for cesium removal is required for the total waste blend. NCAW would require minimal treatment (cesium decontamination factor, D_f = 2.3). Treating NCAW to the Class C cesium limit with CST would result in 380 canisters, while IE-96 would result in 1300 canisters. If 1/10th of the Class A limit for cesium were required, the number of HLW canisters would be

significantly increased. Additional results are summarized in Tables S.1 through S.3.

Assuming Class A limits, the number of HLW glass canisters produced when using CST could be reduced significantly under two conditions: 1) higher titania limits in the glass and/or 2) higher cesium distribution coefficients (K_d). It may be possible to load more than 1 wt% titania into the currently formulated glass, and an altered formulation may be able to contain relatively large amounts of titania. Laboratory experiments show that the CST K_d for Cs increases rapidly as the pH is lowered from 14 to 10. The best application of in-tank Cs removal with CST would be early pretreatment of a specific waste type which had a relatively low D_f requirement. This would be especially true if high K_d values for Cs could be achieved, and if the titania limit in the glass could be increased.

Other results are summarized as follows:

- A major constituent of CST is a proprietary element. Because there is no explicit limit for this element in the HLW glass, there is an additional degree of uncertainty in the canister estimates.
- A column operation would be preferred over an in-tank operation as a method of treatment due to greater efficiency and, therefore, less ion exchange material required.
- Conservative CST batch distribution coefficients (K_d) were chosen for this study. It is possible (based on experimental information) that much higher K_d values may be achievable in practice. Lowering the pH of the waste could result in significantly higher K_d values, and therefore, fewer HLW canisters.
- It is possible that 1/10th of Class A for Cs (0.1 Ci/m^3) may be required for the LLW. If 1/10th of Class A were required, significantly more ion exchange material would be required, resulting in significantly more glass. For CST, reducing the limit would increase the number of HLW canisters by a factor of 2 (one contact) to 10 (five contacts).

TABLE S.1. Total Number of HLW Glass Canisters for Five Contacts Between Waste and Ion Exchanger Using the Class A Cesium Limit

Class A Cesium Limit. (1 Ci/m^3)	Total Waste Blend		NCAW	
	CST	IE-96	CST	IE-96
HWVP Reference Feed Limit	150,000	320,000	3,200	34,000
HWVP Limit w/16% Titania	36,000	n/a	430	n/a
OWL	41,000	130,000	680	2,800
Wash + Elutable IX	26,000		370	

TABLE S.2. Total Number of HLW Glass Canisters for Five Contacts Between Waste and Ion Exchanger Using the Class C Cesium Limit

Class C Cesium Limit. (4600 Ci/m^3)	Total Waste Blend		NCAW	
	CST	IE-96	CST	IE-96
HWVP Reference Feed Limit	n/a		380	1,300
HWVP Limit w/16% Titania			380	n/a
OWL			370	420
Wash + Elutable IX	26,000		370	

TABLE S.3. Total Number of HLW Glass Canisters for Five Contacts Between Waste and Ion Exchanger Using 1/10th Class A Cesium Limit

1/10th Class A Cesium Limit. (0.1 Ci/m^3)	Total Waste Blend		NCAW	
	CST	IE-96	CST	IE-96
HWVP Reference Feed Limit	150,000	1,600,000	5,400	58,000
HWVP Limit w/16% Titania	36,000	n/a	460	n/a
OWL	61,000	230,000	1,000	4,700
Wash + Elutable IX	26,000		370	

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1.0 INTRODUCTION

1.1 BACKGROUND

Presently, the Hanford Site contains approximately 230,000 m^3 of mixed waste stored in 177 underground tanks. Approximately 55,000 m^3 of this waste is sludge, 90,000 m^3 is salt cake, and 80,000 m^3 is supernate. Although the pretreatment and final disposal requirements for the waste have not been entirely defined, it is likely that some supernatant pretreatment will be required to remove ^{137}Cs and possibly ^{90}Sr and the transuranic components.

Crystalline Silico-Titanates (CST) and zeolites such as IE-96 (Bray et al. 1993, Bray et al. 1984, Lumetta et al. 1993) have shown potential as a removal technology for cesium, strontium, and plutonium in alkaline streams. Experimental data shows that CST has significantly higher distribution coefficient (K_d) values than other inorganic ion exchange materials. However, eluting the loaded CST is difficult, and the loaded material would probably be sent to HLW vitrification, or possibly converted into another waste form for storage. Production of CST in a form which would allow its use in a column operation is currently under study, and preliminary engineered forms have been produced. However, it is not known whether a suitable form can be produced on a large scale. This is an advantage of an in-tank or other batch processing method, as it could use CST without requiring an engineered form.

1.2 OBJECTIVE

The objective of this study was to estimate the number of HLW glass canisters resulting from the use of inorganic ion exchanger materials as in-tank pretreatment technology. The variables in the study were:

- number of contacts between waste and ion exchange material;
- Ion exchange material (CST or IE-96); and
- Decontamination requirement (Class C, Class A, or 1/10th Class A).

1.3 SCOPE

This conceptual study investigates a generic in-tank Cs removal flowsheet using CST and IE-96 zeolites, and the impact of each ion exchanger on the number of glass canisters produced. In determining glass formulation, data based on current reference technology was used. Calculations were performed on a spreadsheet software program (Microsoft Excel, Version 4.0), as well as software developed at Battelle (Optimal Waste Loading model, or OWL). Sample calculations from the worksheets and summaries of final calculated results are included at the end of this report (Appendices B and D, respectively).

1.4 APPROACH

This evaluation utilized existing efforts, including a previous evaluation of in-tank processing methods (Silva and Duncan 1992), and the development of an in-tank pretreatment flowsheet (Silva et al. 1993) using precipitation to remove selected radionuclides from the supernate. The key focus of this study was the impact on vitrification (specifically, the amount of HLW glass produced). A sensitivity study assessed the effect of the titania (TiO_2) limit on the mass of glass produced. Because in-tank precipitation is an inefficient batch process compared to continuous separations processes, relatively large quantities of material can be expected to be generated. Consequently, the use of the inorganic materials on a limited basis was evaluated for the treatment of individual wastes, such as Neutralized Current Acid Waste (NCAW).

2.0 STUDY BASIS AND ASSUMPTIONS

2.1 WASTE STREAM

Two separate waste streams were chosen for investigation. These were one double shell tank (DST) waste type (NCAW), and a complete blending of all single shell tank (SST) and DST wastes. A complete blending of all wastes is probably not achievable in a practical situation. Assuming a total blend was a simplification for the purposes of this study. The NCAW waste was evaluated separately because it has the greatest decontamination requirements of the individual waste types, and because there is a significant solids fraction of known composition with which the exchanger could be mixed for vitrification. Both waste streams were assumed to undergo a sludge washing step and an enhanced sludge washing step before the addition of ion exchange material. In the wash step, the waste was assumed to be washed with a solution of 0.01 M NaOH and 0.011 M $NaNO_2$ to remove water soluble compounds from the solids. The purpose of the enhanced sludge wash was to leach additional aluminum and chromium from the solids (the leached material ends up in the liquid stream), by contacting the waste with a solution of 3 M NaOH, and then with a solution of 0.1 M $KMnO_4$ and 0.01 M NaOH. The composition of NCAW waste was based on a previous conceptual study of sludge washing (Kurath et al. 1991). For the blend stream, the waste composition after an enhanced sludge wash was taken from a computer simulation (Silva et al. 1993) which had been run as a part of an earlier study.

The waste stream compositions are listed in Appendix A. Key attributes of the liquid phases of the waste streams (after washing) used in the study are listed in Table 2.1.

TABLE 2.1. Key Attributes of the Liquid Phases of the Waste Streams, After Washing

	Total Waste Blend	NCAW Waste
Volume, L (based on 5 M Na)	6.40 E8	5.40 E6
Volume, L (based on 20 % Na20 in LLW glass)	1.30 E8	1.10 E6
Total Cs, kg (all Cs isotopes)	1,570	330
Cs-137, kg	450	140
Na/Cs (mole ratio)	2.80 E5	1.10 E4
K/Cs (mole ratio)	3.50 E3	1.70 E2
D_f(a) for Cs Class A	270	4,500
D_f for Cs Class C	None	2
D_f for 1/10th of Class A	2,700	45,000

(a) The decontamination factor (D_f) for Cs is defined as the activity of Cs in the initial waste stream divided by the activity of Cs in the final stream.

2.2 BATCH DISTRIBUTION COEFFICIENTS (K_d)

The K_d values for Cs assumed for this study are as follows.

IE-96:	40 ml/g
CST:	1000 ml/g

The batch K_d is defined as follows:

$$\frac{C_{x/A}}{C_{x/B}} = K_d \qquad (1)$$

Where: $C_{x/A}$ = the equilibrium concentration of the ion in the liquid phase, and

$C_{x/B}$ = the equilibrium concentration of the ion on the ion exchange material.

The batch K_d value for IE-96 for the removal of Cs was taken from experimental data using synthetic CC and NCAW type wastes (Bray et al. 1992).

These data were taken at varying sodium concentrations and at a temperature of 25°C. The batch K_d for CST was taken from recent experimental work (Bray et al. 1993) using synthetic double-shell slurry feed (DSSF) type waste. The data for Cs were listed at various pH levels, sodium concentrations, and a temperature of 25°C. The exact pH level of the feed streams was not calculated, however, both waste streams were considered to be highly alkaline (pH >13). The sodium concentration in all liquid phase streams was assumed to be 5 $\underline{M}$.

There are many factors which can cause deviations in the K_d values, and with the complex chemistry of the waste tanks, it is difficult to predict exactly how the K_d will behave in a practical situation. It is possible that the K_d values could be significantly lower or higher than the values used in this study. Experimental results indicate that the Cs K_d for CST can be ten times greater than the value assumed here. However, in light of the many uncertainties, it was decided that using a conservative estimation of the data was the best choice for the study.

2.3 MODELING THE TREATMENT PROCESS

2.3.1 Major Assumptions

The major assumptions for modeling the in-tank removal of Cs for this study are:

- The process was modeled as a cross-flow batch process (see Eq. 2, described below).
- The liquid phase of the waste stream was treated with the ion exchange material.
- There was complete separation of the solid and liquid phases after each step.
- The volume of the liquid was calculated by assuming a 5 $\underline{M}$ Na concentration (the mass of Na was known and held constant during treatment with the ion exchangers).
- The final waste form for the LLW was considered to be a glass. The LLW glass volume was determined by assuming that 20% of the mass of the glass was Na, and that the density was 2.6 g/cc. These numbers were based on the assumption that the waste loading in the glass would be limited by Na, and that a borosilicate type glass would be used.

- Sufficient ion exchange material was added so that the final LLW form met the given Cs limit (Class C, Class A, or 1/10th of Class A limit). The activity per volume of the final waste form was calculated using the LLW glass volume (see above).
- The ion exchange material was combined with the solids and vitrified as HLW.

It was assumed that the liquid stream was treated with the ion exchange material and then sent to LLW vitrification. The partially loaded exchanger was combined with the solids, and sent to HLW vitrification. The number of contacts between ion exchanger and liquid was varied between 1 and 5. The Class A limit for Cs (1 Ci/m^3) was used as a decontamination requirement for the LLW stream after treatment with the ion exchange material. Presently, Case Beta assumes Class C limits on all radionuclides except Cs, which is restricted to its Class A limit.[1] Since it is possible that the Class C limit for Cs (4600 Ci/m^3) could be applied, this limit was also investigated. It is also possible that the LLW may be restricted to 1/10th of Class A (0.1 Ci/m^3), so the effect of this limit on the HLW glass was investigated. Other radionuclides were not specifically targeted, therefore the final LLW stream may not necessarily meet the given limits for all radionuclides. The extent of Cs decontamination was held constant as the number of contacts was varied, therefore the mass of ion exchange material added varied as a function of the contacts.

For comparison, a baseline case of no ion exchanger addition was also included (which is referred to as "wash only" in subsequent tables). This provided an easy reference point for determining how much of an impact the added ion exchanger had on the mass of HLW glass produced. The baseline case is representative of the sludge wash with an elutable ion exchange step, as ion exchange with elution does not significantly increase the number of HLW glass canisters produced (Boomer 1993).

2.3.2 Practical Analogy for Model

The idealized and simplified in-tank process modeled in this study is as follows. After the waste is washed and leached, the liquid portion would be

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[1] Memorandum, J. O. Honeyman (WHC) to J. L. Straalsund (PNL), "DOE Planning Basis for TWRS," Correspondence No. 9360588, December 10, 1993.

separated and placed into a holding tank, while the solids would be placed in storage until vitrification. The ion exchange material would then be added to the liquid. Proper mixing in the tank would allow for good contact between ion exchanger and liquid. The liquid and ion exchange material would be separated (most likely through settling), with the ion exchange material being added to the solids. For multiple contacts, fresh ion exchange material would be added to the liquid for each contact. Processes of these sorts are commonly referred to as cross-flow batch processes. The operational complexity and/or the residence time of the waste increases with the number of contacts. For this study, in order to maintain a relatively simple process, no more than five contacts were considered. It should also be noted that the gain in efficiency (in terms of less material added) increases less rapidly as the number of contacts are increased, especially for contacts beyond five.

2.3.3 Calculation of Mass of Ion Exchanger Added

The mass of ion exchange material required for a certain level of decontamination in a generic cross-flow batch process can be calculated from the following equation:

$$m=\frac{nV}{K_d}\left[\left(\frac{x_n}{x_0}\right)^{-\frac{1}{n}}-1\right] \tag{2}$$

Where:
m = mass of ion exchange material, kg
V = volume of stream after treatment, L
x_n = mass of Cs-137 after treatment, kg
x_0 = mass of Cs-137 in feed stream, kg
n = number of contacts

K_d is assumed not to be a function of the variables listed above. This, of course, is not true but is an approximation of the actual behavior. The derivation of this equation is listed in Appendix C.

2.3.4 Cross-Flow Batch Process vs. Other Processing Techniques

A cross-flow batch process, which is the process modeled in this study, is not a very efficient use of material. A countercurrent batch process is more efficient (a schematic of both processes is given in Figure 2.1). Unlike

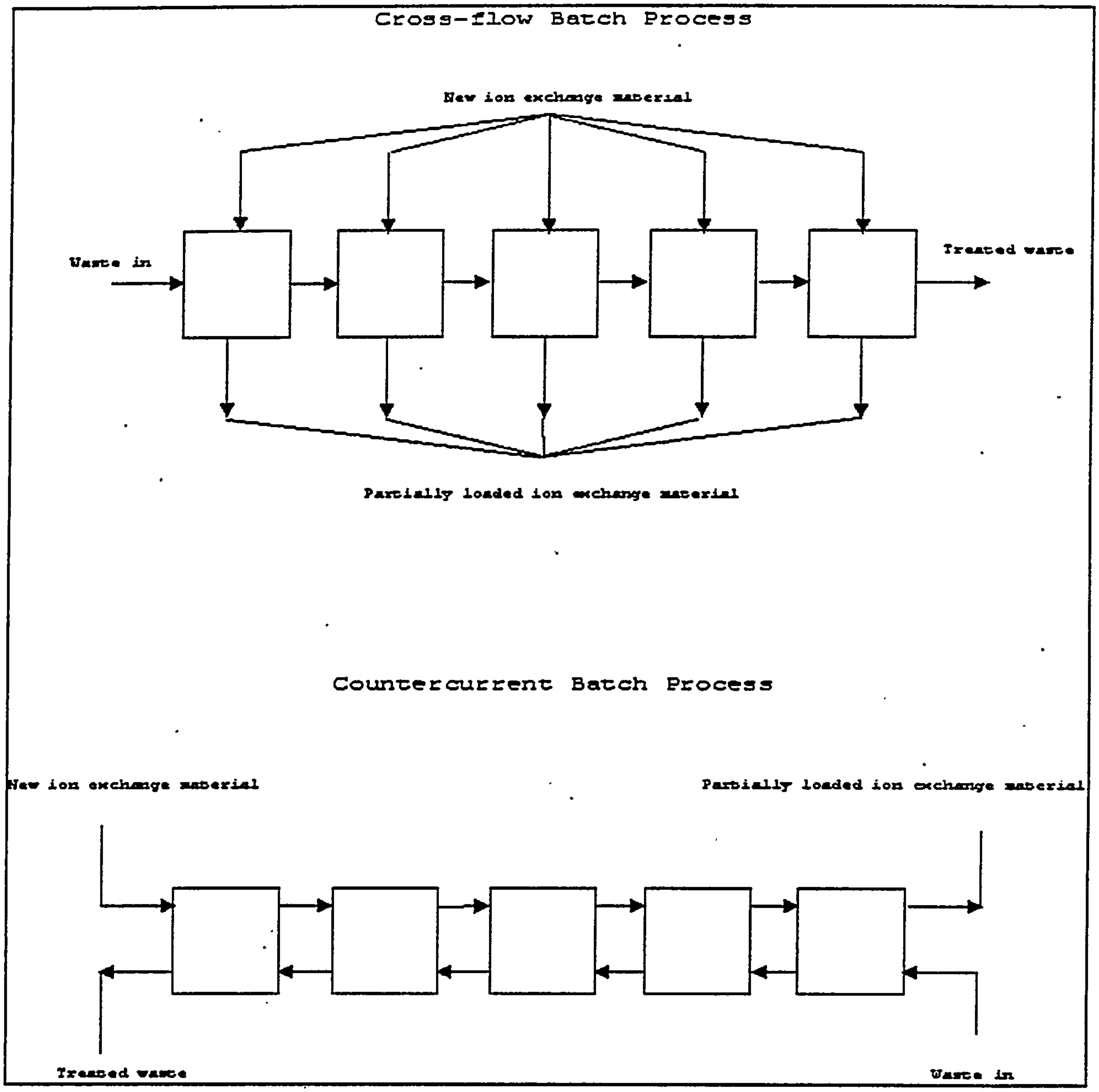

FIGURE 2.1. Generic Cross-flow and Countercurrent Batch Processes

a cross-flow batch process, in a countercurrent batch process the ion exchange material is used again after an initial contact. Essentially, the waste and ion exchange material "flow" from stage to stage in opposite directions. Therefore, the fresh ion exchange material is added to the waste stream after most of the target ions have been removed, and the untreated waste is contacted first with ion exchange material which is already partially loaded. While this is a more efficient use of ion exchange material and would result in less material being added, it is much more complex in to design and operate an actual process operating in this mode. Because of this, and because of the scope of this study, only the cross-flow process was considered.

In a column process, two or more columns containing the ion exchange material are placed in series. The first column is allowed to come to equilibrium with the feed, and is then removed from the series. The loaded exchange material is taken to disposal, and fresh material is added. The next column in the series becomes the first, and the process is repeated. Because the ion exchange material reaches equilibrium with the feed, the loading is controlled by the concentration of the feed, rather than the concentration of the product. This is the most efficient use of the ion exchange material, and is much more efficient than either batch process. To determine the mass of ion exchange material needed for a column process, the following equation is used:

$$K_d = \frac{\text{Concentration of Cs on Exchanger}}{\text{Concentration of Cs in feed}} \tag{3}$$

$$K_d = \frac{\text{kg Cs/kg exchanger}}{\text{kg Cs/L feed}} \tag{4}$$

It can be shown that the equation for the mass of ion exchange material used in a countercurrent batch operation approaches the above equation for a column operation as the number of contacts increases to infinity. In other words, from a mathematical stand-point, a column operation is a countercurrent batch process with an infinite number of contacts.

2.4 HIGH-LEVEL WASTE AND LOW-LEVEL WASTE GLASS CALCULATIONS

At the time of this study, there was only limited information on the composition and limits of the LLW glass. Since there is such a large quantity of Na in the LLW stream, it is expected that the loading of waste in the glass will most likely be limited by this element. Based on current data, it is expected that the glass will be able to contain no more than between 15 and 25 wt% Na_2O. Therefore, the glass was assumed to be limited to 20 wt% Na_2O. A borosilicate glass with this level of sodium is expected to have a density of around 2.6 g/cc. Based on this sodium concentration and density, the volume of LLW glass was calculated from the known quantity of sodium in the LLW stream. While the mass of LLW glass produced was not calculated, the volume was used in determining the activity per volume of the LLW glass.

To calculate the amount of HLW glass produced in each case, the first step was to convert the components in the feed from ions to their equivalent oxides. This is done because the limits of individual components in the glass are listed in terms of oxides. Compounds in the HLW stream, such as cancrinite, nickel ferrocyanides, and the ion exchange materials, were broken down into their atomic components, which were subsequently converted to oxides. The oxide breakdown (when vitrified) for CST was assumed to be[2]:

CST: 36% TiO_2, 16% Na_2O, 14% SiO_2, 34% Water, proprietary elements, and minor components.

For IE-96, the oxide breakdown (when vitrified) was assumed to be as follows:

IE-96: 67.5% SiO_2, 17.4% Al_2O_3, 7.9% Na_2O, 3.9% Fe_2O_3, 0.8% MgO, 2.5% other components (not counted).

Two calculation methods were used to estimate the number of glass canisters produced. The first was a direct comparison of the stream composition to the High Level Waste Vitrification Plant (HWVP) feed criteria (High Level Waste Vitrification Plant Project Technical Data Package, Revision 6), using 25% as a reference weight loading of waste in the glass. These limits are summarized in Table 2.2. The other method was to use the Optimal Waste Loading (OWL) software (Hoza 1993) to calculate the maximum loading of a

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[2] The composition for CST is currently considered proprietary by Sandia National Laboratories and their potential industrial partner.

particular waste composition. The OWL program is based on current data for the chemical limits (the same limits as listed in Table 2.2), and the physical properties of glass. An advantage of the OWL model is its ability to adjust the composition of the frit to minimize the number of glass canisters produced.

TABLE 2.2. HWVP Reference Feed Limits (WHC 1992)

Component	Limit, Wt%
Al_2O_3	26.0%
BaO	20.0%
CaO	20.0%
CdO	10.0%
Fe_2O_3	60.0%
$(La,Ce)_2O_3$	8.0%
MnO_2	20.0%
MoO_3	8.0%
Na_2O	22.0%
NiO	8.0%
SiO_2	17.5%
TiO_2	4.0%
U_3O_8	32.0%
ZrO_2	40.0%
Cr_2O_3	2.0%
$(Rh, Ru)_2O$	1.0%
P_2O_5	4.0%
SO_3	2.0%
F	6.9%

3.0 RESULTS AND DISCUSSION

A summary of the number of HLW glass canisters produced when using the Class A Cs limit are given in Tables 3.1 and 3.2 and Figure 3.1. The detailed numerical results are presented in the tables in Appendix D.

It was found from the analysis, for 1 to 5 contacts between ion exchange material and waste, using CST resulted in fewer HLW glass canisters than IE-96 for a given level of Cs decontamination for both NCAW and the total waste blend. Both ion exchange materials had a greater impact on NCAW waste than the total waste blend compared to the baseline case, due to the higher ^{137}Cs concentration in NCAW. IE-96, due to its lower Cs K_d, was required in significantly higher amounts of material than CST to achieve the same amount of decontamination for both wastes. Because of this, even at high waste loading in the glass, the use of IE-96 resulted in significantly higher canister counts than CST. However, even with 5 contacts, both ion exchange materials added a significant number of HLW glass canisters relative to the baseline case. While it is possible to increase the number of contacts beyond five, to do so in a practical situation increases the complexity of the operation. Also, as the number of contacts is increased, the savings in ion exchange material becomes smaller. Therefore, this study did not consider more than 5 contacts.

As expected, the titania in the CST had the greatest effect on the waste loading in glass. The current HWVP limit for titania in glass is 1 wt%. However, the present reference glass might be able to accommodate higher levels of titania, and by using a different HLW glass formulation the limit could be raised significantly higher. For example, some commercially produced glasses contain titania in amounts of 15% or more. Calculations were made using a higher titania limit than the current reference limit. It was felt that assuming a 4% limit in the glass (equivalent to 16% titania in the feed with 25% waste loading in the glass) was a reasonable assumption, although it should be stressed that there is no experimental data at this time to either support or contradict this number. As should be expected, when the limit was raised from 1 to 4%, the number of HLW glass canisters produced decreased by

75%. This highlights the importance of formulating a HLW glass which can contain larger amounts of titania when considering the use of CST.

A limit for the proprietary element in CST is not explicitly listed in the HWVP Reference Feed Limits. This element comprises a large fraction of CST, although not as large as the fraction of titania present. In the case where the loading of waste in the glass is limited by titania, the amount of the proprietary element which would be present in the glass would be less than 3 wt%. At this level, it is expected that the proprietary element can be easily incorporated into the glass. However, there is no experimental data currently available to back up this claim. Therefore the presence of this proprietary element in the glass presents additional uncertainty in the HLW glass canister calculations.

The OWL program used a relatively small number of components (14) in calculating the number of HLW glass canisters produced. Neither titania nor the proprietary element were directly taken into account; instead, the masses of both were combined along with the masses of all the other components which did not have explicit limits into a single category. There was a limit as to the total mass of these non-listed components which could be loaded into to the glass. Because of the lack of an explicit limit for titania, some of the glass compositions resulting from the OWL program had titania levels higher than the 1% listed in the HWVP limits. However, this does not mean that the results are necessarily invalid, it means that there is little or no experimental data to validate the calculated glass formulations. The model may therefore be operating outside of its normal boundaries, and the uncertainty in the calculated results is greater.

Because the OWL program could adjust the frit to maximize the waste loading, and because there was no specific titania limit, the number of HLW glass canisters calculated by OWL and the number calculated by using the HWVP limits were sometimes very different for both CST and IE-96.

Because of the complex chemistry in the underground storage tanks, it is difficult to predict exactly what the K_d values would be in a practical situation. The numbers chosen for this study were felt to represent conservative estimates of what actual K_d values could be, based on existing data. However, experimental data suggests that the K_d values could be significantly higher, especially if the pH of the waste stream was lowered. If higher K_d values could be achieved in practice there would be a great reduction in the number of HLW glass canisters produced. To demonstrate this, the number of canisters produced using CST were calculated using K_d values greater than the K_d value originally assumed. The results for K_d values from 1000 to 3000 are presented in Table 3.3. Increasing the IE-96 K_d values by the same magnitude also decreased the number of canisters produced, but did not approach the baseline case. The Cs K_d values for CST have been much higher under laboratory conditions (Bray 1993). The K_d values for CST have a strong pH dependence, and increase rapidly as the pH is lowered. It has been demonstrated that the pH of the waste can be lowered.

Radionuclides other than Cs were not directly studied. Experimental data (Bray et al. 1993) show that CST has a much higher K_d for both Pu and Sr compared to IE-96, and would, therefore, be more efficient at removing these radionuclides in an actual process. These K_d values are listed in Table 3.5. There is insufficient data at this time to determine the CST K_d values for Am and Tc.

The Class A limit for Cs in the LLW stream was used in this study; however, it is likely that a Cs limit of 1/10th of Class A (0.1 Ci/m^3) will be required for the feed to the LLW vitrification plant. This would result in greater amounts of ion exchange material being added to the waste, which would result in more HLW glass being formed. While the impact was not studied extensively, a few calculations were made. These results are shown in Table 3.4 for the total waste blend using HWVP limits.

Although some initial calculations based on a column operation were performed, a full investigation on column processing was not completed due to time constraints. The number of HLW glass canisters produced in a column operation were estimated for both waste types and both ion exchange materials. The results are presented in Table 3.6 in comparison with the mass of ion exchanger added for a 5 contact cross-flow batch process. As can be seen, significantly less material ends up in the HLW feed when an column process is used. This is because a column process is a more efficient use of material.

TABLE 3.1. Total Number of HLW Glass Canisters Produced: Total Waste Blend, Class A

	Wash Only	1	2	3	4	5
CST:	Total Number of HLW Glass Canisters Produced					
HWVP Feed Limits	26,000	3,700,000	430,000	230,000	170,000	140,000
HWVP Feed Limits + 16% Ti	26,000	940,000	110,000	57,000	43,000	36,000
OWL	26,000	640,000	88,000	55,000	45,000	41,000
IE-96:						
HWVP Feed Limits	26,000	41,000,000	6,400,000	2,500,000	1,800,000	1,600,000
OWL	26,000	3,100,000	370,000	200,000	150,000	130,000

TABLE 3.2. Total Number of HLW Glass Canisters Produced: NCAW Waste, Class A

	Wash Only	1	2	3	4	5
CST:	Total Number of HLW Glass Canisters Produced					
HWVP Feed Limits	370	1,300,000	24,000	7,500	4,400	3,200
HWVP Feed Limits + 16% Ti	370	64,000	1,200	500	450	430
OWL	350	210,000	4,100	1,400	860	680
IE-96:						
HWVP Feed Limits	370	14,000,000	260,000	80,000	47,000	34,000
OWL	350	1,100,000	20,000	6,400	3,800	2,800

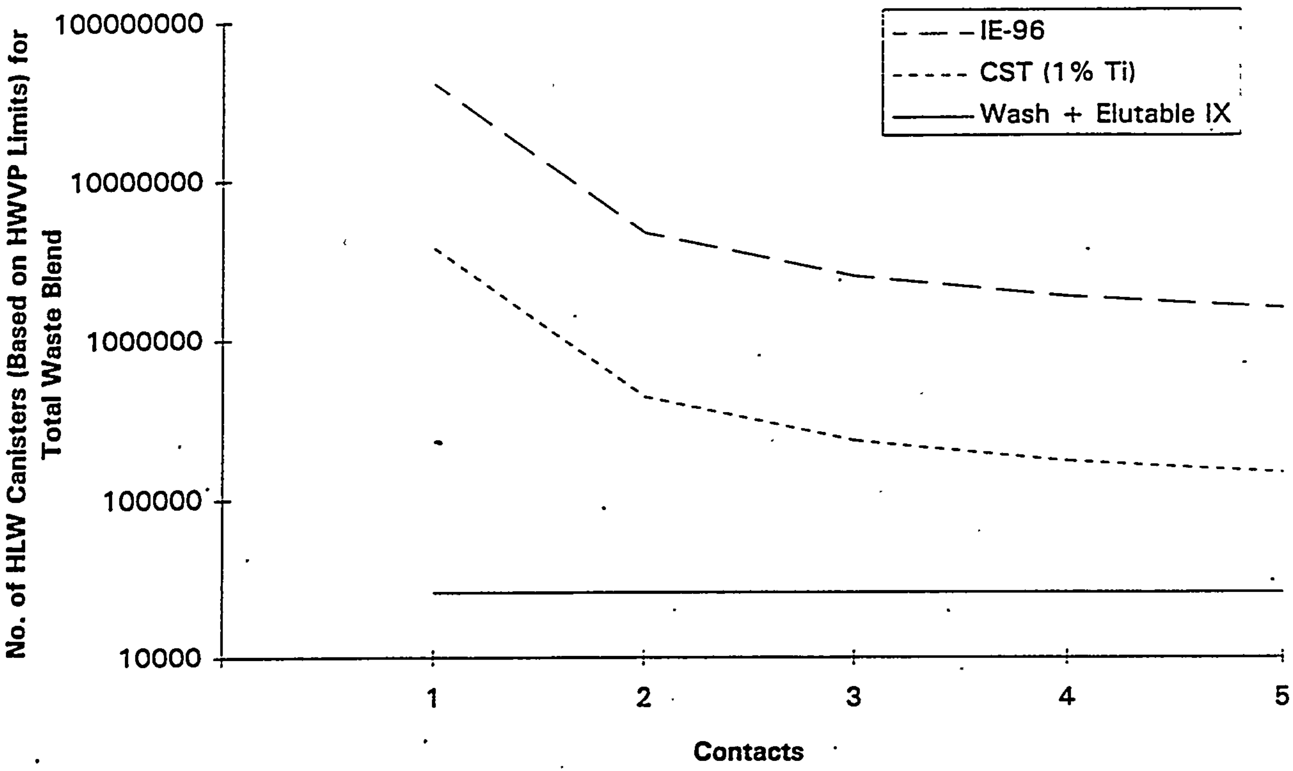

FIGURE 3.1. HLW Glass Canisters vs. Number of Contacts for Class A Cs Limit (1 Ci/m^3)

TABLE 3.3. HLW Glass Canisters vs. CST Kd Values for Class A

Contacts:	Wash Only	1	5
CST K_d values:	Total Number of HLW Glass Canisters Produced (HWVP Limits)		
1000	26,000	3,700,000	140,000
1500		2,500,000	96,000
2000		1,900,000	72,000
3000		1,300,000	48,000
CST K_d values:	Total Number of HLW Glass Canisters Produced (HWVP Limits + 16% Titania)		
1000	26,000	940,000	36,000
1500		630,000	31,000
2000		470,000	29,000
3000		320,000	27,000

TABLE 3.4. Effects of Cs Limit (Class A vs. 1/10th Class A) on Glass Canisters for Total Waste Blend

Contacts:	Wash Only	1	5
Cs Class A	Total Number of HLW Glass Canisters Produced		
CST (HWVP limits)	2,6000	1,000,000	120,000
CST (HWVP limits + 16% Ti)		260,000	29,000
IE-96 (HWVP limits)		8,100,000	930,000
1/10 Cs Class A	Total Number of HLW Glass Canisters Produced		
CST (HWVP limits)	2,6000	10,000,000	240,000
CST (HWVP limits + 16% Ti)		2,600,000	60,000
IE-96 (HWVP limits)		81,000,000	1,900,000

TABLE 3.5. Batch Distribution Ratios (ml/g) for Radionuclides Other Than Cs (Bray 1993; Lumetta 1993)

	Sr	Pu	Am	Tc
CST (TAM-70)	100,000	2,000	--	--
IE-96	0.1	24	17	2

TABLE 3.6. Mass of Ion Exchange Material Required; Column vs. Batch Process Class A Limit

	Batch Process, 5 contacts	Column Process
Total Blend:	Total Number of HLW Glass Canisters Produced (HWVP Limits)	
CST (kg)	140,000	26,000
IE-96 (kg)	1,500,000	160,000
NCAW	Total Number of HLW Glass Canisters Produced (HWVP Limits)	
CST (kg)	3,200	370
IE-96 (kg)	34,000	1,400

4.0 CONCLUSIONS AND DISCUSSION

The following are the important conclusions for this study, based on existing data and the assumptions previously stated:

- For the Class A Cs limit and the total waste blend, using CST as an in-tank Cs removal technique results in a large increase in the number of HLW glass produced over the baseline case. In the same case IE-96 results in even more canisters than using CST. Both also result in a large increase in canisters for NCAW waste.
- The number of HLW glass canisters produced from CST is very sensitive to the titania limit in glass and the batch K_d value for Cs.
- For the Class C Cs limit, the total waste blend needs no additional treatment for Cs. For NCAW waste, the D_f for Cs is low, and a relatively small amount of CST is needed, therefore, there are few additional HLW glass canisters produced.
- If 1/10th of the Class A limit for cesium were required, the number of HLW canisters would be significantly increased.
- A column operation is more efficient than a batch operation.

This study shows that in-tank Cs removal techniques using either CST or IE-96 result in far too many HLW glass canisters to be considered as an overall pretreatment strategy. However, under certain conditions, in-tank processing with CST could produce few additional HLW glass canisters. These conditions are high Cs K_d values, and higher titania limits in the HLW glass. Recent experimental data shows that the Cs K_d for CST can be significantly higher than the conservative value used in this study. When the pH of the liquid waste stream is lowered from 14 to 10, the Cs K_d increases approximately by a factor of 10 (Bray 1993). There are also indications that titania limits can be higher than the present HWVP limits. CST would also result in few additional HLW glass canisters if the Class C limit for Cs was require, or in any case where a specific waste had a relatively low decontamination factor. The best application of in-tank Cs removal with CST would therefore be pretreatment of a specific waste type with a relatively low D_f, especially if high K_d values for Cs could be achieved, and the titania limit in the glass could be increased. This would be especially true if some degree of pretreatment were required before suitable facilities could be built.

The numbers generated in this study represent a very idealized case. There are many other parameters and issues not addressed in this study, such as the ability to mix the liquid and ion exchange material efficiently, the storage and ultimate disposal of the loaded CST, the availability of adequate tank space, the availability of an engineer form which would allow a column process, and solid/liquid separations.

5.0 REFERENCES

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APPENDIX A

WASTE STREAM COMPOSITIONS

Feed Streams

	Total Waste Blend Enhanced Sludge Wash		NCAW Enhanced Sludge Wash	
	Liq phase tot kg	Sol phase tot kg	Liq phase tot kg	Sol Phase tot kg
AG+	3.24E+01	4.09E+02	2.93E+01	3.22E+02
AL+3	4.19E+06	2.75E+05	3.07E+04	3.67E+04
AM+3	9.70E+00	6.44E+01	2.72E-02	3.85E+01
AS+5	1.89E+02	6.52E+02	1.82E+02	3.48E+02
B+3	7.86E+02	1.76E+03	8.13E+01	2.38E+02
BA+2	1.03E+03	1.54E+03	9.82E+00	3.80E+02
BE+2	7.41E-01	9.20E+00	7.17E-01	9.23E+00
BI+3	6.43E+04	1.97E+05		
CA+2	1.71E+04	1.47E+05	4.21E+01	1.62E+03
CD+2	2.27E+03	8.29E+03	1.80E+01	6.07E+03
CE+3	4.44E+03	2.32E+05	2.04E+01	3.59E+02
CM+3	4.52E-04	2.31E-02		
CO+3	5.15E+01	7.62E+02	3.28E+01	7.81E+02
CR+3	1.37E+05	2.49E+04	4.97E+03	1.28E+03
CS+	1.57E+03	1.75E+02	2.79E+02	1.29E+01
CU+2	2.00E+02	7.62E+02	1.04E+01	2.33E+02
FE+3	4.09E+04	6.91E+05	8.53E+01	5.94E+04
H+	6.48E-05	3.76E-07		
HG+2	1.13E+03	8.84E+00		
K+	1.56E+06	4.21E+04	1.92E+04	2.88E+03
LA+3	4.35E+03	3.44E+04	4.05E+01	4.19E+03
LI+	6.99E+00	3.40E+01	1.79E+00	3.06E+01
MG+2	3.42E+03	1.91E+03	1.12E+01	4.63E+02
MN+7	6.14E+04	9.53E+04		
MO+6	7.79E+03	3.60E+02	4.59E+02	7.16E+01
NA+	7.38E+07	1.86E+05	5.31E+05	5.78E+04
NB+5		6.88E-04		
NI+3	6.12E+03	4.39E+03	1.39E+01	3.43E+03
NP+4	4.71E+00	4.29E+01	5.85E-01	3.13E+01
PB+4	2.43E+03	9.98E+02	3.42E+01	4.83E+02
PU+4	5.19E+01	4.63E+02	1.12E+00	3.99E+01
RB+	6.22E+01	2.60E+00	5.59E+01	8.93E+00
RE+7	4.62E+00	3.84E+01		

Feed Streams (cont.)

	Total Waste Blend Enhanced Sludge Wash		NCAW Enhanced Sludge Wash	
	Liq phase tot kg	Sol phase tot kg	Liq phase tot kg	Sol Phase tot kg
RH+3	1.21E+01	4.29E+02	4.11E+00	3.89E+01
RU+3	2.62E+01	5.26E+02	1.07E+01	7.53E+01
SB+5	5.59E+01	1.81E+03	2.43E+01	2.66E+02
SE+6	5.50E+02	1.83E+03		
SI+4	2.56E+05	2.51E+04		
SM+3	3.09E-01	3.19E+01	2.14E+03	3.19E+03
SN+4	4.94E+00	1.46E+01	4.57E-02	5.89E+00
SR+2	1.48E+03	3.47E+04		
TE+6	5.13E+00	2.46E+02	1.34E+00	4.03E+02
TI+4	6.47E+00	4.39E+02	4.55E+00	6.35E+01
TL+3	2.98E+02	5.20E+03	1.98E+01	5.16E+02
TH+4	2.82E+02	1.34E+04	4.59E+00	2.21E+02
UO2+2	8.99E+04	1.45E+06		
V+5	9.56E+00	3.85E+01	5.28E+03	3.41E+03
W+6	3.27E+03	1.47E-01		
ZN+2	1.74E+03	5.23E+02		
CL-	4.33E+05	2.33E+03	4.33E+01	1.63E+02
CO3-2	2.59E+06	8.81E+04	7.41E+02	9.77E+01
F-	1.03E+06	5.15E+04	3.44E+04	7.57E+03
FECN6-3	1.23E+03	5.55E-02	7.64E+03	1.42E+03
I-	2.33E+02	2.91E+00		
NO2-	9.55E+06	1.34E+04	9.14E-02	8.32E-01
NO3-	1.08E+08	3.00E+05	1.27E+05	1.63E+04
OH-	2.20E+07	2.36E+06	3.76E+05	1.81E+04
PO4-3	8.39E+06	5.69E+05	6.39E+04	
SO4-2	1.97E+06	3.94E+04	4.54E+04	4.50E+03
TCO4-	3.17E+03	1.23E+02	1.04E+05	1.00E+04
C14	1.10E+00	1.10E-02	3.83E+02	2.63E+02
CANCRINI		1.35E+06	2.03E-03	2.98E-04
H2O	6.35E+08	8.86E+06		
MNO2	2.14E+04	1.91E+05	6.54E+06	
NI2FECN6		4.98E+05	8.67E+00	2.77E+03
TOC	7.65E+05	3.33E+04		
ZRO2:2H2	2.34E+04	9.63E+05	8.24E+03	4.39E+03
P2O5:24W	5.37E+03	1.47E+04	63.93432	27629.84
TOTALS	8.71E+08	1.88E+07	7.90E+06	2.79E+05
Cs-137 (Ci)	3.24E+07	3.61E+06	1.23E+07	6.53E+05

APPENDIX B

SAMPLE CALCULATIONS

APPENDIX B

SAMPLE CALCULATIONS

Sample calculation: Conversion of components in feed stream from ionic form to equivalent oxide.

Aluminum in blend feed stream:

Case: No treatment, solid stream to vitrification.

Mass Al^{+3} = 409 kg x 1000 g/kg ÷ 27 g/mole = 15,148 moles ion

15,148 moles ion ÷ 2 moles Al in oxide/mole ion = 7574 moles oxide

7574 moles oxide x 102 g/mole Al_2O_3 ÷ 1000 g/kg = <u>772 kg Al_2O_3</u>

Sample calculation: Glass canister calculation for a particular waste composition.

Blend feed stream:

Case: No treatment, solid stream to vitrification.

Total Mass of oxides: 7.09E+6 kg

No. of glass cans based on 25% loading:

7.09E+6 kg oxide ÷ 25% = 2.84E+7 kg

2.84E+7 kg ÷ 1650 kg glass/can = 17,185 cans

Limiting component (found through comparison): P2O5

Frac of P2O5 in oxides = 0.0605
Frac of P2O5 allowed in feed[1] = 0.04

0.0605 ÷ 0.04 = 1.5119

17,185 x 1.5119 = <u>25,983 cans</u>

Mass of glass:

25,983 x 1650 kg/can = 4.28E+7 kg glass

Waste Loading:

7.09E+6 ÷ 4.28E+7 = <u>16.5% loading</u>

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[1] From HWVP Technical Data Package, Revision 5. Represents limit in the feed stream, not in the final glass product.

Sample calculation: Fraction of Cs-137 (out of all Cs isotopes) in waste stream.[1,2]

Total Waste Blend:

Total Cs-137:	450 kg
Total Cs in stream:	1745 kg
Frac of Cs-137:	.26

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[1] Boomer, K. D. 1993. Tank Waste Technical Options Report. WHC-EP-0616. Westinghouse Hanford Company, Richland, Washington.

[2] Swanson, J. L. 1993. Clean Option: An Alternative Strategy for Hanford Tank Waste Remediation. PNL-8388, Vol. 2. Pacific Northwest Laboratory, Richland, Washington.

Sample calculation: Amount of CST required for Cs removal.

Total Waste Blend:

Class A Limit for Cs: 1 Ci/m^3

Na mass in liq. stream: 7.38 E+7 kg

Volume of liquid (assuming 5 <u>M</u> Na):

7.38 E+7 kg ÷ 23 kg-mole ÷ 5 kg-mole/kL x 1 m^3/kL

= 6.4 E+5 m^3

Permitted activity of Cs-137 after treatment:

6.4 E+5 m3 ÷ 1 Ci/m3 = 6.4 E+5 Ci

6.4 E+5 Ci ÷ 86.6 Ci/g ÷ 1000 g/kg = 7.4 kg Cs-137

Amount of TOTAL Cs (Cs-137 + other Cs isotopes) allowed in LLW:

7.4 kg ÷ .26 = 28 kg Cs

Amount of CST required to reach decontamination requirements:

Cs Kd = 1000 mL/g
Mass of Cs in liquid feed = 1570 kg
Number of contacts =1

Formula used (see Appendix C):

$$m=\frac{V}{K_d}\left[\left(\frac{x_n}{x_0}\right)^{-\frac{1}{n}}-1\right] \tag{B1}$$

$$\frac{6.4E{+}8\ L}{1000\ L/kg}\left[\left(\frac{28\ kg}{1570\ kg}\right)^{-1}-1\right] \tag{B2}$$

= <u>3.5 E+7 kg CST</u>

Sample calculation: Ion exchange column.

Total Waste Blend, CST:

$$K_D = \frac{kg\ Cs/kg\ exchanger}{kg\ Cs/L\ feed} \tag{B3}$$

$$1000\ kg/L = \frac{450\ kg\ Cs/X\ kg\ CST}{450\ kg\ Cs/6.42E8\ L\ feed} \tag{B4}$$

$$X = 640{,}000\ kg\ CST \tag{B5}$$

Total waste blend, IE-96:

$$40\ kg/L = \frac{450\ kg\ Cs/X\ kg\ IE\text{-}96}{450\ kg\ Cs/6.42E8\ L\ feed} \tag{B6}$$

$$X = 1.6E7\ kg\ IE\text{-}96 \tag{B7}$$

APPENDIX C

MATHEMATICAL FORMULAE

APPENDIX C

DESCRIPTION AND DERIVATION OF MATHEMATICAL FORMULAE

From: Tchobanoglous, G, and Schroeder, E. D. Water Quality. Addison-Wesley Publishing Co. (1985).

Page 311:

$$\frac{C_{x/A}}{C_{x/B}}=K_d \tag{C1}$$

Where:

$C_{x/A}$ = concentration of x in A
$C_{x/B}$ = concentration of x in B
K_d = distribution coefficient

This is defined for liquid-liquid extractions, where A and B are the volumes of the liquid extractant and the feed stream, respectively. For a solid exchanger, the mass of the sorbate can be substituted for the volume of the liquid extractant (A).

$$C_{x/A}=\frac{x_0-x_1}{m} \tag{C2}$$

$$C_{x/B}=\frac{x_1}{V} \tag{C3}$$

Where:

x_0 = mass of contaminant in feed
x_1 = mass of contaminant remaining after treatment
m = mass of sorbate
V = volume of stream to be treated

Substitution yields:

$$\frac{V(x_0-x_1)}{mx_1}=K_d \tag{C4}$$

$$x_1=x_0\left(\frac{V}{V+K_dA}\right) \tag{C5}$$

For multiple contacts:

$$x_n=x_0\left(\frac{V}{V+K_d m}\right)^n \tag{C6}$$

Where:

n = number of contacts

Solving for the mass of the ion exchange material (per contact):

$$m=\frac{V}{K_d}\left[\left(\frac{x_n}{x_0}\right)^{-\frac{1}{n}}-1\right] \tag{C7}$$

So the total mass is:

$$m=\frac{nV}{K_d}\left[\left(\frac{x_n}{x_0}\right)^{-\frac{1}{n}}-1\right] \tag{C8}$$

To determine the mass of ion exchange material needed, the above formula was solved using K_d's for Cs, with volumes determined by setting both the feed and exit streams equal to 5M Na^+, and requiring that the exit stream meet Class A limits for Cs (1 Ci/m^3).

These equations are valid only where the K_ds remain constant over the range of concentrations. While this is not entirely true for the K_ds of IE-96 and CST, it is a reasonable assumption for this study.

APPENDIX D

COMPLETE NUMERICAL RESULTS

(1) CST and IE-96 Summary sheet: HLW Glass Calculations

Total Waste Blend, Class A Cs Limit

CST

4% Ti limit in HWVP feed

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	25,983	3,773,610	432,685	229,749	171,212	144,649
Waste loading	17%	3%	4%	4%	5%	6%
Oxide mass	7.37E+06	1.61E+08	2.50E+07	1.67E+07	1.44E+07	1.33E+07
Limiting component	P2O5	TIO2	TIO2	TIO2	TIO2	TIO2

16% Ti limit in HWVP feed

Can count	25,983	943,403	108,171	57,437	42,803	36,162
Waste loading	17%	10%	14%	18%	20%	22%
Oxide mass	7.37E+06	1.61E+08	2.50E+07	1.67E+07	1.44E+07	1.33E+07
Limiting component	P2O5	TIO2	TIO2	TIO2	TIO2	TIO2

OWL

Can count	25,983	635,354	87,814	54,555	44,961	40,608
Waste loading	17%	15%	17%	19%	19%	20%
Oxide mass	7.37E+06	1.61E+08	2.50E+07	1.67E+07	1.44E+07	1.33E+07
Limiting component	P2O5	"Other"	"Other"	"Other"	"Other"	"Other"

CST added (kg)		1.73E+08	1.98E+07	1.05E+07	7.85E+06	6.63E+06

IE-96

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	25,983	40,456,392	4,644,858	2,469,568	1,842,116	1,557,385
Waste loading	17%	6%	6%	6%	7%	7%
Oxide mass	7.09E+06	4.02E+09	4.91E+08	2.64E+08	1.98E+08	1.69E+08
Limiting component	P2O5	SIO2	SIO2	SIO2	SIO2	SIO2

OWL

Can count	25,983	3,105,206	370,962	198,581	148,859	126,295
Waste loading	17%	79%	80%	81%	81%	81%
Oxide mass	7.09E+06	4.02E+09	4.91E+08	2.64E+08	1.98E+08	1.69E+08
Limiting component	P2O5	SIO2	"Viscosity"	"Viscosity"	"Viscosity"	"Viscosity"

IE-96 added (kg)		4.32E+09	4.96E+08	2.63E+08	1.96E+08	1.66E+08

(2) CST: HLW Glass Calculations

NCAW, Class A Cs Limit

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	1,258,643	24,193	7,461	4,339	3,192
Waste loading	28%	2%	3%	4%	5%	6%
Oxide mass	1.74E+05	5.15E+07	1.16E+06	4.79E+05	3.55E+05	3.05E+05
Limiting component	NA2O	TIO2	TIO2	TIO2	TIO2	TIO2

16% Titanium Limit

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	63,540	1,221	496	445	426
Waste loading	28%	10%	19%	29%	29%	29%
Oxide mass	1.73E+05	1.05E+07	3.74E+05	2.36E+05	2.13E+05	2.01E+05
Limiting component	NA2O	TIO2	TIO2	NA2O	NA2O	NA2O
OWL						
Can count	351	206,428	4,118	1,376	862	677
Waste loading	30%	15%	17%	21%	25%	27%
Oxide mass	1.74E+05	5.15E+07	1.16E+06	4.79E+05	3.55E+05	3.05E+05
Limiting component	SO3	"Other"	"Other"	"Other"	"Other"	"Other"
CST added (kg)		1.16E+07	2.24E+05	6.91E+04	4.02E+04	2.95E+04

(3) IE-96: HLW Glass Calculations

NCAW, Class A Cs Limit

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	13,491,559	259,434	80,077	46,616	34,321
Waste loading	28%	6%	6%	6%	7%	7%
Oxide mass	1.73E+05	1.41E+09	2.72E+07	8.51E+06	5.02E+06	3.74E+06
Limiting component	NA2O	SIO2	SIO2	SIO2	SIO2	SIO2
OWL						
Can count	345	1,069,204	20,626	6,413	3,761	2,787
Waste loading	30%	80%	80%	80%	81%	81%
Oxide mass	1.73E+05	1.41E+09	2.72E+07	8.51E+06	5.02E+06	3.74E+06
Limiting component	NA2O	"Viscosity"	"Viscosity"	"Viscosity"	"Viscosity"	"Viscosity"
IE-96 added (kg)		1.44E+09	2.77E+07	8.55E+06	4.97E+06	3.66E+06

(4) CST and IE-96: HLW Glass Calculations

NCAW Waste, Class C Cs Limit

CST

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	387	384	383	383	383
Waste loading	28%	28%	28%	28%	28%	28%
Oxide mass	1.73E+05	1.80E+05	1.79E+05	1.79E+05	1.79E+05	1.79E+05
Limiting component	NA2O	NA2O	NA2O	NA2O	NA2O	NA2O

16% Titanium Limit

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	387	384	383	383	383
Waste loading	28%	28%	28%	28%	28%	28%
Oxide mass	1.73E+05	1.80E+05	1.79E+05	1.79E+05	1.78E+05	1.79E+05
Limiting component	NA2O	NA2O	NA2O	NA2O	NA2O	NA2O
OWL						
Can count	345	357	356	355	355	355
Waste loading	30%	31%	31%	31%	31%	31%
Oxide mass	1.73E+05	1.80E+05	1.79E+05	1.79E+05	1.79E+05	1.79E+05
Limiting component	SO3	"Xtal 3"	"Xtal 3"	"Xtal 3"	"Xtal 3"	"Xtal 3"
CST added (kg)		7.11E+03	5.64E+03	5.24E+03	5.06E+03	4.95E+03

IE-96

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	1,767	1,424	1,331	1,287	1,262
Waste loading	28%	12%	13%	14%	14%	14%
Oxide mass	1.73E+05	3.47E+05	3.11E+05	3.02E+05	2.97E+05	2.95E+05
Limiting component	NA2O	SIO2	SIO2	SIO2	SIO2	SIO2
OWL						
Can count	344	448	428	422	419	418
Waste loading	31%	47%	44%	43%	43%	43%
Oxide mass	1.73E+05	3.47E+05	3.11E+05	3.02E+05	2.97E+05	2.95E+05
Limiting component	SO3	"Xtal 3"	"Xtal 3"	"Xtal 3"	"Xtal 3"	"Xtal 3"
IE-96 added (kg)		1.78E+05	1.41E+05	1.31E+05	1.26E+05	1.24E+05

(5) CST and IE-96: HLW Glass Calculations

Total Waste Blend, 1/10th Class A Cs limit

CST

Contacts	Wash only	1	2	3	4	5
HWVP Limits	**4% Ti limit in HWVP feed**					
Can count	25,983	37,861,764	1,428,747	543,436	348,033	270,189
Waste loading	17%	2%	3%	3%	4%	4%
Oxide mass	7.37E+06	1.55E+09	6.56E+07	2.95E+07	2.16E+07	1.84E+07
Limiting component	P2O5	TIO2	TIO2	TIO2	TIO2	TIO2
	16% Ti limit in HWVP feed					
Can count	25,983	9,465,441	357,187	135,859	87,008	67,547
Waste loading	17%	10%	11%	13%	15%	17%
Oxide mass	7.37E+06	1.55E+09	6.56E+07	2.95E+07	2.16E+07	1.84E+07
Limiting component	P2O5	TIO2	TIO2	TIO2	TIO2	TIO2
OWL						
Can count		No Data	No Data	No Data	No Data	61,183
Waste loading						18%
Oxide mass						1.84E+07
Limiting component						"Other"
CST added (kg)		1.74E+09	6.55E+07	2.49E+07	1.59E+07	1.24E+07

IE-96

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	25,983	405,848,931	15,321,692	5,831,996	3,737,462	2,903,053
Waste loading	17%	6%	6%	6%	6%	6%
Oxide mass	7.09E+06	4.03E+10	1.60E+09	6.14E+08	3.96E+08	3.09E+08
Limiting component	P2O5	SIO2	SIO2	SIO2	SIO2	SIO2
OWL						
Can count		No Data	No Data	No Data	No Data	232,933
Waste loading						80%
Oxide mass						3.09E+08
Limiting component						"Viscosity"
IE-96 added (kg)		4.34E+10	1.64E+09	6.23E+08	3.99E+08	3.10E+08

(6) CST: HLW Glass Calculations

NCAW, 1/10th Class A Cs Limit

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	12,587,497	77,019	16,484	8,085	5,406
Waste loading	28%	2%	3%	3%	4%	4%
Oxide mass	1.74E+05	5.14E+08	3.32E+06	8.47E+05	5.08E+05	3.95E+05
Limiting component	NA2O	TIO2	TIO2	TIO2	TIO2	TIO2

16% Titanium Limit

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	635,452	3,888	643	506	462
Waste loading	28%	10%	13%	29%	29%	29%
Oxide mass	1.73E+05	1.04E+08	8.09E+05	3.10E+05	2.44E+05	2.19E+05
Limiting component	NA2O	TIO2	TIO2	NA2O	NA2O	NA2O

OWL

Can count		No Data	No Data	No Data	No Data	1,039
Waste loading						23%
Oxide mass						3.95E+05
Limiting component						"Other"

CST added (kg)		1.16E+07	2.24E+05	6.91E+04	4.02E+04	2.95E+04

(7) IE-96: HLW Glass Calculations

NCAW, 1/10th Class A Cs Limit

Contacts	Wash only	1	2	3	4	5
HWVP Limits						
Can count	374	134,926,081	825,670	176,801	86,770	58,050
Waste loading	28%	6%	6%	6%	6%	6%
Oxide mass	1.73E+05	1.41E+10	8.63E+07	1.86E+07	9.21E+06	6.22E+06
Limiting component	NA2O	SIO2	SIO2	SIO2	SIO2	SIO2
OWL						
Can count		No Data	No Data	No Data	No Data	4,667
Waste loading						81%
Oxide mass						6.22E+06
Limiting component						"Viscosity"
IE-96 added (kg)		1.44E+10	8.83E+07	1.89E+07	9.26E+06	6.19E+06