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THE IMPACT OF THE ACTINIDE REMOVAL PROCESS (ARP) ON THE SB4 PROJECTED OPERATING WINDOWS

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Immobilization Technology Section
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EXECUTIVE SUMMARY

The model-based assessments of nominal Sludge Batch 4 (SB4) compositions suggest that a viable frit candidate does not appear to be a limiting factor as the Closure Business Unit (CBU) considers various tank blending options for SB4 with or without the Actinide Removal Process (ARP) streams. This statement is based solely on the projected operating windows derived from model predictions and does not include experimental assessments of SO_4 solubility or melt rate issues.

To assess the impact of the various ARP options on the projected operating windows, the 1100 canister SB4 baseline options served as the technical baseline or reference point for the comparisons. With respect to the various ARP options being considered, the impacts to the projected operating windows were relatively consistent with the impacts being dependent upon the property limiting access to higher WLs. More specifically, for those 1100 canister SB4 systems (without ARP) which were T_L-limited, the general impact was an increase in the upper WL which was classified as acceptable resulting in an overall increase in the operating window size. The anticipated negative impact of TiO_2 (due to an assumed increase in T_L which would further reduce the size of the operating window of such systems) was not observed. The hypothesis is that the negative impact was countered or compensated by a positive impact due to the additional Na_2O from the ARP process. The overall result was a net increase in the size of the operating window for the SB4 1100 canister options which were T_L-limited. This trend was observed for all five ARP options with the only difference being the magnitude of the increase (ranging from a 1% - 4% increase) which was strictly based on the specific ARP composition and blending strategy.

Another general observation for all five ARP options was a negative impact with their addition to a 1100 canister system that was initially low viscosity limited or durability limited. For these systems, addition of each ARP stream resulted in a negative impact to the upper WL defining the operating window as a result of the additional Na_2O introduced which drove both viscosity and durability predictions lower at the same WL. The magnitude of the impact ranged from a 1 – 2% reduction for low viscosity limited systems to complete elimination of the operating windows for durability limited systems. The latter situation (i.e., complete elimination of the operating window for a given SB4 blending option with a specified frit) would require a change in frit to compositionally compensate for the ARP addition.

One of the most interesting ARP options was the introduction of the ARP-K case. Model-based predictions and projected TiO_2 concentrations, would require an increase in the current PCCS TiO_2 limit from 1 wt% to 2 wt% (if WLs targeting 39% or greater are desired). With this increase, there appears to be some potential advantages of this ARP stream relative to the other four ARP options. One potential advantage is based on the ~ 4% increase in the upper WL defining the projected window for most of the options being considered (which were initially T_L limited). Although potentially advantageous for some systems, the addition of the ARP-K stream could be devastating to other systems if compositional adjustments are not made (i.e., a frit change). Frits could be selected that are robust to the inclusion of the ARP but they may not be optimized for other properties (e.g., melt rate).

Although ARP-K has potential advantages on the projected operating windows, the other ARP options evaluated should not be dismissed as other criteria (e.g., melt rate and/or CPC processing issues) should be considered prior to pursuing a particular ARP processing scenario. More specifically, based on the assessments performed in this report, there are no show-stoppers for any of the ARP options being considered – although some options could require a frit change between a "sludge-only" flowsheet and its "coupled" (sludge plus ARP) counterpart.

Based on the SB4 – ARP blending strategies, the additions of TiO_2 and SO_4 from the ARP streams could result in these oxides exceeding some critical value that would give rise to uncertainties or questions associated with the applicability of select models or exceeding individual solubility limits. In general, establishing a PCCS SO_4 limit of 0.5 or 0.6 wt% (in glass) appears to be sufficient to avoid the SB4 – ARP systems from being SO_4 limited at the upper WLs. With respect to model applicability issues, the primary PCCS model of concern was the T_L model which was developed over TiO_2 concentrations ranging from 0.0 – 1.8549 wt% (in glass). Although the ARP- K option would require the TiO_2 limit to be raised to 2.0 wt%, maximum TiO_2 concentrations in glass are well below the 2 wt% limit established by Lorier and Jantzen (2003).

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LIST OF ACRONYMS

ARP	Actinide Removal Process
ASTM	American Society for Testing and Materials
CBU	Closure Business Unit
CPC	Chemical Processing Cell
DWPF	Defense Waste Processing Facility
ΔG_P	preliminary glass dissolution estimator
MAR	Measurement Acceptability Region
MCU	Modular Caustic Side Solvent Extraction Unit
MST	monosodium titanate
NL [B]	normalized boron release (in g/L)
PCCS	Product Composition Control System
PCT	Product Consistency Test
SB	sludge batch
SRAT	Sludge Receipt and Adjustment Tank
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
T_L	liquidus temperature
η	viscosity
WL	waste loading
WSRC	Westinghouse Savannah River Company

1.0 INTRODUCTION

The Defense Waste Processing Facility (DWPF) is currently processing Sludge Batch 3 (SB3) as a "sludge-only" composition by combining SB3 with Frit 418, melting the slurry mix of sludge and frit, and pouring the molten glass in stainless steel canisters to create the final waste form for this high-level waste at the Savannah River Site (SRS). In preparation for the qualification and receipt of the next sludge batch, Sludge Batch 4 (SB4), development and definition of the baseline flowsheet have been initiated (Lilliston 2005). Various tank blending strategies are being contemplated for SB4 in an effort to meet critical Closure Business Unit (CBU) objectives including issues associated with the durability of the DWPF glass waste form and the efficiency and effectiveness of the DWPF operation. SB4, as currently projected, will be a blend of Tanks 4, 5, 6, 11, and heels from Tanks 7 and 8. In addition, excess Pu and Np streams from canyon disposition and streams from the Actinide Removal Process (ARP) and the Modular Caustic Side Solvent Extraction Unit (MCU) may also be added during the processing of SB4.

Critical components of DWPF's operational efficiency and effectiveness include sludge/frit processability, melter attainment (the percentage of time DWPF's melter is pouring), melt rate, waste loading, and canister production rates. An early yet meaningful assessment of the processability of a sludge option and of the durability of the final waste form for candidate frits at various waste loadings is provided by using predictions generated by property/composition models. Peeler and Edwards (2005) have identified various frit compositions that provide attractive operating windows (defined in terms of an upper and lower waste loading (WL) in which all glass properties meet DWPF acceptability requirements) based on model assessments. Those assessments were specifically focused on the 20 options provided by Lilliston (2005) that accounted for the uncertainty in sludge volumes remaining in each tank, the possibility that not all of the tanks will be included in SB4, and two different blend points with the heel of SB3. The assessments did not include or address the potential impacts of ARP, MCU, and/or Pu streams that could be blended with SB4.

The impact (or lack thereof) of the MCU stream on the need for a variability study has been addressed in a separate memo (Peeler et al. 2005). Conclusions from that study indicated that although direct applicability of the durability (ΔG_P) model can not be demonstrated to the specific SB4 flowsheet (given the premature nature of the inputs needed to define the glass composition region of interest), one can conclude with high confidence that the incorporation of the MCU stream in the final SB4 flowsheet (regardless of its composition) will have no impact on the decision to perform a variability study. That is, the minimal compositional changes to the SB4 flowsheet from MCU incorporation are practically insignificant and will not influence the decision to perform a variability study for SB4. One can take that conclusion a step further to state that the compositional impacts of MCU will not govern or have any practical impact on the need to reformulate a frit to retain or regain model-based projected operating windows.

Therefore, the primary focus of this report is on the potential impacts of ARP on frit development efforts. That is, could the compositional changes resulting from the assumed ARP blending strategies be sufficient enough to warrant a change in the frit selection process for SB4? The technical baseline that Peeler and Edwards (2005) established for SB4 (without ARP) will serve as the reference point for such comparisons. In addition to monitoring the impact of ARP on the projected operating windows, identification of "troublesome" components introduced through the ARP process which may ultimately influence the projected windows and/or cause concern of either model applicability or individual solubility issues will be of utmost concern.

The Savannah River National Laboratory (SRNL) has been asked via a technical task request (Washburn 2004) to provide frit development support for SB4. In response, SRNL has issued a task technical and quality assurance plan (Peeler 2004), and it is under the auspices of that plan that this report has been prepared.

Objectives for this task are specified in Section 2.0. In Section 3.0, a brief review of the strategy or approach for developing and assessing new or existing frits is provided as well as the criteria used to make acceptability decisions. Projected SB4 nominal compositions are summarized in Section 4.0 from which the model-based assessments will be founded. Section 5.0 summarizes the Nominal Stage, Measurement Acceptability Region (MAR) based assessments for the 20 SB4 blending scenarios without ARP which serve as a baseline for comparing the impacts of the ARP streams. Section 6.0 summarizes the projected operating windows for the nominal SB4 cases with ARP and discusses the general trends observed. Section 7.0 provides a summary of these assessments.

2.0 OBJECTIVE

The objective of this task is to assess the impact of various ARP processing alternatives on the SB4 projected operating windows. This information will be provided to the CBU and will identify the potential need for augmenting the frit selection process to accommodate inclusion of the ARP stream into SB4. In addition, model applicability and/or individual solubility limit issues will be monitored for select oxides introduced by the ARP streams or that when combined with the projected SB4 compositions exceed some critical value. The information provided in this report is solely focused on model-based projections of the Product Composition Control System (PCCS) operational windows for various SB4 blending strategies of interest. Experimental assessments of melt rate or SO_4 solubility are not addressed in this report but are being addressed in parallel tasks. Although not included in the scope of this report, such experimental work is planned as part of the support for SB4 (Peeler and Smith 2004 and Peeler 2004) since these are critical inputs to the final selection of a frit for SB4.

3.0 THE APPROACH AND CRITERIA FOR ACCEPTABILITY

To meet the programmatic objectives, the Nominal Stage assessments as proposed by Peeler and Edwards (2002) were used to assess various frit/sludge combinations. The assessment utilized nominal SB4 compositions representing potential tank blending scenarios as outlined by Lilliston (2005). In general, this stage assessed candidate frit compositions with respect to their ability to provide a relatively large projected operating window based solely on a specific nominal composition – no sludge variation was accounted for in this phase. Assessments were made using predictions from models currently implemented in DWPF's PCCS over the waste loading (WL) interval of interest (25 – 60 wt%). The primary property predictions assessed included those for liquidus temperature (T_L), viscosity (η), and durability (normalized boron release – NL[B] as defined by the Product Consistency Test (PCT) [ASTM 2002]).

It is recognized that the Nominal Stage assessments do not account for anticipated compositional variation. However, the compositional projections provided by Lilliston (2005) were based on various percentages of possible tanks that could represent or be included in SB4. Therefore, the compositions do represent or provide a measure of sludge variation that provides some insight into the robustness of candidate frits with respect to compositional variation. If needed, and as the SB4 flowsheet becomes more mature (primary blending options are further defined), a formal Variation Stage assessment could be performed to address this issue.

As previously mentioned, the property predictions assessed in this study included durability (as defined by the PCT response in terms of the preliminary glass dissolution estimator (ΔG_P) (Jantzen et al. 1995)), viscosity at 1150°C ($\eta_{1150°C}$), T_L, and Al_2O_3 and alkali concentrations. Jantzen et al. (1995) and Brown et al. (2001) provide a more detailed discussion on the development of these models. To determine projected operational windows for sludge/frit scenarios of interest, the predicted properties must be assessed relative to established acceptance criteria. Acceptable predicted properties for this assessment were based on satisfying their respective MAR limit values. Brown, Postles, and Edwards (2002) provide a detailed discussion of how the MAR limits are utilized in PCCS.

Addition of the various ARP streams does cause some concern regarding the introduction of TiO_2 into the system at concentrations that either exceed the current PCCS TiO_2 limit of 1 wt% (in glass) and/or challenge the range over which the current T_L model is applicable. Brown et al. (2001) indicated that the current T_L model was developed over a TiO_2 range from 0.0 to 1.8549 wt% (in glass). Lorier and Jantzen (2003) used this range to establish a technical basis for increasing the current TiO_2 limit from 1 wt% to 2 wt% (if required).[1] Although the 2 wt% limit is available for implementation, the initial model based assessments to be performed will utilize the 1 wt% constraint. Use of this "conservative" lower limit will flag the need for raising the limit for the various ARP options. That is, there may be blending strategies that would not require the limit to be increased while other options may require the 2 wt% limit to be utilized. Use of the 1 wt% limit will expeditiously identify these cases. If the 1 wt% limit is found to be restrictive (in terms of the projected operating windows), the restricted option (or set of options) will be "re-evaluated" using the 2 wt% limit.

Although the PCCS SO_4 limit for SB4 has not been established, various SO_4 limits can be used (e.g., 0.4, 0.5, and 0.6 wt% in glass) to assess if SO_4 will have a negative impact on the projected operating window. For this assessment, the SO_4 concentrations in glass will be calculated, but an assumed SO_4 limit will not be used to restrict the projected operating windows based on the model predictions. Given there is no MAR uncertainty associated with the SO_4 concentration, the maximum WL for each SB4 option can be determined as a function of an assumed SO_4 solubility limit based strictly on mathematics (i.e., the assumed SO_4 solubility limit divided by the SO_4 concentration in sludge times 100). For example, if the SO_4 concentration in sludge was 1.09 wt% and the assumed SO_4 solubility limit was 0.4 wt% (in glass), then the maximum WL achievable (based strictly on the SO_4 solubility limit) would be ~36.7 wt%. If the SO_4 solubility limit was 0.5 wt%, then the maximum achievable WL ((based strictly on the SO_4 solubility limit) would be 45.9%. Although one can easily calculate the maximum WL for a given SO_4 solubility limit, properties other than SO_4 solubility may restrict access to higher WLs. Therefore, a nominal SO_4 value (1.09 wt%) has been added to each of the 20 options but a SO_4 solubility limit in PCCS was not activated with respect to limiting or imposing restrictions on the MAR based assessments for the initial assessments.[2]

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[1] Lorier and Jantzen (2003) indicate that the substitution of the T_L model for an absolute solubility limit is based on the fact that not all of the literature glasses surveyed for this study with TiO_2 levels <2 wt% satisfy the currently implemented T_L constraint. Since the impact of the TiO_2 content of a glass on the T_L is not linear (i.e., there are interactive effects from other components such as Cr_2O_3, Fe_2O_3 and MnO), the use of the T_L model up to a TiO_2 solubility limit of 2 wt% is the only validated approach that can be used for processing in the DWPF.

[2] Shah et.al. (2004) provided the nominal supernate composition for SB4, which included sulfate. For this study, all of the sulfate was assumed to be soluble and the sulfate in the calcined solids was estimated to be 1.09 wt% assuming a calcine factor similar to that seen for SB4 simulant flowsheet testing.

4.0 COMPOSITIONAL BASIS: SB4, ARP, AND FRIT

Three primary inputs are required to support the assessment of the impacts of ARP on the SB4 projected operating windows. The primary inputs are: sludge (or waste stream), ARP, and frit compositions as well as blending strategies. Given the focus of this study is to assess the impact of ARP on the projected operating windows, the SB4 and primary frit compositions used by Peeler and Edwards (2005) will serve as the technical baseline. Therefore, the only required input is to define the ARP compositions and assumed blending or processing strategies.

Herman (2005) provides a detailed summary of the preliminary ARP compositions and an overview of the processing strategy. Given both are still being defined, some uncertainty exists with regards to the composition and volume of the stream that will be transferred to DWPF. The ARP stream to be transferred to DWPF will contain monosodium titanate (MST), entrained sludge, and various soluble sodium compounds as the result of filter cleaning and stream composition adjustment for transfer. Herman (2005) reviewed the various material balances for several different processing scenarios provided by Subosits (2004). Twenty-four ARP processing scenarios were reviewed, and five were selected to bound the range of possible components (with potential impacts on the glass formulation) that could be transferred to DWPF. The assumption being that if glass formulation efforts can accommodate the bounding components, then concentrations of the ARP components within the bounds should also be acceptable. Table 4-1 provides a general description of the supporting facilities, feed compositions, nominal flow rates, and selection basis for each option. The five ARP options selected were identified as ARP-A, -E, -K, -M, and -V and the nominal composition of each (calcined, oxide basis) is listed in Table 4-2.[3]

Table 4-1. General Description of the Five ARP Cases.

Case	**ARP-A**	**ARP-E**	**ARP-K**	**ARP-M**	**ARP-V**
Facility(ies)	512-S Only	241-96H with 512-S ARP	241-96H with 512-S ARP	512-S Only	241-96H with 512-S ARP
Alpha Reactors	Single	Dual	Dual	Single	Dual
Feed Composition	Average	Worst Inhalation Dose	Average	Average	Average
MST Strike Time (hr)	24	24	8	N/A	8
Filter Size (μm)	0.5 Mott	0.5 Mott	0.1	0.1	0.5 Mott
Filter Flux (gpm/ft^2)	0.02	0.02	0.02	0.02	0.036
Nominal Flow rates (lb/hr)	28.38	102.410	152.044	89.267	111.978
Reason for Selection	Nominal Feed Composition and Volume	High MST and Sludge Content with Large Stream Volume	Highest Combined Na, Sludge, and MST, Volume	Filter Only Case with No MST	Intermediate sludge, MST, and Na level

[3] Herman (2005) identified the five ARP options as Appendices A, E, K, M, and V. These ARP options are referred to as ARP-A, ARP-E, ARP-K, ARP-M, and ARP-V, respectively, throughput this report to avoid confusion with the appendices supporting the MAR assessments.

Table 4-2. ARP Stream Oxide Compositions (wt%).[4]

Oxide	ARP-A	ARP-E	ARP-K	ARP-M	ARP-V
Al_2O_3	6.26	7.84	6.23	10.84	6.24
BaO	0.087	0.116	0.086	0.169	0.086
CaO	1.009	1.347	0.994	1.950	0.996
Ce_2O_3	0.167	0.223	0.165	0.323	0.165
Cr_2O_3	0.107	0.144	0.106	0.207	0.106
Cs_2O	0.0010	0.0012	0.0009	0.0018	0.0009
CuO	0.045	0.060	0.045	0.087	0.045
Fe_2O_3	12.4	16.5	12.2	24.0	12.2
K_2O	0.117	0.137	0.117	0.201	0.117
La_2O_3	0.068	0.091	0.067	0.132	0.067
MgO	0.106	0.141	0.104	0.204	0.104
MnO	4.65	6.21	4.58	8.98	4.59
Na_2O	39.6	38.5	40.3	38.6	40.2
NiO	1.39	1.85	1.37	2.68	1.37
PbO	0.123	0.164	0.121	0.238	0.121
SO_4	2.84	3.09	2.90	3.24	2.90
SiO_2	0.692	0.924	0.682	1.338	0.684
ThO_2	0.0000	0.0000	0.0000	0.0000	0.0000
TiO_2	26.8	17.9	26.4	0.0	26.4
U_3O_8	3.28	4.39	3.24	6.35	3.24
ZnO	0.076	0.101	0.075	0.147	0.076
ZrO_2	0.205	0.274	0.203	0.397	0.203

From a glass formulation perspective, the oxides introduced from the ARP options of particular interest include TiO_2, SO_4, and Na_2O. This does not suggest that the other components are not important but only the fact that the concentrations of these major components have a higher probability of influencing the projected operating windows based on model predictions or individual solubility limits. As expected the TiO_2 concentrations are relatively high in all ARP options with the exception of ARP-M (which is 0%). The ARP-M case represents a scenario where an MST strike is not performed and only filtration is used. The primary concerns for TiO_2 are the impacts to T_L (in general, as TiO_2 concentrations increase, T_L increases) and the applicability of the T_L model (i.e., the range of TiO_2 over which the T_L model was developed).[5] Consider a SB4 blending option (without ARP) that is T_L-limited. The additional TiO_2 from the ARP stream could reduce the maximum WL achievable due to an increased T_L prediction. This statement assumes that the negative impact of TiO_2 is not countered by a reduction in T_L due to another component in the ARP stream (e.g., Na_2O). Another troublesome component is SO_4, which represents approximately 3.0 wt% of the solids in all five ARP options (see Table 4-2). Depending upon the SB4 blending or processing strategy, the additional SO_4 from the ARP streams could transition a SB4 system that is T_L or low viscosity limited (at the upper WL) to one that is SO_4 limited. This potential shift or transition obviously depends on the combined SO_4 concentration between SB4 and the ARP as well as the solubility limit established for the specific system. With respect to Na_2O additions from the ARP, it is anticipated that when comparing a specific SB4 option (e.g., 1100 canister baseline option) with and without ARP, adjustments to the frit composition may be required to counter or compensate for the incoming Na_2O

[4] As previously noted, the compositions shown for ARP-A, -E, -K, -M, and -V in this report are consistent with the nomenclature of Appendix A, E, K, M and V as denoted by Herman (2005).
[5] As noted in Section 3.0, the lower and upper TiO_2 bounds over which the model was developed were 0.0 wt% up to 1.8549 wt%.

content – the "sliding Na_2O scale" concept as described by Peeler and Edwards (2005). The projected impacts of the ARP streams on the projected operating windows ultimately depend on compositional changes to the overall SRAT product which will be governed by the blending or processing strategy (mass of SB4 and mass of ARP to be blended).

To determine the impact of each ARP stream on the DWPF Sludge Receipt and Adjustment Tank (SRAT) product or glass composition, the five projected ARP stream compositions (see Table 4-1) were individually blended with the 20 SB4 options provided by Lilliston (2005). Herman (2005) used the estimated transfer volumes for each ARP option and blended them with a nominal 6,000 gallon SRAT sludge batch. To estimate the sludge oxide mass contribution, the sludge was assumed to have a total/dried solids of 22 wt%, a calcine factor of 0.72, and a sludge density of 1.18 kg/L for all of the SB4 projected compositions. The total oxides were summed and then renormalized to include the ARP contribution. The resulting SB4 + ARP SRAT products are summarized in Appendix A.

5.0 PROJECTED OPERATING WINDOWS FOR THE 20 SB4 BLENDING OPTIONS WITHOUT ARP

Peeler and Edwards (2005) provide a detailed assessment of the MAR results for the 20 SB4 options (without ARP and Pu additions) provided by the CBU. That assessment serves as a technical baseline from which the impacts (positive or negative) of ARP on the projected operating windows will be based. As previously mentioned, introduction of TiO_2, SO_4, and/or Na_2O from the ARP process will probably have the largest impact on the projected operating windows assuming compositional compensations of the frit are not made.

For completeness, projected operating windows for the MAR based assessments for all 20 options (i.e., SB4-Only, 1100 canister, and 1200 canister cases) are summarized in Table 5-1 through Table 5-3, respectively. The projected operating windows in terms of upper and lower WLs that satisfy the MAR constraints for the specific sludge / frit blend as well as the property that limits access to higher WLs are also provided. As previously mentioned, although the SO_4 concentration in glass was monitored, the assessments did not impose or activate a SO_4 solubility limit and therefore did not restrict or influence the projected operating windows.[6] Also shown in Table 5-1 through 5-3 is the nominal Na_2O concentration (in wt%) in the frit ranging from 8% (Frit 418) to 13% (Frit 431).

Table 5-1. SB4 Only Options without ARP - MAR Results

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	(high η) 33 - 36 (T_L)	25 – 37 (T_L)	25 – 38 (T_L)	25-39 (T_L)	25 – 40 (T_L)	25 – 40 (T_L)
Max Al	-	-	-	-	25 – 60	25 – 60
Min Al	(high η) 27 – 32 (T_L)	25 – 33 (T_L)	25 – 34 (T_L)	25 – 35 (T_L)	25 – 35 (T_L)	25 – 36 (T_L)

[6] Imposing a 0.5 or 0.6 wt% SO_4 limit in PCCS typically does not limit the projected windows for any of the 20 SB4 blending options being considered. If the SO_4 limit were set at 0.4 wt%, upper WLs would be limited to ~ 36% based on the projected SO_4 concentrations in SB4.

Table 5-2. 1100 Canister Options without ARP - MAR Results

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 44 (low η)	(ΔG_P) 27 – 41 (low η)
2^{nd} transfer baseline	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 43 (low η)
Min Al	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 41 (low η)	-
Max Al	(high η) 27 – 51 (T_L)	25 – 52 (T_L)	25 – 53 (T_L)	25 – 54 (T_L)	25 – 53 (low η)	25 – 50 (low η)
Min Ce	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)
Min Fe	(high η) 26 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)
Max Mg	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 43 (low η)	(ΔG_P) 32 – 40 (low η)
Max Ni	25 – 36 (T_L)	25 – 37 (T_L)	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L/low η)
Max Ti	25 – 50 (T_L)	25 – 51 (T_L)	25 – 52 (T_L)	25 – 52 (low η)	25 – 49 (low η)	25 – 46 (low η)

Table 5-3. 1200 Canister Options without ARP - MAR Results

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 -41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L/low η)	25 – 42 (low η)
2[nd] transfer baseline	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 44 (low η)
Min Al	25 – 39 (T_L)	25 – 40 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L/low η)	(ΔG_P) 35 – 39 (low η)
Max Al	(high η) 29 – 53 (T_L)	25 – 54 (T_L)	25 – 54 (T_L)	25 – 55 (T_L)	25 – 56 (T_L/low η)	25 – 53 (low η)
Max Ni	25 – 36 (T_L)	25 – 37 (T_L)	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L/low η)
Min Ce	(high η) 26 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)
Min Mg	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 42 (T_L)
Max Mg	(high η) 26 – 51 (T_L)	25 – 52 (T_L)	25 – 53 (T_L)	25 – 54 (T_L/low η)	25 – 51 (low η)	25 – 48 (low η)

6.0 PROJECTED OPERATING WINDOWS FOR THE 1100 CANISTER BASELINE WITH ARP

Given there are 20 nominal SB4 cases, 5 ARP options (referred to as ARP-A, -E, -K, -M, and -V), and 6 different candidate frits, a total of 600 glass systems can be developed. Within each glass system, 36 individual WLs exist which results in 21,600 specific glasses to be assessed against the MAR. Obviously, the number of comparisons one can make among the various systems is extremely large and exceeds the number of comparisons that will be made in this report. In addition, predictions of various properties at each WL within a specific system become too numerous to list and if listed, could be of limited use.[7] Therefore, in this report, an example of the impact of the various ARP streams on the projected operating windows will be provided to demonstrate various concepts that can then be used to make specific comparisons of interest to the individual reader. The SB4 blending option of choice will be the 1100 canister baseline case given its current classification as the "baseline" flowsheet. Details regarding each of the 600 glass systems are provided in Appendix B so the reader can make specific comparisons as warranted. In addition to the specific discussions for the 1100 canister baseline option, some high-level, general statements will be summarized for each of the 5 ARP options. For example, if a particular ARP option results in complete elimination of an operating window that option will be highlighted. The projected operating windows for the various SB4 1100 canister – ARP processing options are provided in Tables 6-1 through Table 6-6.

6.1 ARP-A

Table 6-1 summarizes the projected operating windows for the SB4 + ARP-A cases. Although discussions or comparisons with these options relative to the SB4 with no ARP cases may be considered extensive, this does not suggest that this option is more advantageous relative to another ARP option. The more detailed discussions are provided to established "similar" effects of the ARP streams which will only be highlighted in subsequent discussions. The primary focus of later systems will be to highlight differences among the ARP options that may provide distinguishing beneficial impacts that could be used to down select or target on one or more ARP options, if warranted.

[7] Detailed property predictions for each glass system can be found in WSRC-NB-2004-00134.

Table 6-1. MAR Results for the SB4 1100 Canister + ARP-A Cases

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 43 (low η)	(ΔG_P) 31 – 40 (low η)
2nd transfer baseline	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 43 (low η)
Min Al	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 43 (low η)	25 – 40 (low η)	-
Max Al	(high η) 26 – 52 (T_L)	25 – 53 (T_L)	25 – 54 (T_L)	25 – 55 (T_L/low η)	25 – 52 (low η)	25 – 49 (low η)
Min Ce	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)
Min Fe	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 46 (T_L)
Max Mg	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L/low η)	25 – 42 (low η)	(ΔG_P) 38 – 39 (low η)
Max Ni	25 – 37 (T_L)	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	(ΔG_P) 28 – 41 (low η)
Max Ti	25 – 51 (T_L)	25 – 52 (T_L)	25 – 53 (T_L/low η)	25 – 51 (low η)	25 – 48 (low η)	25 – 45 (low η)

Comparing the MAR based projected operating windows shown in Table 6-1 (with ARP) to those of the SB4 1100 canister options without ARP (Table 5-2) shows only a minimal impact of introducing the ARP-A stream into the SB4 flowsheet. More specifically, consider the 1100 canister baseline option. From Table 5-2, when Frits 418, 426, 425, and 417 are used, the systems are T_L-limited (at the upper WL) and have projected operating windows ranging from 25% WL to 42% (with Frit 418) and from 25% WL to 45% (with Frit 417) with 1% WL increments for the frits in between. This shift toward higher WLs is attributed to the additional Na_2O in the frit as its impact is to lower T_L which provides access to higher WLs. When higher Na_2O-based frits are used (Frit 320 and Frit 431), the systems become low viscosity limited. This transition suggests that the glasses contain sufficient alkali to lower T_L as well as viscosity leading to predictions of low viscosity limiting access to higher WLs. When the ARP-A stream is blended with the 1100 canister baseline option, the impacts to the projected windows are dependent upon the property limiting access to higher WLs. For those non-ARP systems which were T_L-limited, introduction of the ARP-A stream has no effect on the projected operating windows. For those non-ARP options which were low viscosity limited (Frit 320 and Frit 431), adding the ARP-A stream has a slightly negative impact (1% reduction in the upper WL) in the projected windows. This negative impact is a result of the additional Na_2O being introduced from the ARP stream which continually lowers viscosity. The additional Na_2O from the ARP-A stream also results in further limitations of lower WLs due to predictions of durability (ΔG_P) (i.e., the lower WL limit increases from 27% without ARP to 31% with ARP-A).

For select SB4 blending scenarios there is a positive impact on the addition of the ARP-A stream. Consider the "1100 canister 2nd transfer baseline", "Min Al", "Max Al", "Min Fe", "Max Mg", "Max Ni", and "Max Ti" cases. When the non-ARP based systems are T_L limited, introduction of the ARP-A stream has a slight positive impact on the projected windows. More specifically, a 1% increase in the upper WL is observed for these ARP-A based cases. This positive impact is a result of the additional Na_2O from the ARP stream lowering T_L which allows higher WLs to be achieved. As was observed in the 1100 canister baseline options, if the system (without ARP) was low viscosity limited, addition of the ARP stream had a slightly negative impact on the upper WL – although not severe enough to warrant eliminating this ARP option from further consideration.

Based on the MAR assessments, the ARP-A option has minimal impact on the projected operating windows and would not require a frit change to accommodate this stream. This latter statement is based solely on the model based projections and does not consider any impacts on melt rate and/or other CPC processing issues. It is interesting to note that TiO_2 is not a limiting component within this system even at the 1% TiO_2 limit being used for the MAR assessments. Although not specifically tabulated, the results of the SB4-Only and 1200 canister options show no significant deviations from the general trends discussed (see Appendix A for more details).

The impacts (both positive and negative) observed with the ARP-A option are typical of all other ARP options. The difference being the magnitude of the impact which is strictly a result of the ARP nominal sludge composition and the projected blending strategy differences (i.e., volumes or masses). As previously noted, subsequent discussions will highlight the magnitude of these impacts as well as highlight any additional primary differences observed.

6.2 ARP-E

The projected operating windows for the 1100 canister –ARP-E options are provided in Table 6-2. The general trends for these systems are in line with the previous assessment of the ARP-A stream. These include a positive impact for those systems which were initially T_L-limited (without ARP-E included). In general, there is a 2% WL increase for these systems relative to the "non-ARP" based systems shown in Table 5-2. When the systems are low viscosity or durability limited, introduction of ARP-E has a negative impact which ranges from a 1 – 2% WL reduction to complete elimination of the projected operating window. Consider the 1100 canister baseline case when coupled with Frit 417, Frit 320, and Frit 431. When ARP-E is not present (Table 5-2), the projected operating windows are 25 – 45 (T_L), 24 – 44 (low η), and (ΔG_P) 27 – 41 (low η), respectively.[8] When ARP-E is added, the projected operating windows are 25 – 44 (low η), 25 – 42 (low η), and non-existent (no operating window), respectively. The transition from a T_L to low viscosity limited system with Frit 417 is not surprising given the additional Na_2O from the ARP stream which has an anticipated slightly negative impact on the projected window. With Frit 320, including the ARP-E stream continues to lower viscosity and the negative impact to the window (relative to the non-ARP option) is a 2% reduction. With Frit 431, predictions of durability begin to limit lower WLs (i.e., WLs of 26 wt% and lower) in the non-ARP option. When the ARP-E stream is added, the projected operating window is completely eliminated. Although the specific property predictions for each glass within this system are not shown in Appendix A, the previous trends regarding the impacts of ARP suggest that the complete elimination is not associated with viscosity predictions but are durability related. That is, the increase in Na_2O has a significant negative impact on durability predictions to the point of eliminating the use of Frit 431 with the 1100 canister baseline – ARP-E flowsheet. This does not suggest that the ARP-E option should be dismissed, only that if DWPF were using Frit 431 to process the 1100 canister baseline option (without ARP), a frit change would be required to transition to a "coupled" flowsheet

[8] The use of Frit 431 is also limited at lower WLs (26% and less) by predictions of durability as indicated by the ΔG_P listed before the projected operating window.

based on ARP-E.[9] The model predictions also restrict the use of Frit 431 with the “Min Al”, “Max Mg”, and “Max Ti” cases for the ARP-E option.

Based on model predictions, introduction of the ARP-E stream is a viable option for the 1100 canister cases. Although not specifically tabulated, the results of the SB4-Only and 1200 canister options show no significant deviations from the general trends discussed. With respect to the ARP-A option, there is essentially no practical difference in the impacts to the projected windows. A choice between one of these two options should not be influenced by the model predictions, but differences could exist based on CPC processing issues or melt rate.

[9] Frit 431 is a viable candidate for the 1100 canister baseline option without ARP based on the model assessments provided by Peeler and Edwards (2005) and its use may lead to enhanced melt rate given the higher Na_2O concentration. However, the sensitivity of the projected operating windows to slight compositional variation (either due to washing or the addition of an ARP stream) would probably result in this frit not being recommended.

Table 6-2. MAR Results for the SB4 1100 Canister + ARP-E Cases

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 44 (low η)	25 – 42 (low η)	-
2nd transfer baseline	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 45 (T_L)	25 – 44 (low η)	(ΔG_P) 31 – 41 (low η)
Min Al	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L/low η)	25 – 42 (low η)	25 – 39 (low η)	-
Max Al	25 – 54 (T_L)	25 – 55 (T_L)	25 – 55 (low η)	25 – 52 (low η)	25 – 49 (low η)	25 – 46 (low η)
Min Ce	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 43 (low η)
Min Fe	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 47 (T_L)	25 – 45 (low η)
Max Mg	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L/low η)	25 – 44 (low η)	25 – 41 (low η)	-
Max Ni	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L/low η)	-
Max Ti	25 – 52 (T_L)	25 – 53 (T_L)	25 – 51 (low η)	25 – 49 (low η)	25 – 46 (low η)	25 – 43 (low η)

6.3 ARP-K

Table 6-3 summarizes the projected operating windows for the various 1100 canister –ARP-K flowsheets. The most significant observation is that TiO_2 becomes the limiting constraint for almost every system (the exception being the "Min Al" case with Frit 320, where durability limits access to WLs of 36% and higher). Although the TiO_2 content of the calcined ARP-K stream is slightly lower than that of ARP-A (26.4 wt% versus 26.8 wt%, respectively – see Table 4-1 and Appendix A), the ARP stream volume associated with this case is much higher. Therefore, the TiO_2 in the final blended SRAT product (SB4 with ARP-K) is much higher and exceeds the 1 wt% limit at approximately 39% WL (once the MAR uncertainty is applied), regardless of the SB4 blending option or frit selection.

When the TiO_2 limit is increased to 2 wt% in PCCS , the primary properties limiting access to higher WLs transition back to either T_L or low viscosity resulting in "more typical" projected operating windows (see Table 6-4). When comparing the ARP-K impact (with the 2 wt% TiO_2 limit) with the 1100 canister options (shown in Table 5-2), there is a significant, positive impact on the projected windows for those systems which were T_L-limited prior to the introduction of the ARP stream. More specifically, an approximate 4 wt% increase in the upper WL is observed relative to those same systems without ARP added. As observed with ARP-A and ARP-E, when the non-ARP flowsheet is low viscosity limited, the impact of adding the ARP-K stream is typically a 2% WL reduction in the upper WL defining the projected operating window. For those non-ARP systems in which predictions of durability limit some portion of the 25 – 60% window, once the ARP-K stream is added, complete elimination of the projected operating windows occurs. It is also interesting to note that for some of the initial systems (without ARP) that were T_L-limited, addition of ARP-K transitions these systems to durability limited (not low viscosity limited as previously observed) which results in impacts ranging from slight to significant depending on the specific SB4 option and frit being considered. The impact of ARP-K to systems that were low viscosity limited is more significant than observed in previous systems. Again, the results of the SB4-Only and 1200 canister options show no significant deviations from the general trends discussed.

Based on model-predictions, introduction of ARP-K to the SB4 options would require an increase in the current PCCS TiO_2 limit from 1 wt% to 2 wt% (if WLs targeting 39% or greater are desired). With this increase, there appear to be some advantages of this ARP stream relative to the other options (including ARP-M and ARP-V not discussed as of yet). This advantage is based on the ~ 4% increase in the upper WL defining the projected window for most of the options being considered (which were initially T_L limited). Although potentially advantageous for some frit/sludge combinations, the addition of the ARP-K stream could be devastating to other systems if compositional adjustments are not made (i.e., a frit change). Frits could be selected that are robust to the inclusion of the ARP, but they may not be optimized for other properties (e.g., melt rate). Again, this report only assesses the impact on the projected operating windows and the impacts of ARP-K on melt rate or other CPC processing issues must also be considered as part of the overall evaluation.

Table 6-3. MAR Results for the SB4 1100 Canister + ARP-K Cases

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	-
2^{nd} transfer baseline	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	-
Min Al	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 35 (ΔG_P)	-
Max Al	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)
Min Ce	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	(ΔG_P) 31 – 39 (TiO_2)
Min Fe	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	(ΔG_P) 26 – 39 (TiO_2)
Max Mg	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	-
Max Ni	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	-
Max Ti	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	25 – 39 (TiO_2)	(ΔG_P) 30 – 39 (TiO_2)

Table 6-4. MAR Results for the SB4 1100 Canister + ARP-K Cases

(2 wt% TiO_2 Limit)

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 – 46 (T_L)	25 – 47 (T_L)	25 – 46 (low η)	25 – 43 (low η)	25 – 41 (low η)	-
2nd transfer baseline	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 46 (low η)	25 – 43 (low η)	-
Min Al	25 – 44 (T_L)	25 – 45 (T_L)	25 – 44 (low η)	25 – 41 (low η)	25 – 35 (ΔG_P)	-
Max Al	25 – 56 (T_L)	25 – 55 (low η)	25 – 53 (low η)	25 – 51 (low η)	25 – 48 (low η)	25 – 45 (low η)
Min Ce	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L/low η)	(ΔG_P) 31 – 42 (low η)
Min Fe	25 – 45 (T_L)	25 – 46 (T_L)	25 – 47 (T_L)	25 – 48 (T_L)	25 – 46 (low η)	(ΔG_P) 26 – 43 (low η)
Max Mg	25 – 45 (T_L)	25 – 46 (T_L)	25 – 45 (low η)	25 – 43 (low η)	25 – 40 (low η)	-
Max Ni	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 42 (low η)	-
Max Ti	25 – 54 (T_L/low η)	25 – 52 (low η)	25 – 50 (low η)	25 – 48 (low η)	25 – 45 (low η)	(ΔG_P) 30 – 42 (low η)

6.4 ARP-M

Table 6-5 summarizes the projected operating windows for the SB4 1100 canister options with ARP-M. Introduction of ARP-M results in very similar effects as were observed with ARP-A and ARP-E. More specifically, for those systems which were T_L limited without the ARP stream, the upper WL that can be achieved is typically increased by 1 – 2%. For those systems which were low viscosity limited, the introduction of the ARP-M stream results in a slightly negative impact to the upper WL.

As shown in Table 4-1, the TiO_2 concentration in ARP-M is 0.00 wt% therefore, the use of the 1 wt% TiO_2 limit did not constrain any of the windows. As with previous systems, the introduction of additional Na_2O via the ARP stream restricts the use of Frit 431 for most systems. Coupling the high alkali frit with enriched alkali sludges results in predictions of durability shutting down projected operating windows or drastically reducing their size. Although not specifically tabulated, the results of the SB4-Only and 1200 canister options show no significant deviations from the general trends discussed with the inclusion of the ARP-M option.

Table 6-5. MAR Results for the SB4 1100 Canister + ARP-M Cases

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 45 (low η)	25 – 42 (low η)	-
2nd transfer baseline	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 45 (T_L/low η)	(ΔG_P) 31 – 41 (low η)
Min Al	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 42 (low η)	25 – 40 (low η)	-
Max Al	25 – 53 (T_L)	25 – 54 (T_L)	25 – 55 (T_L/low η)	25 – 53 (low η)	25 – 50 (low η)	25 – 47 (low η)
Min Ce	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L/low η)
Min Fe	25 – 43 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 45 (low η)
Max Mg	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 44 (low η)	25 – 41 (low η)	-
Max Ni	25 – 38 (T_L)	25 – 39 (T_L)	25 – 40 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	-
Max Ti	25 – 51 (T_L)	25 – 52 (T_L)	25 – 52 (low η)	25 – 49 (low η)	25 – 47 (low η)	25 – 43 (low η)

6.5 ARP-V

The last ARP stream to be assessed is ARP-V. The projected operating windows for the SB4 1100 canister options with ARP-V are shown in Table 6-6. In general, a ~3% WL increase is shown relative to the 1100 canister options that were T_L limited (see Table 5-2). Again, the enhancement to the projected operating windows is consistent with previous assessments. For those non-ARP based systems that are low viscosity limited, the impact is typically a 2 – 4% reduction in the upper WLs achievable. As previously observed, for those non-ARP systems where durability was an issue, addition of the ARP-V stream results in a dramatic reduction if not complete elimination of the projected operating windows.

Table 6-6. MAR Results for the SB4 1100 Canister + ARP-V Cases

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Baseline	25 – 45 (T_L)	25 – 46 (T_L)	25 – 47 (T_L/low η)	25 – 44 (low η)	25 – 41 (low η)	-
2nd transfer baseline	25 – 43 (T_L)	25 – 44 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 44 (low η)	(ΔG_P) 33 – 41 (low η)
Min Al	25 – 43 (T_L)	25 – 44 (T_L)	25 – 44 (low η)	25 – 42 (low η)	25 – 39 (low η)	-
Max Al	25 – 51 (TiO_2)	25 – 51 (TiO_2)	25 – 51 (TiO_2)	25 – 51 (TiO_2)	25 – 49 (low η)	25 – 46 (low η)
Min Ce	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 43 (T_L)	25 – 44 (T_L)	(ΔG_P) 26 – 43 (low η)
Min Fe	25 – 45 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 47 (T_L)	25 – 47 (T_L)	25 – 44 (low η)
Max Mg	25 – 45 (T_L)	25 – 45 (T_L)	25 – 46 (T_L)	25 – 43 (low η)	25 – 41 (low η)	-
Max Ni	25 – 39 (T_L)	25 – 40 (T_L)	25 – 41 (T_L)	25 – 42 (T_L)	25 – 42 (low η)	-
Max Ti	25 – 51 (TiO_2)	25 – 51 (TiO_2)	25 – 51 (TiO_2/low η)	25 – 49 (low η)	25 – 46 (low η)	25 – 43 (low η)

Other interesting systems based on the ARP-V stream include the "Max Al" and "Max Ti" blending options (see "yellow" shaded cells). The 1 wt% TiO_2 limit becomes the limiting constraint at WLs of 52% or greater for these options (compared to the 39% WL with the ARP-K scenarios – the differences being that the ARP-V blended SRAT product contains significantly less TiO_2 allowing access to higher WLs prior to reaching the 1 wt% limit). If the TiO_2 limit were increased to 2 wt%, the projected operating windows would revert back to being either T_L or low viscosity limited (see Table 6-7) for these two SB4 blending options. The "revised" projected operating windows indicate that upper WLs for these systems could be increased by 1 – 4% (depending upon the frit) with the change to the PCCS TiO_2 constraint. The results of the SB4-Only and 1200 canister options show no significant deviations from the general trends discussed with the inclusion of the ARP-V option.

Table 6-7. MAR Results for the SB4 1100 Canister + ARP-V for the "Max Al" and "Max Ti" Blending Options (2 wt% TiO_2 Limit)

	Frit 418	Frit 426	Frit 425	Frit 417	Frit 320	Frit 431
% Na_2O (in frit)	8	9	10	11	12	13
Max Al	25 – 55 (T_L)	25 – 55 (T_L)	25 – 54 (low η)	25 – 52 (low η)	25 – 49 (low η)	25 – 46 (low η)
Max Ti	25 – 53 (T_L)	25 – 53 (low η)	25 – 51 (low η)	25 – 49 (low η)	25 – 46 (low η)	25 – 43 (low η)

6.6 Impact of SO_4 Solubility

As mentioned in Section 3.0, the PCCS SO_4 limit for SB4 has not been established at this point but it is recognized that there is the potential that this limit could have negative impacts on the projected operating windows. The projected operating windows presented in the previous sections were based on compositions including SO_4 concentrations in glass but an assumed SO_4 limit was not used as a restriction. Given there is no MAR uncertainty associated with the SO_4 concentration, the maximum WL for each SB4 option can be determined as a function of an assumed SO_4 solubility limit based strictly on mathematics (i.e., the assumed SO_4 solubility limit divided by the SO_4 concentration in sludge times 100). For example, the normalized SO_4 concentration in the 1100 canister baseline sludge was 1.099 wt% and assuming the PCCS SO_4 solubility limit was established at 0.4 wt% (in glass), then the maximum WL achievable (based strictly on the SO_4 solubility limit) would be 36.4%. Table 5-2 indicates that the projected operating windows range from 25% WL to 42% (or greater) for most of the frits evaluated. Imposing a 0.4 wt% SO_4 limit, these windows would transition from T_L or low viscosity limited to SO_4 limited at 36% WL. That is, regardless of the frit compositions utilized, the operating windows would be restricted to 36% or less for the 1100 canister baseline sludge. Increasing the PCCS SO_4 limit to 0.5 or 0.6 wt% allows WLs of 45 and 55%, respectively, prior to SO_4 becoming a limiting constraint. These SO_4 solubility limits do not restrict the projected operating windows. Table 6-8 summarizes the maximum WLs achievable for the 1100 canister baseline options with and without the 5 ARP streams as a function of an assumed PCCS SO_4 limit. Given each of the ARP options adds SO_4 to the flowsheet, the impact on the projected operating windows relative to the 1100 canister baseline case (without ARP) is negative for a given (or assumed) SO_4 limit. The projected operating windows are negatively affected with both the 0.4 and 0.5 wt% limits – one possible exception is the ARP-A case at a 0.5 wt% limit when coupled with select frits. However, using a 0.6 wt% limit the projected operating windows are not SO_4 limited but transition back to either T_L or low viscosity limited systems.

Appendix C summarizes the maximum WLs achievable for all of the SB4 blending options with each of the ARP streams as a function of the assumed SO_4 solubility limits. Obviously, the number of comparisons that could be made are large but the information is provided so specific systems could be evaluated as warranted.

Table 6-8. The Impact of SO_4 of the Projected Operating Windows

Type	Sludge SO_4 (wt%)	MAX WL 0.4	MAX WL 0.5	MAX WL 0.6
1100 Can Baseline	1.099	36.4	45.5	54.6
SB4 1100 Can Baseline + ARP-A SRAT Product Solids	1.131	35.4	44.2	53.0
SB4 1100 Can Baseline + ARP-E SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 1100 Can Baseline + ARP-K SRAT Product Solids	1.264	31.7	39.6	47.5
SB4 1100 Can Baseline + ARP-M SRAT Product Solids	1.212	33.0	41.3	49.5
SB4 1100 Can Baseline + ARP-V SRAT Product Solids	1.223	32.7	40.9	49.0

6.7 Impact of "Troublesome" Components on Model Applicability

One of the secondary objectives of this evaluation was to assess potential issues associated with model applicability and/or individual solubility limits with the introduction of the ARP streams. More specifically, based on the blending strategies, the additions of TiO_2 and SO_4 from the ARP streams could result in these oxides exceeding some critical value that would give rise to uncertainties or questions associated with the applicability of select models or exceeding individual solubility limits. In Section 6.6, issues associated with SO_4 as they relate to assumed SO_4 limits in PCCS were discussed. In general, SO_4 limits of 0.5 and 0.6 wt% (in glass) appear to be sufficient to avoid the SB4 – ARP systems from being SO_4 limited at the upper WLs.

With respect to model applicability issues, the primary PCCS model of concern was the T_L model which was developed over TiO_2 concentrations ranging from 0.0 – 1.8549 wt% (in glass). Based on the projected blending strategies and TiO_2 concentrations, model applicability issues are of minimal concern. More specifically, the maximum TiO_2 concentrations in glass are well below the 2 wt% limit established by Lorier and Jantzen (2003).

7.0 SUMMARY

The model-based assessments of nominal Sludge Batch 4 (SB4) compositions suggest that a viable frit candidate does not appear to be a limiting factor as the Closure Business Unit (CBU) considers various tank blending options for SB4 with or without the Actinide Removal Process (ARP) streams. This statement is based solely on the projected operating windows derived from model predictions and does not include experimental assessments of SO_4 solubility or melt rate issues. The viable frit candidates covered a range of Na_2O concentrations (from 8% to 13%) using a "sliding Na_2O scale" concept (i.e., 1% increase in Na_2O being balanced by a 1% reduction in SiO_2) which effectively balanced the alkali content of the incoming sludge with that in the frit to maintain and/or increase the projected operating window size while potentially leading to improved melt rate and/or waste loadings. This strategy or approach allows alternative tank blending strategies to be considered and accounted for in an effective manner without wholesale changes to the frit composition.

To assess the impact of the various ARP options on the projected operating windows, the 1100 canister SB4 baseline options served as the technical baseline or reference point for the comparisons. With respect to the various ARP options being considered, the impacts to the projected operating windows were relatively consistent. For those 1100 canister SB4 systems (without ARP) which were T_L-limited, the general impact was an increase in the upper WL which was classified as acceptable resulting in an overall increase in the operating window size. The anticipated negative impact of TiO_2 (due to an assumed increase in T_L which would further reduce the size of the operating window of such systems) was not observed. The hypothesis is that the negative impact was countered or compensated by a positive impact due to the additional Na_2O from the ARP process. The overall result was a net increase in the size of the operating window for the SB4 1100 canister options which were T_L-limited. This trend was observed for all five ARP options with the only difference being the magnitude of the increase (ranging from a 1% - 4% increase) which was strictly based on the specific ARP composition and blending strategy.

Another general observation for all five ARP options was a negative impact with their addition to a 1100 canister system that was initially low viscosity limited or durability limited. For these systems, addition of each ARP stream resulted in a negative impact to the upper WL defining the operating window as a result of the additional Na_2O introduced which drove both viscosity and durability predictions lower at the same WL. The magnitude of the impact ranged from a 1 – 2% reduction for low viscosity limited systems to complete elimination of the operating windows for durability limited systems. The latter situation (i.e., complete elimination of the operating window for a given SB4 blending option with a specified frit) would require a change in frit to compositionally compensate for the ARP addition.

One of the most interesting ARP options was the introduction of the ARP-K case. Model-based predictions and projected TiO_2 concentrations, would require an increase in the current PCCS TiO_2 limit from 1 wt% to 2 wt% (if WLs targeting 39% or greater are desired). With this increase, there appears to be some potential advantages of this ARP stream relative to the other four ARP options. One potential advantage is based on the ~ 4% increase in the upper WL defining the projected window for most of the options being considered (which were initially T_L limited). Although potentially advantageous for some systems, the addition of the ARP-K stream could be devastating to other systems if compositional adjustments are not made (i.e., a frit change). Frits could be selected that are robust to the inclusion of the ARP but they may not be optimized for other properties (e.g., melt rate).

Although ARP-K has potential advantages on the projected operating windows, the other ARP options evaluated should not be dismissed as other criteria (e.g., melt rate and/or CPC processing issues) should be considered prior to pursuing a particular ARP processing scenario. More specifically, based on the assessments performed in this report, there are no show-stoppers for any of the ARP options being considered – although some options could require a frit change between a "sludge-only" flowsheet and its "coupled" (sludge plus ARP) counterpart.

Based on the SB4 – ARP blending strategies, the additions of TiO_2 and SO_4 from the ARP streams could result in these oxides exceeding some critical value that would give rise to uncertainties or questions associated with the applicability of select models or exceeding individual solubility limits. In general, establishing a PCCS SO_4 limit of 0.5 or 0.6 wt% (in glass) appears to be sufficient to avoid the SB4 – ARP systems from being SO_4 limited at the upper WLs. With respect to model applicability issues, the primary PCCS model of concern was the T_L model which was developed over TiO_2 concentrations ranging from 0.0 – 1.8549 wt% (in glass). Although the ARP- K option would require the TiO_2 limit to be raised to 2.0 wt%, maximum TiO_2 concentrations in glass are well below the 2 wt% limit established by Lorier and Jantzen (2003).

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APPENDIX A

Projected SB4 and ARP SRAT Compositions

Table A.1 – Projected SRAT Products with ARP-A.

	SB4 Baseline	**SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U**	**SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U**	**SB4 1100 Can Baseline**	**SB4 1100 Can 2nd Transfer, Baseline**	**SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U**	**SB4 1100 Can Max Al, Na; Min Mn, Ni, U**	**SB4 1100 Can Min Ce, Mg, Ti**	**SB4 1100 Can Min Fe**	**SB4 1100 Can Max Mg**
Al_2O_3	30.6	25.2	45.9	22.4	24.8	19.3	31.1	26.1	28.1	21.4
BaO	0.185	0.223	0.081	0.160	0.167	0.175	0.107	0.183	0.156	0.161
CaO	1.65	1.58	1.71	2.21	2.01	2.24	2.19	1.78	1.89	2.24
Ce_2O_3	0.190	0.187	0.189	0.207	0.200	0.208	0.205	0.191	0.193	0.207
Cr_2O_3	0.282	0.299	0.235	0.249	0.258	0.254	0.227	0.270	0.253	0.246
CuO	0.078	0.084	0.057	0.083	0.081	0.086	0.071	0.079	0.074	0.082
Fe_2O_3	20.3	21.8	15.2	25.8	23.8	27.0	22.5	22.0	22.0	26.3
K_2O	1.88	1.47	3.01	1.01	1.27	0.748	1.68	1.46	1.54	0.892
La_2O_3	0.079	0.080	0.068	0.092	0.087	0.095	0.085	0.081	0.081	0.092
MgO	0.348	0.330	0.404	1.91	1.40	2.06	1.80	0.862	1.23	2.11
MnO	5.12	5.90	3.30	5.82	5.55	6.24	4.78	5.51	5.36	6.08
Na_2O	20.4	19.8	21.8	22.4	22.3	22.1	23.2	22.1	22.5	22.3
NiO	5.78	7.65	1.25	3.67	4.31	4.28	1.46	5.52	4.21	3.74
PbO	0.199	0.172	0.263	0.165	0.174	0.150	0.201	0.176	0.182	0.156
SO_4	1.13	1.13	1.14	1.13	1.13	1.13	1.14	1.13	1.13	1.13
SiO_2	2.37	2.02	3.32	2.69	2.57	2.58	3.16	2.35	2.64	2.71
ThO_2	0.039	0.030	0.065	0.034	0.036	0.030	0.048	0.035	0.040	0.034
TiO_2	0.520	0.517	0.528	0.528	0.525	0.528	0.532	0.522	0.525	0.529
U_3O_8	8.50	11.0	1.21	9.16	8.88	10.4	5.24	9.14	7.59	9.27
ZnO	0.113	0.125	0.065	0.127	0.122	0.134	0.100	0.116	0.105	0.124
ZrO_2	0.315	0.336	0.235	0.277	0.287	0.284	0.237	0.299	0.268	0.266

Table A.1 – Projected SRAT Products with ARP-A.

	SB4 1100 Can Max Ni	SB4 1100 Can Max Ti	SB4 1200 Can Baseline	SB4 1200 Can 2nd Transfer Baseline	SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U	SB4 1200 Can Max	SB4 1200 Can Min Ce	SB4 1200 Can Min Mg, Ti	SB4 1200 Can Max Mg, Ti
Al_2O_3	22.1	28.1	23.9	25.2	20.3	32.7	22.1	28.2	26.0	29.8
BaO	0.198	0.114	0.164	0.168	0.183	0.103	0.198	0.156	0.182	0.110
CaO	1.87	2.30	2.08	1.98	2.11	2.12	1.87	1.88	1.79	2.23
Ce_2O_3	0.195	0.209	0.202	0.198	0.203	0.201	0.194	0.192	0.191	0.206
Cr_2O_3	0.274	0.226	0.254	0.259	0.261	0.226	0.274	0.253	0.269	0.226
CuO	0.084	0.075	0.081	0.080	0.085	0.069	0.084	0.073	0.079	0.072
Fe_2O_3	24.0	24.2	24.5	23.5	25.9	21.5	23.9	21.8	22.2	23.2
K_2O	1.11	1.40	1.18	1.32	0.878	1.83	1.12	1.56	1.44	1.56
La_2O_3	0.086	0.090	0.089	0.086	0.091	0.083	0.086	0.080	0.082	0.087
MgO	1.14	2.11	1.58	1.31	1.73	1.62	1.13	1.20	0.904	1.93
MnO	5.98	5.12	5.65	5.51	6.16	4.60	5.99	5.35	5.53	4.94
Na_2O	21.9	23.0	22.3	22.3	22.0	23.3	21.9	22.5	22.2	23.1
NiO	5.98	1.51	4.08	4.42	4.89	1.43	5.99	4.24	5.46	1.48
PbO	0.160	0.189	0.170	0.175	0.153	0.207	0.159	0.182	0.175	0.195
SO_4	1.13	1.14	1.13	1.13	1.13	1.14	1.13	1.13	1.13	1.14
SiO_2	2.25	3.14	2.62	2.56	2.47	3.17	2.26	2.64	2.37	3.16
ThO_2	0.030	0.045	0.035	0.036	0.029	0.050	0.029	0.040	0.035	0.046
TiO_2	0.522	0.532	0.526	0.525	0.526	0.531	0.522	0.525	0.522	0.532
U_3O_8	10.6	6.13	8.99	8.84	10.4	4.74	10.6	7.56	9.15	5.63
ZnO	0.128	0.109	0.123	0.120	0.131	0.095	0.127	0.104	0.117	0.103
ZrO_2	0.307	0.239	0.282	0.287	0.290	0.234	0.306	0.267	0.297	0.236

Table A.2 – Projected SRAT Products with ARP-E.

	SB4 Baseline	SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	SB4 1100 Can Baseline	SB4 1100 Can 2nd Transfer, Baseline	SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1100 Can Max Al, Na; Min Mn, Ni, U	SB4 1100 Can Min Ce, Mg, Ti	SB4 1100 Can Min Fe	SB4 1100 Can Max Mg
Al_2O_3	29.6	24.4	44.1	21.7	24.0	18.8	30.0	25.3	27.1	20.8
BaO	0.182	0.219	0.083	0.159	0.165	0.173	0.108	0.181	0.155	0.159
CaO	1.64	1.58	1.70	2.18	1.99	2.21	2.15	1.76	1.88	2.20
Ce_2O_3	0.192	0.190	0.191	0.209	0.202	0.210	0.207	0.193	0.196	0.209
Cr_2O_3	0.277	0.292	0.231	0.245	0.253	0.250	0.223	0.265	0.249	0.242
CuO	0.078	0.083	0.057	0.082	0.080	0.085	0.071	0.078	0.073	0.081
Fe_2O_3	20.2	21.6	15.3	25.4	23.5	26.6	22.3	21.8	21.8	25.9
K_2O	1.80	1.41	2.88	0.967	1.22	0.720	1.60	1.40	1.47	0.857
La_2O_3	0.080	0.081	0.070	0.093	0.088	0.095	0.086	0.082	0.082	0.093
MgO	0.339	0.322	0.392	1.83	1.34	1.97	1.72	0.828	1.18	2.02
MnO	5.20	5.94	3.46	5.86	5.61	6.27	4.87	5.57	5.43	6.11
Na_2O	21.2	20.7	22.6	23.1	23.1	22.8	23.9	22.9	23.2	23.0
NiO	5.61	7.39	1.29	3.59	4.20	4.18	1.48	5.35	4.11	3.66
PbO	0.198	0.172	0.259	0.165	0.174	0.152	0.200	0.176	0.182	0.157
SO_4	1.23	1.22	1.24	1.23	1.23	1.23	1.23	1.23	1.23	1.23
SiO_2	2.31	1.97	3.21	2.61	2.50	2.50	3.06	2.29	2.57	2.63
ThO_2	0.037	0.029	0.062	0.033	0.034	0.028	0.046	0.033	0.038	0.032
TiO_2	1.17	1.17	1.18	1.18	1.18	1.18	1.19	1.18	1.18	1.18
U_3O_8	8.33	10.8	1.38	8.96	8.69	10.1	5.22	8.94	7.46	9.06
ZnO	0.113	0.124	0.067	0.126	0.121	0.133	0.101	0.116	0.106	0.124
ZrO_2	0.314	0.335	0.238	0.278	0.288	0.284	0.240	0.299	0.270	0.268

Table A.2 – Projected SRAT Products with ARP-E.

	SB4 1100 Can Max Ni	SB4 1100 Can Max Ti	SB4 1200 Can Baseline	SB4 1200 Can 2nd Transfer Baseline	SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U	SB4 1200 Can Max	SB4 1200 Can Min Ce	SB4 1200 Can Min Mg, Ti	SB4 1200 Can Max Mg, Ti
Al_2O_3	21.5	27.1	23.2	24.4	19.7	31.6	21.5	27.3	25.1	28.8
BaO	0.195	0.114	0.162	0.166	0.180	0.105	0.195	0.154	0.180	0.110
CaO	1.85	2.26	2.05	1.96	2.08	2.09	1.85	1.86	1.78	2.20
Ce_2O_3	0.197	0.211	0.204	0.201	0.205	0.203	0.197	0.195	0.194	0.208
Cr_2O_3	0.269	0.223	0.250	0.254	0.256	0.223	0.269	0.249	0.264	0.223
CuO	0.083	0.074	0.080	0.079	0.084	0.069	0.083	0.073	0.078	0.072
Fe_2O_3	23.7	23.9	24.2	23.2	25.6	21.4	23.7	21.7	22.0	23.0
K_2O	1.07	1.34	1.13	1.26	0.84	1.75	1.07	1.49	1.38	1.49
La_2O_3	0.087	0.090	0.089	0.087	0.092	0.084	0.086	0.081	0.083	0.087
MgO	1.09	2.02	1.52	1.26	1.66	1.56	1.08	1.15	0.868	1.85
MnO	6.02	5.20	5.71	5.57	6.19	4.70	6.03	5.42	5.59	5.03
Na_2O	22.6	23.7	23.1	23.1	22.8	24.0	22.6	23.2	22.9	23.8
NiO	5.79	1.53	3.98	4.31	4.76	1.46	5.81	4.14	5.30	1.50
PbO	0.160	0.188	0.171	0.175	0.154	0.206	0.160	0.182	0.175	0.194
SO_4	1.22	1.23	1.23	1.23	1.23	1.23	1.22	1.23	1.23	1.23
SiO_2	2.20	3.04	2.55	2.48	2.40	3.07	2.20	2.56	2.30	3.06
ThO_2	0.028	0.043	0.033	0.034	0.028	0.047	0.028	0.038	0.033	0.044
TiO_2	1.18	1.19	1.18	1.18	1.18	1.19	1.18	1.18	1.18	1.19
U_3O_8	10.3	6.07	8.79	8.65	10.2	4.74	10.3	7.43	8.95	5.59
ZnO	0.127	0.109	0.122	0.120	0.130	0.096	0.126	0.105	0.116	0.103
ZrO_2	0.307	0.242	0.282	0.288	0.290	0.237	0.306	0.269	0.297	0.239

Table A.3 – Projected SRAT Products with ARP-K.

	SB4 Baseline	SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	SB4 1100 Can Baseline	SB4 1100 Can 2nd Transfer, Baseline	SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1100 Can Max Al, Na; Min Mn, Ni, U	SB4 1100 Can Min Ce, Mg, Ti	SB4 1100 Can Min Fe	SB4 1100 Can Max Mg
Al_2O_3	28.8	23.8	43.0	21.2	23.4	18.3	29.2	24.7	26.4	20.2
BaO	0.177	0.213	0.081	0.155	0.161	0.169	0.106	0.176	0.151	0.155
CaO	1.60	1.54	1.66	2.12	1.94	2.15	2.10	1.72	1.83	2.15
Ce_2O_3	0.188	0.185	0.187	0.204	0.197	0.205	0.202	0.189	0.191	0.204
Cr_2O_3	0.269	0.285	0.225	0.239	0.247	0.243	0.218	0.258	0.242	0.236
CuO	0.076	0.081	0.056	0.080	0.078	0.083	0.069	0.076	0.072	0.079
Fe_2O_3	19.6	21.1	14.9	24.7	22.9	25.9	21.8	21.3	21.2	25.2
K_2O	1.75	1.37	2.80	0.941	1.19	0.701	1.56	1.36	1.43	0.835
La_2O_3	0.078	0.079	0.068	0.091	0.086	0.093	0.084	0.080	0.080	0.090
MgO	0.330	0.313	0.382	1.77	1.30	1.92	1.67	0.805	1.15	1.96
MnO	5.08	5.80	3.39	5.72	5.48	6.12	4.76	5.44	5.30	5.97
Na_2O	21.9	21.3	23.2	23.7	23.7	23.5	24.5	23.5	23.8	23.6
NiO	5.45	7.19	1.26	3.50	4.09	4.07	1.45	5.21	4.00	3.56
PbO	0.193	0.168	0.252	0.161	0.170	0.148	0.195	0.172	0.177	0.154
SO_4	1.26	1.26	1.27	1.26	1.26	1.26	1.27	1.26	1.27	1.26
SiO_2	2.25	1.92	3.13	2.54	2.43	2.44	2.97	2.23	2.50	2.56
ThO_2	0.036	0.028	0.060	0.032	0.033	0.028	0.044	0.032	0.037	0.031
TiO_2	2.44	2.43	2.44	2.44	2.44	2.44	2.45	2.44	2.44	2.44
U_3O_8	8.11	10.5	1.36	8.72	8.46	9.83	5.09	8.70	7.27	8.82
ZnO	0.110	0.121	0.066	0.123	0.118	0.130	0.098	0.113	0.103	0.121
ZrO_2	0.307	0.326	0.232	0.272	0.281	0.278	0.235	0.292	0.263	0.262

Table A.3 – Projected SRAT Products with ARP-K.

	SB4 1100 Can Max Ni	SB4 1100 Can Max Ti	SB4 1200 Can Baseline	SB4 1200 Can 2nd Transfer Baseline	SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U	SB4 1200 Can Max	SB4 1200 Can Min Ce	SB4 1200 Can Min Mg, Ti	SB4 1200 Can Max Mg, Ti
Al_2O_3	20.9	26.4	22.6	23.8	19.3	30.8	21.0	26.6	24.5	28.0
BaO	0.190	0.112	0.158	0.162	0.176	0.102	0.190	0.151	0.175	0.108
CaO	1.81	2.21	2.00	1.91	2.02	2.04	1.80	1.81	1.73	2.14
Ce_2O_3	0.192	0.206	0.199	0.196	0.200	0.199	0.192	0.190	0.189	0.203
Cr_2O_3	0.262	0.217	0.243	0.248	0.249	0.217	0.261	0.242	0.257	0.217
CuO	0.081	0.072	0.079	0.078	0.082	0.067	0.081	0.071	0.076	0.070
Fe_2O_3	23.1	23.3	23.6	22.6	24.9	20.8	23.1	21.1	21.4	22.4
K_2O	1.04	1.30	1.10	1.23	0.822	1.70	1.04	1.45	1.34	1.45
La_2O_3	0.085	0.088	0.087	0.085	0.089	0.082	0.084	0.079	0.081	0.085
MgO	1.06	1.96	1.47	1.22	1.61	1.51	1.05	1.12	0.844	1.79
MnO	5.88	5.08	5.57	5.44	6.04	4.59	5.88	5.29	5.46	4.91
Na_2O	23.3	24.3	23.7	23.7	23.4	24.5	23.3	23.8	23.5	24.4
NiO	5.63	1.50	3.88	4.19	4.63	1.42	5.65	4.03	5.15	1.47
PbO	0.157	0.184	0.166	0.171	0.150	0.201	0.156	0.177	0.171	0.189
SO_4	1.26	1.27	1.26	1.26	1.26	1.27	1.26	1.27	1.26	1.27
SiO_2	2.14	2.96	2.48	2.42	2.34	2.99	2.14	2.50	2.24	2.97
ThO_2	0.027	0.041	0.032	0.033	0.027	0.046	0.027	0.037	0.032	0.043
TiO_2	2.44	2.45	2.44	2.44	2.44	2.45	2.44	2.44	2.44	2.45
U_3O_8	10.0	5.92	8.56	8.42	9.90	4.63	10.0	7.24	8.71	5.45
ZnO	0.124	0.106	0.119	0.117	0.127	0.093	0.123	0.102	0.113	0.101
ZrO_2	0.300	0.237	0.276	0.281	0.283	0.232	0.299	0.262	0.290	0.233

Table A.4 – Projected SRAT Products with ARP-M.

	SB4 Baseline	SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	SB4 1100 Can Baseline	SB4 1100 Can 2nd Transfer, Baseline	SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1100 Can Max Al, Na; Min Mn, Ni, U	SB4 1100 Can Min Ce, Mg, Ti	SB4 1100 Can Min Fe	SB4 1100 Can Max Mg
Al_2O_3	30.0	24.8	44.8	22.1	24.4	19.1	30.4	25.7	27.5	21.1
BaO	0.186	0.223	0.085	0.162	0.168	0.177	0.111	0.184	0.158	0.162
CaO	1.67	1.61	1.73	2.22	2.03	2.25	2.20	1.80	1.91	2.25
Ce_2O_3	0.197	0.195	0.196	0.214	0.207	0.215	0.212	0.198	0.201	0.214
Cr_2O_3	0.282	0.298	0.236	0.250	0.258	0.254	0.228	0.270	0.253	0.247
CuO	0.079	0.085	0.059	0.084	0.082	0.087	0.072	0.080	0.075	0.083
Fe_2O_3	20.6	22.1	15.7	25.9	24.0	27.2	22.8	22.3	22.3	26.4
K_2O	1.82	1.43	2.91	0.981	1.24	0.73	1.63	1.42	1.49	0.870
La_2O_3	0.082	0.083	0.072	0.095	0.090	0.097	0.088	0.084	0.084	0.095
MgO	0.345	0.327	0.399	1.85	1.36	2.00	1.74	0.841	1.20	2.04
MnO	5.33	6.09	3.57	6.00	5.75	6.41	5.00	5.70	5.57	6.26
Na_2O	21.0	20.4	22.4	22.9	22.9	22.6	23.7	22.7	23.0	22.8
NiO	5.70	7.50	1.33	3.66	4.28	4.25	1.52	5.44	4.18	3.73
PbO	0.202	0.176	0.264	0.169	0.178	0.155	0.204	0.180	0.186	0.161
SO_4	1.21	1.21	1.22	1.21	1.21	1.21	1.22	1.21	1.21	1.21
SiO_2	2.35	2.01	3.27	2.66	2.54	2.55	3.10	2.33	2.61	2.68
ThO_2	0.038	0.029	0.063	0.033	0.034	0.029	0.046	0.034	0.039	0.032
TiO_2	0.012	0.009	0.020	0.020	0.017	0.020	0.024	0.014	0.018	0.021
U_3O_8	8.48	10.9	1.44	9.12	8.85	10.3	5.33	9.10	7.60	9.22
ZnO	0.115	0.127	0.069	0.129	0.124	0.136	0.103	0.119	0.108	0.126
ZrO_2	0.321	0.342	0.244	0.285	0.294	0.291	0.246	0.306	0.276	0.274

Table A.4 – Projected SRAT Products with ARP-M.

	SB4 1100 Can Max Ni	SB4 1100 Can Max Ti	SB4 1200 Can Baseline	SB4 1200 Can 2nd Transfer Baseline	SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U	SB4 1200 Can Max	SB4 1200 Can Min Ce	SB4 1200 Can Min Mg, Ti	SB4 1200 Can Max Mg, Ti
Al_2O_3	21.8	27.5	23.6	24.8	20.1	32.1	21.8	27.7	25.5	29.2
BaO	0.199	0.117	0.166	0.169	0.184	0.107	0.198	0.158	0.183	0.113
CaO	1.89	2.31	2.09	1.99	2.12	2.13	1.89	1.90	1.81	2.24
Ce_2O_3	0.202	0.216	0.209	0.206	0.210	0.208	0.201	0.200	0.198	0.213
Cr_2O_3	0.274	0.227	0.255	0.259	0.261	0.228	0.274	0.253	0.269	0.227
CuO	0.085	0.076	0.082	0.081	0.086	0.070	0.084	0.075	0.080	0.073
Fe_2O_3	24.2	24.4	24.7	23.7	26.1	21.8	24.1	22.1	22.4	23.5
K_2O	1.08	1.36	1.15	1.28	0.856	1.78	1.09	1.51	1.40	1.51
La_2O_3	0.089	0.092	0.091	0.089	0.094	0.086	0.088	0.083	0.085	0.090
MgO	1.11	2.04	1.54	1.28	1.68	1.58	1.10	1.17	0.881	1.87
MnO	6.17	5.34	5.85	5.71	6.34	4.83	6.17	5.56	5.73	5.16
Na_2O	22.4	23.6	22.9	22.9	22.6	23.8	22.4	23.0	22.7	23.6
NiO	5.89	1.57	4.06	4.38	4.84	1.49	5.90	4.21	5.39	1.54
PbO	0.164	0.193	0.175	0.179	0.158	0.210	0.164	0.186	0.180	0.198
SO_4	1.21	1.22	1.21	1.21	1.21	1.22	1.21	1.21	1.21	1.22
SiO_2	2.23	3.09	2.59	2.53	2.44	3.12	2.24	2.61	2.34	3.11
ThO_2	0.029	0.043	0.034	0.034	0.028	0.048	0.028	0.039	0.034	0.045
TiO_2	0.014	0.025	0.019	0.017	0.018	0.023	0.014	0.018	0.014	0.024
U_3O_8	10.5	6.20	8.95	8.81	10.4	4.85	10.5	7.57	9.11	5.71
ZnO	0.130	0.111	0.125	0.122	0.133	0.098	0.129	0.107	0.119	0.106
ZrO_2	0.314	0.248	0.289	0.294	0.297	0.243	0.313	0.275	0.304	0.245

Table A.5 – Projected SRAT Products with ARP-V.

	SB4 Baseline	SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	SB4 1100 Can Baseline	SB4 1100 Can 2nd Transfer, Baseline	SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1100 Can Max Al, Na; Min Mn, Ni, U	SB4 1100 Can Min Ce, Mg, Ti	SB4 1100 Can Min Fe	SB4 1100 Can Max Mg
Al_2O_3	29.4	24.3	43.9	21.5	23.8	18.6	29.8	25.1	26.9	20.6
BaO	0.180	0.216	0.081	0.157	0.163	0.171	0.106	0.178	0.152	0.157
CaO	1.61	1.55	1.67	2.15	1.96	2.18	2.13	1.74	1.85	2.18
Ce_2O_3	0.188	0.186	0.188	0.205	0.198	0.206	0.203	0.189	0.192	0.205
Cr_2O_3	0.273	0.289	0.228	0.242	0.250	0.246	0.220	0.262	0.246	0.239
CuO	0.077	0.082	0.056	0.081	0.079	0.084	0.070	0.077	0.072	0.080
Fe_2O_3	19.8	21.3	15.0	25.1	23.2	26.3	22.0	21.5	21.5	25.5
K_2O	1.79	1.40	2.86	0.962	1.22	0.716	1.60	1.39	1.47	0.853
La_2O_3	0.078	0.080	0.068	0.091	0.086	0.093	0.085	0.081	0.080	0.091
MgO	0.335	0.318	0.389	1.82	1.33	1.96	1.71	0.823	1.17	2.01
MnO	5.09	5.83	3.36	5.75	5.50	6.15	4.77	5.46	5.32	6.00
Na_2O	21.4	20.9	22.8	23.3	23.3	23.0	24.1	23.1	23.4	23.2
NiO	5.56	7.33	1.26	3.55	4.16	4.13	1.45	5.31	4.06	3.62
PbO	0.195	0.169	0.255	0.163	0.171	0.149	0.197	0.173	0.179	0.155
SO_4	1.22	1.22	1.23	1.22	1.22	1.22	1.23	1.22	1.22	1.22
SiO_2	2.29	1.95	3.19	2.59	2.47	2.48	3.03	2.27	2.54	2.61
ThO_2	0.037	0.029	0.062	0.032	0.034	0.028	0.046	0.033	0.038	0.032
TiO_2	1.84	1.84	1.85	1.85	1.85	1.85	1.85	1.84	1.85	1.85
U_3O_8	8.23	10.6	1.31	8.86	8.59	9.99	5.14	8.84	7.37	8.96
ZnO	0.111	0.122	0.066	0.125	0.119	0.131	0.099	0.114	0.104	0.122
ZrO_2	0.309	0.329	0.233	0.273	0.283	0.279	0.236	0.294	0.265	0.263

Table A.5 – Projected SRAT Products with ARP-V.

	SB4 1100 Can Max Ni	SB4 1100 Can Max Ti	SB4 1200 Can Baseline	SB4 1200 Can 2nd Transfer Baseline	SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U	SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U	SB4 1200 Can Max	SB4 1200 Can Min Ce	SB4 1200 Can Min Mg, Ti	SB4 1200 Can Max Mg, Ti
Al_2O_3	21.3	26.9	23.0	24.2	19.6	31.4	21.3	27.1	25.0	28.6
BaO	0.192	0.112	0.160	0.163	0.178	0.103	0.192	0.152	0.177	0.108
CaO	1.83	2.24	2.03	1.93	2.05	2.06	1.82	1.83	1.75	2.17
Ce_2O_3	0.193	0.207	0.200	0.197	0.201	0.200	0.193	0.191	0.190	0.204
Cr_2O_3	0.266	0.220	0.247	0.251	0.253	0.220	0.265	0.246	0.261	0.220
CuO	0.082	0.073	0.079	0.078	0.083	0.068	0.082	0.072	0.077	0.071
Fe_2O_3	23.4	23.6	23.9	22.9	25.2	21.1	23.3	21.3	21.6	22.7
K_2O	1.06	1.33	1.12	1.26	0.84	1.74	1.07	1.48	1.37	1.48
La_2O_3	0.085	0.089	0.088	0.085	0.090	0.082	0.085	0.080	0.081	0.086
MgO	1.08	2.00	1.51	1.25	1.65	1.55	1.076	1.142	0.863	1.838
MnO	5.91	5.10	5.60	5.46	6.08	4.59	5.92	5.31	5.48	4.92
Na_2O	22.8	23.9	23.3	23.3	23.0	24.1	22.8	23.4	23.1	24.0
NiO	5.74	1.50	3.94	4.26	4.71	1.42	5.76	4.10	5.25	1.47
PbO	0.158	0.185	0.168	0.172	0.151	0.203	0.157	0.179	0.172	0.191
SO_4	1.22	1.23	1.22	1.22	1.22	1.23	1.22	1.22	1.22	1.23
SiO_2	2.17	3.01	2.52	2.46	2.38	3.04	2.17	2.54	2.28	3.03
ThO_2	0.028	0.042	0.033	0.034	0.028	0.047	0.028	0.038	0.033	0.044
TiO_2	1.84	1.85	1.85	1.85	1.85	1.85	1.84	1.85	1.84	1.85
U_3O_8	10.2	5.98	8.69	8.55	10.1	4.66	10.21	7.34	8.85	5.50
ZnO	0.125	0.107	0.120	0.118	0.128	0.094	0.124	0.103	0.114	0.101
ZrO_2	0.302	0.238	0.277	0.283	0.285	0.233	0.301	0.264	0.292	0.234

APPENDIX B

Results of MAR Assessments for SB4 Options

Table B.1. MAR Results and Various Predicted Properties for the Nominal SB4 Blending Options.

Type	Frit ID	Min WL	Max WL	Limited Below By	Limited Above By	Del Gp (min)	Visc (min)	TL (min)	Del Gp (max)	Visc (max)	TL (max)
SB4 Only Baseline	320	25	40		TL	-11.6951	50.37	790.7	-10.8755	66.81	1000.1
SB4 Only Baseline	417	25	39		TL	-11.0022	59.3	801.9	-10.3665	76.71	998.2
SB4 Only Baseline	418	33	36	hvisc	TL	-8.7817	94.1	956	-8.7286	99.65	994.1
SB4 Only Baseline	425	25	38		TL	-10.3092	69.48	813.5	-9.839	87.75	996.6
SB4 Only Baseline	426	25	37		TL	-9.6162	81.04	825.5	-9.2931	100.03	995.2
SB4 Only Baseline	431	25	40		TL	-12.3881	43.6	779.8	-11.4299	57.97	990.6
SB4 Only Baseline	441	30	42	Del Gp	TL	-13.3623	30.72	837.9	-12.3739	39.66	995.7
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	320	25	60			-10.7009	90.55	721.4	-7.3962	95.19	971.9
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	417	.	.			.	.	.	.	.	.
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	418	.	.			.	.	.	.	.	.
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	425	.	.			.	.	.	.	.	.
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	426	.	.			.	.	.	.	.	.
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	431	25	60			-11.3938	78.95	713.5	-7.7658	83.64	968.9
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	441	25	60			-12.7798	59.3	698.2	-8.505	63.89	962.8
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	320	25	35		TL	-12.0464	47.53	817.8	-11.6404	60.27	984.8
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	417	25	35		TL	-11.3534	54.8	830.5	-11.0398	69.32	997.1
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	418	27	32	hvisc	TL	-9.2672	88.53	907.4	-9.249	99.03	990.6
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	425	25	34		TL	-10.6604	64.61	843.6	-10.4614	79.42	994.7
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	426	25	33		TL	-9.9674	75.81	857.2	-9.8644	90.67	992.5
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	431	25	36		TL	-12.7394	39.94	805.6	-12.1912	52.21	987.9
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	441	36	38	Del Gp	TL	-13.3739	27.72	965	-13.2373	29.43	994.7
1100 Can Baseline	320	25	44		lvisc	-12.7645	24.51	741.7	-12.5389	51.08	989.7
1100 Can Baseline	417	25	45		TL	-12.0715	27.03	752.8	-12.0189	58.85	1009.7
1100 Can Baseline	418	25	42		TL	-10.419	47.81	788.4	-9.9925	88.04	1008.2
1100 Can Baseline	425	25	44		TL	-11.5041	32.9	764.2	-11.3785	67.55	1008.9
1100 Can Baseline	426	25	43		TL	-10.9708	39.78	776.1	-10.6855	77.25	1008.4

Type	Frit ID	Min WL	Max WL	Limited Below By	Limited Above By	Del Gp (min)	Visc (min)	TL (min)	Del Gp (max)	Visc (max)	TL (max)
1100 Can Baseline	431	27	41	Del Gp	lvisc	-13.4153	24.36	762.1	-13.1197	41.56	946.9
1100 Can Baseline	441	.	.			.	.	.	.	.	.
1100 Can 2nd Transfer, Baseline	320	25	44		TL	-12.5731	28.43	752.7	-12.202	54.48	1000.9
1100 Can 2nd Transfer, Baseline	417	25	43		TL	-11.8801	34.42	763.7	-11.6948	62.71	999.6
1100 Can 2nd Transfer, Baseline	418	25	40		TL	-10.0625	58.93	799.2	-9.8011	93.6	997.4
1100 Can 2nd Transfer, Baseline	425	25	42		TL	-11.1871	41.41	775.1	-11.1692	71.92	998.6
1100 Can 2nd Transfer, Baseline	426	25	41		TL	-10.6251	49.54	786.9	-10.4941	82.19	997.8
1100 Can 2nd Transfer, Baseline	431	25	43		lvisc	-13.266	25.56	742	-12.7482	47.14	980.9
1100 Can 2nd Transfer, Baseline	441	.	.			.	.	.	.	.	.
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	320	25	41		lvisc	-12.9716	24.82	746.8	-12.9142	47.91	971.7
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	417	25	43		TL	-12.3803	25.94	758.4	-12.2786	55.24	1005.9
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	418	25	40		TL	-10.7002	46.32	795.8	-10.1996	82.86	1004.5
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	425	25	42		TL	-11.8388	31.68	770.4	-11.5856	63.47	1005.1
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	426	25	41		TL	-11.2787	38.42	782.9	-10.8926	72.64	1004.6
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	431	.	.			.	.	.	.	.	.
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	441	.	.			.	.	.	.	.	.
1100 Can Max Al, Na; Min Mn, Ni, U	320	25	53		lvisc	-12.2079	25.61	715.3	-11.252	60.89	991.3
1100 Can Max Al, Na; Min Mn, Ni, U	417	25	54		TL	-11.5149	28.23	724.7	-10.7928	69.96	1003.9
1100 Can Max Al, Na; Min Mn, Ni, U	418	27	51	hvisc	TL	-9.5093	49.05	781.3	-9.4415	99.81	1002.5
1100 Can Max Al, Na; Min Mn, Ni, U	425	25	53		TL	-10.8219	34.14	734.4	-10.3834	80.09	1003.2
1100 Can Max Al, Na; Min Mn, Ni, U	426	25	52		TL	-10.1289	41.04	744.4	-9.9556	91.36	1002.7
1100 Can Max Al, Na; Min Mn, Ni, U	431	25	50		lvisc	-12.9008	25.27	706.1	-11.8164	52.79	963.7
1100 Can Max Al, Na; Min Mn, Ni, U	441	40	42	Del Gp	lvisc	-13.359	25.14	864.4	-13.2352	26.81	883.4
1100 Can Min Ce, Mg, Ti	320	25	41		TL	-12.4479	35.59	770.9	-12.0553	57.1	993.3
1100 Can Min Ce, Mg, Ti	417	25	41		TL	-11.7549	41.14	782.2	-11.5101	65.7	1003.3
1100 Can Min Ce, Mg, Ti	418	25	38		TL	-9.8374	68.85	818.6	-9.6759	97.92	1000.3
1100 Can Min Ce, Mg, Ti	425	25	40		TL	-11.0619	49.11	793.9	-10.971	75.31	1002
1100 Can Min Ce, Mg, Ti	426	25	39		TL	-10.4134	58.3	806	-10.3689	86.02	1001
1100 Can Min Ce, Mg, Ti	431	25	42		TL	-13.1409	29.52	760	-12.5666	49.43	995.2
1100 Can Min Ce, Mg, Ti	441	.	.			.	.	.	.	.	.

Type	Frit ID	Min WL	Max WL	Limited Below By	Limited Above By	Del Gp (min)	Visc (min)	TL (min)	Del Gp (max)	Visc (max)	TL (max)
1100 Can Min Fe	320	25	45		TL	-12.3563	32.67	753.2	-11.7924	58.8	1002.1
1100 Can Min Fe	417	25	44		TL	-11.6634	39.25	763.8	-11.3031	67.62	1000.8
1100 Can Min Fe	418	26	41	hvisc	TL	-9.7246	65.82	813.2	-9.5931	98.49	998.6
1100 Can Min Fe	425	25	43		TL	-10.9704	46.88	774.8	-10.7954	77.47	999.8
1100 Can Min Fe	426	25	42		TL	-10.2774	55.7	786.1	-10.2692	88.44	999
1100 Can Min Fe	431	25	46		TL	-13.0493	27.03	742.8	-12.2631	50.94	1003.6
1100 Can Min Fe	441	.	.			.	.	.	.	.	.
1100 Can Max Mg	320	25	43		lvisc	-12.8438	24.59	742	-12.6872	50.02	982
1100 Can Max Mg	417	25	44		TL	-12.161	27.12	753.2	-12.1508	57.64	1002.8
1100 Can Max Mg	418	25	41		TL	-10.524	48	789.2	-10.0718	86.29	1001.2
1100 Can Max Mg	425	25	43		TL	-11.6338	33.01	764.8	-11.4578	66.18	1001.9
1100 Can Max Mg	426	25	42		TL	-11.0881	39.93	776.8	-10.7648	75.7	1001.4
1100 Can Max Mg	431	32	40	Del Gp	lvisc	-13.4112	24.45	835.2	-13.2677	34.13	937.7
1100 Can Max Mg	441	.	.			.	.	.	.	.	.
1100 Can Max Ni	320	25	40		TL	-12.7227	30.97	774.9	-12.5195	52.27	997.3
1100 Can Max Ni	417	25	39		TL	-12.0297	37.42	786.9	-11.9694	60.21	995.6
1100 Can Max Ni	418	25	36		TL	-10.2083	63.73	825.4	-9.9507	90.06	992.2
1100 Can Max Ni	425	25	38		TL	-11.4009	44.94	799.3	-11.3367	69.11	994.2
1100 Can Max Ni	426	25	37		TL	-10.8138	53.67	812.1	-10.6437	79.03	993
1100 Can Max Ni	431	25	41		TL lvisc	-13.4157	25.47	763.4	-13.0511	45.19	999.4
1100 Can Max Ni	441	.	.			.	.	.	.	.	.
1100 Can Max Ti	320	25	49		lvisc	-12.4189	25.2	715.4	-11.8022	56.83	973.1
1100 Can Max Ti	417	25	52		lvisc	-11.7259	25.05	725.1	-11.2816	65.36	1003
1100 Can Max Ti	418	25	50		TL	-9.9286	42.27	756.3	-9.647	97.3	1009
1100 Can Max Ti	425	25	52		TL	-11.0329	28.94	735.2	-10.8381	74.9	1009.6
1100 Can Max Ti	426	25	51		TL	-10.3926	35.09	745.6	-10.34	85.51	1009.2
1100 Can Max Ti	431	25	46		lvisc	-13.1119	24.9	705.9	-12.3783	49.22	941
1100 Can Max Ti	441	.	.			.	.	.	.	.	.
1200 Can Baseline	320	25	45		TL lvisc	-12.6418	25.73	748.7	-12.3063	53.27	1007.5
1200 Can Baseline	417	25	44		TL	-11.9489	31.29	759.8	-11.8056	61.34	1006.3

Type	Frit ID	Min WL	Max WL	Limited Below By	Limited Above By	Del Gp (min)	Visc (min)	TL (min)	Del Gp (max)	Visc (max)	TL (max)
1200 Can Baseline	418	25	41		TL	-10.1928	54.26	795.3	-9.8699	91.61	1004.4
1200 Can Baseline	425	25	43		TL	-11.2865	37.82	771.2	-11.2559	70.36	1005.4
1200 Can Baseline	426	25	42		TL	-10.7489	45.43	783	-10.5629	80.43	1004.7
1200 Can Baseline	431	25	42		lvisc	-13.3348	25.43	738.1	-12.8925	46.08	965.7
1200 Can Baseline	441	.	.			.	.	.	.	.	.
1200 Can 2nd Transfer, Baseline	320	25	44		TL	-12.5407	29.18	754.4	-12.1451	55.1	1002.5
1200 Can 2nd Transfer, Baseline	417	25	43		TL	-11.8478	35.28	765.4	-11.6393	63.42	1001.2
1200 Can 2nd Transfer, Baseline	418	25	40		TL	-10.0108	60.2	800.8	-9.7688	94.61	998.9
1200 Can 2nd Transfer, Baseline	425	25	42		TL	-11.1548	42.4	776.8	-11.1149	72.72	1000.1
1200 Can 2nd Transfer, Baseline	426	25	41		TL	-10.5721	50.67	788.6	-10.4618	83.09	999.4
1200 Can 2nd Transfer, Baseline	431	25	44		lvisc	-13.2337	25.09	743.7	-12.6625	47.68	993.4
1200 Can 2nd Transfer, Baseline	441	.	.			.	.	.	.	.	.
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	320	25	42		TL lvisc	-12.8827	25.2	756.8	-12.7612	49.45	997.7
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	417	25	41		TL	-12.2232	30.73	768.6	-12.1897	57.01	996.3
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	418	25	39		TL	-10.5281	51.42	806.4	-10.1107	85.42	1006.4
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	425	25	40		TL	-11.6667	37.24	780.7	-11.4967	65.47	995.2
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	426	25	40		TL	-11.1123	42.87	793.3	-10.8037	74.91	1006.7
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	431	35	39	Del Gp	lvisc	-13.4118	25.02	896.7	-13.3463	29.81	949.8
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	441	.	.			.	.	.	.	.	.
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	320	25	56		TL lvisc	-12.0878	25.44	714.8	-10.8808	63.34	1002.8
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	417	25	55		TL	-11.3949	30.82	724	-10.5039	72.74	1001.9
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	418	29	53	hvisc	TL	-9.308	50.72	803.9	-9.2605	100.19	1006.5
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	425	25	54		TL	-10.7019	37.1	733.5	-10.1086	83.23	1001.2
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	426	25	54		TL	-10.0089	42.54	743.3	-9.6835	94.89	1006.8
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	431	25	53		lvisc	-12.7808	25.15	705.8	-11.4318	54.94	978.1
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	441	37	45	Del Gp	lvisc	-13.3669	25.01	831.6	-12.8337	31.5	905.6
1200 Can Max Ni	320	25	40		TL	-12.7206	31.04	775.1	-12.5162	52.32	997.6
1200 Can Max Ni	417	25	39		TL	-12.0276	37.5	787	-11.9662	60.28	995.8
1200 Can Max Ni	418	25	36		TL	-10.2053	63.84	825.6	-9.9487	90.16	992.4
1200 Can Max Ni	425	25	38		TL	-11.3977	45.03	799.4	-11.3346	69.19	994.4

Type	Frit ID	Min WL	Max WL	Limited Below By	Limited Above By	Del Gp (min)	Visc (min)	TL (min)	Del Gp (max)	Visc (max)	TL (max)
1200 Can Max Ni	426	25	37		TL	-10.8108	53.77	812.3	-10.6417	79.12	993.2
1200 Can Max Ni	431	25	41		TL lvisc	-13.4136	25.53	763.5	-13.0477	45.24	999.6
1200 Can Max Ni	441	.	.			.	.	.	.	.	.
1200 Can Min Ce	320	25	45		TL	-12.3425	33.08	753.6	-11.7675	59.11	1002.3
1200 Can Min Ce	417	25	44		TL	-11.6495	39.71	764.2	-11.2788	67.97	1001
1200 Can Min Ce	418	26	41	hvisc	TL	-9.7019	66.48	813.6	-9.5788	98.99	998.8
1200 Can Min Ce	425	25	43		TL	-10.9565	47.41	775.2	-10.7717	77.86	1000
1200 Can Min Ce	426	25	42		TL	-10.2636	56.29	786.6	-10.246	88.88	999.2
1200 Can Min Ce	431	25	46		TL	-13.0355	27.38	743.3	-12.2377	51.2	1003.8
1200 Can Min Ce	441	.	.			.	.	.	.	.	.
1200 Can Min Mg, Ti	320	25	42		TL	-12.4624	33.93	769.9	-12.0552	56.83	1003.7
1200 Can Min Mg, Ti	417	25	41		TL	-11.7695	40.75	781.2	-11.534	65.4	1002.2
1200 Can Min Mg, Ti	418	25	38		TL	-9.8596	68.29	817.6	-9.6905	97.48	999.2
1200 Can Min Mg, Ti	425	25	40		TL	-11.0765	48.67	792.9	-10.9944	74.97	1000.9
1200 Can Min Mg, Ti	426	25	39		TL	-10.4362	57.8	805	-10.3835	85.63	999.9
1200 Can Min Mg, Ti	431	25	42		TL	-13.1554	29.22	759	-12.5911	49.2	994.1
1200 Can Min Mg, Ti	441	.	.			.	.	.	.	.	.
1200 Can Max Mg, Ti	320	25	51		lvisc	-12.2967	25.75	715.3	-11.5016	59.17	982.3
1200 Can Max Mg, Ti	417	25	54		TL lvisc	-11.6037	25.65	724.9	-10.9848	68.02	1009.7
1200 Can Max Mg, Ti	418	26	51	hvisc	TL	-9.6905	45.17	769.1	-9.5311	98.98	1008.4
1200 Can Max Mg, Ti	425	25	53		TL	-10.9107	31.17	734.7	-10.5718	77.89	1009
1200 Can Max Mg, Ti	426	25	52		TL	-10.2178	37.64	744.9	-10.1404	88.89	1008.6
1200 Can Max Mg, Ti	431	25	48		lvisc	-12.9897	25.39	706	-12.0738	51.28	952.5
1200 Can Max Mg, Ti	441	.	.			.	.	.	.	.	.

APPENDIX C

Maximum Waste Loading as a Function of an Assumed PCCS SO_4 Solubility Limit

Table C.1. Maximum WLs as a Function of an Assumed SO_4 Solubility Limit.

Type	Sludge SO_4 (wt%)	MAX WL 0.4	MAX WL 0.5	MAX WL 0.6
SB4 Only Baseline	1.098	36.4	45.5	54.6
SB4 Only Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U	1.095	36.5	45.7	54.8
SB4 Only Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U	1.109	36.1	45.1	54.1
1100 Can Baseline	1.099	36.4	45.5	54.6
1100 Can 2nd Transfer, Baseline	1.098	36.4	45.5	54.6
1100 Can Min Al, Na; Max Ce, Fe, Mn, U	1.097	36.5	45.6	54.7
1100 Can Max Al, Na; Min Mn, Ni, U	1.104	36.2	45.3	54.3
1100 Can Min Ce, Mg, Ti	1.097	36.5	45.6	54.7
1100 Can Min Fe	1.100	36.4	45.5	54.5
1100 Can Max Mg	1.099	36.4	45.5	54.6
1100 Can Max Ni	1.095	36.5	45.6	54.8
1100 Can Max Ti	1.103	36.3	45.3	54.4
1200 Can Baseline	1.098	36.4	45.5	54.6
1200 Can 2nd Transfer, Baseline	1.098	36.4	45.5	54.6
1200 Can Min Al, Na; Max Ce, Fe, Mn, U	1.096	36.5	45.6	54.7
1200 Can Max Al, Na; Min Fe, Mn, Ni, U	1.105	36.2	45.3	54.3
1200 Can Max Ni	1.095	36.5	45.6	54.8
1200 Can Min Ce	1.100	36.4	45.5	54.5
1200 Can Min Mg, Ti	1.097	36.5	45.6	54.7
1200 Can Max Mg, Ti	1.104	36.2	45.3	54.4
SB4 Baseline -App. A / ARP Stream + SRAT Product Solids	1.131	35.4	44.2	53.0
SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U - App. A / ARP Stream + SRAT Product Solids	1.128	35.5	44.3	53.2
SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U - App. A / ARP Stream + SRAT Product Solids	1.142	35.0	43.8	52.5
SB4 1100 Can Baseline - App. A / ARP Stream + SRAT Product Solids	1.131	35.4	44.2	53.0
SB4 1100 Can 2nd Transfer, Baseline - App.A / ARP Stream + SRAT Product Solids	1.131	35.4	44.2	53.0
SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U - App. A / ARP Stream + SRAT Product Solids	1.130	35.4	44.3	53.1

Type	Sludge SO_4 (wt%)	MAX WL 0.4	MAX WL 0.5	MAX WL 0.6
SB4 1100 Can Max Al, Na; Min Mn, Ni, U - App. A / ARP Stream + SRAT Product Solids	1.137	35.2	44.0	52.8
SB4 1100 Can Min Ce, Mg, Ti - App.A / ARP Stream + SRAT Product Solids	1.130	35.4	44.2	53.1
SB4 1100 Can Min Fe - App.A / ARP Stream + SRAT Product Solids	1.133	35.3	44.1	53.0
SB4 1100 Can Max Mg - App.A / ARP Stream + SRAT Product Solids	1.131	35.4	44.2	53.0
SB4 1100 Can Max Ni - App.A / ARP Stream + SRAT Product Solids	1.128	35.4	44.3	53.2
SB4 1100 Can Max Ti - App.A / ARP Stream + SRAT Product Solids	1.136	35.2	44.0	52.8
SB4 1200 Can Baseline - App.A / ARP Stream + SRAT Product Solids	1.131	35.4	44.2	53.0
SB4 1200 Can 2nd Transfer Baseline - App.A / ARP Stream + SRAT Product Solids	1.131	35.4	44.2	53.0
SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U - App.A / ARP Stream + SRAT Product Solids	1.129	35.4	44.3	53.1
SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U - App.A / ARP Stream + SRAT Product Solids	1.138	35.2	44.0	52.7
SB4 1200 Can Max Ni - App.A / ARP Stream + SRAT Product Solids	1.128	35.4	44.3	53.2
SB4 1200 Can Min Ce - App.A / ARP Stream + SRAT Product Solids	1.133	35.3	44.1	53.0
SB4 1200 Can Min Mg, Ti - App.A / ARP Stream + SRAT Product Solids	1.130	35.4	44.2	53.1
SB4 1200 Can Max Mg, Ti - App.A / ARP Stream + SRAT Product Solids	1.137	35.2	44.0	52.8
SB4 Baseline -App. E / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U - App. E / ARP Stream + SRAT Product Solids	1.224	32.7	40.8	49.0
SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U - App. E / ARP Stream + SRAT Product Solids	1.238	32.3	40.4	48.5
SB4 1100 Can Baseline - App. E / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 1100 Can 2nd Transfer, Baseline - App. E / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U - App. E / ARP Stream + SRAT Product Solids	1.226	32.6	40.8	48.9
SB4 1100 Can Max Al, Na; Min Mn, Ni, U - App. E / ARP Stream + SRAT Product Solids	1.233	32.4	40.5	48.7
SB4 1100 Can Min Ce, Mg, Ti - App. E / ARP Stream + SRAT Product Solids	1.227	32.6	40.8	48.9
SB4 1100 Can Min Fe - App. E / ARP Stream + SRAT Product Solids	1.229	32.5	40.7	48.8
SB4 1100 Can Max Mg - App. E / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 1100 Can Max Ni - App. E / ARP Stream + SRAT Product Solids	1.225	32.7	40.8	49.0
SB4 1100 Can Max Ti - App. E / ARP Stream + SRAT Product Solids	1.232	32.5	40.6	48.7
SB4 1200 Can Baseline - App. E / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 1200 Can 2nd Transfer Baseline - App. E / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U - App. E / ARP Stream + SRAT Product Solids	1.226	32.6	40.8	48.9

Type	Sludge SO_4 (wt%)	MAX WL 0.4	MAX WL 0.5	MAX WL 0.6
SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U - App. E / ARP Stream + SRAT Product Solids	1.234	32.4	40.5	48.6
SB4 1200 Can Max Ni - App. E / ARP Stream + SRAT Product Solids	1.225	32.7	40.8	49.0
SB4 1200 Can Min Ce - App. E / ARP Stream + SRAT Product Solids	1.229	32.5	40.7	48.8
SB4 1200 Can Min Mg, Ti - App. E / ARP Stream + SRAT Product Solids	1.227	32.6	40.8	48.9
SB4 1200 Can Max Mg, Ti - App. E / ARP Stream + SRAT Product Solids	1.233	32.4	40.6	48.7
SB4 Baseline -App. K / ARP Stream + SRAT Product Solids	1.264	31.7	39.6	47.5
SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U - App. K / ARP Stream + SRAT Product Solids	1.260	31.7	39.7	47.6
SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U - App. K / ARP Stream + SRAT Product Solids	1.274	31.4	39.3	47.1
SB4 1100 Can Baseline - App. K / ARP Stream + SRAT Product Solids	1.264	31.7	39.6	47.5
SB4 1100 Can 2nd Transfer, Baseline - App. K / ARP Stream + SRAT Product Solids	1.264	31.7	39.6	47.5
SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U - App. K / ARP Stream + SRAT Product Solids	1.262	31.7	39.6	47.5
SB4 1100 Can Max Al, Na; Min Mn, Ni, U - App. K / ARP Stream + SRAT Product Solids	1.269	31.5	39.4	47.3
SB4 1100 Can Min Ce, Mg, Ti - App. K / ARP Stream + SRAT Product Solids	1.263	31.7	39.6	47.5
SB4 1100 Can Min Fe - App. K / ARP Stream + SRAT Product Solids	1.265	31.6	39.5	47.4
SB4 1100 Can Max Mg - App. K / ARP Stream + SRAT Product Solids	1.264	31.7	39.6	47.5
SB4 1100 Can Max Ni - App. K / ARP Stream + SRAT Product Solids	1.261	31.7	39.6	47.6
SB4 1100 Can Max Ti - App. K / ARP Stream + SRAT Product Solids	1.268	31.5	39.4	47.3
SB4 1200 Can Baseline - App. K / ARP Stream + SRAT Product Solids	1.264	31.7	39.6	47.5
SB4 1200 Can 2nd Transfer Baseline - App. K / ARP Stream + SRAT Product Solids	1.264	31.7	39.6	47.5
SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U - App. K / ARP Stream + SRAT Product Solids	1.262	31.7	39.6	47.5
SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U - App. K / ARP Stream + SRAT Product Solids	1.269	31.5	39.4	47.3
SB4 1200 Can Max Ni - App. K / ARP Stream + SRAT Product Solids	1.261	31.7	39.6	47.6
SB4 1200 Can Min Ce - App. K / ARP Stream + SRAT Product Solids	1.265	31.6	39.5	47.4
SB4 1200 Can Min Mg, Ti - App. K / ARP Stream + SRAT Product Solids	1.263	31.7	39.6	47.5
SB4 1200 Can Max Mg, Ti - App. K / ARP Stream + SRAT Product Solids	1.269	31.5	39.4	47.3
SB4 Baseline -App. M / ARP Stream + SRAT Product Solids	1.212	33.0	41.3	49.5
SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U - App. M / ARP Stream + SRAT Product Solids	1.208	33.1	41.4	49.7
SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U - App. M / ARP Stream + SRAT Product Solids	1.222	32.7	40.9	49.1
SB4 1100 Can Baseline - App. M / ARP Stream + SRAT Product Solids	1.212	33.0	41.3	49.5

Type	Sludge SO_4 (wt%)	MAX WL 0.4	MAX WL 0.5	MAX WL 0.6
SB4 1100 Can 2nd Transfer, Baseline - App. M / ARP Stream + SRAT Product Solids	1.211	33.0	41.3	49.5
SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U - App. M / ARP Stream + SRAT Product Solids	1.210	33.1	41.3	49.6
SB4 1100 Can Max Al, Na; Min Mn, Ni, U - App. M / ARP Stream + SRAT Product Solids	1.217	32.9	41.1	49.3
SB4 1100 Can Min Ce, Mg, Ti - App. M / ARP Stream + SRAT Product Solids	1.210	33.0	41.3	49.6
SB4 1100 Can Min Fe - App. M / ARP Stream + SRAT Product Solids	1.213	33.0	41.2	49.5
SB4 1100 Can Max Mg - App. M / ARP Stream + SRAT Product Solids	1.212	33.0	41.3	49.5
SB4 1100 Can Max Ni - App. M / ARP Stream + SRAT Product Solids	1.209	33.1	41.4	49.6
SB4 1100 Can Max Ti - App. M / ARP Stream + SRAT Product Solids	1.216	32.9	41.1	49.3
SB4 1200 Can Baseline - App. M / ARP Stream + SRAT Product Solids	1.212	33.0	41.3	49.5
SB4 1200 Can 2nd Transfer Baseline - App. M / ARP Stream + SRAT Product Solids	1.212	33.0	41.3	49.5
SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U - App. M / ARP Stream + SRAT Product Solids	1.210	33.1	41.3	49.6
SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U - App. M / ARP Stream + SRAT Product Solids	1.218	32.9	41.1	49.3
SB4 1200 Can Max Ni - App. M / ARP Stream + SRAT Product Solids	1.209	33.1	41.4	49.6
SB4 1200 Can Min Ce - App. M / ARP Stream + SRAT Product Solids	1.213	33.0	41.2	49.5
SB4 1200 Can Min Mg, Ti - App. M / ARP Stream + SRAT Product Solids	1.211	33.0	41.3	49.6
SB4 1200 Can Max Mg, Ti - App. M / ARP Stream + SRAT Product Solids	1.217	32.9	41.1	49.3
SB4 Baseline -App. V / ARP Stream + SRAT Product Solids	1.223	32.7	40.9	49.0
SB4 Min Al, Na, Mg, Ti; Max Ce, Fe, Mg, Ni, U - App. V / ARP Stream + SRAT Product Solids	1.220	32.8	41.0	49.2
SB4 Max Al, Na, Mg, Ti; Min Ce, Fe, Mn, Ni, U - App. V / ARP Stream + SRAT Product Solids	1.233	32.4	40.5	48.6
SB4 1100 Can Baseline - App. V / ARP Stream + SRAT Product Solids	1.223	32.7	40.9	49.0
SB4 1100 Can 2nd Transfer, Baseline - App. V / ARP Stream + SRAT Product Solids	1.223	32.7	40.9	49.0
SB4 1100 Can Min Al, Na; Max Ce, Fe, Mn, U - App. V / ARP Stream + SRAT Product Solids	1.222	32.7	40.9	49.1
SB4 1100 Can Max Al, Na; Min Mn, Ni, U - App. V / ARP Stream + SRAT Product Solids	1.229	32.6	40.7	48.8
SB4 1100 Can Min Ce, Mg, Ti - App. V / ARP Stream + SRAT Product Solids	1.222	32.7	40.9	49.1
SB4 1100 Can Min Fe - App. V / ARP Stream + SRAT Product Solids	1.225	32.7	40.8	49.0
SB4 1100 Can Max Mg - App. V / ARP Stream + SRAT Product Solids	1.223	32.7	40.9	49.0
SB4 1100 Can Max Ni - App. V / ARP Stream + SRAT Product Solids	1.221	32.8	41.0	49.2
SB4 1100 Can Max Ti - App. V / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.9
SB4 1200 Can Baseline - App. V / ARP Stream + SRAT Product Solids	1.223	32.7	40.9	49.0

Type	Sludge SO_4 (wt%)	MAX WL 0.4	MAX WL 0.5	MAX WL 0.6
SB4 1200 Can 2nd Transfer Baseline - App. V / ARP Stream + SRAT Product Solids	1.223	32.7	40.9	49.0
SB4 1200 Can Min Al, Na; Max Ce, Fe, Mn, U - App. V / ARP Stream + SRAT Product Solids	1.222	32.7	40.9	49.1
SB4 1200 Can Max Al, Na; Min Fe, Mn, Ni, U - App. V / ARP Stream + SRAT Product Solids	1.229	32.5	40.7	48.8
SB4 1200 Can Max Ni - App. V / ARP Stream + SRAT Product Solids	1.221	32.8	41.0	49.2
SB4 1200 Can Min Ce - App. V / ARP Stream + SRAT Product Solids	1.225	32.7	40.8	49.0
SB4 1200 Can Min Mg, Ti - App. V / ARP Stream + SRAT Product Solids	1.222	32.7	40.9	49.1
SB4 1200 Can Max Mg, Ti - App. V / ARP Stream + SRAT Product Solids	1.228	32.6	40.7	48.8

Distribution:

E.W. Holtzscheiter, 773-A
D.A. Crowley, 999-W
S.L. Marra, 999-W
T.B. Calloway, 999-W
N.E. Bibler, 773-A
C.M. Jantzen, 773-A
J.R. Harbour, 773-42A
G.G. Wicks, 773-A
D.K. Peeler, 999-W
T.B. Edwards, 773-42A
C.C. Herman, 773-42A
M.S. Miller, 704-S
J.E. Occhipinti, 704-S
R.M. Hoeppel, 704-27S
J.F. Iaukea, 704-30S
J.W. Ray, 704-S
F.A. Washburn, 704-27S
A.V. Staub, 704-27S
H.H. Elder, 766-H
D.C. Bumgardner, 766-H
W.B. Van Pelt, 704-S
H.B. Shah, 766-H
E.W. Harrison, 766-H