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**PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC09-96SR18500**

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# Executive Summary

The Defense Waste Processing Facility (DWPF) is currently processing Sludge Batch 2 (SB2) and plans to initiate processing of SB3 in the spring of 2004 (WSRC 2001). In addition, the Savannah River High Level Waste Division proposes to transfer existing excess Pu and Am/Cm materials through the Liquid Radioactive Waste Handling Facility directly to the Extended Sludge Processing Facility (ESPF) (Elder 2001). Current blending strategies have both the Pu and Am/Cm materials being vitrified within SB3 in the DWPF.

Before committing these additional materials to the ESPF and ultimately to DWPF, the Savannah River Technology Center (SRTC) was requested to assess the potential impacts on SB3 processing and product quality after adding Am/Cm (Patel 2002). This task also considers the impacts of adding Pu/Gd (Jilani 2002), as current blending strategies assume that both the Am/Cm and Pu/Gd waste streams will be blended with SB3. In case this strategy is not realized due to unforeseen issues, this study made assessments covering the following six potential blending scenarios:

(1) Case #1 (Baseline): SB3 (including the Tank 51 heel and sand associated with Tank 7)

(2) Case #2: SB3 baseline with only the Pu/Gd addition

(3) Case #3: SB3 baseline with only the Am/Cm addition

(4) Case #4: SB3 baseline with both Am/Cm and Pu/Gd additions

(5) Case #5: SB3 (including the Tank 51 heel—excluding Tank 7 sand)

(6) Case #6: SB3 (including the Tank 51 heel—excluding Tank 7 sand) with both Am/Cm and Pu/Gd additions.

Nominal sludge compositions and three existing frits were used as the basis for these assessments. It is assumed that the individual waste streams (e.g., Am/Cm, Pu/Gd and Tank 7 sand) or sludges (e.g., SB3) are essentially "compositional centroids" representing on average that which is expected to be blended. The blending calculations assume that individual streams will be evenly distributed or uniformly blended, resulting in a "constant" feed to the melter (once frit additions are made) and were based on weighted mass averages.

The primary objective of this task was to assess the impacts of Am/Cm and/or Pu/Gd on the predicted glass properties of interest as well as $H_2$ generation rates, alpha dose, and heat loading to the glass. In light of the task objectives, general conclusions regarding the impact (or lack thereof) are bulletized below.

- Based on process/product model predictions, adding the Am/Cm or the Pu/Gd secondary waste streams (either individually or combined) to SB3 does not have a practical impact on glass quality, product performance, and/or processability. By practical, the authors mean that although minimal differences may exist for predicted properties for adding a particular waste stream or waste-stream combinations, the relative difference of those predictions is not of practical concern.
- Based on model predictions, there appears to be no need to add terms to the current Product Composition Control System (PCCS) $\Delta G_P$ prediction (the indicator of durability used by DWPF to meet acceptance criteria) for the minor components that will be added to SB3 after adding the Am/Cm and Pu/Gd waste streams. In fact, the use of the current

$\Delta G_P$ model is conservative as the addition of each of these streams is predicted to increase durability—although of no practical difference.

- Adding the Am/Cm and Pu/Gd waste streams will not increase the concentrations of noble metals in the waste; thus, a significant effect on $H_2$ production in the DWPF Sludge Receipt and Adjustment Tank (SRAT) and Slurry Mix Evaporator (SME) is not expected.
- Adding the Am/Cm and Pu/Gd waste streams to SB3 will increase the rate of radiolytic $H_2$ production by ~ 1.7×. Even with this increase, the maximum estimated rate (5.83E-04 lb $H_2$/h per processing batch) is ~ 400× less than the allowable rates in the SRAT and SME processing vessels in the DWPF (Rios-Armstrong 2000).
- Adding the Am/Cm waste stream will significantly increase the dose rate of neutrons from the SB3 glass because of alpha-induced nuclear reactions and spontaneous fission of the $^{244}$Cm. However, the rate will still be ~ 1.6 less than that from the design-basis glass (Baxter 1988). Adding the Pu/Gd stream will not affect the neutron dose rate.
- Adding the Am/Cm and Pu/Gd waste streams will increase the long-term alpha dose to the glass by a factor of ~ 2.4×. However, the dose after a million years will still be ~ 10× less than the largest alpha dose that a borosilicate high-level waste glass has accumulated without showing deleterious effects.
- Adding the Am/Cm and Pu/Gd waste streams will increase the number of canisters to process SB3 from 546 to 553 and increase the watts/canister from 52 to 63. This higher value is still much less than that for the design-basis glass—690 watts (Baxter 1988).

Although not fully assessed in this report, other potential processing issues for SB3 were identified. These included the potential impacts of coal and/or oxalate on glass properties or reduction-oxidation (REDOX) and an evaluation of anion concentrations in glass relative to solubility limits.

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# Acronyms

| | |
|---|---|
| Am | americium |
| ASTM | American Society for Testing and Materials |
| CIM | Cylindrical Induction Melter |
| Cm | curium |
| $\Delta G_P$ | preliminary glass dissolution estimator based on free energy of hydration (in kcal/mol) |
| DB | design basis |
| DWPF | Defense Waste Processing Facility |
| EMF | electromotive force |
| ESPF | Extended Sludge Processing Facility |
| Gd | gadolinium |
| HLW | High Level Waste |
| ICP | inductively coupled plasma |
| MAR | Measurement Acceptability Region |
| MS | mass spectrometry |
| PAR | Property Acceptability Region |
| PCCS | Product Composition Control System |
| PCT | Product Consistency Test |
| Pu | plutonium |
| REDOX | reduction-oxidation |
| SB | sludge batch |
| SME | Slurry Mix Evaporator |
| SRAT | Sludge Receipt and Adjustment Tank |
| SRS | Savannah River Site |
| SRTC | Savannah River Technology Center |
| $T_L$ | liquidus temperature |
| TAR | technical assistance request |
| TTR | technical task request |
| $\eta_{1150°C}$ | melt viscosity at 1150°C |
| WCS | Waste Characterization System |
| WL | waste loading |
| WSRC | Westinghouse Savannah River Company |

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**Appendices**

# Tables

# 1.0 Introduction

Approximately 130M L of sludge/supernate high-level radioactive waste (HLW) is currently stored in underground carbon steel tanks at the Savannah River Site (SRS) in Aiken, South Carolina. The Defense Waste Processing Facility (DWPF) began immobilizing these wastes in borosilicate glass in 1996. Currently, the radioactive glass is being produced as a "sludge-only" composition by combining washed high-level sludge with glass frit and melting. The glass is poured into stainless steel canisters that will eventually be disposed of in a permanent geological repository.

Currently, DWPF is processing Sludge Batch 2 (SB2) and is planning to start processing SB3 in the spring of 2004 (WSRC 2001). In addition, the Savannah River High Level Waste Division proposes to transfer existing americium/curium (Am/Cm) and excess plutonium (Pu) materials through the Liquid Radioactive Waste Handling Facility directly to the Extended Sludge Processing Facility (ESPF) (Elder 2001). Current blending strategies have both the Am/Cm and Pu materials being vitrified within Sludge Batch 3 (SB3) in the DWPF.

Before committing these additional materials to ESPF and ultimately to DWPF, an assessment of the potential impacts on glass processing and product quality must be performed. The Savannah River Technology Center (SRTC) has been requested by DWPF to evaluate the potential impacts of processing SB3 containing Am/Cm (Patel 2002). This task also considers the impacts of adding Pu/Gd[(a)] (Jilani 2002), as current blending strategies assume that both the Am/Cm and Pu/Gd waste streams will be blended. Specific issues to be addressed are the potential impacts of these additional waste streams to SB3 on hydrogen generation rates in the DWPF Sludge Receipt and Adjustment Tank (SRAT) and/or Slurry Mix Evaporator (SME) as well as potential impacts on glass quality.

This report documents SRTC's assessment of the potential impacts of these additional materials (henceforth referred to as additional or secondary waste streams) on processing SB3. In Section 2.0, various SB3 blending scenarios are presented that form the basis of the assessment. Included in these blending scenarios are options to evaluate the impact of individual or multiple waste-stream contributions. The nominal sludge compositions (as a result of the specific blending scenarios) and frit compositions used to develop glass compositions as a function of waste loading (WL) are presented in Section 3.0. Section 4.0 provides the acceptance criteria used to project operational windows based on predicted properties.

In Section 5.0, an assessment of the predicted impacts of these secondary waste streams on glass quality is presented. Glass quality is defined not only by the potential impact to durability, but also by predictions regarding processability (e.g., viscosity and liquidus temperature [$T_L$]). Current Product Composition Control System (PCCS) (Brown and Postles 1996) property models (including the current $T_L$ model and viscosity models (Jantzen 1991) and the new $T_L$ model (Brown et al. 2001), which should be implemented prior to SB3 being processed), are used as the basis for these assessments. Section 6.0 provides a summary of these assessments.

It must be recognized that these assessments and associated conclusions are based solely on model predictions and/or technical calculations with no experimental work being performed. Although the property predictions provide the foundation from which these assessments are

(a) Gd = gadolinium

made, the evaluation of other potential processing issues (e.g., single components solubility limits, and/or reduction-oxidation [REDOX] issues) is also discussed for completeness.

In Section 7.0, an assessment of the impact of these additional waste streams on the following items is addressed.

(1) Chemical hydrogen production in the SRAT and SME

(2) Radiolytic hydrogen production in the Tank Farm and the DWPF

(3) Neutron dose rate from the SB3 glasses

(4) Alpha radiation effects on the SB3 glasses.

(5) Wattages per canister of glass produced.

Although not fully assessed in this report, other potential processing issues for SB3 are identified and discussed in Section 8.0. These included the potential impacts of coal on glass REDOX and an evaluation of anion concentrations in glass relative to solubility limits.

## 2.0 Blending Scenarios Considered

Current blending strategies assume that both the Am/Cm and Pu/Gd waste streams will be blended with SB3 (Patel 2002; Jilani 2002; Elder 2001). In case this strategy is not realized because of unforeseen issues, this paper study covers six potential blending scenarios. These scenarios will provide the basis for evaluating the impact of individual or multiple waste streams to SB3. These scenarios include:

(1) Case #1 (Baseline): SB3 (including the Tank 51 heel and sand associated with Tank 7)

(2) Case #2: SB3 baseline with only the Pu/Gd addition

(3) Case #3: SB3 baseline with only the Am/Cm addition

(4) Case #4: SB3 baseline with both Am/Cm and Pu/Gd additions

(5) Case #5: SB3 (including the Tank 51 heel—excluding Tank 7 sand)

(6) Case #6: SB3 (including the Tank 51 heel—excluding Tank 7 sand) with both Am/Cm and Pu/Gd additions.

Case #1 (SB3, including the Tank 51 heel and sand associated with Tank 7) will establish a baseline from which predicted properties of the various blending scenarios (Cases #2 through #6) can be compared. The baseline case considers the blending scenario in which the compositional estimates of the Tank 51 heel and sand from Tank 7 are evenly distributed and blended with SB3 and processed through DWPF. Properties will be predicted, excluding the additions of either Pu/Gd or Am/Cm streams for this base case. The properties of primary interest will include viscosity at 1150ºC ($\eta_{1150°C}$[a]), homogeneity, durability ($\Delta G_P$), and $T_L$ (both current and new models) as defined by Jantzen (1991), Jantzen et al. (1995), Brown et al. (2001), and Brown and Postles (1996).

Cases #2 and #3 will provide an assessment of the individual contributions and predicted impacts of the Am/Cm and Pu/Gd streams to SB3, respectively. The assessment of these "single additive" cases will provide insight into the impact of each waste stream relative to the baseline, assuming the current blending strategy is not realized. Case #4 presents the current blending strategy being pursued in which both the waste streams are blended with SB3.

Cases #5 and #6 were specifically developed to address the ability to partially or completely transfer the sand associated with Tank 7 into SB3. More specifically, Case #5 establishes a second baseline case (i.e., SB3 with only the Tank 51 heel) from which the additions of both the Am/Cm and Pu/Gd streams can be compared (Case #6).

It should be recognized that there are several blending combinations that could result when considering four "individual" waste streams (e.g., SB3 [including the Tank 51 heel], Tank 7 sand, Pu/Gd, and Am/Cm). This study does not attempt to assess all combinations but does provide insight into the predicted property impacts for those blending scenarios considered viable or highly probable. These options should bound the predicted impacts of any blending strategy that may ultimately be implemented for SB3.

(a) $\eta_{1150°C}$ = melt viscosity at 1150°C.

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# 3.0 Basis for Compositional Analysis

To assess the potential impact or magnitude these blending strategies may have on predicted glass properties, the glass compositions (or regions) must be defined. To establish glass compositions or regions, compositional definitions of two primary inputs are required: sludge(s) or waste stream(s), compositions, and frit(s) compositions. Given these two inputs, one can define the glass compositional region or operating window based on the established acceptability criteria (see Section 4.0).

## 3.1 Definition of Individual Waste-Stream Compositions

Although the six blending scenarios to be assessed were outlined in Section 2.0, specific information regarding the individual sludge compositions was not presented. Before establishing the nominal blend compositions for each case being considered, the individual waste-stream compositions and masses must be defined. Table 1 summarizes the nominal individual sludge compositions (in oxide wt%) and masses (in kgs on an oxide basis) used in this study.

Elder provided compositional and total mass estimates of SB3 (including the Tank 51 heel).[(a)] These compositional and total mass estimates were based on total masses and Curies tracked by the SRS Waste Characterization System (WCS). Appendix A provides the compositional (elemental wt%, calcine basis) for SB3 for the nonradioactive elements and uranium that are tracked. On a calcined oxide basis, the total mass for SB3 was reported to be 353216.8 kgs. This total SB3 mass does not include the contribution from the Tank 7 sand. The information reported and/or provided by Elder also did not include the rare-earth elements Pr, Nd, Sm, Gd, Tb, Dy, Ho, and Er, or the noble metals Ag, Ru, Rh, and Pd, elements that are not tracked by the WCS. These elements are in SB3 because they are present in HLW as products of the fission of $^{235}U$ in the SRS reactors. Another fission product, $^{139}La$, is tracked by WCS, and thus it is possible to calculate the concentrations of the additional rare-earth fission products and noble metals (see Appendix B) based on $^{139}La$ concentration estimated by Elder to be in SB3 and the known $^{235}U$ fission yields.[(b)] The contributions of these rare earths and noble metals were added to SB3 compositional estimates and total mass provided by Elder. The total Curies of the radionuclides of $^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Pu$, $^{242}Pu$, $^{241}Am$, $^{242m}Am$, $^{244}Cm$, and $^{245}Cm$ are tracked by the WCS. Masses for these in SB3 were calculated knowing the specific activities of the respective radionuclides (see Appendix B). The final SB3 composition (without Tank 7 sand) and the final total mass (358253.7-kg) are provided in Column two of Table 1. These data provide the SB3 compositional estimate from which programmatic objectives can be baselined.

(a) Personal communication with H.H. Elder via email dated 3/25/02. Appendix A provides the data transmitted in the personal communication (elemental wt%, calcine basis). Minor compositional differences did exist between the values reported via email and those reported by Elder (2001). Although differences exist, the basis for this assessment will be the latest information reported (i.e., Appendix A).

(b) Calculations of noble metals, rare earths, and actinides that are not tracked by WCS performed by N.E. Bibler and are shown in Appendix B. The WCS does not track these additional rare earth and noble metals and thus their masses are not accounted for (i.e., the reported mass in the WCS is low). The total mass added was approximately 5036 kgs. It should also be noted that the minor mass contributions from Tb and Dy (0.15 and 0.01 kg, respectively) were added to Nd.

**Table 1.** Nominal Individual Sludge Compositions (in wt%, calcine oxide basis)

| Oxide | SB3 | Tank 7 Sand | Am/Cm | Pu/Gd |
|---|---|---|---|---|
| Ag | 6.90E-04 | 0.000 | 1.07E-03 | 0.000 |
| $Al_2O_3$ | 18.528 | 0.000 | 1.040 | 0.000 |
| $AmO_2$ | 1.47E-03 | 0.000 | 0.275 | 0.000 |
| BaO | 0.256 | 0.000 | 0.000 | 0.000 |
| CaO | 3.686 | 0.000 | 0.000 | 0.000 |
| CdO | 0.000 | 0.000 | 1.14E-03 | 0.000 |
| $Ce_2O_3$ | 0.357 | 0.000 | 0.598 | 0.000 |
| $Cm_2O_3$ | 1.01E-08 | 0.000 | 0.063 | 0.000 |
| $Cr_2O_3$ | 0.379 | 0.000 | 0.404 | 0.000 |
| CuO | 0.203 | 0.000 | 0.000 | 0.000 |
| $Eu_2O_3$ | 4.75E-03 | 0.000 | 4.48E-03 | 0.000 |
| $Fe_2O_3$ | 41.200 | 0.000 | 4.020 | 0.000 |
| $Gd_2O_3$ | 2.00E-03 | 0.000 | 0.159 | 60.398 |
| $K_2O$ | 0.441 | 0.000 | 0.000 | 0.000 |
| $La_2O_3$ | 0.206 | 0.000 | 0.427 | 0.000 |
| $Li_2O$ | 0.000 | 0.000 | 0.284 | 0.000 |
| MgO | 0.193 | 0.000 | 6.63E-03 | 0.000 |
| MnO | 7.348 | 0.000 | 0.143 | 0.000 |
| $MoO_3$ | 0.000 | 0.000 | 0.021 | 0.000 |
| $Na_2O$ | 10.885 | 0.000 | 0.000 | 0.000 |
| $Nb_2O_3$ | 0.000 | 0.000 | 0.000 | 0.000 |
| $Nd_2O_3$ | 0.685 | 0.000 | 1.234 | 0.000 |
| NiO | 1.647 | 0.000 | 0.237 | 0.000 |
| PbO | 0.307 | 0.000 | 0.226 | 0.000 |
| Pd | 0.038 | 0.000 | 2.30E-03 | 0.000 |
| $Pr_2O_3$ | 0.188 | 0.000 | 0.301 | 0.000 |
| $PuO_2$ | 0.021 | 0.000 | 0.045 | 39.602 |
| $RuO_2$ | 0.284 | 0.000 | 0.043 | 0.000 |
| Rh | 0.080 | 0.000 | 1.31E-03 | 0.000 |
| $SiO_2$ | 2.145 | 100.000 | 0.817 | 0.000 |
| $Sm_2O_3$ | 0.101 | 0.000 | 0.121 | 0.000 |
| $ThO_2$ | 0.147 | 0.000 | 0.000 | 0.000 |
| $TiO_2$ | 0.000 | 0.000 | 0.010 | 0.000 |
| $U_3O_8$ | 9.486 | 0.000 | 89.430 | 0.000 |
| ZnO | 0.421 | 0.000 | 0.017 | 0.000 |
| $ZrO_2$ | 0.761 | 0.000 | 0.026 | 0.000 |
| **Total** | 100.000 | 100.000 | 100.000 | 100.000 |
| **Mass (in kg)** | 358253.7 | 4550 | 3796.2 | 286.35 |

Current blending strategies assume that the sand from Tank 7 will be transferred into SB3. Given compositional estimates provided by Elder did not include the sand, values from the WCSystem.xls (dated 4/17/2000) were obtained and used in this assessment. The reported total mass of sand associated with Tank 7 is 4550 kgs. It is assumed that the sand contains no impurities and is represented by 100% $SiO_2$. These data are provided in Column three of Table 1.

Current blending strategies for SB3 include adding 100 kg of Pu and 150 kg of Gd. On a calcined oxide basis, this translates into 113.4 and 172.95 kg of $PuO_2$ and $Gd_2O_3$, respectively (or a total mass of 286.35 kg of oxide). These data are in Column five of Table 1.

Information reported by Peters (2002) and Lambert and Peters (2001) provided the basis for determining the Am/Cm waste-stream composition. Based on actual Tank 17.1 samples, which were subsequently neutralized with 50-wt% NaOH and a 350 g/L U solution, measured values were reported and are summarized in Appendix C. Adding the 350 g/L-U solution is intended to dilute the high activity of the solids, given the concerns of potential exposure issues, as this material is transferred from the F-area to the H-area. The neutralization dilution process adds significant quantities of Na and U to this stream (6569.29 kg and 2870 kg, respectively). In addition to the concentrations reported and/or provided by Peters (2002), additional rare-earth (Pr, Nd, Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu) and actinide (Am, Cm, Pu, and Th) concentrations were calculated based on the inductively coupled plasma-mass spectrometry (ICP-MS) analysis.[(a)] The contributions of the rare earth and actinides were added to Am/Cm compositional and total-mass estimates provided by Peters (2002). It was assumed that the high Na concentration in the washed Am/Cm material (as reported by Peters 2002) will be forced to 0% as a result of sludge washing. Therefore, the reported and calculated mass values were converted to wt% by eliminating the Na contribution and renormalizing. The resulting Am/Cm waste stream is high in $U_3O_8$ (~ 89.4 wt%) and yields 3796.2 kg of oxides. These results are in Column four of Table 1.

It is assumed that the individual waste streams or sludges presented in Table 1 are essentially "compositional centroids" representing an average that is expected to be blended in SB3. It should also be noted that the nominal compositions (and thus the assessments based upon them) do not account for any compositional sludge variation.

Table 2 summarizes the nominal compositions of the six blending scenarios. The resulting blended sludge compositions are weighted averages based on the oxide wt%s and total masses either reported or calculated (see Table 1). The blending calculations (and thus the assessments based upon them) assume that individual streams will be evenly distributed or uniformly blended, resulting in a "constant" feed to the melter (once frit additions are made). More specifically, it is assumed that the individual waste streams or sludges will not constitute a "spike" in composition during processing of a limited portion of SB3.

(a) Appendix D shows calculations of rare earths and actinides that were performed by Bibler, but not reported by Peters (2002). The total mass added was approximately 3796.2 kg (oxide basis). It should be noted that the contributions of Tb, Dy, Ho, Er, Tm, Yb, and Lu were tracked as Eu, given the negligible total mass of these oxides (~0.17 kg).

**Table 2.** Nominal Sludge Compositions for Various Blending Scenarios (in wt%, calcine oxide basis)

| Oxide | Case #1 (baseline) SB3 (including the Tank 51 heel) with Tank 7 sand | Case #2 SB3 baseline with Pu/Gd | Case #3 SB3 baseline with Am/Cm | Case #4 SB3 baseline with Pu/Gd and Am/Cm | Case #5 SB3 with Tank 51 Heel | Case #6 SB3 with Tank 51 Heel, Pu/Gd, and Am/Cm |
|---|---|---|---|---|---|---|
| Ag | 6.81E-04 | 6.80E-04 | 6.85E-04 | 6.85E-04 | 6.90E-04 | 6.93E-04 |
| $Al_2O_3$ | 18.295 | 18.281 | 18.117 | 18.102 | 18.528 | 18.330 |
| $AmO_2$ | 1.45E-03 | 1.45E-03 | 4.28E-03 | 4.28E-03 | 1.47E-03 | 4.33E-03 |
| BaO | 0.253 | 0.253 | 0.250 | 0.250 | 0.256 | 0.253 |
| CaO | 3.640 | 3.637 | 3.603 | 3.600 | 3.686 | 3.645 |
| CdO | 0.000 | 0.000 | 1.18E-05 | 1.18E-05 | 0.000 | 1.20E-05 |
| $Ce_2O_3$ | 0.353 | 0.353 | 0.355 | 0.355 | 0.357 | 0.360 |
| $Cm_2O_3$ | 9.98E-09 | 9.97E-09 | 6.48E-04 | 6.47E-04 | 1.01E-08 | 6.55E-04 |
| $Cr_2O_3$ | 0.374 | 0.374 | 0.375 | 0.374 | 0.379 | 0.379 |
| CuO | 0.200 | 0.200 | 0.198 | 0.198 | 0.203 | 0.201 |
| $Eu_2O_3$ | 4.69E-03 | 4.68E-03 | 4.68E-05 | 4.68E-05 | 4.75E-03 | 4.74E-05 |
| $Fe_2O_3$ | 40.681 | 40.649 | 40.302 | 40.270 | 41.198 | 40.776 |
| $Gd_2O_3$ | 1.97E-03 | 0.050 | 3.60E-03 | 0.051 | 2.00E-03 | 0.051 |
| $K_2O$ | 0.435 | 0.435 | 0.431 | 0.431 | 0.441 | 0.436 |
| $La_2O_3$ | 0.203 | 0.203 | 0.206 | 0.206 | 0.206 | 0.208 |
| $Li_2O$ | 0.000 | 0.000 | 2.94E-03 | 2.94E-03 | 0.000 | 2.98E-03 |
| MgO | 0.191 | 0.191 | 0.189 | 0.189 | 0.193 | 0.191 |
| MnO | 7.256 | 7.250 | 7.182 | 7.177 | 7.348 | 7.267 |
| $MoO_3$ | 0.000 | 0.000 | 2.17E-04 | 2.17E-04 | 0.000 | 2.20E-04 |
| $Na_2O$ | 10.749 | 10.740 | 10.638 | 10.629 | 10.885 | 10.763 |
| $Nd_2O_3$ | 0.677 | 0.676 | 0.683 | 0.682 | 0.685 | 0.691 |
| NiO | 1.627 | 1.625 | 1.612 | 1.611 | 1.648 | 1.631 |
| PbO | 0.303 | 0.303 | 0.303 | 0.302 | 0.307 | 0.306 |
| Pd | 0.037 | 0.037 | 0.037 | 0.037 | 0.038 | 0.037 |
| $Pr_2O_3$ | 0.185 | 0.185 | 0.187 | 0.186 | 0.188 | 0.189 |
| $PuO_2$ | 0.021 | 0.052 | 0.021 | 0.052 | 0.021 | 0.053 |
| $RuO_2$ | 0.281 | 0.280 | 0.278 | 0.278 | 0.284 | 0.281 |
| Rh | 0.079 | 0.079 | 0.078 | 0.078 | 0.080 | 0.079 |
| $SiO_2$ | 3.373 | 3.370 | 3.346 | 3.343 | 2.145 | 2.130 |
| $Sm_2O_3$ | 0.100 | 0.100 | 0.100 | 0.100 | 0.101 | 0.101 |
| $ThO_2$ | 0.145 | 0.145 | 0.143 | 0.143 | 0.147 | 0.145 |
| $TiO_2$ | 0.000 | 0.000 | 1.04E-04 | 1.04E-04 | 0.000 | 1.05E-04 |
| $U_3O_8$ | 9.367 | 9.360 | 10.196 | 10.188 | 9.486 | 10.316 |
| ZnO | 0.416 | 0.415 | 0.412 | 0.411 | 0.421 | 0.416 |
| $ZrO_2$ | 0.751 | 0.751 | 0.744 | 0.743 | 0.761 | 0.752 |
| **Total** | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 |
| **Mass (in kg)** | 362803.69 | 363090.04 | 366599.89 | 366886.24 | 358253.69 | 362336.24 |

### 3.2 Frit Selection

To make assessments on glass-quality impacts, not only does one have to define the sludge streams (see Section 3.1) but also the frit(s) that may be mixed with the sludge to produce an acceptable product. Table 3 summarizes the nominal compositions of the three frits that were considered in this study: Frit 165, Frit 200, and Frit 320. Soper et al. (1983) defined an "optimum" sludge-only frit as "one which produced waste glass with leachability as low as possible, with a maximum viscosity at 1150°C as near 15 N-s/$m^2$ (or 15 Pa-s [150 Poise]) as possible, with a $T_L$ as low as possible and with a coefficient of thermal expansion as low as possible." Through a statistically designed study and after only 25 trials, a frit meeting this definition was found in spite of the fact that eight chemical components were evaluated. Frit 165 was found to be superior to other potential frit candidates (including Frit 131) for sludge-only processing, based on blending projections and process knowledge in the early 1980s. Although not designed as a "sludge-only" frit (Jantzen 1988), Frit 200 is currently considered a "baseline" frit as it was used to process SB1a and SB1b, and is currently being used to process SB2. However, Lambert et al. (2001) have recommended that DWPF use Frit 320 for SB2 to improve the melt rate without compromising either processing or product-performance properties. Based on an assessment by Peeler, Brown and Edwards (2001), Frit 320 does appear to be viable for not only SB2 but also SB3 and SB4 (even though not specifically designed for either).[(a)]

Given that process/product models are readily available, all three frits will be assessed in this report. Evaluating the predicted impacts and projected operating windows for all three frits will provide insight to DWPF as they finalize blending strategies. It is not the intent of this study to recommend a frit to DWPF for SB3—only to provide insight into the frit selection process.

**Table 3.** Nominal Frits Compositions (in wt%)

| Frit Oxide | Frit 165 | Frit 200 | Frit 320 |
|---|---|---|---|
| $B_2O_3$ | 10 | 12 | 8 |
| $SiO_2$ | 68 | 70 | 72 |
| MgO | 1 | 2 | 0 |
| $Li_2O$ | 7 | 5 | 8 |
| $Na_2O$ | 13 | 11 | 12 |
| $ZrO_2$ | 1 | 0 | 0 |
| Total | 100 | 100 | 100 |

(a) Assessments were made as to whether the homogeneity constraint has the potential to restrict composition regions of projected sludge-only processing. The composition region covered by Peeler et al. (2001) included five individual waste types, SB3, and SB4, based on Rev 12 of the HLW Systems Plan (WSRC 2001). Assessments were made using both centroid and extreme sludge compositions coupled with Frit 320, 200, and 165, but did not include the addition of the Pu/Gd and/or Am/Cm waste streams.

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# 4.0 Property Acceptability Region (PAR) Limits Used for Assessments

The assessments discussed in this report are based solely on property predictions generated by glass-property models. Property measurements were not performed (experimentally) as part of this study. Glass-property models are implemented in PCCS, which is used to determine the acceptability of each batch of DWPF melter feed in the SME. This system imposes several constraints on the composition of the contents of the SME to define acceptability. These constraints relate process or product properties to composition via prediction models. A SME batch is deemed acceptable if its sample-composition measurements lead to acceptable property predictions after accounting for modeling, analytic, and/or measurement uncertainties. The baseline document guiding the use of these data and models is "SME Acceptability Determination for DWPF Process Control (U)" by Brown and Postles (1996).

The properties assessed in this study included durability (Product Consisteny Test [PCT] [ASTM 1997]) response in terms of $\Delta G_P$), viscosity at 1150°C ($\eta_{1150°C}$), $T_L$ (using both the current and newly developed models), homogeneity, 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 establish or project operational windows for the various blending scenarios, predicted properties must be assessed relative to established acceptance criteria. Acceptable predicted properties for this assessment are based on satisfying their respective PAR limit values (see Table 4)—not the more restrictive Measurement Acceptability Region (MAR) limits.[a] Because the PAR limit for the new $T_L$ model is compositionally dependent (Brown et al. 2001), the PAR limit was conservatively set at 1010ºC to allow for a quick assessment. In fact, Brown et al. (2001) have demonstrated that the PAR limits for the new model will not be this restrictive (in terms of limiting the projected compositional operating window) for various glass-forming systems. Therefore, in the assessment discussions that follow, when the new $T_L$ model limits the projected operational window, one must remember the use of this conservatively set PAR limit. More specifically, failing this constraint (as currently defined) does not necessarily mean that it would be an unacceptable glass given the conservative 1010ºC PAR limit.

**Table 4.** PAR Limits for Various Properties

| Property | PAR Limit |
|---|---|
| $T_L$ (current) | < 1024.95°C |
| $T_L$ (new) | < 1010°C |
| Homogeneity | > 210.92 wt% |
| $\Delta G_P$ (durability) | > -12.7178 kcal/mol |
| $\eta_{1150°C}$ (melt viscosity) | 21.5–105.4 Poise |
| $Al_2O_3$ | ≥ 3.0 wt% (in glass)[b] |
| Σalkali | < 19.3 wt% (in glass) |

[a] The PAR is the set of compositions that produce acceptable predicted properties. That is, the PAR accounts for only one source of uncertainty—that due to modeling or prediction. The MAR adds measurement error to the PAR.

[b] The $Al_2O_3$ and Σalkali limits were developed by Edwards and Brown (1998) to allow the homogeneity constraint to be relaxed from the MAR to the PAR. An alternative criterion would be a minimum $Al_2O_3$ content of 4 wt% with no constraint on the sum of alkali over the composition region evaluated.

Note that three $\Delta G_P$ calculations were used. The first uses the glass durability/composition ($\Delta G_P$) model currently implemented in PCCS and used by DWPF. This model uses specific $\Delta G_{P,i}$ values reported by Jantzen et al. (1995) (typically for elements whose oxide concentrations are present at > 0.5 wt% in glass) to predict the $\Delta G_P$ for a specific SME composition which, before processing, is then compared to three SME acceptability criteria, the most restrictive of which is -12.7178 kcal/mol. The second glass-durability calculation (henceforth referred to as the modified $\Delta G_P^*$) used in this study builds upon the PCCS version in which $\Delta G_{P,i}$ values for additional minor components are tracked in this study. For those oxides tracked in this study that are currently not included in the PCCS prediction (e.g. $AmO_2$, $Ce_2O_3$, $MoO_3$, SrO, and $PuO_2$) the appropriate $\Delta G_{P,i}$ values reported by Jantzen et al. (1995) were added to the PCCS prediction to account for their contribution. The current PCCS prediction does account for $Cs_2O$, $La_2O_3$, and $ThO_2$, but these oxides are not currently measured by DWPF. For those oxides (e.g., $Cm_2O_3$, $Eu_2O_3$, $Gd_2O_3$, $Pr_2O_3$, and $Sm_2O_3$) tracked in this study that are neither included in the PCCS prediction nor $\Delta G_{P,i}$ values reported by Jantzen et al. (1995), the authors used $\Delta G_{P,i}$ values associated with oxides that are thought to have a similar effect on the durability response. More specifically, the $\Delta G_{P,i}$ value for $Nd_2O_3$ (-37.79 kcal/mol) was used for the rare earths ($Eu_2O_3$, $Gd_2O_3$, $Pr_2O_3$, and $Sm_2O_3$). For example, the contribution of $Gd_2O_3$ to the PCT response was included as (-37.79 kcal/mol) × ($Gd_2O_3$ concentration in glass in wt%)/(molecular weight of $Gd_2O_3$). The $\Delta G_{P,i}$ value for $AmO_2$ was used for $Cm_2O_3$. Based on the electromotive force (EMF) series reported by Schreiber and Hockman (1987), the noble metals, Pd and Rh, and Ag should be metallic at nominal DWPF melt temperatures and are assumed to remain metallic in the glass. Therefore, $\Delta G_{P,i}$ values for Pd, Rh, or Ag were not reported by Jantzen et al (1995). $RuO_2$ is predicted as the oxide which is consistent with the observations of Bickford and Jantzen (1986).

The third glass-durability calculation is a bounding approach in which the mass contributions of the Am/Cm and Pu/Gd streams are considered to be $Li_2O$ – the oxide having the most deleterious effect on $\Delta G_P$. That is, all of the oxides associated with the secondary waste streams are assumed to be $Li_2O$. Although this latter approach is considered bounding in terms of the predicted impact on durability, it will only be calculated for the Frit 320-based blending scenarios as a comparison. The PCCS version of $\Delta G_P$ will be used as the basis for this bounding calculation

# 5.0 Assessment of the Potential Impacts on Glass Quality

Predicted glass properties and projected operating windows (i.e., waste-loading ranges) for the six blending scenarios are discussed in this section. Although the individual scenarios are discussed in detailed in this section, Section 6.0 provides a detailed discussion of the relative changes in the property predictions after adding the Am/Cm and/or Pu/Gd secondary waste streams (either individually or combined) to SB3 relative to the baseline. Comparisons are made among the various scenarios to provide a measure of the impact each waste stream has on glass quality relative to the baseline case. In this study, glass quality is defined not only by the potential impact to durability but also by predictions regarding processability (e.g., $\eta_{1150°C}$ and $T_L$). Current PCCS (Brown and Postles 1996) property predictions (including the new $T_L$ model [Brown et al. 2001], which should be implemented prior to SB3 being processed) are used as the basis for this assessment. It must be recognized that the assessments and comparisons are based solely on predictions and that no experimental work was performed.

Although the property predictions provide the foundation from which these assessments are made, other potential processing issues (e.g., single components solubility limits and/or REDOX issues) are also briefly discussed for completeness. Specific issues regarding coal, REDOX control, and primary phase fields are discussed in Section 7.0.

## 5.1 Case #1 (Baseline): Nominal SB3 (including the Tank 51 Heel) with Tank 7 Sand

To be able to assess the potential impacts of added Am/Cm and/or Pu/Gd, a baseline case must be established. The baseline case assumes that DWPF would process SB3 without adding either Pu/Gd or Am/Cm. Note that the 1.6% sand from Tank 7 (4550 kg) and the Tank 51 heel estimated composition have been factored into the baseline case. Table 5 summarizes the nominal baseline sludge composition based on a weighted mass average of each individual stream. The major oxides (i.e., defined in this study as those exceeding 0.5 wt% in sludge) include $Al_2O_3$, CaO, $Fe_2O_3$, MnO, $Na_2O$, $Nd_2O_3$, NiO, $SiO_2$, $U_3O_8$, and $ZrO_2$. Note that all of the major oxides are currently associated with the PCCS $\Delta G_P$ prediction.

Again, the primary objective of this particular case is to baseline projected waste-loading ranges (or operational window) and property predictions, so differences can be assessed relative to various blending scenarios outlined in Section 2.0.

### 5.1.1 Frit 165 Assessment

Table 6 summarizes the property predictions of the baseline SB3 sludge composition when blended with Frit 165 over the nominal WL range of interest (23.5 to 36%). The column identified as "Satisfies PAR" represents the comparison of the predicted property versus the PAR limits as shown in Table 4. For example, the "Satisfies PAR" nomenclature for the Frit 165-based glass at 23.5% WL indicates "Durable, Visc, $T_L$, *Not Homog*, New $T_L$, $Al_2O_3$, and alkali." This nomenclature indicates that this particular glass satisfies the PAR limits (based on predictions using target compositions) for durability, viscosity, the current $T_L$ model ($T_L$), the new $T_L$ model (New $T_L$), the $Al_2O_3$ lower limit, and the sum of alkali. However, this glass is predicted to be inhomogeneous (as noted by "*Not Homog*"). (Note that the property that results in an "unacceptable" classification is shown in italics.) A parallel study is being performed to assess the potential to eliminate the homogeneity constraint (Peeler, Brown, and Edwards 2001), given

that the glass satisfies the $Al_2O_3$ lower limit and/or sum of alkali criteria. Given that the task is successful, the 23.5% WL glass would be processable, although this is a lower waste-loading glass and may be of minimal interest.

**Table 5.** Nominal Sludge Composition for Baseline Blending Scenario (Case #1) (in wt%, oxide basis)

| Oxide | SB3 (including the Tank 51 Heel) with Tank 7 sand | Oxide | SB3 (including the Tank 51 Heel) with Tank 7 sand |
|---|---|---|---|
| $Ag_2O$ | 6.81E-04 | $Na_2O$ | 10.749 |
| $Al_2O_3$ | 18.296 | $Nb_2O_3$ | 0.000 |
| $AmO_2$ | 1.45E-03 | $Nd_2O_3$ | 0.677 |
| $B_2O_3$ | 0.000 | NiO | 1.627 |
| BaO | 0.253 | $P_2O_5$ | 0.000 |
| CaO | 3.640 | PbO | 0.303 |
| CdO | 0.000 | PdO | 0.037 |
| $Ce_2O_3$ | 0.353 | $Pr_2O_3$ | 0.185 |
| $Cm_2O_3$ | 9.98E-09 | $PuO_2$ | 0.021 |
| $Cr_2O_3$ | 0.374 | $RuO_2$ | 0.281 |
| $Cs_2O$ | 0.000 | $RhO_2$ | 0.079 |
| CuO | 0.200 | $SiO_2$ | 3.373 |
| $Eu_2O_3$ | 0.000 | $Sm_2O_3$ | 0.100 |
| $Fe_2O_3$ | 40.683 | $SnO_2$ | 0.000 |
| $Gd_2O_3$ | 1.97E-03 | SrO | 0.000 |
| $K_2O$ | 0.435 | $ThO_2$ | 0.145 |
| $La_2O_3$ | 0.203 | $TiO_2$ | 0.000 |
| $Li_2O$ | 0.000 | $U_3O_8$ | 9.367 |
| MgO | 0.191 | $Y_2O_3$ | 0.000 |
| MnO | 7.256 | ZnO | 0.416 |
| $MoO_3$ | 0.000 | $ZrO_2$ | 0.751 |
| | | | |
| | | **Total** | 100.00 |
| | | **Mass (in kgs)** | 362803.69 |

As another example, consider the 24.0 wt% WL Frit 165—SB3 baseline glass. The "Satisfies PAR" nomenclature indicates that this glass satisfies the PAR limits for durability, viscosity, homogeneity, and both $T_L$ models, the lower $Al_2O_3$ limit and the sum of alkali limit. This glass defines the lower WL limit for "acceptability" (for the specific glass being considered, recognizing that compositional variation in sludge has not been accounted for) given current PAR limit constraints. Based on the current $T_L$ model, the upper limit is defined by the glass at 30.0% WL. Implementation of the new $T_L$ model (Brown et al. 2001) would yield an upper WL limit of 35.5%. Although operating-window projections could be made for both the current and new $T_L$ models, this study will assume that the new $T_L$ model will be implemented before and/or during SB3 processing. Therefore, upper WL ranges discussed will be based on the new model that typically yields higher WLs.

**Table 6.** Property Predictions as a Function of WL for Frit 165 and SB3 Baseline (Case #1)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 165-Case 1 | 23.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04300 | 0.179 | 49.4 | 210.4 | -11.196 | -11.163 | 954.1 | 806.6 |
| 165-Case 1 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04391 | 0.179 | 48.8 | 211.6 | -11.140 | -11.106 | 958.7 | 815.8 |
| 165-Case 1 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04483 | 0.178 | 48.2 | 212.7 | -11.083 | -11.048 | 963.5 | 824.8 |
| 165-Case 1 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04574 | 0.178 | 47.6 | 213.8 | -11.027 | -10.991 | 968.4 | 833.8 |
| 165-Case 1 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04666 | 0.178 | 47.0 | 215.0 | -10.970 | -10.934 | 973.3 | 842.7 |
| 165-Case 1 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04757 | 0.177 | 46.4 | 216.1 | -10.914 | -10.877 | 978.4 | 851.4 |
| 165-Case 1 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04848 | 0.177 | 45.9 | 217.3 | -10.858 | -10.820 | 983.5 | 860.1 |
| 165-Case 1 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04940 | 0.176 | 45.3 | 218.4 | -10.801 | -10.763 | 988.8 | 868.7 |
| 165-Case 1 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05031 | 0.176 | 44.7 | 219.5 | -10.745 | -10.706 | 994.2 | 877.2 |
| 165-Case 1 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05123 | 0.175 | 44.1 | 220.7 | -10.689 | -10.649 | 999.6 | 885.7 |
| 165-Case 1 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05214 | 0.175 | 43.5 | 221.8 | -10.632 | -10.592 | 1005.2 | 894.0 |
| 165-Case 1 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05306 | 0.174 | 42.9 | 222.9 | -10.576 | -10.535 | 1011.0 | 902.3 |
| 165-Case 1 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05397 | 0.174 | 42.4 | 224.1 | -10.519 | -10.478 | 1016.8 | 910.5 |
| 165-Case 1 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05489 | 0.174 | 41.8 | 225.2 | -10.463 | -10.421 | 1022.8 | 918.6 |
| 165-Case 1 | 30.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05580 | 0.173 | 41.2 | 226.3 | -10.407 | -10.363 | 1028.9 | 926.6 |
| 165-Case 1 | 31 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05672 | 0.173 | 40.6 | 227.5 | -10.350 | -10.306 | 1035.1 | 934.5 |
| 165-Case 1 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05763 | 0.172 | 40.0 | 228.6 | -10.294 | -10.249 | 1041.5 | 942.4 |
| 165-Case 1 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05855 | 0.172 | 39.5 | 229.7 | -10.238 | -10.192 | 1048.0 | 950.2 |
| 165-Case 1 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05946 | 0.171 | 38.9 | 230.9 | -10.181 | -10.135 | 1054.7 | 958.0 |
| 165-Case 1 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06038 | 0.171 | 38.3 | 232.0 | -10.125 | -10.078 | 1061.5 | 965.6 |
| 165-Case 1 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06129 | 0.170 | 37.7 | 233.1 | -10.068 | -10.021 | 1068.5 | 973.2 |
| 165-Case 1 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06221 | 0.170 | 37.2 | 234.3 | -10.012 | -9.964 | 1075.6 | 980.8 |
| 165-Case 1 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06312 | 0.170 | 36.6 | 235.4 | -9.956 | -9.907 | 1082.9 | 988.2 |
| 165-Case 1 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06404 | 0.169 | 36.0 | 236.5 | -9.899 | -9.850 | 1090.5 | 995.6 |
| 165-Case 1 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06495 | 0.169 | 35.4 | 237.7 | -9.843 | -9.793 | 1098.1 | 1002.9 |
| 165-Case 1 | 36 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06587 | 0.168 | 34.9 | 238.8 | -9.787 | -9.736 | 1106.0 | 1010.2 |

For the Frit 165 baseline case, the projected operational window covers the 24.0 to 35.5% WL range. At lower WLs, homogeneity is not satisfied while $T_L$ predictions (even with the proposed $T_L$ model) continue to limit attainment of higher WLs.

Property predictions of the Frit 165 baseline case are also shown in Table 6. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 48.8 Poise, 958.7°C, 815.8°C, -11.14 kcal/mol, and -11.106 kcal/mol, respectively, at the lower waste-loading limit (i.e., 24.0%). At the upper waste-loading limit (35.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 35.4 Poise, 1098.1°C, 1002.9°C, -9.84 kcal/mol, and -9.793 kcal/mol, respectively. Note that as WLs increase, the $\Delta G_P$ values become more positive (or less negative) indicating that the predicted durability is increasing (based upon the linear correlation of $\Delta G_P$ with normalized releases). It is this indicator ($\Delta G_P$)—not normalized boron release—that is used throughout this report in the assessment of glass quality for each blending scenario. These predicted properties establish a baseline from which the various blending strategies can be assessed in terms of their potential impacts to glass processing or product quality for the various Frit 165-based cases.

#### 5.1.2 Frit 200 Assessment

For the Frit 200 baseline case, the projected operational window exists from 24.0 to 30.5% WL (see Table 7). At low WLs, homogeneity is not satisfied while $T_L$ predictions (both the current and new models) continue to limit access to higher WLs exceeding 30.5 wt%. Of particular interest for this glass region is the fact that both $T_L$ models limit WLs to the 30.5-wt% level. The use of the conservative 1010ºC PAR limit for the new $T_L$ model may overly restrict this region as shown by Brown et al. (2001). It is, however, anticipated that the true PAR limit would not yield WLs higher than either Frit 165 or Frit 320.

Property predictions of the Frit 200 baseline case are shown in Table 7. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 89.8 Poise, 953.8°C, 902.5°C, -8.864 kcal/mol, and -8.830 kcal/mol respectively, at the lower WL limit (i.e., 24.0%). At the upper WL limit (30.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 75.9 Poise, 1021.4°C, 1008.3°C, -8.325 kcal/mol, and -8.282 kcal/mol respectively. Note that as WLs increase, predictions of durability increase. This is reflected by the $\Delta G_P$ values being more positive (or less negative). Compared to either the Frit 165- or Frit 320-based cases, the impact of using Frit 200 can be generalized as increasing viscosity, $T_L$, and durability but having a significant (negative) impact on WL. These predicted properties establish a baseline from which the various blending strategies can be assessed in terms of their potential impacts to glass processing or product quality for the various Frit 200-based cases.

#### 5.1.3 Frit 320 Assessment

For the Frit 320 baseline case, the projected operational window exists from 23.0 to 37.5% WL (see Table 8). Note that the use of Frit 320 extends the operational window (for the baseline case relative to either Frit 165 or 200) to both higher and lower WLs. Access to lower WL (i.e., < 24.0% for both Frit 165 and 200 cases) is a result of glasses produced using Frit 320 not challenging the homogeneity constraint, which is consistent with observations by Peeler, Brown, and Edwards (2001). More importantly, the use of Frit 320 allows for higher WLs to be obtained (based on property predictions) compared to either Frit 165 or Frit 200 for the baseline SB3 sludge. Although higher WLs are predicted, it should be recognized that this frit was developed specifically for SB2 to improve the melt rate (Peeler et al. 2001; Lambert et al. 2001).

**Table 7.** Property Predictions as a Function of WL for Frit 200 and SB3 Baseline (Case #1)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_D$ (kcal/mol) | Modified $DG_D^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 200-Case 1 | 23.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04300 | 0.149 | 90.8 | 210.4 | -8.905 | -8.872 | 949.3 | 893.6 |
| 200-Case 1 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04391 | 0.148 | 89.8 | 211.6 | -8.864 | -8.830 | 953.8 | 902.5 |
| 200-Case 1 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04483 | 0.148 | 88.7 | 212.7 | -8.822 | -8.788 | 958.4 | 911.2 |
| 200-Case 1 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04574 | 0.148 | 87.6 | 213.8 | -8.781 | -8.745 | 963.1 | 919.8 |
| 200-Case 1 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04666 | 0.148 | 86.6 | 215.0 | -8.739 | -8.703 | 967.9 | 928.4 |
| 200-Case 1 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04757 | 0.147 | 85.5 | 216.1 | -8.698 | -8.661 | 972.8 | 936.8 |
| 200-Case 1 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04848 | 0.147 | 84.4 | 217.3 | -8.657 | -8.619 | 977.7 | 945.1 |
| 200-Case 1 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04940 | 0.147 | 83.4 | 218.4 | -8.615 | -8.577 | 982.8 | 953.3 |
| 200-Case 1 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05031 | 0.147 | 82.3 | 219.5 | -8.574 | -8.535 | 988.0 | 961.5 |
| 200-Case 1 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05123 | 0.147 | 81.2 | 220.7 | -8.532 | -8.493 | 993.3 | 969.5 |
| 200-Case 1 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05214 | 0.146 | 80.2 | 221.8 | -8.491 | -8.451 | 998.7 | 977.4 |
| 200-Case 1 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05306 | 0.146 | 79.1 | 222.9 | -8.450 | -8.409 | 1004.2 | 985.3 |
| 200-Case 1 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05397 | 0.146 | 78.0 | 224.1 | -8.408 | -8.366 | 1009.8 | 993.0 |
| 200-Case 1 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05489 | 0.146 | 77.0 | 225.2 | -8.367 | -8.324 | 1015.6 | 1000.7 |
| 200-Case 1 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05580 | 0.145 | 75.9 | 226.3 | -8.325 | -8.282 | 1021.4 | 1008.3 |
| 200-Case 1 | 31 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.05672 | 0.145 | 74.9 | 227.5 | -8.284 | -8.240 | 1027.4 | 1015.8 |

**Table 8.** Property Predictions as a Function of WL for Frit 320 and SB3 Baseline (Case #1)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 320-Case 1 | 22.5 | Durable; Visc; TL; *Not Homog;* New TL; $Al_2O_3$; alkali | 0.04117 | 0.180 | 60.6 | 210.7 | -10.701 | -10.669 | 936.4 | 759.7 |
| 320-Case 1 | 23 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04208 | 0.180 | 59.9 | 211.8 | -10.648 | -10.616 | 940.6 | 769.3 |
| 320-Case 1 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04300 | 0.179 | 59.2 | 212.9 | -10.596 | -10.563 | 944.9 | 778.7 |
| 320-Case 1 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04391 | 0.179 | 58.6 | 214.0 | -10.544 | -10.510 | 949.2 | 788.1 |
| 320-Case 1 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04483 | 0.178 | 57.9 | 215.1 | -10.491 | -10.456 | 953.7 | 797.4 |
| 320-Case 1 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04574 | 0.178 | 57.2 | 216.3 | -10.439 | -10.403 | 958.2 | 806.6 |
| 320-Case 1 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04666 | 0.178 | 56.6 | 217.4 | -10.386 | -10.350 | 962.8 | 815.7 |
| 320-Case 1 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04757 | 0.177 | 55.9 | 218.5 | -10.334 | -10.297 | 967.5 | 824.7 |
| 320-Case 1 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04848 | 0.177 | 55.2 | 219.6 | -10.281 | -10.244 | 972.3 | 833.7 |
| 320-Case 1 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04940 | 0.176 | 54.6 | 220.7 | -10.229 | -10.191 | 977.2 | 842.5 |
| 320-Case 1 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05031 | 0.176 | 53.9 | 221.8 | -10.176 | -10.137 | 982.2 | 851.2 |
| 320-Case 1 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05123 | 0.175 | 53.2 | 223.0 | -10.124 | -10.084 | 987.3 | 859.9 |
| 320-Case 1 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05214 | 0.175 | 52.6 | 224.1 | -10.072 | -10.031 | 992.5 | 868.5 |
| 320-Case 1 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05306 | 0.174 | 51.9 | 225.2 | -10.019 | -9.978 | 997.8 | 877.0 |
| 320-Case 1 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05397 | 0.174 | 51.2 | 226.3 | -9.967 | -9.925 | 1003.3 | 885.4 |
| 320-Case 1 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05489 | 0.174 | 50.6 | 227.4 | -9.914 | -9.872 | 1008.8 | 893.7 |
| 320-Case 1 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05580 | 0.173 | 49.9 | 228.6 | -9.862 | -9.818 | 1014.5 | 902.0 |
| 320-Case 1 | 31 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05672 | 0.173 | 49.2 | 229.7 | -9.809 | -9.765 | 1020.2 | 910.1 |
| 320-Case 1 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05763 | 0.172 | 48.6 | 230.8 | -9.757 | -9.712 | 1026.2 | 918.2 |
| 320-Case 1 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05855 | 0.172 | 47.9 | 231.9 | -9.704 | -9.659 | 1032.2 | 926.3 |
| 320-Case 1 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05946 | 0.171 | 47.2 | 233.0 | -9.652 | -9.606 | 1038.4 | 934.2 |
| 320-Case 1 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06038 | 0.171 | 46.5 | 234.1 | -9.599 | -9.553 | 1044.7 | 942.1 |
| 320-Case 1 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06129 | 0.170 | 45.9 | 235.3 | -9.547 | -9.499 | 1051.2 | 949.9 |
| 320-Case 1 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06221 | 0.170 | 45.2 | 236.4 | -9.495 | -9.446 | 1057.8 | 957.7 |
| 320-Case 1 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06312 | 0.170 | 44.5 | 237.5 | -9.442 | -9.393 | 1064.5 | 965.3 |
| 320-Case 1 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06404 | 0.169 | 43.9 | 238.6 | -9.390 | -9.340 | 1071.5 | 972.9 |
| 320-Case 1 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06495 | 0.169 | 43.2 | 239.7 | -9.337 | -9.287 | 1078.6 | 980.5 |
| 320-Case 1 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06587 | 0.168 | 42.5 | 240.9 | -9.285 | -9.234 | 1085.8 | 988.0 |
| 320-Case 1 | 36.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06678 | 0.168 | 41.9 | 242.0 | -9.232 | -9.181 | 1093.3 | 995.4 |
| 320-Case 1 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06770 | 0.167 | 41.2 | 243.1 | -9.180 | -9.127 | 1100.9 | 1002.7 |
| 320-Case 1 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06861 | 0.167 | 40.5 | 244.2 | -9.127 | -9.074 | 1108.8 | 1010.0 |
| 320-Case 1 | 38 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06953 | 0.167 | 39.9 | 245.3 | -9.075 | -9.021 | 1116.8 | 1017.2 |

Property predictions of the Frit 320 baseline case are also shown in Table 8. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 59.9 Poise, 940.6°C, 769.3°C, -10.648 kcal/mol, and -10.616 kcal/mol, respectively, at the lower waste-loading limit (i.e., 23.0%). At the upper waste-loading limit (37.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 40.5 Poise, 1108.8°C, 1010.0°C, -9.127 kcal/mol, and -9.074 kcal/mol, respectively. As with the two previous cases, as WLs increase, predictions of durability increase. This is reflected by the $\Delta G_P$ values being more positive (or less negative). These predicted properties establish a baseline from which the various blending strategies can be assessed in terms of their potential impacts to glass processing or product quality for the various Frit 320-based cases.

### 5.2 Case #2: SB3 Baseline with Pu/Gd

Current blending strategies project adding 100 kg of Pu (113.4 kg $PuO_2$) and 150 kg of Gd (172.95 kg $Gd_2O_3$) to SB3. Although additions of the Am/Cm stream are also projected, Case #2 assesses the impacts to property predictions, given the individual addition of $PuO_2$ and $Gd_2O_3$ relative to the baseline (Case #1) in the event that anticipated blending strategies are not realized.

Table 9 summarizes the resulting nominal SB3 sludge composition when blended with the 286.35 kg of $PuO_2/Gd_2O_3$. The resulting total mass is estimated to be 363090.04 kg (oxide basis). As with the nominal baseline case (Case #1), the major oxides (i.e., those exceeding 0.5 wt% in sludge) include $Al_2O_3$, CaO, $Fe_2O_3$, MnO, $Na_2O$, $Nd_2O_3$, NiO, $SiO_2$, $U_3O_8$, and $ZrO_2$. This is not surprising given the low total mass of the Pu/Gd waste stream. Again, note that all of the major oxides are currently associated with the PCCS $\Delta G_P$ prediction.

Compositional differences between the SB3 baseline sludge with and without the Pu/Gd addition are minimal—refer to Table 2 for a direct comparison. The concentrations of $PuO_2$ and $Gd_2O_3$ in the sludge are 0.052 and 0.05 wt%, respectively. Therefore, projecting this nominal sludge composition into glass over a waste-loading range of interest should have a minimal impact on predicted glass properties relative to the baseline case. In fact, Plodinec et al. (1995) indicated that trace components (elements whose oxides are present in the glass at concentrations less than 0.5 wt%) do not have a significant impact on glass durability. Based on the projected concentrations of the added components from the $PuO_2$ and $Gd_2O_3$ waste stream to the baseline case and the conclusions drawn by Plodinec et al. (1995), one would anticipate any change to predicted properties to be a function of the minimal dilution of those oxide components forming the basis for the model predictions and/or the addition of components that were not associated with the baseline case (but are accounted for by the PCCS models currently used by DWPF). Regardless, changes to predictions are expected to be minimal given the low total mass of this stream.

To demonstrate this hypothesis, properties were assessed using the blended Case #2 composition (see Tables 10 through 12). A review of the "Satisfies PAR" column provides a rapid assessment of the projected operational window for the specific blending scenario under consideration when blended with the three frits of interest.

**Table 9.** Nominal Sludge Composition for Case #2 (SB3 Baseline with Pu/Gd) (in wt%, oxide basis)

| Oxide | SB3 baseline with Pu/Gd | Oxide | SB3 baseline with Pu/Gd |
|---|---|---|---|
| Ag | 6.80E-04 | $Na_2O$ | 10.740 |
| $Al_2O_3$ | 18.281 | $Nb_2O_3$ | 0.000 |
| $AmO_2$ | 1.45E-03 | $Nd_2O_3$ | 0.676 |
| $B_2O_3$ | 0.000 | NiO | 1.625 |
| BaO | 0.253 | $P_2O_5$ | 0.000 |
| CaO | 3.637 | PbO | 0.303 |
| CdO | 0.000 | Pd | 0.037 |
| $Ce_2O_3$ | 0.353 | $Pr_2O_3$ | 0.185 |
| $Cm_2O_3$ | 9.97E-09 | $PuO_2$ | 0.052 |
| $Cr_2O_3$ | 0.374 | $RuO_2$ | 0.280 |
| $Cs_2O$ | 0.000 | Rh | 0.079 |
| CuO | 0.200 | $SiO_2$ | 3.370 |
| $Eu_2O_3$ | 4.68E-03 | $Sm_2O_3$ | 0.100 |
| $Fe_2O_3$ | 40.649 | $SnO_2$ | 0.000 |
| $Gd_2O_3$ | 0.050 | SrO | 0.000 |
| $K_2O$ | 0.435 | $ThO_2$ | 0.145 |
| $La_2O_3$ | 0.203 | $TiO_2$ | 0.000 |
| $Li_2O$ | 0.000 | $U_3O_8$ | 9.360 |
| MgO | 0.191 | $Y_2O_3$ | 0.000 |
| MnO | 7.250 | ZnO | 0.415 |
| $MoO_3$ | 0.000 | $ZrO_2$ | 0.751 |
| | | | |
| | | **Total** | 100.000 |
| | | **Mass (in kgs)** | 363090.04 |

#### 5.2.1 Frit 165 Assessment

For Case #2 (SB3 baseline with Pu/Gd) using Frit 165, the projected operational window is 24.0 to 36.0% WL (see Table 10). As with previous cases, lower WLs (although probably of minimal interest) are limited by homogeneity while $T_L$ predictions continued to limit access to higher WLs.

Property predictions of the Frit 165-based Case #2 are also shown in Table 10. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 48.8 Poise, 958.6°C, 815.5°C, -11.139 kcal/mol, and -11.105 kcal/mol, respectively, at the lower waste-loading limit (i.e., 24.0%). At the upper waste-loading limit (36.0 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 34.9 Poise, 1105.7°C, 1009.9°C, -9.786 kcal/mol, and -9.735 kcal/mol, respectively.

**Table 10.** Property Predictions as a Function of WL for Frit 165 and SB3 Baseline with Pu/Gd (Case #2)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 165-Case 2 | 23.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04296 | 0.179 | 49.4 | 210.4 | -11.195 | -11.162 | 953.9 | 806.4 |
| 165-Case 2 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04388 | 0.179 | 48.8 | 211.5 | -11.139 | -11.105 | 958.6 | 815.5 |
| 165-Case 2 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04479 | 0.178 | 48.2 | 212.6 | -11.083 | -11.048 | 963.4 | 824.6 |
| 165-Case 2 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04570 | 0.178 | 47.6 | 213.8 | -11.026 | -10.991 | 968.2 | 833.5 |
| 165-Case 2 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04662 | 0.177 | 47.0 | 214.9 | -10.970 | -10.934 | 973.2 | 842.4 |
| 165-Case 2 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04753 | 0.177 | 46.5 | 216.0 | -10.914 | -10.877 | 978.2 | 851.2 |
| 165-Case 2 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04845 | 0.177 | 45.9 | 217.2 | -10.857 | -10.820 | 983.4 | 859.8 |
| 165-Case 2 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04936 | 0.176 | 45.3 | 218.3 | -10.801 | -10.763 | 988.6 | 868.4 |
| 165-Case 2 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05027 | 0.176 | 44.7 | 219.4 | -10.744 | -10.706 | 994.0 | 877.0 |
| 165-Case 2 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05119 | 0.175 | 44.1 | 220.6 | -10.688 | -10.649 | 999.5 | 885.4 |
| 165-Case 2 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05210 | 0.175 | 43.5 | 221.7 | -10.632 | -10.592 | 1005.1 | 893.7 |
| 165-Case 2 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05302 | 0.174 | 43.0 | 222.8 | -10.575 | -10.535 | 1010.8 | 902.0 |
| 165-Case 2 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05393 | 0.174 | 42.4 | 224.0 | -10.519 | -10.477 | 1016.6 | 910.2 |
| 165-Case 2 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05485 | 0.174 | 41.8 | 225.1 | -10.462 | -10.420 | 1022.6 | 918.3 |
| 165-Case 2 | 30.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05576 | 0.173 | 41.2 | 226.2 | -10.406 | -10.363 | 1028.7 | 926.3 |
| 165-Case 2 | 31 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05667 | 0.173 | 40.6 | 227.4 | -10.350 | -10.306 | 1034.9 | 934.3 |
| 165-Case 2 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05759 | 0.172 | 40.1 | 228.5 | -10.293 | -10.249 | 1041.2 | 942.2 |
| 165-Case 2 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05850 | 0.172 | 39.5 | 229.6 | -10.237 | -10.192 | 1047.8 | 950.0 |
| 165-Case 2 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05942 | 0.171 | 38.9 | 230.8 | -10.181 | -10.135 | 1054.4 | 957.7 |
| 165-Case 2 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06033 | 0.171 | 38.3 | 231.9 | -10.124 | -10.078 | 1061.2 | 965.4 |
| 165-Case 2 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06124 | 0.170 | 37.7 | 233.0 | -10.068 | -10.021 | 1068.2 | 973.0 |
| 165-Case 2 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06216 | 0.170 | 37.2 | 234.2 | -10.011 | -9.964 | 1075.4 | 980.5 |
| 165-Case 2 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06307 | 0.170 | 36.6 | 235.3 | -9.955 | -9.907 | 1082.7 | 988.0 |
| 165-Case 2 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06399 | 0.169 | 36.0 | 236.4 | -9.899 | -9.850 | 1090.2 | 995.3 |
| 165-Case 2 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06490 | 0.169 | 35.4 | 237.6 | -9.842 | -9.792 | 1097.9 | 1002.7 |
| 165-Case 2 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06581 | 0.168 | 34.9 | 238.7 | -9.786 | -9.735 | 1105.7 | 1009.9 |
| 165-Case 2 | 36.5 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06673 | 0.168 | 34.3 | 239.8 | -9.729 | -9.678 | 1113.8 | 1017.1 |

**Table 11.** Property Predictions as a Function of WL for Frit 200 and SB3 Baseline with Pu/Gd (Case #2)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 200-Case 2 | 23.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04296 | 0.149 | 90.8 | 210.4 | -8.905 | -8.872 | 949.2 | 893.4 |
| 200-Case 2 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04388 | 0.148 | 89.8 | 211.5 | -8.863 | -8.829 | 953.7 | 902.2 |
| 200-Case 2 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04479 | 0.148 | 88.7 | 212.6 | -8.822 | -8.787 | 958.3 | 911.0 |
| 200-Case 2 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04570 | 0.148 | 87.7 | 213.8 | -8.780 | -8.745 | 963.0 | 919.6 |
| 200-Case 2 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04662 | 0.148 | 86.6 | 214.9 | -8.739 | -8.703 | 967.8 | 928.1 |
| 200-Case 2 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04753 | 0.147 | 85.5 | 216.0 | -8.698 | -8.661 | 972.6 | 936.5 |
| 200-Case 2 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04845 | 0.147 | 84.5 | 217.2 | -8.656 | -8.619 | 977.6 | 944.9 |
| 200-Case 2 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04936 | 0.147 | 83.4 | 218.3 | -8.615 | -8.577 | 982.7 | 953.1 |
| 200-Case 2 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05027 | 0.147 | 82.3 | 219.4 | -8.573 | -8.535 | 987.8 | 961.2 |
| 200-Case 2 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05119 | 0.146 | 81.3 | 220.6 | -8.532 | -8.493 | 993.1 | 969.2 |
| 200-Case 2 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05210 | 0.146 | 80.2 | 221.7 | -8.490 | -8.450 | 998.5 | 977.2 |
| 200-Case 2 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05302 | 0.146 | 79.1 | 222.8 | -8.449 | -8.408 | 1004.0 | 985.0 |
| 200-Case 2 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05393 | 0.146 | 78.1 | 224.0 | -8.408 | -8.366 | 1009.6 | 992.8 |
| 200-Case 2 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05485 | 0.146 | 77.0 | 225.1 | -8.366 | -8.324 | 1015.4 | 1000.4 |
| 200-Case 2 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05576 | 0.145 | 75.9 | 226.2 | -8.325 | -8.282 | 1021.2 | 1008.0 |
| 200-Case 2 | 31 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.05667 | 0.145 | 74.9 | 227.4 | -8.283 | -8.240 | 1027.2 | 1015.5 |

**Table 12.** Property Predictions as a Function of WL for Frit 320 and SB3 Baseline with Pu/Gd (Case #2)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 320-Case 2 | 22.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04113 | 0.180 | 60.6 | 210.6 | -10.700 | -10.669 | 936.3 | 759.4 |
| 320-Case 2 | 23 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04205 | 0.180 | 59.9 | 211.7 | -10.648 | -10.616 | 940.5 | 769.0 |
| 320-Case 2 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04296 | 0.179 | 59.3 | 212.8 | -10.596 | -10.563 | 944.8 | 778.5 |
| 320-Case 2 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04388 | 0.179 | 58.6 | 213.9 | -10.543 | -10.509 | 949.1 | 787.9 |
| 320-Case 2 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04479 | 0.178 | 57.9 | 215.1 | -10.491 | -10.456 | 953.5 | 797.2 |
| 320-Case 2 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04570 | 0.178 | 57.3 | 216.2 | -10.438 | -10.403 | 958.1 | 806.4 |
| 320-Case 2 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04662 | 0.177 | 56.6 | 217.3 | -10.386 | -10.350 | 962.7 | 815.5 |
| 320-Case 2 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04753 | 0.177 | 55.9 | 218.4 | -10.333 | -10.297 | 967.4 | 824.5 |
| 320-Case 2 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04845 | 0.177 | 55.3 | 219.5 | -10.281 | -10.244 | 972.2 | 833.4 |
| 320-Case 2 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04936 | 0.176 | 54.6 | 220.6 | -10.228 | -10.190 | 977.1 | 842.2 |
| 320-Case 2 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05027 | 0.176 | 53.9 | 221.8 | -10.176 | -10.137 | 982.1 | 851.0 |
| 320-Case 2 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05119 | 0.175 | 53.3 | 222.9 | -10.123 | -10.084 | 987.2 | 859.6 |
| 320-Case 2 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05210 | 0.175 | 52.6 | 224.0 | -10.071 | -10.031 | 992.4 | 868.2 |
| 320-Case 2 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05302 | 0.174 | 51.9 | 225.1 | -10.018 | -9.978 | 997.7 | 876.7 |
| 320-Case 2 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05393 | 0.174 | 51.3 | 226.2 | -9.966 | -9.925 | 1003.1 | 885.1 |
| 320-Case 2 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05485 | 0.174 | 50.6 | 227.3 | -9.914 | -9.871 | 1008.6 | 893.4 |
| 320-Case 2 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05576 | 0.173 | 49.9 | 228.5 | -9.861 | -9.818 | 1014.3 | 901.7 |
| 320-Case 2 | 31 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05667 | 0.173 | 49.2 | 229.6 | -9.809 | -9.765 | 1020.1 | 909.9 |
| 320-Case 2 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05759 | 0.172 | 48.6 | 230.7 | -9.756 | -9.712 | 1026.0 | 918.0 |
| 320-Case 2 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05850 | 0.172 | 47.9 | 231.8 | -9.704 | -9.659 | 1032.0 | 926.0 |
| 320-Case 2 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05942 | 0.171 | 47.2 | 232.9 | -9.651 | -9.606 | 1038.2 | 933.9 |
| 320-Case 2 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06033 | 0.171 | 46.6 | 234.0 | -9.599 | -9.552 | 1044.5 | 941.8 |
| 320-Case 2 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06124 | 0.170 | 45.9 | 235.2 | -9.546 | -9.499 | 1050.9 | 949.6 |
| 320-Case 2 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06216 | 0.170 | 45.2 | 236.3 | -9.494 | -9.446 | 1057.5 | 957.4 |
| 320-Case 2 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06307 | 0.170 | 44.6 | 237.4 | -9.441 | -9.393 | 1064.3 | 965.1 |
| 320-Case 2 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06399 | 0.169 | 43.9 | 238.5 | -9.389 | -9.340 | 1071.2 | 972.7 |
| 320-Case 2 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06490 | 0.169 | 43.2 | 239.6 | -9.336 | -9.287 | 1078.3 | 980.2 |
| 320-Case 2 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06581 | 0.168 | 42.6 | 240.7 | -9.284 | -9.233 | 1085.6 | 987.7 |
| 320-Case 2 | 36.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06673 | 0.168 | 41.9 | 241.9 | -9.232 | -9.180 | 1093.0 | 995.1 |
| 320-Case 2 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06764 | 0.167 | 41.2 | 243.0 | -9.179 | -9.127 | 1100.6 | 1002.4 |
| 320-Case 2 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06856 | 0.167 | 40.6 | 244.1 | -9.127 | -9.074 | 1108.5 | 1009.7 |
| 320-Case 2 | 38 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06947 | 0.166 | 39.9 | 245.2 | -9.074 | -9.021 | 1116.5 | 1016.9 |

#### 5.2.2 Frit 200 Assessment

For Case #2 (SB3 baseline with Pu/Gd) using Frit 200, the projected operational window is 24.0 to 30.5% WL (see Table 11). As with the baseline case, both $T_L$ models limit WLs to the 30.5 wt% levels. The use of the conservative 1010ºC PAR limit for the new $T_L$ model may overly restrict this region (Brown et al. 2001). It is, however, anticipated that the true PAR limit would not yield WLs higher than either Frit 165 or Frit 320. Compared to either the Frit 165- or Frit 320-based cases, the impact of using Frit 200 can be generalized as increasing predicted viscosity, $T_L$, and durability but having a significant (negative) impact on WL. As with previous cases, lower WLs (although probably not of interest) are limited by homogeneity while $T_L$ predictions continued to limit access to higher WLs.

Property predictions of the Frit 200-based Case #2 are also shown in Table 11. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 89.8 Poise, 953.7°C, 902.2°C, -8.863 kcal/mol, and -8.829 kcal/mol, respectively, at the lower WL limit (i.e., 24.0%). At the upper WL limit (30.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 75.9 Poise, 1021.2°C, 1008.0°C, -8.325 kcal/mol, and -8.282 kcal/mol, respectively.

#### 5.2.3 Frit 320 Assessment

For Case #2 (SB3 baseline with Pu/Gd) using Frit 320, the projected operational window exists from 23.0 to 37.5% WL (see Table 12). Note that the use of Frit 320 extends the operational window (for Case #2 relative to either Frit 165 or 200) to both higher and lower WLs. Access to lower WLs is a result of Frit 320 not challenging the homogeneity constraint, which is consistent with observations by Peeler, Brown, and Edwards (2001). More importantly, the use of Frit 320 allows for higher WLs to be obtained (based on property predictions) compared to either Frit 165 or Frit 200. Although higher WLs are predicted, it should be recognized that this frit was developed specifically for SB2 to improve melt rate (Peeler et al. 2001; Lambert et al. 2001).

Property predictions of the Frit 320-based Case #2 are also shown in Table 12. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 59.9 Poise, 940.5°C, 769.0°C, -10.648 kcal/mol, and -10.616 kcal/mol, respectively, at the lower WL limit (i.e., 23.0%). At the upper WL limit (37.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 40.6 Poise, 1108.5°C, 1009.7°C, -9.127 kcal/mol, and -9.074 kcal/mol, respectively.

### 5.3 Case #3: SB3 Baseline with Am/Cm

Current blending strategies project adding 3796.2 kg of the Am/Cm waste stream to SB3. Although additions of the Pu/Gd stream are also projected, Case #3 assesses the impacts to property predictions given the individual addition of the Am/Cm stream in the event anticipated blending strategies are not realized.

Table 13 summarizes the resulting nominal SB3 sludge composition when blended with the Am/Cm waste stream. The resulting total mass is estimated to be 366599.89 kg (oxide basis). As with the nominal baseline case (Case #1), the major oxides (i.e., those exceeding 0.5 wt% in sludge) include $Al_2O_3$, CaO, $Fe_2O_3$, MnO, $Na_2O$, $Nd_2O_3$, NiO, $SiO_2$, $U_3O_8$, and $ZrO_2$. Adding the 350 g/L U solution (to dilute the high activity of the solids) provides an additional 3394.94 of $U_3O_8$. This results in a higher $U_3O_8$ concentration in the Case #3 sludge (10.196 wt%) relative to

the baseline case (9.367 wt%). Compositional differences among the other major oxides exist, but are minimal and should result in a negligible impact on predicted properties.

**Table 13.** Nominal Sludge Composition for Case #3 (SB3 Baseline with Am/Cm) (in wt%, oxide basis)

| Oxide | SB3 baseline with Am/Cm | Oxide | SB3 baseline with Am/Cm |
|---|---|---|---|
| Ag | 6.85E-04 | $Na_2O$ | 10.638 |
| $Al_2O_3$ | 18.117 | $Nb_2O_3$ | 0.000 |
| $AmO_2$ | 4.28E-03 | $Nd_2O_3$ | 0.683 |
| $B_2O_3$ | 0.000 | NiO | 1.612 |
| BaO | 0.250 | $P_2O_5$ | 0.000 |
| CaO | 3.603 | PbO | 0.303 |
| CdO | 1.18E-05 | Pd | 0.037 |
| $Ce_2O_3$ | 0.355 | $Pr_2O_3$ | 0.187 |
| $Cm_2O_3$ | 6.48E-04 | $PuO_2$ | 0.021 |
| $Cr_2O_3$ | 0.375 | $RuO_2$ | 0.278 |
| $Cs_2O$ | 0.000 | Rh | 0.078 |
| CuO | 0.198 | $SiO_2$ | 3.346 |
| $Eu_2O_3$ | 4.68E-05 | $Sm_2O_3$ | 0.100 |
| $Fe_2O_3$ | 40.302 | $SnO_2$ | 0.000 |
| $Gd_2O_3$ | 3.60E-03 | SrO | 0.000 |
| $K_2O$ | 0.431 | $ThO_2$ | 0.143 |
| $La_2O_3$ | 0.206 | $TiO_2$ | 1.04E-04 |
| $Li_2O$ | 2.94E-03 | $U_3O_8$ | 10.196 |
| MgO | 0.189 | $Y_2O_3$ | 0.000 |
| MnO | 7.182 | ZnO | 0.412 |
| $MoO_3$ | 2.17E-04 | $ZrO_2$ | 0.744 |
| | | | |
| | | **Total** | 100.000 |
| | | **Mass (in kgs)** | 366599.89 |

#### 5.3.1 Frit 165 Assessment

For Case #3 (SB3 baseline with Am/Cm) using Frit 165, the projected operational window is 24.5 to 36.0% WL (see Table 14). As with previous cases, lower WLs (although probably not of interest) are limited by homogeneity while $T_L$ predictions continued to limit access to higher WLs.

Property predictions of the Frit 165-based Case #3 are also shown in Table 14. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 48.4 Poise, 961.8°C, 822.0°C, -11.082 kcal/mol, and -11.048 kcal/mol, respectively, at the lower WL limit (i.e., 24.5%). At the upper WL limit (36.0 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 35.1 Poise, 1102.6°C, 1007.6°C, -9.785 kcal/mol, and -9.735 kcal/mol, respectively.

### 5.3.2 Frit 200 Assessment

For Case #3 (SB3 baseline with Am/Cm) using Frit 200, the projected operational window is 24.5 to 30.5% WL (see Table 15). As with the single addition of Pu/Gd, both $T_L$ models limit WLs to the 30.5 wt% level. The use of the conservative 1010ºC PAR limit for the new $T_L$ model may overly restrict this region (Brown et al. 2001). It is, however, anticipated that the true PAR limit would not yield WLs higher than either Frit 165 or Frit 320. Compared to either the Frit 165 or Frit 320-based cases, the impact of using Frit 200 can be generalized as increasing viscosity, $T_L$, and durability but having a significant (negative) impact on WL. As with previous cases, lower WLs (although probably of minimal interest) are limited by homogeneity while $T_L$ predictions continued to limit access to higher WLs.

Property predictions of the Frit 200-based Case #3 are also shown in Table 15. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 89.1 Poise, 956.8°C, 908.6°C, -8.821 kcal/mol, and -8.787 kcal/mol, respectively, at the lower WL limit (i.e., 24.5%). At the upper WL limit (30.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 76.3 Poise, 1019.1°C, 1005.7°C, -8.324 kcal/mol, and -8.282 kcal/mol, respectively.

### 5.3.3 Frit 320 Assessment

For the Case #3 (SB3 baseline with Am/Cm) using Frit 320, the projected operational window exists from 23.0 to 37.5% WL (see Table 16). Note that the use of Frit 320 extends the operational window (for Case #3 relative to either Frit 165 or 200) to both higher and lower WLs. Access to lower WLs is a result of Frit 320 not challenging the homogeneity constraint, which is consistent with observations by Peeler, Brown, and Edwards (2001). More importantly, the use of Frit 320 allows for higher WLs to be obtained (based on property predictions) compared to either Frit 165 or Frit 200. Although higher WLs are predicted, it should be recognized that this frit was developed specifically for SB2 to improve melt rate (Peeler et al. 2001; Lambert et al. 2001).

Property predictions of the Frit 320-based Case #3 are also shown in Table 16. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 60.1 Poise, 939.2, 766.4, -10.648, and -10.615, respectively, at the lower WL limit (i.e., 23.0%). At the upper WL limit (37.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 40.8 Poise, 1105.2°C, 1007.3°C, -9.126 kcal/mol, and -9.073 kcal/mol, respectively.

**Table 14.** Property Predictions as a Function of WL for Frit 165 and SB3 Baseline with Am/Cm (Case #3)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 165-Case 3 | 24 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04348 | 0.179 | 49.0 | 210.7 | -11.139 | -11.105 | 957.1 | 813.0 |
| 165-Case 3 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04439 | 0.178 | 48.4 | 211.9 | -11.082 | -11.048 | 961.8 | 822.0 |
| 165-Case 3 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04529 | 0.178 | 47.8 | 213.0 | -11.026 | -10.991 | 966.6 | 831.0 |
| 165-Case 3 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04620 | 0.177 | 47.2 | 214.1 | -10.970 | -10.934 | 971.5 | 839.9 |
| 165-Case 3 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04711 | 0.177 | 46.7 | 215.2 | -10.913 | -10.877 | 976.5 | 848.6 |
| 165-Case 3 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04801 | 0.176 | 46.1 | 216.3 | -10.857 | -10.820 | 981.6 | 857.3 |
| 165-Case 3 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04892 | 0.176 | 45.5 | 217.4 | -10.800 | -10.763 | 986.8 | 865.9 |
| 165-Case 3 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04982 | 0.175 | 44.9 | 218.6 | -10.744 | -10.705 | 992.1 | 874.4 |
| 165-Case 3 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05073 | 0.175 | 44.3 | 219.7 | -10.688 | -10.648 | 997.5 | 882.9 |
| 165-Case 3 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05164 | 0.175 | 43.8 | 220.8 | -10.631 | -10.591 | 1003.1 | 891.2 |
| 165-Case 3 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05254 | 0.174 | 43.2 | 221.9 | -10.575 | -10.534 | 1008.7 | 899.5 |
| 165-Case 3 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05345 | 0.174 | 42.6 | 223.0 | -10.518 | -10.477 | 1014.5 | 907.7 |
| 165-Case 3 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05435 | 0.173 | 42.0 | 224.1 | -10.462 | -10.420 | 1020.4 | 915.8 |
| 165-Case 3 | 30.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05526 | 0.173 | 41.4 | 225.2 | -10.406 | -10.363 | 1026.4 | 923.8 |
| 165-Case 3 | 31 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05616 | 0.172 | 40.9 | 226.4 | -10.349 | -10.306 | 1032.6 | 931.8 |
| 165-Case 3 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05707 | 0.172 | 40.3 | 227.5 | -10.293 | -10.249 | 1038.8 | 939.7 |
| 165-Case 3 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05798 | 0.171 | 39.7 | 228.6 | -10.236 | -10.192 | 1045.3 | 947.5 |
| 165-Case 3 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05888 | 0.171 | 39.1 | 229.7 | -10.180 | -10.134 | 1051.9 | 955.2 |
| 165-Case 3 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05979 | 0.171 | 38.6 | 230.8 | -10.124 | -10.077 | 1058.6 | 962.9 |
| 165-Case 3 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06069 | 0.170 | 38.0 | 231.9 | -10.067 | -10.020 | 1065.5 | 970.5 |
| 165-Case 3 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06160 | 0.170 | 37.4 | 233.1 | -10.011 | -9.963 | 1072.6 | 978.1 |
| 165-Case 3 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06251 | 0.169 | 36.8 | 234.2 | -9.954 | -9.906 | 1079.8 | 985.5 |
| 165-Case 3 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06341 | 0.169 | 36.3 | 235.3 | -9.898 | -9.849 | 1087.2 | 992.9 |
| 165-Case 3 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06432 | 0.168 | 35.7 | 236.4 | -9.842 | -9.792 | 1094.8 | 1000.3 |
| 165-Case 3 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06522 | 0.168 | 35.1 | 237.5 | -9.785 | -9.735 | 1102.6 | 1007.6 |
| 165-Case 3 | 36.5 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06613 | 0.167 | 34.5 | 238.6 | -9.729 | -9.678 | 1110.5 | 1014.8 |

**Table 15.** Property Predictions as a Function of WL for Frit 200 and SB3 Baseline with Am/Cm (Case #3)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 200-Case 3 | 24 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04348 | 0.148 | 90.1 | 210.7 | -8.863 | -8.829 | 952.3 | 899.9 |
| 200-Case 3 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04439 | 0.148 | 89.1 | 211.9 | -8.821 | -8.787 | 956.8 | 908.6 |
| 200-Case 3 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04529 | 0.148 | 88.0 | 213.0 | -8.780 | -8.745 | 961.5 | 917.2 |
| 200-Case 3 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04620 | 0.147 | 86.9 | 214.1 | -8.739 | -8.703 | 966.2 | 925.8 |
| 200-Case 3 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04711 | 0.147 | 85.9 | 215.2 | -8.697 | -8.661 | 971.0 | 934.2 |
| 200-Case 3 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04801 | 0.147 | 84.8 | 216.3 | -8.656 | -8.619 | 975.9 | 942.5 |
| 200-Case 3 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04892 | 0.147 | 83.8 | 217.4 | -8.614 | -8.576 | 980.9 | 950.7 |
| 200-Case 3 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04982 | 0.146 | 82.7 | 218.6 | -8.573 | -8.534 | 986.0 | 958.9 |
| 200-Case 3 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05073 | 0.146 | 81.6 | 219.7 | -8.531 | -8.492 | 991.3 | 966.9 |
| 200-Case 3 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05164 | 0.146 | 80.6 | 220.8 | -8.490 | -8.450 | 996.6 | 974.8 |
| 200-Case 3 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05254 | 0.146 | 79.5 | 221.9 | -8.449 | -8.408 | 1002.0 | 982.7 |
| 200-Case 3 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05345 | 0.145 | 78.5 | 223.0 | -8.407 | -8.366 | 1007.6 | 990.5 |
| 200-Case 3 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05435 | 0.145 | 77.4 | 224.1 | -8.366 | -8.324 | 1013.3 | 998.2 |
| 200-Case 3 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05526 | 0.145 | 76.3 | 225.2 | -8.324 | -8.282 | 1019.1 | 1005.7 |
| 200-Case 3 | 31 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.05616 | 0.145 | 75.3 | 226.4 | -8.283 | -8.239 | 1025.0 | 1013.3 |

**Table 16.** Property Predictions as a Function of WL for Frit 320 and SB3 Baseline with Am/Cm (Case #3)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 320-Case 3 | 22.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04076 | 0.180 | 60.8 | 209.9 | -10.700 | -10.669 | 935.0 | 756.8 |
| 320-Case 3 | 23 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04167 | 0.179 | 60.1 | 211.0 | -10.648 | -10.615 | 939.2 | 766.4 |
| 320-Case 3 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04258 | 0.179 | 59.5 | 212.1 | -10.595 | -10.562 | 943.4 | 775.9 |
| 320-Case 3 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04348 | 0.179 | 58.8 | 213.2 | -10.543 | -10.509 | 947.7 | 785.3 |
| 320-Case 3 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04439 | 0.178 | 58.1 | 214.3 | -10.490 | -10.456 | 952.1 | 794.6 |
| 320-Case 3 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04529 | 0.178 | 57.5 | 215.4 | -10.438 | -10.403 | 956.6 | 803.7 |
| 320-Case 3 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04620 | 0.177 | 56.8 | 216.5 | -10.385 | -10.350 | 961.2 | 812.8 |
| 320-Case 3 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04711 | 0.177 | 56.2 | 217.6 | -10.333 | -10.296 | 965.8 | 821.9 |
| 320-Case 3 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04801 | 0.176 | 55.5 | 218.7 | -10.280 | -10.243 | 970.6 | 830.8 |
| 320-Case 3 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04892 | 0.176 | 54.8 | 219.8 | -10.228 | -10.190 | 975.4 | 839.6 |
| 320-Case 3 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04982 | 0.175 | 54.2 | 220.9 | -10.175 | -10.137 | 980.3 | 848.3 |
| 320-Case 3 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05073 | 0.175 | 53.5 | 222.0 | -10.123 | -10.084 | 985.4 | 857.0 |
| 320-Case 3 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05164 | 0.175 | 52.8 | 223.1 | -10.070 | -10.031 | 990.5 | 865.6 |
| 320-Case 3 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05254 | 0.174 | 52.2 | 224.2 | -10.018 | -9.977 | 995.8 | 874.1 |
| 320-Case 3 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05345 | 0.174 | 51.5 | 225.3 | -9.966 | -9.924 | 1001.1 | 882.5 |
| 320-Case 3 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05435 | 0.173 | 50.8 | 226.4 | -9.913 | -9.871 | 1006.6 | 890.8 |
| 320-Case 3 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05526 | 0.173 | 50.2 | 227.5 | -9.861 | -9.818 | 1012.2 | 899.1 |
| 320-Case 3 | 31 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05616 | 0.172 | 49.5 | 228.6 | -9.808 | -9.765 | 1017.9 | 907.3 |
| 320-Case 3 | 31.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05707 | 0.172 | 48.8 | 229.7 | -9.756 | -9.712 | 1023.7 | 915.4 |
| 320-Case 3 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05798 | 0.171 | 48.2 | 230.8 | -9.703 | -9.658 | 1029.7 | 923.4 |
| 320-Case 3 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05888 | 0.171 | 47.5 | 231.9 | -9.651 | -9.605 | 1035.8 | 931.4 |
| 320-Case 3 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05979 | 0.171 | 46.8 | 233.0 | -9.598 | -9.552 | 1042.0 | 939.3 |
| 320-Case 3 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06069 | 0.170 | 46.2 | 234.1 | -9.546 | -9.499 | 1048.4 | 947.1 |
| 320-Case 3 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06160 | 0.170 | 45.5 | 235.2 | -9.493 | -9.446 | 1054.9 | 954.9 |
| 320-Case 3 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06251 | 0.169 | 44.8 | 236.3 | -9.441 | -9.392 | 1061.6 | 962.6 |
| 320-Case 3 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06341 | 0.169 | 44.2 | 237.4 | -9.388 | -9.339 | 1068.5 | 970.2 |
| 320-Case 3 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06432 | 0.168 | 43.5 | 238.5 | -9.336 | -9.286 | 1075.5 | 977.7 |
| 320-Case 3 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06522 | 0.168 | 42.8 | 239.6 | -9.283 | -9.233 | 1082.6 | 985.2 |
| 320-Case 3 | 36.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06613 | 0.167 | 42.2 | 240.7 | -9.231 | -9.180 | 1090.0 | 992.6 |
| 320-Case 3 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06703 | 0.167 | 41.5 | 241.8 | -9.178 | -9.127 | 1097.5 | 1000.0 |
| 320-Case 3 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06794 | 0.167 | 40.8 | 242.9 | -9.126 | -9.073 | 1105.2 | 1007.3 |
| 320-Case 3 | 38 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06885 | 0.166 | 40.2 | 244.0 | -9.074 | -9.020 | 1113.2 | 1014.5 |

## 5.4 Case #4: SB3 Baseline with Pu/Gd and Am/Cm

Case #4 represents the current blending strategy being pursued. In this case, both $PuO_2/Gd_2O_3$ (286.35 kg) and Am/Cm (3796.2 kg; mostly $U_3O_8$) are blended with SB3 (including the Tank 51 heel and the Tank 7 sand). The nominal composition of this scenario is shown in Table 17. This case provides a total mass of calcined solids (oxide basis) of ~ 366886.24 kg.

**Table 17.** Nominal Sludge Composition for Case #4 (SB3 Baseline with Pu/Gd and Am/Cm) (in wt%, oxide basis)

| Oxide | SB3 baseline with Pu/Gd and Am/Cm | Oxide | SB3 baseline with Am/Cm and Pu/Gd |
|---|---|---|---|
| Ag | 6.85E-04 | $Na_2O$ | 10.629 |
| $Al_2O_3$ | 18.102 | $Nb_2O_3$ | 0.000 |
| $AmO_2$ | 4.28E-03 | $Nd_2O_3$ | 0.682 |
| $B_2O_3$ | 0.000 | NiO | 1.611 |
| BaO | 0.250 | $P_2O_5$ | 0.000 |
| CaO | 3.600 | PbO | 0.302 |
| CdO | 1.18E-05 | Pd | 0.037 |
| $Ce_2O_3$ | 0.355 | $Pr_2O_3$ | 0.186 |
| $Cm_2O_3$ | 6.47E-04 | $PuO_2$ | 0.052 |
| $Cr_2O_3$ | 0.374 | $RuO_2$ | 0.278 |
| $Cs_2O$ | 0.000 | Rh | 0.078 |
| CuO | 0.198 | $SiO_2$ | 3.343 |
| $Eu_2O_3$ | 4.68E-05 | $Sm_2O_3$ | 0.100 |
| $Fe_2O_3$ | 40.270 | $SnO_2$ | 0.000 |
| $Gd_2O_3$ | 0.051 | SrO | 0.000 |
| $K_2O$ | 0.431 | $ThO_2$ | 0.143 |
| $La_2O_3$ | 0.206 | $TiO_2$ | 1.04E-04 |
| $Li_2O$ | 2.94E-03 | $U_3O_8$ | 10.188 |
| MgO | 0.189 | $Y_2O_3$ | 0.000 |
| MnO | 7.177 | ZnO | 0.411 |
| $MoO_3$ | 2.17E-04 | $ZrO_2$ | 0.743 |
| | | **Total** | 100.000 |
| | | **Mass (in kgs)** | 366886.24 |

### 5.4.1 Frit 165 Assessment

Table 18 provides a summary of the projected operational window for the Frit 165-based Case #4 scenario. The projected operational window ranges from 24.5 to 36.0 wt% WL. At low WLs (< 24.5%), homogeneity is not satisfied while $T_L$ predictions continue to limit access to higher WLs.

**Table 18.** Property Predictions as a Function of WL for Frit 165 and SB3 Baseline with Am/Cm and Pu/Gd (Case #4)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_D$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 165-Case 4 | 24 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04345 | 0.179 | 49.0 | 210.7 | -11.138 | -11.105 | 957.0 | 812.7 |
| 165-Case 4 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04435 | 0.178 | 48.4 | 211.8 | -11.082 | -11.048 | 961.7 | 821.8 |
| 165-Case 4 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04526 | 0.178 | 47.8 | 212.9 | -11.025 | -10.991 | 966.5 | 830.7 |
| 165-Case 4 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04616 | 0.177 | 47.3 | 214.0 | -10.969 | -10.934 | 971.4 | 839.6 |
| 165-Case 4 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04707 | 0.177 | 46.7 | 215.1 | -10.913 | -10.877 | 976.4 | 848.4 |
| 165-Case 4 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04797 | 0.176 | 46.1 | 216.2 | -10.856 | -10.819 | 981.5 | 857.1 |
| 165-Case 4 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04888 | 0.176 | 45.5 | 217.4 | -10.800 | -10.762 | 986.7 | 865.7 |
| 165-Case 4 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04978 | 0.175 | 44.9 | 218.5 | -10.743 | -10.705 | 992.0 | 874.2 |
| 165-Case 4 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05069 | 0.175 | 44.4 | 219.6 | -10.687 | -10.648 | 997.4 | 882.6 |
| 165-Case 4 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05159 | 0.175 | 43.8 | 220.7 | -10.631 | -10.591 | 1002.9 | 890.9 |
| 165-Case 4 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05250 | 0.174 | 43.2 | 221.8 | -10.574 | -10.534 | 1008.5 | 899.2 |
| 165-Case 4 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05341 | 0.174 | 42.6 | 222.9 | -10.518 | -10.477 | 1014.3 | 907.4 |
| 165-Case 4 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05431 | 0.173 | 42.0 | 224.0 | -10.461 | -10.420 | 1020.2 | 915.5 |
| 165-Case 4 | 30.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05522 | 0.173 | 41.5 | 225.2 | -10.405 | -10.363 | 1026.2 | 923.6 |
| 165-Case 4 | 31 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05612 | 0.172 | 40.9 | 226.3 | -10.349 | -10.306 | 1032.3 | 931.5 |
| 165-Case 4 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05703 | 0.172 | 40.3 | 227.4 | -10.292 | -10.249 | 1038.6 | 939.4 |
| 165-Case 4 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05793 | 0.171 | 39.7 | 228.5 | -10.236 | -10.191 | 1045.1 | 947.2 |
| 165-Case 4 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05884 | 0.171 | 39.1 | 229.6 | -10.179 | -10.134 | 1051.6 | 955.0 |
| 165-Case 4 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05974 | 0.171 | 38.6 | 230.7 | -10.123 | -10.077 | 1058.4 | 962.7 |
| 165-Case 4 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06065 | 0.170 | 38.0 | 231.8 | -10.067 | -10.020 | 1065.3 | 970.3 |
| 165-Case 4 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06155 | 0.170 | 37.4 | 233.0 | -10.010 | -9.963 | 1072.3 | 977.8 |
| 165-Case 4 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06246 | 0.169 | 36.8 | 234.1 | -9.954 | -9.906 | 1079.5 | 985.3 |
| 165-Case 4 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06336 | 0.169 | 36.3 | 235.2 | -9.897 | -9.849 | 1086.9 | 992.7 |
| 165-Case 4 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06427 | 0.168 | 35.7 | 236.3 | -9.841 | -9.792 | 1094.5 | 1000.0 |
| 165-Case 4 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06517 | 0.168 | 35.1 | 237.4 | -9.785 | -9.735 | 1102.3 | 1007.3 |
| 165-Case 4 | 36.5 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06608 | 0.167 | 34.6 | 238.5 | -9.728 | -9.678 | 1110.2 | 1014.5 |

Property predictions of the Frit 165-based Case #4 are also shown in Table 18. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 48.4 Poise, 961.7°C, 821.8°C, -11.082 kcal/mol, and -11.048 kcal/mol, respectively, at the lower WL limit (i.e., 24.5%). At the upper WL limit (36.0 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 35.1 Poise, 1102.3°C, 1007.3°C, -9.785 kcal/mol, and -9.735 kcal/mol, respectively.

### 5.4.2 Frit 200 Assessment

For the Frit 200-based Case #4 scenario, the projected operational window exists from 24.5 to 30.5 wt% WL (see Table 19). At low WLs (< 24.5%), homogeneity is not satisfied while $T_L$ predictions continue to limit access to higher WLs. Unlike previous Frit 200-based scenarios, the new $T_L$ model limits WL to 30.5% while the current $T_L$ model would allow for a 31% WL to be processed. This may be a function of the conservative 1010ºC PAR limit (see Brown et al. 2001). However, implementation and use of the new $T_L$ model should be pursued with a transition to a "sludge-only" frit (Frit 165 or Frit 320)—assuming that a frit specifically developed for SB3 is not considered.

Property predictions of the Frit 200-based Case #4 are also shown in Table 19. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 89.1 Poise, 956.7°C, 908.3°C, -8.821 kcal/mol, and -8.787 kcal/mol, respectively, at the lower WL limit (i.e., 24.5%). At the upper WL limit (30.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 76.4 Poise, 1018.9°C, 1005.5°C, -8.324 kcal/mol, and -8.281 kcal/mol, respectively.

### 5.4.3 Frit 320 Assessment

For the Frit 320-based Case #4 scenario, the projected operational window exists from 23.5 to 37.5 wt% WL (see Table 20). At low WLs (< 23.5%), homogeneity is not satisfied while $T_L$ predictions continue to limit access to higher WLs. The use of Frit 320 extends the operational window to both higher and lower WLs compared to the use of either Frit 165 or Frit 200. Access to lower WLs (i.e., < 24.5% for both Frit 165 and 200 cases) is a result of glasses produced using Frit 320 not challenging the homogeneity constraint, which is consistent with observations by Peeler, Brown, and Edwards (2001). More importantly, the use of Frit 320 allows for higher WLs to be obtained (based on property predictions) compared to either Frit 165 of Frit 200. Although higher WLs are predicted, it should be recognized that this frit was developed specifically for SB2 to improve the melt rate (Peeler et al. 2001; Lambert et al. 2001).

Property predictions for the Frit 320-based Case #4 are also shown in Table 20. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 59.5 Poise, 943.3°C, 775.6°C, -10.595 kcal/mol, and -10.562 kcal/mol, respectively, at the lower WL limit (i.e., 23.5%). At the upper WL limit (37.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 40.9 Poise, 1105.0°C, 1007.0°C, -9.125 kcal/mol, and -9.073 kcal/mol, respectively. Again, as WLs increase, predictions of durability increase. This is reflected by the $\Delta G_P$ values being more positive (or less negative). Although the Frit 200-based Case #4 yielded a higher durability over a limited WL range (maximum WL is 30.5% with a $\Delta G_P$ of -8.324 kcal/mol), the use of Frit 320 provides a 7% increase in WL without compromising product quality significantly ($\Delta G_P$ of -9.125 kcal/mol).

**Table 19.** Property Predictions as a Function of WL for Frit 200 and SB3 Baseline with Am/Cm and Pu/Gd (Case #4)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 200-Case 4 | 24 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04345 | 0.148 | 90.2 | 210.7 | -8.862 | -8.829 | 952.1 | 899.6 |
| 200-Case 4 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04435 | 0.148 | 89.1 | 211.8 | -8.821 | -8.787 | 956.7 | 908.3 |
| 200-Case 4 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04526 | 0.148 | 88.0 | 212.9 | -8.779 | -8.745 | 961.3 | 917.0 |
| 200-Case 4 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04616 | 0.147 | 87.0 | 214.0 | -8.738 | -8.703 | 966.0 | 925.5 |
| 200-Case 4 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04707 | 0.147 | 85.9 | 215.1 | -8.697 | -8.661 | 970.9 | 933.9 |
| 200-Case 4 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04797 | 0.147 | 84.9 | 216.2 | -8.655 | -8.618 | 975.8 | 942.2 |
| 200-Case 4 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04888 | 0.147 | 83.8 | 217.4 | -8.614 | -8.576 | 980.8 | 950.5 |
| 200-Case 4 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04978 | 0.146 | 82.7 | 218.5 | -8.572 | -8.534 | 985.9 | 958.6 |
| 200-Case 4 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05069 | 0.146 | 81.7 | 219.6 | -8.531 | -8.492 | 991.1 | 966.6 |
| 200-Case 4 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05159 | 0.146 | 80.6 | 220.7 | -8.489 | -8.450 | 996.4 | 974.6 |
| 200-Case 4 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05250 | 0.146 | 79.6 | 221.8 | -8.448 | -8.408 | 1001.9 | 982.5 |
| 200-Case 4 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05341 | 0.145 | 78.5 | 222.9 | -8.407 | -8.366 | 1007.4 | 990.2 |
| 200-Case 4 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05431 | 0.145 | 77.4 | 224.0 | -8.365 | -8.324 | 1013.1 | 997.9 |
| 200-Case 4 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05522 | 0.145 | 76.4 | 225.2 | -8.324 | -8.281 | 1018.9 | 1005.5 |
| 200-Case 4 | 31 | Durable; Visc; TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.05612 | 0.145 | 75.3 | 226.3 | -8.282 | -8.239 | 1024.8 | 1013.0 |
| 200-Case 4 | 31.5 | Durable; Visc; Not TL; Homog; Not New TL; $Al_2O_3$; alkali | 0.05703 | 0.144 | 74.3 | 227.4 | -8.241 | -8.197 | 1030.8 | 1020.4 |

**Table 20.** Property Predictions as a Function of WL for Frit 320 and SB3 Baseline with Am/Cm and Pu/Gd (Case #4)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 320-Case 4 | 23 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04164 | 0.179 | 60.2 | 210.9 | -10.647 | -10.615 | 939.1 | 766.1 |
| 320-Case 4 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04254 | 0.179 | 59.5 | 212.0 | -10.595 | -10.562 | 943.3 | 775.6 |
| 320-Case 4 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04345 | 0.179 | 58.8 | 213.1 | -10.542 | -10.509 | 947.6 | 785.0 |
| 320-Case 4 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04435 | 0.178 | 58.2 | 214.2 | -10.490 | -10.456 | 952.0 | 794.3 |
| 320-Case 4 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04526 | 0.178 | 57.5 | 215.3 | -10.437 | -10.403 | 956.5 | 803.5 |
| 320-Case 4 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04616 | 0.177 | 56.8 | 216.4 | -10.385 | -10.349 | 961.0 | 812.6 |
| 320-Case 4 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04707 | 0.177 | 56.2 | 217.5 | -10.332 | -10.296 | 965.7 | 821.6 |
| 320-Case 4 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04797 | 0.176 | 55.5 | 218.6 | -10.280 | -10.243 | 970.4 | 830.5 |
| 320-Case 4 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04888 | 0.176 | 54.9 | 219.7 | -10.227 | -10.190 | 975.2 | 839.3 |
| 320-Case 4 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04978 | 0.175 | 54.2 | 220.8 | -10.175 | -10.137 | 980.2 | 848.1 |
| 320-Case 4 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05069 | 0.175 | 53.5 | 221.9 | -10.122 | -10.084 | 985.2 | 856.7 |
| 320-Case 4 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05159 | 0.175 | 52.9 | 223.0 | -10.070 | -10.030 | 990.3 | 865.3 |
| 320-Case 4 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05250 | 0.174 | 52.2 | 224.1 | -10.017 | -9.977 | 995.6 | 873.8 |
| 320-Case 4 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05341 | 0.174 | 51.5 | 225.2 | -9.965 | -9.924 | 1000.9 | 882.2 |
| 320-Case 4 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05431 | 0.173 | 50.9 | 226.3 | -9.912 | -9.871 | 1006.4 | 890.6 |
| 320-Case 4 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05522 | 0.173 | 50.2 | 227.4 | -9.860 | -9.818 | 1012.0 | 898.8 |
| 320-Case 4 | 31 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05612 | 0.172 | 49.5 | 228.5 | -9.807 | -9.765 | 1017.7 | 907.0 |
| 320-Case 4 | 31.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05703 | 0.172 | 48.9 | 229.6 | -9.755 | -9.711 | 1023.5 | 915.1 |
| 320-Case 4 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05793 | 0.171 | 48.2 | 230.7 | -9.703 | -9.658 | 1029.5 | 923.2 |
| 320-Case 4 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05884 | 0.171 | 47.5 | 231.8 | -9.650 | -9.605 | 1035.6 | 931.1 |
| 320-Case 4 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05974 | 0.171 | 46.9 | 232.9 | -9.598 | -9.552 | 1041.8 | 939.0 |
| 320-Case 4 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06065 | 0.170 | 46.2 | 234.0 | -9.545 | -9.499 | 1048.2 | 946.8 |
| 320-Case 4 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06155 | 0.170 | 45.5 | 235.1 | -9.493 | -9.445 | 1054.7 | 954.6 |
| 320-Case 4 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06246 | 0.169 | 44.9 | 236.2 | -9.440 | -9.392 | 1061.4 | 962.3 |
| 320-Case 4 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06336 | 0.169 | 44.2 | 237.3 | -9.388 | -9.339 | 1068.2 | 969.9 |
| 320-Case 4 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06427 | 0.168 | 43.5 | 238.4 | -9.335 | -9.286 | 1075.2 | 977.5 |
| 320-Case 4 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06517 | 0.168 | 42.9 | 239.5 | -9.283 | -9.233 | 1082.4 | 984.9 |
| 320-Case 4 | 36.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06608 | 0.167 | 42.2 | 240.6 | -9.230 | -9.180 | 1089.7 | 992.4 |
| 320-Case 4 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06698 | 0.167 | 41.5 | 241.7 | -9.178 | -9.126 | 1097.2 | 999.7 |
| 320-Case 4 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06789 | 0.166 | 40.9 | 242.8 | -9.125 | -9.073 | 1105.0 | 1007.0 |
| 320-Case 4 | 38 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06879 | 0.166 | 40.2 | 243.9 | -9.073 | -9.020 | 1112.9 | 1014.3 |

## 5.5 Case #5: SB3 (with Tank 51 heel) Without the Tank 7 Sand

Cases #5 and #6 were specifically developed to address the ability to partially or completely transfer the sand associated with Tank 7 into SB3. More specifically, Case #5 establishes a second baseline case (i.e., SB3 with only the Tank 51 heel) from which the additions of both the Am/Cm and Pu/Gd streams can be compared (Case #6).

Table 21 summarizes the resulting nominal SB3 sludge composition for Case #5. The resulting total mass is estimated to be 358253.69 kg (oxide basis) or 4550 kg (i.e., the reported Tank 7 sand amount) less than Case #1. As with the nominal baseline case (Case #1), the major oxides (i.e., those exceeding 0.5 wt% in sludge) include $Al_2O_3$, CaO, $Fe_2O_3$, MnO, $Na_2O$, $Nd_2O_3$, NiO, $SiO_2$, $U_3O_8$, and $ZrO_2$. Assuming that the Tank 7 sand is not transferred and it is represented as 100% $SiO_2$, it is not surprising that this case has a lower $SiO_2$ concentration (2.145 wt%) relative to the baseline (3.373 wt%). Compositional differences among the other major oxides exist but are minimal and should result in a negligible impact on predicted properties.

**Table 21.** Nominal Sludge Composition for Case #5 (SB3 including the Tank 51 heel but without the Tank 7 sand) (in wt%, oxide basis)

| Oxide | SB3 with Tank 51 Heel | Oxide | SB3 with Tank 51 Heel |
|---|---|---|---|
| Ag | 6.90E-04 | $Na_2O$ | 10.885 |
| $Al_2O_3$ | 18.528 | $Nb_2O_3$ | 0.000 |
| $AmO_2$ | 1.47E-03 | $Nd_2O_3$ | 0.685 |
| $B_2O_3$ | 0.000 | NiO | 1.648 |
| BaO | 0.256 | $P_2O_5$ | 0.000 |
| CaO | 3.686 | PbO | 0.307 |
| CdO | 0.000 | Pd | 0.038 |
| $Ce_2O_3$ | 0.357 | $Pr_2O_3$ | 0.188 |
| $Cm_2O_3$ | 1.01E-08 | $PuO_2$ | 0.021 |
| $Cr_2O_3$ | 0.379 | $RuO_2$ | 0.284 |
| $Cs_2O$ | 0.000 | Rh | 0.080 |
| CuO | 0.203 | $SiO_2$ | 2.145 |
| $Eu_2O_3$ | 4.75E-03 | $Sm_2O_3$ | 0.101 |
| $Fe_2O_3$ | 41.198 | $SnO_2$ | 0.000 |
| $Gd_2O_3$ | 2.00E-03 | SrO | 0.000 |
| $K_2O$ | 0.441 | $ThO_2$ | 0.147 |
| $La_2O_3$ | 0.206 | $TiO_2$ | 0.000 |
| $Li_2O$ | 0.000 | $U_3O_8$ | 9.486 |
| MgO | 0.193 | $Y_2O_3$ | 0.000 |
| MnO | 7.348 | ZnO | 0.421 |
| $MoO_3$ | 0.000 | $ZrO_2$ | 0.761 |
| | | **Total** | 100.000 |
| | | **Mass (in kgs)** | 358253.69 |

### 5.5.1 Frit 165 Assessment

For the Frit 165-based Case #5 scenario, the projected operational window exists from 23.5 to 35.5 wt% WL (see Table 22). At low WLs (< 23.5%), homogeneity is not satisfied while $T_L$ predictions continue to limit access to higher WLs.

Property predictions of the Frit 165-based Case #5 are also shown in Table 22. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 48.1 Poise, 957.2°C, 811.2°C, -11.224 kcal/mol, and -11.190 kcal/mol, respectively, at the lower WL limit (i.e., 23.5%). At the upper WL limit (35.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 33.7 Poise, 1106.5°C, 1007.9°C, -9.885 kcal/mol, and -9.834 kcal/mol, respectively.

#### 5.5.2 Frit 200 Assessment

For the Frit 200-based Case #5 scenario, the projected operational window exists from 23.5 to 30.0 wt% WL (see Table 23). At low WLs (< 23.5%), homogeneity is not satisfied while $T_L$ predictions continue to limit access to higher WLs. As in previous cases, both $T_L$ models limit WL to 30%. This is a function of the conservative 1010ºC PAR limit (see Section 4.0) as demonstrated by Brown et al. (2001). However, implementation and use of the new $T_L$ model should be pursued with a transition to a "sludge-only" frit (Frit 165 or Frit 320)—assuming that a frit specifically developed for SB3 is not considered.

Property predictions of the Frit 200-based Case #5 are also shown in Table 23. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 88.8 Poise, 952.3°C, 898.2°C, -8.933 kcal/mol, and -8.899 kcal/mol, respectively, at the lower WL limit (i.e., 23.5%). At the upper WL limit (30.0 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 74.6 Poise, 1020.6°C, 1005.5°C, -8.402 kcal/mol, and -8.359 kcal/mol, respectively.

#### 5.5.3 Frit 320 Assessment

For the Frit 320-based Case #5 scenario, the projected operational window exists from 22.5 to 37.0 wt% WL (see Table 24). At low WLs (< 22.5%), homogeneity is not satisfied while $T_L$ predictions continue to limit access to higher WLs. The use of Frit 320 extends the operational window to both higher and lower WLs compared to the use of either Frit 165 or Frit 200 for Case #5. Access to lower WLs (i.e., < 23.5% for both Frit 165 and 200 cases) is a result of glasses produced using Frit 320 not challenging the homogeneity constraint, which is consistent with observations by Peeler, Brown, and Edwards (2001). More importantly, the use of Frit 320 allows for higher WLs to be obtained (based on property predictions) compared to either Frit 165 of Frit 200. Although higher WLs are predicted, it should be recognized that this frit was developed specifically for SB2 to improve the melt rate (Peeler et al. 2001).

Property predictions for the Frit 320-based Case #5 are also shown in Table 24. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 59.2 Poise, 939.0°C, 764.2°C, -10.728 kcal/mol, and -10.695 kcal/mol, respectively, at the lower WL limit (i.e., 22.5%). At the upper WL limit (37.0 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 39.3 Poise, 1109.4°C, 1007.8°C, -9.224 kcal/mol, and -9.170 kcal/mol, respectively. Again, as WLs increase, predictions of durability increase. This is reflected by the $\Delta G_P$ values being more positive (or less negative). Although the Frit 200-based Case #5 yielded a higher durability over a limited WL range (maximum WL is 30.0% [using the conservative PAR limit] with a $\Delta G_P$ of -8.402 kcal/mol), the use of Frit 320 provides a ~ 23% increase in WL (maximum WL of 37%) without compromising product quality significantly ($\Delta G_P$ of -9.224 kcal/mol).

**Table 22.** Property Predictions as a Function of WL for Frit 165 and SB3 Without Tank 7 Sand (Case #5)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 165-Case 5 | 23 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04262 | 0.180 | 48.7 | 210.0 | -11.280 | -11.246 | 952.4 | 801.9 |
| 165-Case 5 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04354 | 0.180 | 48.1 | 211.1 | -11.224 | -11.190 | 957.2 | 811.2 |
| 165-Case 5 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04447 | 0.179 | 47.5 | 212.3 | -11.168 | -11.133 | 962.0 | 820.4 |
| 165-Case 5 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04540 | 0.179 | 46.9 | 213.4 | -11.112 | -11.077 | 966.9 | 829.4 |
| 165-Case 5 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04632 | 0.178 | 46.3 | 214.6 | -11.056 | -11.020 | 971.9 | 838.4 |
| 165-Case 5 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04725 | 0.178 | 45.7 | 215.7 | -11.001 | -10.964 | 977.0 | 847.3 |
| 165-Case 5 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04817 | 0.177 | 45.1 | 216.9 | -10.945 | -10.907 | 982.2 | 856.1 |
| 165-Case 5 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04910 | 0.177 | 44.5 | 218.0 | -10.889 | -10.851 | 987.5 | 864.8 |
| 165-Case 5 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05003 | 0.177 | 43.9 | 219.2 | -10.833 | -10.794 | 992.9 | 873.4 |
| 165-Case 5 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05095 | 0.176 | 43.2 | 220.3 | -10.777 | -10.738 | 998.5 | 882.0 |
| 165-Case 5 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05188 | 0.176 | 42.6 | 221.4 | -10.722 | -10.681 | 1004.1 | 890.4 |
| 165-Case 5 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05281 | 0.175 | 42.0 | 222.6 | -10.666 | -10.625 | 1009.9 | 898.8 |
| 165-Case 5 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05373 | 0.175 | 41.4 | 223.7 | -10.610 | -10.568 | 1015.8 | 907.1 |
| 165-Case 5 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05466 | 0.174 | 40.8 | 224.9 | -10.554 | -10.512 | 1021.9 | 915.3 |
| 165-Case 5 | 30 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05559 | 0.174 | 40.2 | 226.0 | -10.499 | -10.455 | 1028.1 | 923.4 |
| 165-Case 5 | 30.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05651 | 0.174 | 39.6 | 227.2 | -10.443 | -10.399 | 1034.4 | 931.5 |
| 165-Case 5 | 31 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05744 | 0.173 | 39.0 | 228.3 | -10.387 | -10.342 | 1040.8 | 939.4 |
| 165-Case 5 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05836 | 0.173 | 38.4 | 229.5 | -10.331 | -10.286 | 1047.5 | 947.3 |
| 165-Case 5 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05929 | 0.172 | 37.8 | 230.6 | -10.275 | -10.229 | 1054.2 | 955.1 |
| 165-Case 5 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06022 | 0.172 | 37.3 | 231.8 | -10.220 | -10.173 | 1061.2 | 962.9 |
| 165-Case 5 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06114 | 0.171 | 36.7 | 232.9 | -10.164 | -10.116 | 1068.3 | 970.6 |
| 165-Case 5 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06207 | 0.171 | 36.1 | 234.1 | -10.108 | -10.060 | 1075.5 | 978.2 |
| 165-Case 5 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06300 | 0.171 | 35.5 | 235.2 | -10.052 | -10.003 | 1083.0 | 985.7 |
| 165-Case 5 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06392 | 0.170 | 34.9 | 236.4 | -9.997 | -9.947 | 1090.6 | 993.2 |
| 165-Case 5 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06485 | 0.170 | 34.3 | 237.5 | -9.941 | -9.890 | 1098.4 | 1000.6 |
| 165-Case 5 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06578 | 0.169 | 33.7 | 238.7 | -9.885 | -9.834 | 1106.5 | 1007.9 |
| 165-Case 5 | 36 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06670 | 0.169 | 33.1 | 239.8 | -9.829 | -9.777 | 1114.7 | 1015.2 |

**Table 23.** Property Predictions as a Function of WL for Frit 200 and SB3 Without Tank 7 Sand (Case #5)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 200-Case 5 | 23 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04262 | 0.149 | 89.9 | 210.0 | -8.974 | -8.941 | 947.7 | 889.2 |
| 200-Case 5 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04354 | 0.149 | 88.8 | 211.1 | -8.933 | -8.899 | 952.3 | 898.2 |
| 200-Case 5 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04447 | 0.149 | 87.7 | 212.3 | -8.892 | -8.858 | 956.9 | 907.1 |
| 200-Case 5 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04540 | 0.149 | 86.6 | 213.4 | -8.851 | -8.816 | 961.7 | 915.8 |
| 200-Case 5 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04632 | 0.148 | 85.5 | 214.6 | -8.810 | -8.775 | 966.5 | 924.5 |
| 200-Case 5 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04725 | 0.148 | 84.4 | 215.7 | -8.770 | -8.733 | 971.4 | 933.0 |
| 200-Case 5 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04817 | 0.148 | 83.3 | 216.9 | -8.729 | -8.691 | 976.4 | 941.5 |
| 200-Case 5 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04910 | 0.148 | 82.2 | 218.0 | -8.688 | -8.650 | 981.5 | 949.8 |
| 200-Case 5 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05003 | 0.147 | 81.1 | 219.2 | -8.647 | -8.608 | 986.8 | 958.0 |
| 200-Case 5 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05095 | 0.147 | 80.0 | 220.3 | -8.606 | -8.567 | 992.1 | 966.2 |
| 200-Case 5 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05188 | 0.147 | 78.9 | 221.4 | -8.566 | -8.525 | 997.6 | 974.2 |
| 200-Case 5 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05281 | 0.147 | 77.8 | 222.6 | -8.525 | -8.484 | 1003.1 | 982.2 |
| 200-Case 5 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05373 | 0.146 | 76.7 | 223.7 | -8.484 | -8.442 | 1008.8 | 990.0 |
| 200-Case 5 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05466 | 0.146 | 75.6 | 224.9 | -8.443 | -8.401 | 1014.7 | 997.8 |
| 200-Case 5 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05559 | 0.146 | 74.6 | 226.0 | -8.402 | -8.359 | 1020.6 | 1005.5 |
| 200-Case 5 | 30.5 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.05651 | 0.146 | 73.5 | 227.2 | -8.362 | -8.318 | 1026.7 | 1013.1 |

**Table 24.** Property Predictions as a Function of WL for Frit 320 and SB3 Without Tank 7 Sand (Case #5)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 320-Case 5 | 22 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04076 | 0.181 | 59.9 | 210.2 | -10.779 | -10.748 | 934.8 | 754.5 |
| 320-Case 5 | 22.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04169 | 0.180 | 59.2 | 211.3 | -10.728 | -10.695 | 939.0 | 764.2 |
| 320-Case 5 | 23 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04262 | 0.180 | 58.5 | 212.4 | -10.676 | -10.643 | 943.3 | 773.9 |
| 320-Case 5 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04354 | 0.180 | 57.9 | 213.6 | -10.624 | -10.590 | 947.7 | 783.4 |
| 320-Case 5 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04447 | 0.179 | 57.2 | 214.7 | -10.572 | -10.537 | 952.2 | 792.8 |
| 320-Case 5 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04540 | 0.179 | 56.5 | 215.8 | -10.520 | -10.485 | 956.8 | 802.1 |
| 320-Case 5 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04632 | 0.178 | 55.8 | 217.0 | -10.468 | -10.432 | 961.4 | 811.4 |
| 320-Case 5 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04725 | 0.178 | 55.1 | 218.1 | -10.416 | -10.380 | 966.2 | 820.5 |
| 320-Case 5 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04817 | 0.177 | 54.4 | 219.2 | -10.365 | -10.327 | 971.0 | 829.5 |
| 320-Case 5 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04910 | 0.177 | 53.7 | 220.4 | -10.313 | -10.275 | 976.0 | 838.5 |
| 320-Case 5 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05003 | 0.177 | 53.0 | 221.5 | -10.261 | -10.222 | 981.0 | 847.3 |
| 320-Case 5 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05095 | 0.176 | 52.3 | 222.6 | -10.209 | -10.169 | 986.2 | 856.1 |
| 320-Case 5 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05188 | 0.176 | 51.6 | 223.8 | -10.157 | -10.117 | 991.4 | 864.8 |
| 320-Case 5 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05281 | 0.175 | 50.9 | 224.9 | -10.105 | -10.064 | 996.8 | 873.4 |
| 320-Case 5 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05373 | 0.175 | 50.2 | 226.0 | -10.053 | -10.012 | 1002.3 | 881.9 |
| 320-Case 5 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05466 | 0.174 | 49.6 | 227.2 | -10.001 | -9.959 | 1007.9 | 890.3 |
| 320-Case 5 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05559 | 0.174 | 48.9 | 228.3 | -9.950 | -9.907 | 1013.6 | 898.6 |
| 320-Case 5 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05651 | 0.174 | 48.2 | 229.4 | -9.898 | -9.854 | 1019.5 | 906.9 |
| 320-Case 5 | 31 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05744 | 0.173 | 47.5 | 230.6 | -9.846 | -9.801 | 1025.5 | 915.1 |
| 320-Case 5 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05836 | 0.173 | 46.8 | 231.7 | -9.794 | -9.749 | 1031.6 | 923.2 |
| 320-Case 5 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05929 | 0.172 | 46.1 | 232.8 | -9.742 | -9.696 | 1037.8 | 931.3 |
| 320-Case 5 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06022 | 0.172 | 45.4 | 233.9 | -9.690 | -9.644 | 1044.3 | 939.2 |
| 320-Case 5 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06114 | 0.171 | 44.7 | 235.1 | -9.638 | -9.591 | 1050.8 | 947.1 |
| 320-Case 5 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06207 | 0.171 | 44.0 | 236.2 | -9.587 | -9.538 | 1057.5 | 954.9 |
| 320-Case 5 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06300 | 0.171 | 43.4 | 237.3 | -9.535 | -9.486 | 1064.4 | 962.7 |
| 320-Case 5 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06392 | 0.170 | 42.7 | 238.5 | -9.483 | -9.433 | 1071.4 | 970.4 |
| 320-Case 5 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06485 | 0.170 | 42.0 | 239.6 | -9.431 | -9.381 | 1078.6 | 978.0 |
| 320-Case 5 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06578 | 0.169 | 41.3 | 240.7 | -9.379 | -9.328 | 1086.0 | 985.5 |
| 320-Case 5 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06670 | 0.169 | 40.6 | 241.9 | -9.327 | -9.276 | 1093.6 | 993.0 |
| 320-Case 5 | 36.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06763 | 0.168 | 39.9 | 243.0 | -9.275 | -9.223 | 1101.4 | 1000.4 |
| 320-Case 5 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06856 | 0.168 | 39.3 | 244.1 | -9.224 | -9.170 | 1109.4 | 1007.8 |
| 320-Case 5 | 37.5 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06948 | 0.167 | 38.6 | 245.3 | -9.172 | -9.118 | 1117.5 | 1015.1 |

## 5.6 Case #6: SB3 (with Tank 51 heel, Pu/Gd, and Am/Cm) Without the Tank 7 Sand

As previously mentioned, Case #5 and Case #6 were specifically developed to address the ability to partially or completely transfer the sand associated with Tank 7 into SB3. More specifically, Case #5 established a second baseline case (i.e., SB3 with only the Tank 51 heel) from which the additions of both the Am/Cm and Pu/Gd streams can be compared (Case #6).

Table 25 summarizes the resulting nominal SB3 sludge composition for Case #6 (SB3 including the Tank 51 heel, additions of Am/Cm and Pu/Gd but excluding the sand from Tank 7). The resulting total mass is estimated to be 362336.24 kg (oxide basis) or 4550 kg (the reported Tank 7 sand amount) less than Case #4. The major oxides (i.e., those exceeding 0.5 wt% in sludge) include $Al_2O_3$, CaO, $Fe_2O_3$, MnO, $Na_2O$, $Nd_2O_3$, NiO, $SiO_2$, $U_3O_8$, and $ZrO_2$. Assuming that the Tank 7 sand is not transferred and it is represented as 100% $SiO_2$, the lower $SiO_2$ concentration (2.130 wt%) relative to baseline (3.373 wt%) or Case #4 (3.343 wt%) is not surprising. Compositional differences among the other major oxides exist, but are minimal and should result in a negligible impact on predicted properties.

**Table 25.** Nominal Sludge Composition for Case #6 (SB3 including the Tank 51 heel, Pu/Gd, and Am/Cm without the Tank 7 sand) (in wt%, oxide basis)

| Oxide | SB3 with Tank 51 Heel, Pu/Gd, and Am/Cm | Oxide | SB3 with Tank 51 Heel, Pu/Gd, and Am/Cm |
|---|---|---|---|
| Ag | 6.93E-04 | $Na_2O$ | 10.763 |
| $Al_2O_3$ | 18.330 | $Nb_2O_3$ | 0.000 |
| $AmO_2$ | 4.33E-03 | $Nd_2O_3$ | 0.691 |
| $B_2O_3$ | 0.000 | NiO | 1.631 |
| BaO | 0.253 | $P_2O_5$ | 0.000 |
| CaO | 3.645 | PbO | 0.306 |
| CdO | 1.20E-05 | Pd | 0.037 |
| $Ce_2O_3$ | 0.360 | $Pr_2O_3$ | 0.189 |
| $Cm_2O_3$ | 6.55E-04 | $PuO_2$ | 0.053 |
| $Cr_2O_3$ | 0.379 | $RuO_2$ | 0.281 |
| $Cs_2O$ | 0.000 | Rh | 0.079 |
| CuO | 0.201 | $SiO_2$ | 2.130 |
| $Eu_2O_3$ | 4.74E-05 | $Sm_2O_3$ | 0.101 |
| $Fe_2O_3$ | 40.776 | $SnO_2$ | 0.000 |
| $Gd_2O_3$ | 0.051 | SrO | 0.000 |
| $K_2O$ | 0.436 | $ThO_2$ | 0.145 |
| $La_2O_3$ | 0.208 | $TiO_2$ | 1.05E-04 |
| $Li_2O$ | 2.98E-03 | $U_3O_8$ | 10.316 |
| MgO | 0.191 | $Y_2O_3$ | 0.000 |
| MnO | 7.267 | ZnO | 0.416 |
| $MoO_3$ | 2.20E-04 | $ZrO_2$ | 0.752 |
| | | **Total** | 100.000 |
| | | **Mass (in kgs)** | 362336.24 |

### 5.6.1 Frit 165 Assessment

For the Frit 165-based Case #6 scenario, the projected operational window exists from 24.0 to 35.5 wt% WL (See Table 26). At low WLs (< 24%), homogeneity is not satisfied while $T_L$ predictions continue to limit access to higher WLs.

Property predictions of the Frit 165-based Case #6 are also shown in Table 26. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 47.7 Poise, 960.1°C, 817.3°C, -11.166 kcal/mol, and -11.133 kcal/mol, respectively, at the lower WL limit (i.e., 24.0%). At the upper WL limit (35.5 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 34.0 Poise, 1102.6°C, 1004.9°C, -9.882 kcal/mol, and -9.833 kcal/mol, respectively.

### 5.6.2 Frit 200 Assessment

For the Frit 200-based Case #6 scenario, the projected operational window exists from 24.0 to 30.0 wt% WL (See Table 27). As with the Frit 200-based Case #4 scenario, the new $T_L$ model initially limits the maximum WL for Case #6. More specifically, if the current $T_L$ model were used, a WL of 30.5% could be obtained. Implementation of the new $T_L$ model, coupled with the conservative 1010ºC PAR limit, restricts the WL to 30.0%. However, implementation and use of the new $T_L$ model should be pursued with a transition to a "sludge-only" frit (Frit 165 or Frit 320)—assuming that a frit specifically developed for SB3 is not considered.

Property predictions of the Frit 200-based Case #6 are also shown in Table 27. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 88.1 Poise, 955.2°C, 904.1°C, -8.890 kcal/mol, and -8.857 kcal/mol, respectively, at the lower WL limit (i.e., 24.0%). At the upper WL limit (30.0 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 75.0 Poise, 1018.0°C, 1002.6°C, -8.400 kcal/mol, and -8.358 kcal/mol, respectively.

### 5.6.3 Frit 320 Assessment

For the Frit 320-based Case #6 scenario, the projected operational window exists from 23.0 to 37.0 wt% WL (see Table 28). At lower WLs (< 23.0%), homogeneity is not satisfied while $T_L$ predictions (even with the proposed $T_L$ model) continue to limit access to higher WLs. The use of Frit 320 extends the operational window to both higher and lower WLs compared to the use of either Frit 165 or Frit 200 for Case #6. Access to lower WLs (i.e., < 24% for both Frit 165 and 200 cases) is a result of glasses produced using Frit 320 not challenging the homogeneity constraint, which is consistent with observations by Peeler, Brown, and Edwards (2001). More importantly, the use of Frit 320 allows for higher WLs to be obtained (based on property predictions) compared to either Frit 165 of Frit 200. Although higher WLs are predicted, it should be recognized that this frit was developed specifically for SB2 to improve the melt rate (Peeler et al. 2001).

Property predictions for the Frit 320-based Case #6 are also shown in Table 28. Predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 58.8 Poise, 941.7°C, 770.7°C, -10.674 kcal/mol, and -10.642 kcal/mol, respectively, at the lower WL limit (i.e., 23.0%). At the upper WL limit (37.0 wt%), predictions of $\eta$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 39.6 Poise, 1105.5°C, 1004.7°C, -9.221 kcal/mol, and -9.169 kcal/mol, respectively. Again, as WLs increase, predictions of durability increase. This is reflected by the $\Delta G_P$ values being more positive (or less negative). Although the Frit 200-based Case #6 yielded a higher durability over a limited WL range (maximum WL is 30.0% with a $\Delta G_P$ of -8.400 kcal/mol), the use of Frit 320 provides an ~ 23% increase in WL (maximum WL of 37%) without compromising product quality significantly ($\Delta G_P$ of -9.221 kcal/mol).

**Table 26.** Property Predictions as a Function of WL for Frit 165 and SB3 (without Tank 7 sand) with Am/Cm and Pu/Gd (Case #6)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 165-Case 6 | 23.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04308 | 0.179 | 48.3 | 210.2 | -11.222 | -11.189 | 955.4 | 808.1 |
| 165-Case 6 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04399 | 0.179 | 47.7 | 211.3 | -11.166 | -11.133 | 960.1 | 817.3 |
| 165-Case 6 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04491 | 0.178 | 47.1 | 212.5 | -11.110 | -11.076 | 965.0 | 826.3 |
| 165-Case 6 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04583 | 0.178 | 46.5 | 213.6 | -11.055 | -11.020 | 969.9 | 835.3 |
| 165-Case 6 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04674 | 0.178 | 45.9 | 214.7 | -10.999 | -10.963 | 975.0 | 844.2 |
| 165-Case 6 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04766 | 0.177 | 45.3 | 215.8 | -10.943 | -10.907 | 980.1 | 853.0 |
| 165-Case 6 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04858 | 0.177 | 44.7 | 217.0 | -10.887 | -10.850 | 985.3 | 861.7 |
| 165-Case 6 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04949 | 0.176 | 44.1 | 218.1 | -10.831 | -10.793 | 990.7 | 870.3 |
| 165-Case 6 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05041 | 0.176 | 43.5 | 219.2 | -10.776 | -10.737 | 996.2 | 878.9 |
| 165-Case 6 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05133 | 0.175 | 42.9 | 220.4 | -10.720 | -10.680 | 1001.8 | 887.3 |
| 165-Case 6 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05224 | 0.175 | 42.3 | 221.5 | -10.664 | -10.624 | 1007.5 | 895.7 |
| 165-Case 6 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05316 | 0.174 | 41.7 | 222.6 | -10.608 | -10.567 | 1013.3 | 904.0 |
| 165-Case 6 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05408 | 0.174 | 41.1 | 223.7 | -10.552 | -10.511 | 1019.3 | 912.2 |
| 165-Case 6 | 30 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05499 | 0.174 | 40.5 | 224.9 | -10.496 | -10.454 | 1025.4 | 920.3 |
| 165-Case 6 | 30.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05591 | 0.173 | 39.9 | 226.0 | -10.441 | -10.398 | 1031.6 | 928.4 |
| 165-Case 6 | 31 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05683 | 0.173 | 39.3 | 227.1 | -10.385 | -10.341 | 1038.0 | 936.3 |
| 165-Case 6 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05774 | 0.172 | 38.7 | 228.3 | -10.329 | -10.285 | 1044.5 | 944.3 |
| 165-Case 6 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05866 | 0.172 | 38.1 | 229.4 | -10.273 | -10.228 | 1051.2 | 952.1 |
| 165-Case 6 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05957 | 0.171 | 37.5 | 230.5 | -10.217 | -10.172 | 1058.0 | 959.8 |
| 165-Case 6 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06049 | 0.171 | 36.9 | 231.6 | -10.162 | -10.115 | 1065.0 | 967.5 |
| 165-Case 6 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06141 | 0.171 | 36.3 | 232.8 | -10.106 | -10.059 | 1072.1 | 975.1 |
| 165-Case 6 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06232 | 0.170 | 35.8 | 233.9 | -10.050 | -10.002 | 1079.5 | 982.7 |
| 165-Case 6 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06324 | 0.170 | 35.2 | 235.0 | -9.994 | -9.946 | 1087.0 | 990.2 |
| 165-Case 6 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06416 | 0.169 | 34.6 | 236.2 | -9.938 | -9.889 | 1094.7 | 997.6 |
| 165-Case 6 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06507 | 0.169 | 34.0 | 237.3 | -9.882 | -9.833 | 1102.6 | 1004.9 |
| 165-Case 6 | 36 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06599 | 0.168 | 33.4 | 238.4 | -9.827 | -9.776 | 1110.7 | 1012.2 |

**Table 27.** Property Predictions as a Function of WL for Frit 200 and SB3 (without Tank 7 sand) with Am/Cm and Pu/Gd (Case #6)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^oC$) | New $T_L$ ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 200-Case 6 | 23.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04308 | 0.149 | 89.2 | 210.2 | -8.931 | -8.898 | 950.6 | 895.3 |
| 200-Case 6 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04399 | 0.148 | 88.1 | 211.3 | -8.890 | -8.857 | 955.2 | 904.1 |
| 200-Case 6 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04491 | 0.148 | 87.1 | 212.5 | -8.850 | -8.815 | 959.8 | 912.9 |
| 200-Case 6 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04583 | 0.148 | 86.0 | 213.6 | -8.809 | -8.774 | 964.6 | 921.5 |
| 200-Case 6 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04674 | 0.148 | 84.9 | 214.7 | -8.768 | -8.732 | 969.5 | 930.1 |
| 200-Case 6 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04766 | 0.148 | 83.8 | 215.8 | -8.727 | -8.691 | 974.4 | 938.5 |
| 200-Case 6 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04858 | 0.147 | 82.7 | 217.0 | -8.686 | -8.649 | 979.5 | 946.9 |
| 200-Case 6 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04949 | 0.147 | 81.6 | 218.1 | -8.645 | -8.607 | 984.6 | 955.1 |
| 200-Case 6 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05041 | 0.147 | 80.5 | 219.2 | -8.604 | -8.566 | 989.9 | 963.3 |
| 200-Case 6 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05133 | 0.147 | 79.4 | 220.4 | -8.564 | -8.524 | 995.3 | 971.3 |
| 200-Case 6 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05224 | 0.146 | 78.3 | 221.5 | -8.523 | -8.483 | 1000.8 | 979.3 |
| 200-Case 6 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05316 | 0.146 | 77.2 | 222.6 | -8.482 | -8.441 | 1006.4 | 987.2 |
| 200-Case 6 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05408 | 0.146 | 76.1 | 223.7 | -8.441 | -8.400 | 1012.1 | 994.9 |
| 200-Case 6 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05499 | 0.146 | 75.0 | 224.9 | -8.400 | -8.358 | 1018.0 | 1002.6 |
| 200-Case 6 | 30.5 | Durable; Visc; TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.05591 | 0.145 | 73.9 | 226.0 | -8.359 | -8.317 | 1024.0 | 1010.2 |
| 200-Case 6 | 31 | Durable; Visc; Not TL; Homog; Not New TL; v; alkali | 0.05683 | 0.145 | 72.9 | 227.1 | -8.319 | -8.275 | 1030.1 | 1017.8 |

**Table 28.** Property Predictions as a Function of WL for Frit 320 and SB3 (without Tank 7 sand) with Am/Cm and Pu/Gd (Case #6)

| Category | Sludge Loading (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt% | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New $T_L$ ($^o$C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 320-Case 6 | 22.5 | Durable; Visc; TL; *Not Homog*; New TL; $Al_2O_3$; alkali | 0.04124 | 0.180 | 59.5 | 210.4 | -10.726 | -10.694 | 937.5 | 761.1 |
| 320-Case 6 | 23 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04216 | 0.180 | 58.8 | 211.5 | -10.674 | -10.642 | 941.7 | 770.7 |
| 320-Case 6 | 23.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04308 | 0.179 | 58.1 | 212.7 | -10.622 | -10.589 | 946.1 | 780.2 |
| 320-Case 6 | 24 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04399 | 0.179 | 57.4 | 213.8 | -10.570 | -10.537 | 950.5 | 789.6 |
| 320-Case 6 | 24.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04491 | 0.178 | 56.7 | 214.9 | -10.518 | -10.484 | 955.0 | 798.9 |
| 320-Case 6 | 25 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04583 | 0.178 | 56.1 | 216.0 | -10.466 | -10.431 | 959.6 | 808.1 |
| 320-Case 6 | 25.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04674 | 0.178 | 55.4 | 217.1 | -10.415 | -10.379 | 964.3 | 817.3 |
| 320-Case 6 | 26 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04766 | 0.177 | 54.7 | 218.2 | -10.363 | -10.326 | 969.1 | 826.3 |
| 320-Case 6 | 26.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04858 | 0.177 | 54.0 | 219.3 | -10.311 | -10.274 | 974.0 | 835.2 |
| 320-Case 6 | 27 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.04949 | 0.176 | 53.3 | 220.4 | -10.259 | -10.221 | 978.9 | 844.1 |
| 320-Case 6 | 27.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05041 | 0.176 | 52.6 | 221.6 | -10.207 | -10.168 | 984.0 | 852.9 |
| 320-Case 6 | 28 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05133 | 0.175 | 51.9 | 222.7 | -10.155 | -10.116 | 989.2 | 861.5 |
| 320-Case 6 | 28.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05224 | 0.175 | 51.2 | 223.8 | -10.103 | -10.063 | 994.5 | 870.1 |
| 320-Case 6 | 29 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05316 | 0.174 | 50.5 | 224.9 | -10.051 | -10.011 | 999.9 | 878.7 |
| 320-Case 6 | 29.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05408 | 0.174 | 49.9 | 226.0 | -9.999 | -9.958 | 1005.5 | 887.1 |
| 320-Case 6 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05499 | 0.174 | 49.2 | 227.1 | -9.948 | -9.905 | 1011.1 | 895.4 |
| 320-Case 6 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05591 | 0.173 | 48.5 | 228.2 | -9.896 | -9.853 | 1016.9 | 903.7 |
| 320-Case 6 | 31 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05683 | 0.173 | 47.8 | 229.3 | -9.844 | -9.800 | 1022.8 | 911.9 |
| 320-Case 6 | 31.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05774 | 0.172 | 47.1 | 230.5 | -9.792 | -9.748 | 1028.8 | 920.0 |
| 320-Case 6 | 32 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05866 | 0.172 | 46.4 | 231.6 | -9.740 | -9.695 | 1035.0 | 928.1 |
| 320-Case 6 | 32.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.05957 | 0.171 | 45.7 | 232.7 | -9.688 | -9.642 | 1041.3 | 936.1 |
| 320-Case 6 | 33 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06049 | 0.171 | 45.0 | 233.8 | -9.636 | -9.590 | 1047.8 | 944.0 |
| 320-Case 6 | 33.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06141 | 0.171 | 44.4 | 234.9 | -9.584 | -9.537 | 1054.4 | 951.8 |
| 320-Case 6 | 34 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06232 | 0.170 | 43.7 | 236.0 | -9.532 | -9.485 | 1061.2 | 959.6 |
| 320-Case 6 | 34.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06324 | 0.170 | 43.0 | 237.1 | -9.480 | -9.432 | 1068.1 | 967.3 |
| 320-Case 6 | 35 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06416 | 0.169 | 42.3 | 238.2 | -9.429 | -9.379 | 1075.2 | 974.9 |
| 320-Case 6 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06507 | 0.169 | 41.6 | 239.4 | -9.377 | -9.327 | 1082.5 | 982.5 |
| 320-Case 6 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06599 | 0.168 | 40.9 | 240.5 | -9.325 | -9.274 | 1090.0 | 990.0 |
| 320-Case 6 | 36.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06691 | 0.168 | 40.3 | 241.6 | -9.273 | -9.222 | 1097.6 | 997.4 |
| 320-Case 6 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06782 | 0.167 | 39.6 | 242.7 | -9.221 | -9.169 | 1105.5 | 1004.7 |
| 320-Case 6 | 37.5 | Durable; Visc; Not TL; Homog; *Not New TL*; $Al_2O_3$; alkali | 0.06874 | 0.167 | 38.9 | 243.8 | -9.169 | -9.116 | 1113.5 | 1012.1 |

# 6.0 Summary of Assessments of the Potential Impacts on Glass Quality

Tables 29 and 30 summarize the predicted properties for each case at the maximum allowable WL (given the PAR limits used in this study). Table 29 summarizes the predicted properties as a function of blending scenarios (or case number). The Table 30 summary is based on the predicted properties for each frit at the maximum WLs. These tables provide a quick reference from which comparisons can be made regarding the impacts of predicted properties for the various blending scenarios. Note that direct comparisons can be made but should be used with caution as the WL basis may not be consistent.

The maximum WLs for the Frit 165, 200, and 320 baseline cases (Case #1) are 35.5, 30.5, and 37.5%, respectively. These predictions indicate that Frit 320 provides the maximum allowable WL for all blending scenarios considered. Again, it must be pointed out that the predictions are based solely on nominal compositions and do not account for any variation in sludge composition.

In general, the use of Frit 200 yields a more durable product (less negative predicted $\Delta G_P$ values) but also limits WL substantially relatively to Frit 165 or 320. The use of Frit 165 or Frit 320 provides increased operational windows and higher targeted WLs without compromising significantly the predicted durability of the product (comparisons should be made within a particular blending strategy or case number). The use of Frit 320 or 165 allows for higher WLs and as WLs are increased, predictions of durability also increase. Therefore, the negative impact of using Frit 320 or Frit 165 on durability (relative to Frit 200 at a fixed WL) is almost balanced as a result of higher WLs. As mentioned in Section 5.0, the lower WLs are always limited by the homogeneity constraint for each blending scenario evaluated (regardless of the frit selection). Maximum WLs were always limited by $T_L$ predictions.

The primary objective of this task was to assess the impacts of Am/Cm and/or Pu/Gd on the predicted properties of interest. Numerous comparisons could be made, and this report does not attempt to cover all cases. However, a general statement can be made regarding the addition of individual and/or combined streams to SB3. These waste streams have no practical impact on predicted properties. By practical, the authors mean that although predicted properties may change for the addition of a particular waste stream or waste-stream combinations, the relative difference of those predictions is not of practical concern. For example, the baseline Frit 320 case yields a predicted $\Delta G_P$ of -9.127 kcal/mol. Adding both the Am/Cm and Pu/Gd streams (Case #4) changes this prediction to -9.125 kcal/mol. Although this suggests that adding both streams has a positive impact on durability (i.e., increases durability), the relative difference is quite small and could not be discerned upon measurement. Case #5 (which assumes that the Tank 7 sand is not transferred to SB3) has the largest (negative) impact on $\Delta G_P$ for all three frits evaluated. Removing the 4550 kg of $SiO_2$ from the Frit 320 baseline case causes the predicted $\Delta G_P$ to decrease to -9.224 kcal/mol (down from -9.127 kcal/mol). Similar impacts are observed with the Frit 165- and Frit-200 based Case #5 glasses. Again, although differences are predicted, the relative differences are of little practical concern as both glasses are well above the $\Delta G_P$ SME acceptability PAR limit of -12.7178 kcal/mol. In fact, the projected operating windows were not durability limited for any blending scenario evaluated.

**Table 29.** Summary of Predicted Properties at Maximum Allowable WL (using the new $T_L$ model and PAR limits)

| Category | WL (%) | Satisfies PAR | $Al_2O_3$ (wt fraction) | Alkalis (wt fraction) | Viscosity (Poise) | Homogeneity wt % | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Current $T_L$ ($^o$C) | New TL(C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 165-Case 1 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06495 | 0.169 | 35.4 | 237.7 | -9.843 | -9.793 | 1098.1 | 1002.9 |
| 200-Case 1 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05580 | 0.145 | 75.9 | 226.3 | -8.325 | -8.282 | 1021.4 | 1008.3 |
| 320-Case 1 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06861 | 0.167 | 40.5 | 244.2 | -9.127 | -9.074 | 1108.8 | 1010.0 |
| 165-Case 2 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06581 | 0.168 | 34.9 | 238.7 | -9.786 | -9.735 | 1105.7 | 1009.9 |
| 200-Case 2 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05576 | 0.145 | 75.9 | 226.2 | -8.325 | -8.282 | 1021.2 | 1008.0 |
| 320-Case 2 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06856 | 0.167 | 40.6 | 244.1 | -9.127 | -9.074 | 1108.5 | 1009.7 |
| 165-Case 3 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06522 | 0.168 | 35.1 | 237.5 | -9.785 | -9.735 | 1102.6 | 1007.6 |
| 200-Case 3 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05526 | 0.145 | 76.3 | 225.2 | -8.324 | -8.282 | 1019.1 | 1005.7 |
| 320-Case 3 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06794 | 0.167 | 40.8 | 242.9 | -9.126 | -9.073 | 1105.2 | 1007.3 |
| 165-Case 4 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06517 | 0.168 | 35.1 | 237.4 | -9.785 | -9.735 | 1102.3 | 1007.3 |
| 200-Case 4 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05522 | 0.145 | 76.4 | 225.2 | -8.324 | -8.281 | 1018.9 | 1005.5 |
| 320-Case 4 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06789 | 0.166 | 40.9 | 242.8 | -9.125 | -9.073 | 1105.0 | 1007.0 |
| 165-Case 5 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06578 | 0.169 | 33.7 | 238.7 | -9.885 | -9.834 | 1106.5 | 1007.9 |
| 200-Case 5 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05559 | 0.146 | 74.6 | 226.0 | -8.402 | -8.359 | 1020.6 | 1005.5 |
| 320-Case 5 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06856 | 0.168 | 39.3 | 244.1 | -9.224 | -9.170 | 1109.4 | 1007.8 |
| 165-Case 6 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06507 | 0.169 | 34.0 | 237.3 | -9.882 | -9.833 | 1102.6 | 1004.9 |
| 200-Case 6 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05499 | 0.146 | 75.0 | 224.9 | -8.400 | -8.358 | 1018.0 | 1002.6 |
| 320-Case 6 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06782 | 0.167 | 39.6 | 242.7 | -9.221 | -9.169 | 1105.5 | 1004.7 |

**Table 30.** Summary of Predicted Properties as a Function of Frit Type At the Maximum Allowable WL

| | WL | | $Al_2O_3$ | Alkalis | Viscosity | Homogeneity | PCCS $DG_p$ | Modified $DG_p^*$ | Current | New |
|---|---|---|---|---|---|---|---|---|---|---|
| **Category** | **(%)** | **Satisfies PAR** | **(wt fraction)** | **(wt fraction)** | **(Poise)** | **wt %** | **(kcal/mol)** | **(kcal/mol)** | **$T_L$ ($^o$C)** | **TL(C)** |
| 165-Case 1 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06495 | 0.169 | 35.4 | 237.7 | -9.843 | -9.793 | 1098.1 | 1002.9 |
| 165-Case 2 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06581 | 0.168 | 34.9 | 238.7 | -9.786 | -9.735 | 1105.7 | 1009.9 |
| 165-Case 3 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06522 | 0.168 | 35.1 | 237.5 | -9.785 | -9.735 | 1102.6 | 1007.6 |
| 165-Case 4 | 36 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06517 | 0.168 | 35.1 | 237.4 | -9.785 | -9.735 | 1102.3 | 1007.3 |
| 165-Case 5 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06578 | 0.169 | 33.7 | 238.7 | -9.885 | -9.834 | 1106.5 | 1007.9 |
| 165-Case 6 | 35.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06507 | 0.169 | 34.0 | 237.3 | -9.882 | -9.833 | 1102.6 | 1004.9 |
| 200-Case 1 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05580 | 0.145 | 75.9 | 226.3 | -8.325 | -8.282 | 1021.4 | 1008.3 |
| 200-Case 2 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05576 | 0.145 | 75.9 | 226.2 | -8.325 | -8.282 | 1021.2 | 1008.0 |
| 200-Case 3 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05526 | 0.145 | 76.3 | 225.2 | -8.324 | -8.282 | 1019.1 | 1005.7 |
| 200-Case 4 | 30.5 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05522 | 0.145 | 76.4 | 225.2 | -8.324 | -8.281 | 1018.9 | 1005.5 |
| 200-Case 5 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05559 | 0.146 | 74.6 | 226.0 | -8.402 | -8.359 | 1020.6 | 1005.5 |
| 200-Case 6 | 30 | Durable; Visc; TL; Homog; New TL; $Al_2O_3$; alkali | 0.05499 | 0.146 | 75.0 | 224.9 | -8.400 | -8.358 | 1018.0 | 1002.6 |
| 320-Case 1 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06861 | 0.167 | 40.5 | 244.2 | -9.127 | -9.074 | 1108.8 | 1010.0 |
| 320-Case 2 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06856 | 0.167 | 40.6 | 244.1 | -9.127 | -9.074 | 1108.5 | 1009.7 |
| 320-Case 3 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06794 | 0.167 | 40.8 | 242.9 | -9.126 | -9.073 | 1105.2 | 1007.3 |
| 320-Case 4 | 37.5 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06789 | 0.166 | 40.9 | 242.8 | -9.125 | -9.073 | 1105.0 | 1007.0 |
| 320-Case 5 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06856 | 0.168 | 39.3 | 244.1 | -9.224 | -9.170 | 1109.4 | 1007.8 |
| 320-Case 6 | 37 | Durable; Visc; Not TL; Homog; New TL; $Al_2O_3$; alkali | 0.06782 | 0.167 | 39.6 | 242.7 | -9.221 | -9.169 | 1105.5 | 1004.7 |

The most negative $\Delta G_P$ predicted (at maximum WL) was -9.885 kcal/mol that was associated with the Frit 165 based Case #5. Again, this value is well above the SME acceptability PAR (and MAR) limit. Based on the predictions of durability, adding the Pu/Gd or the Am/Cm secondary waste streams (either individually or combined) to SB3 does not have a significant impact on product performance (as defined by the predicted PCT response). Again, it should be mentioned that the conclusions drawn from this assessment are based solely on the nominal sludge cases and do not account for any compositional variation in sludge.

As shown in Tables 29 and 30, other property predictions may also be influenced by adding the Am/Cm and Pu/Gd waste streams. Consider the Frit 200 baseline case where $\eta_{1150°C}$ is predicted to be 75.9 Poise at 30.5 wt% WL. Adding the Pu/Gd stream (Case #2 for Frit 200) does not have an impact on the predicted viscosity (75.9 Poise at 30.5% WL)—not surprising given the small mass (286.35 kg) of this stream. Note that neither $PuO_2$ nor $Gd_2O_3$ are terms in the current viscosity model so any change would have been associated with a dilution effect. However, adding the Am/Cm stream (total mass estimated to be 3796.2 kg) has a predicted impact (although minimal) as $\eta_{1150°C}$ is predicted to be 76.3 Poise. This suggests that the high $U_3O_8$-based Am/Cm stream is predicted to increase viscosity slightly at 1150ºC—although it is of little or no practical concern and probably would not be discernable even if measured.

The predicted impact of the Pu/Gd and/or the Am/Cm stream additions is minimal within a particular frit-based system with maximum $\eta_{1150°C}$ differences (over all cases evaluated) being estimated at 1.7, 1.4, and 1.6 Poise for the Frit 165, Frit 200, and Frit 320 cases respectively. Note that adding the Pu/Gd stream to the Frit 200 baseline case has no predicted impact to $\eta_{1150°C}$, but adding the Am/Cm stream is predicted to have a slight positive effect (increase $\eta_{1150°C}$). The Frit 165-based system appears to have the lowest viscosity predictions, while the Frit 200 cases having markedly higher viscosity predictions. As expected, failure to transfer the Tank 7 sand (4550 kg) lowers the predicted viscosity for all three frits. For example, in the Frit 320-based system, the baseline case has a predicted $\eta_{1150°C}$ of 40.5 Poise while Case #5 (SB3 baseline without sand) yields a predicted $\eta_{1150°C}$ of 39.3 Poise. Again, although differences in $\eta_{1150°C}$ predictions exist, they are minimal and would have no practical impact on processability.

In terms of the impacts of these waste streams on $T_L$ predictions (assessing only the new $T_L$ model predictions), adding the Am/Cm and Pu/Gd waste streams to each baseline case has minimal impact. Adding the Pu/Gd waste stream is predicted to slightly decrease $T_L$. Adding the Am/Cm stream also appears to reduce $T_L$. As with the other predicted properties, the impacts of these streams are of little practical significance.

Impact of Adding Am/Cm and Pu/Gd To SB3 Using Frit 320

A few direct comparisons will be made in the following paragraphs to provide predicted impacts on adding these waste streams to SB3. The comparisons will be made on the Frit 320-based scenarios as it is assumed that this frit will be used for processing this particular sludge batch. Although the predicted properties for each of the Frit 320 blending scenarios are grouped in Table 30, Table 31 provides a condensed version, isolating various Frit 320-based property predictions. Also shown in Table 31 is the bounding (or conservative) $\Delta G_P$ calculation in which it was assumed that the effect of each component associated with the Am/Cm and Pu/Gd waste streams has the same (negative) impact on predicted durability as $Li_2O$. Nominal glass compositions for each Frit 320-based blending scenario at the maximum allowable WL (using PAR limits) are summarized in Table 32.

**Table 31.** Predicted Properties for the Frit 320-Based Blending Scenarios

| | WL (wt%) | Viscosity (Poise) | Homogeneity (wt%) | PCCS $DG_p$ (kcal/mol) | Modified $DG_p^*$ (kcal/mol) | Bounding $DG_p$ [(a)] | Current $T_L$ ($^oC$) | New $T_L$(C) |
|---|---|---|---|---|---|---|---|---|
| 320-Case 1 | 37.5 | 40.5 | 244.2 | -9.127 | -9.074 | -9.127 | 1108.8 | 1010.0 |
| 320-Case 2 | 37.5 | 40.6 | 244.1 | -9.127 | -9.074 | -9.150 | 1108.5 | 1009.7 |
| 320-Case 3 | 37.5 | 40.8 | 242.9 | -9.126 | -9.073 | -9.430 | 1105.2 | 1007.3 |
| 320-Case 4 | 37.5 | 40.9 | 242.8 | -9.125 | -9.073 | -9.452 | 1105.0 | 1007.0 |
| 320-Case 5 | 37 | 39.3 | 244.1 | -9.224 | -9.170 | -9.224 | 1109.4 | 1007.8 |
| 320-Case 6 | 37 | 39.6 | 242.7 | -9.221 | -9.169 | -9.548 | 1105.5 | 1004.7 |

[(a)] Bounding calculation in which it was assumed that the effect of each component associated with the Am/Cm and Pu/Gd waste streams has the same (negative) impact on predicted durability as $Li_2O$.

**Case #1**

For the baseline case at the maximum WL (37.5 wt%), predictions of $\eta_{1150°C}$, $T_L$ (current), $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 40.5 Poise, 1108.8°C, 1010.0°C, -9.127 kcal/mol, and -9.074 kcal/mol, respectively. The baseline case assumes that SB3 is processed without adding either Pu/Gd or the Am/Cm streams – hence no change in the bounding $\Delta G_P$ calculation. The baseline case includes adding the Tank 51 heel and the sand associated with Tank 7.

**Case #2**

The individual addition of the Pu/Gd stream (Case #2) has no practical impact on the predicted properties. Predictions of $\Delta G_P$ and $\Delta G_P^*$ for Case #2 are -9.127 and -9.074 kcal/mol, respectively, which are identical to Case #1 predictions to three decimals. The impact to viscosity is essentially nonexistent, although an increase of 0.1 Poise is predicted relative to the baseline. Using the new $T_L$ model, predictions indicate that adding Pu/Gd to SB3 will have no practical impact on $T_L$ (a 0.3ºC decrease is predicted). Given the minimal impact on $T_L$, the WL for this case also remains consistent at 37.5%. Adding the 286.35 kg of $PuO_2$ and $Gd_2O_3$ has no practical impact on predicted properties. Assuming both $PuO_2$ and $Gd_2O_3$ have the same effect on durability as $Li_2O$, the bounding $\Delta G_P$ value is calculated to be -9.150 kcal/mol, which is still well above the -12.7178 kcal/mol limit.

**Case #3**

The individual addition of the 3796.2 kg of Am/Cm (89.4 wt% $U_3O_8$) also has minimal impact on predicted properties relative to the baseline case. Predictions of $\eta_{1150°C}$, $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 40.8 Poise, 1007.3°C, -9.126 kcal/mol, and -9.073 kcal/mol, respectively. Comparing these predictions to those of the baseline (both at 37.5 wt% WL), adding Am/Cm to the SB3 baseline: increases viscosity (0.3ºC increase predicted), has essentially no predicted impact on durability, and decreases $T_L$ (by ~ 3ºC). The relative differences of these predicted properties indicate that they are of no practical concern regarding processability or product quality. Assuming the components associated with the Am/Cm stream have the same deleterious effect on durability as $Li_2O$ (which is admittedly conservative), the bounding $\Delta G_P$ value is calculated to be -9.430 kcal/mol, which is still well above the -12.7178 kcal/mol limit. The more negative bounding $\Delta G_P$ value compared to Case #2 is expected given the higher mass of the Am/Cm stream (3796.2 kg) relative to the Pu/Gd stream (286.35 kg).

**Case #4**

Case #4 represents the current blending strategy being pursued where both Pu/Gd (286.35 kg) and Am/Cm (3796.2 kg; mostly $U_3O_8$) waste streams are to be blended with SB3 (including the Tank

51 heel and the Tank 7 sand). This case provides a total mass of calcined solids (oxide basis) of 366886.24 kg. As with the individual additions of both the Am/Cm and Pu/Gd streams, the maximum WL obtainable for this case is 37.5 wt%. Given that the individual addition of Pu/Gd (comparing Case #1 to Case #2) did not have any impact on predicted properties (exceptions being a predicted 0.3ºC decrease in $T_L$ and a 0.1 Poise increase in viscosity), one would anticipate minimal impacts to predicted properties relative to Case #3.

Table 31 shows that there is essentially no difference in predicted properties between Case #3 and Case #4. Relative to the baseline, similar trends on property predictions are observed for this case as for Case #3—increased viscosity, increased durability, and decreased $T_L$ (albeit slight) when compared at 37.5 wt% WL.

Assuming the components associated with both the Am/Cm and Pu/Gd streams have the same effect on durability as $Li_2O$, the bounding $\Delta G_P$ value is calculated to be -9.452 kcal/mol which is still well above the -12.7178 kcal/mol limit. The more negative bounding $\Delta G_P$ value for this case as compared to either Case #2 or Case #3 is not surprising given the additive contributions of both waste streams.

**Case #5**
Cases #5 and #6 were specifically developed to address the capability to partially or completely transfer the sand associated with Tank 7 into SB3. More specifically, Case #5 establishes a second baseline case (i.e., SB3 with only the Tank 51 heel) from which the additions of both the Am/Cm and Pu/Gd streams can be compared (Case #6).

Table 31 indicates that the maximum WL is 37.0 wt%—0.5% less than the baseline case. With all systems being $T_L$ limited in terms of maximum WLs, the first property that will be discussed is $T_L$. To make a more direct comparison, the predicted properties of the Frit 320-baseline case (Case #1) at 37.0 wt% WL will be used (although a WL of 37.5% would be processable based on the use of the conservative 1010ºC $T_L$ limit—see Table 8). Predictions at 37.0 wt% for Case #1 for $\eta_{1150°C}$, $T_L$ (new), $\Delta G_P$, and $\Delta G_P^*$ are 41.2 Poise, 1002.7°C, -9.180 kcal/mol, and -9.127 kcal/mol, respectively.

The $T_L$ predictions suggest that failure to transfer the Tank 7 sand would increase $T_L$ to 1007.8ºC from 1002.7ºC for the baseline with sand (at 37.0% WL). This is probably a result of the higher relative amounts in other component concentrations that have a deleterious effect on $T_L$. Although an increase in $T_L$ is predicted, this impact is of no practical concern.

The impact of not transferring the 4550 kg of sand on durability is in line with expectations. Given that a decreased $SiO_2$ concentration typically reduces durability (all other factors held constant), the prediction of -9.224 kcal/mol for Case #5 relative to the baseline (-9.180 kcal/mol at 37% WL) is not surprising. Again, although the assumed inability to transfer this material to SB3 has a negative impact on predicted durability, it is of no practical concern (and probably not discernable based on measurement) given the SME acceptability PAR limit of -12.7178 kcal/mol. The bounding $\Delta G_P$ calculation is identical to the PCCS $\Delta G_P$ given no addition of either secondary waste stream.

**Case #6**
This case evaluates the addition of both the Am/Cm and Pu/Gd waste streams to SB3 without the Tank 7 sand. Predictions indicate that there is no practical change in durability relative to Case

#5—although Case #6 is predicted to have a slightly higher durability (less negative $\Delta G_P$). Regardless, the minor differences in predicted durability (as well as other property predictions) are of little practical importance as both are well above the SME acceptability PAR limit.

Assuming the components associated with both the Am/Cm and Pu/Gd streams have the same effect on durability as $Li_2O$, the bounding $\Delta G_P$ value for Case #6 is calculated to be -9.548 kcal/mol which is still well above the -12.7178 kcal/mol limit. This case represents a "worse case" scenario given the Tank 7 sand is not transferred and assuming the additions of all components associated with the Am/Cm and Pu/Gd streams impact durability as negatively as $Li_2O$. This latter statement is based on the nominal waste stream compositions not accounting for any compositional variation in the sludge.

**Table 32.** Nominal Glass Compositions for Frit 320-Based Blending Scenarios at Maximum Allowable WL (in wt%, oxide basis)

| | **Case #1 (baseline)** | **Case #2** | **Case #3** | **Case #4** | **Case #5** | **Case #6** |
|---|---|---|---|---|---|---|
| | **SB3 (including the Tank 51 heel) with Tank 7 sand** | **SB3 baseline with Pu/Gd** | **SB3 baseline with Am/Cm** | **SB3 baseline with Pu/Gd and Am/Cm** | **SB3 with Tank 51 Heel** | **SB3 with Tank 51 Heel, Pu/Gd, and Am/Cm** |
| Max WL | 37.5 | 37.5 | 37.5 | 37.5 | 37.0 | 37.0 |
| Oxide | | | | | | |
| Ag | 2.55E-04 | 2.55E-04 | 2.57E-04 | 2.57E-04 | 2.55E-04 | 2.56E-04 |
| $Al_2O_3$ | 6.861 | 6.856 | 6.794 | 6.789 | 6.856 | 6.782 |
| $AmO_2$ | 5.44E-04 | 5.44E-04 | 1.61E-03 | 1.61E-03 | 5.44E-04 | 1.60E-03 |
| $B_2O_3$ | 5.000 | 5.0000 | 5.000 | 5.000 | 5.0400 | 5.040 |
| BaO | 0.095 | 0.095 | 0.094 | 0.094 | 0.095 | 0.094 |
| CaO | 1.365 | 1.364 | 1.351 | 1.350 | 1.364 | 1.349 |
| $Ce_2O_3$ | 0.132 | 0.132 | 0.133 | 0.133 | 0.132 | 0.133 |
| $Cm_2O_3$ | 3.74E-09 | 3.74E-09 | 2.43E-04 | 2.43E-04 | 3.74E-09 | 2.42E-04 |
| $Cr_2O_3$ | 0.140 | 0.140 | 0.140 | 0.140 | 0.140 | 0.140 |
| CuO | 0.075 | 0.075 | 0.074 | 0.074 | 0.075 | 0.074 |
| $Eu_2O_3$ | 1.76E-03 | 1.76E-03 | 1.76E-05 | 1.76E-05 | 4.76E-03 | 1.75E-05 |
| $Fe_2O_3$ | 15.255 | 15.243 | 15.113 | 15.101 | 15.243 | 15.088 |
| $Gd_2O_3$ | 7.39E-04 | 0.019 | 1.35E-03 | 0.019 | 7.40E-04 | 0.019 |
| $K_2O$ | 0.163 | 0.163 | 0.162 | 0.161 | 0.163 | 0.161 |
| $La_2O_3$ | 0.076 | 0.076 | 0.077 | 0.077 | 0.076 | 0.077 |
| $Li_2O$ | 5.000 | 5.000 | 5.001 | 5.001 | 5.040 | 5.041 |
| MgO | 0.072 | 0.071 | 0.071 | 0.071 | 0.071 | 0.071 |
| MnO | 2.721 | 2.719 | 2.693 | 2.691 | 2.719 | 2.689 |
| $MoO_3$ | 0.000 | 0.000 | 8.14E-05 | 8.15E-05 | 0.0000 | 8.14E-05 |
| $Na_2O$ | 11.531 | 11.528 | 11.489 | 11.486 | 11.588 | 11.542 |
| $Nd_2O_3$ | 0.254 | 0.254 | 0.256 | 0.256 | 0.254 | 0.255 |
| NiO | 0.610 | 0.609 | 0.605 | 0.604 | 0.610 | 0.604 |
| PbO | 0.114 | 0.114 | 0.113 | 0.113 | 0.114 | 0.113 |
| Pd | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 |
| $Pr_2O_3$ | 0.070 | 0.069 | 0.070 | 0.070 | 0.069 | 0.070 |
| $PuO_2$ | 7.85E-03 | 0.020 | 7.95E-03 | 0.020 | 7.85E-03 | 0.020 |
| $RuO_2$ | 0.105 | 0.105 | 0.104 | 0.104 | 0.105 | 0.104 |
| Rh | 0.030 | 0.030 | 0.029 | 0.029 | 0.030 | 0.029 |
| $SiO_2$ | 46.265 | 46.264 | 46.255 | 46.254 | 46.154 | 46.148 |
| $Sm_2O_3$ | 0.038 | 0.038 | 0.038 | 0.038 | 0.038 | 0.038 |
| $ThO_2$ | 0.054 | 0.054 | 0.054 | 0.054 | 0.054 | 0.054 |
| $TiO_2$ | 0.000 | 0.000 | 3.95E-05 | 3.88E-05 | 0.000 | 3.88E-05 |
| $U_3O_8$ | 3.513 | 3.510 | 3.824 | 3.821 | 3.510 | 3.817 |
| ZnO | 0.156 | 0.156 | 0.154 | 0.154 | 0.156 | 0.154 |
| $ZrO_2$ | 0.282 | 0.282 | 0.279 | 0.279 | 0.282 | 0.278 |
| Total | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 |

# 7.0 Assessments of the Potential Impacts on DWPF Processing

Although the effects of adding the Am/Cm and/or Pu/Gd waste streams to SB3 are of no practical concern regarding property predictions (see Sections 5.0 and 6.0), these waste streams could impact DWPF processing of SB3 with respect to increases in

(1) Chemical hydrogen production in the SRAT and SME

(2) Radiolytic hydrogen production in the Tank Farm and the DWPF

(3) Neutron dose rate from the SB3 glasses

(4) Alpha radiation effects on the SB3 glasses.

(5) Watts per canister of glass produced.

In this section, these potential impacts will be addressed for blending cases #1, #2, and #4. If the other blends materialize in reality, the potential impacts of the above on them will be very similar to those considered here. For example, the impacts on Case #5 will be essentially identical to those on Case #1, and potential impacts on Cases #3 and #6 will be very similar to those on Case #4. For the impacts on the glass (Items 3 and 5 above), the impacts have been assessed on the glass with the highest WL, hence the highest radiation dose rate to the glass, to assess the maximum impact. This glass is the Frit 320 glass with 37.5% WL. This is the highest WL that will still make an acceptable glass based on the PAR criterion used in this assessment.

## 7.1 Potential Impact on Chemical Hydrogen Production in the SRAT and SME

In the SRAT and SME processes in the DWPF, $H_2$ is produced by the noble-metal-catalyzed decomposition of formic acid. The higher the noble-metal concentration, the more $H_2$ produced. Noble metals are present in the SB3 baseline sludge from the fission of $^{235}U$ in the SRS reactors when they were operating. Noble metals are also present in the Am/Cm waste stream from neutron-induced fission of $^{239}Pu$ when it was irradiated in the reactors to make Am and Cm. Noble metals are not in the Pu/Gd waste stream. Based on the compositions presented in Table 2, the concentrations of noble metals in sludge compositions for Blends #1, #2, and #4 have been calculated on an elemental basis in the total calcined sludge oxides. These are presented in Table 33. The noble-metal concentrations measured in SB2 (Fellinger et al. [2002]) are presented for comparison. It can be seen that the noble metals concentrations in the three blending scenarios change only slightly; thus, a large change in $H_2$ production is not expected. The concentrations for all the noble metals except Ag actually decrease (through dilution) due to adding Pu/Gd from that waste stream and adding U from the Am/Cm stream. The concentration for Ag increases in Case #4 because the Am/Cm waste stream contains nominally 2× more Ag than the WCS predicts in SB3 baseline (see Table 1). Based on the WCS, the concentrations of Pd, Rh, and Ru will be higher in SB3 than in SB2. On this basis, more $H_2$ may be produced when SB3 is processed in the SRAT and SME compared to that produced during the processing of SB2.

**Table 33.** Calculated Noble Metal Concentrations for Three Blending Scenarios of Sludge Batch 3 (SB3) and Measured Concentrations in Sludge Batch 2 (SB2) (in elemental mass % in total calcined oxides)

| Element | Case #1 | Case # 2 | Case # 4 | SB2 Sludge[(a)] |
|---|---|---|---|---|
| Ag | 6.34E-04 | 6.33E-04 | 6.38E-04 | 1.24E-04 |
| Pd | 3.23E-02 | 3.23E-02 | 3.19E-02 | 1.04E-03 |
| Rh | 5.98E-02 | 5.98E-02 | 5.91E-02 | 9.10E-03 |
| Ru | 2.14E-01 | 2.14E-01 | 2.12E-01 | 3.89E-02 |
| (a) See Fellinger et al. (2002). | | | | |

## 7.2 Potential Impact on Radiolytic Hydrogen Production in the Tank Farm and the DWPF

Hydrogen is produced continuously in the SRS Tank Farm and the DWPF by the effect of alpha, beta, and gamma radiation on the water in the waste. Adding the Pu/Gd and the Am/Cm waste streams to SB3 will increase the radiolytic production of $H_2$ from SB3 because these waste streams will increase the amount of radiation in the blends. This section presents an estimate of that increase.

The radiolytic rate of $H_2$ production is directly proportional to the rate of energy absorbed by the water and the G value for $H_2$ production. The maximum rate of energy absorption for the water can be calculated from the total Curies of each radionuclide present, the decay energies (watts per Curie) associated with the major radiation emitted by that radionuclide, the G value for production of $H_2$, and the assumption that all the radiation is absorbed by the water. The G value is an experimentally determined number and is dependent on the type of radiation. For beta and gamma radiation, the maximum G value for $H_2$ production from water is 0.45 molecules produced for every 100 eV of energy absorbed (Anbar 1968). For alpha radiation, the value is 1.6 molecules per 100 eV (Anbar 1968). In Appendix D, the total Curies for each of the principle radionuclides in each the waste streams are presented. Elder estimated the Curies for the SB3 baseline from the WCS (Elder 2001). The isotopic composition of the Pu in the Pu/Gd stream was 0.5% $^{238}$Pu, 89.9% $^{239}$Pu, 8.7%$^{240}$Pu, 0.6%$^{241}$Pu, and 0.2%$^{242}$Pu.[(a)] The total Curies in the Am/Cm stream were calculated from the results published by Peters (2002). The total Curies for each of the principle radionuclides in SB2 are also presented in Appendix D. These are taken from measured concentrations in SB2 (Fellinger et al. 2002) and using 3.73E05 kg of calcined oxides in SB2.[(b)] Based on the total decay energy for each radionuclide, the dose rate from each major radionuclide in each waste stream was then calculated (see Appendix D). The product of the energy disposition (or dose rate) for each radionuclide in each waste stream times the G value for $H_2$ production appropriate for that radionuclide were then calculated (see Appendix D). The total values for these products were then calculated for each waste stream. These products can then be converted to pounds of $H_2$ produced per hour per batch of sludge processed (see Appendix D). It was assumed that each batch produces eight canisters of glass and that the total amount of canisters produced was 553 (see Section 7.5). The rates of $H_2$ produced for each of the three blending cases and for SB2 are presented in Table 34. Note that Case 4 has the highest rate. The bottom row of Table 34 presents the rates for maximum $H_2$ production relative to that for the

(a) Elder and Jilani, Personal Communication by e-mail, dated 4/11/02.
(b) J. W. Ray, "HLW System Plan, Rev.13," Private Communication, 4/25/02.

baseline Case #1. Note that adding the Pu/Gd waste stream has little impact on the rate of $H_2$ production while adding the Am/Cm stream increases the rate by a factor of ~ 1.7. This large increase is due to the large amount of $^{244}Cm$ added from the Am/Cm stream compared to that predicted to be in SB3 baseline. (The Pu/Gd waste stream contains no $^{244}Cm$.) The maximum rate of radiolytic $H_2$ production from SB2, which the DWPF is currently processing, is ~ 15× less than that for Case #1 and ~ 25× less than that for Case #4. This means that more radiolytic $H_2$ would be produced when either case of SB3 is processed. These rates can be compared to the maximum rates allowed in the DWPF processing vessels, the SRAT and SME. For these vessels, the maximum rates are 0.65 and 0.22 lb/h, respectively, per batch (Rios-Armstrong 2000). The smaller rate (0.22 lb/h) is nominally 400× greater than the largest radiolytic rate in Table 34; thus, radiolytic $H_2$ production will not be a significant factor during processing of any of the blending scenarios of SB3.

**Table 34.** Estimated Rates of Maximum Radiolytic $H_2$ Production During Processing a Batch of the Three Blending Scenarios of Sludge Batch 3 (SB3) and of SB2 and Relative Rates Compared to that for the Baseline Case #1[(a)]

| Element | Case #1 | Case # 2 | Case # 4 | SB2 |
|---|---|---|---|---|
| Rate (lbs $H_2$ per hour) | 3.46E-04 | 3.66E-04 | 5.83E-04 | 2.31E-05 |
| Rate Relative to Case #1 | 1.00 | 1.06 | 1.68 | 0.067 |
| (a) Based on processing 8 canisters per batch and a total of 553 canisters for Case #4 for SB3 (See Section 7.5). | | | | |

## 7.3 Potential Impact on Neutron Dose Rate from a Canister of SB3 DWPF Glass

Neutrons are emitted from DWPF glass as a result of alpha-induced neutron-producing reactions in the glass and from spontaneous fission of certain actinide radionuclides in the glass. Both of these phenomena have been addressed for the DWPF Design Basis (DB) glass (Baxter 1988). The main radionuclides that cause the alpha-induced neutron-producing reactions are $^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Am$, and $^{244}Cm$. The main contributors to neutrons from spontaneous fission are $^{238}Pu$ and $^{244}Cm$. Based on the composition of the DB glass, a total neutron dose rate at the surface of a canister of this glass has been calculated to be 420 mrem/h (Baxter 1988). The isotopic content of the Case #1, Case #2, and Case #4 glasses with 37.5 wt% WL have been compared to the isotopic content of the DB glass (see Appendix E). Knowing the Curie concentration of the radionuclides and their efficiencies to produce neutrons from either alpha-induced neutron-producing reactions or spontaneous fission (taken from Baxter [1988]), the neutron dose rate at the surface of a canister of each of the SB3 glasses was calculated. Results are shown in Table 35. This method was also applied to estimate the neutron dose rate from SB2 glass (see Appendix E), and this estimate appears in Table 35 along with the value published by Baxter (1988) for the DB glass. The neutron rates relative to that from the Case #1 glass are presented in the bottom row of the Table. Adding the Pu/Gd stream increases the rate by 2.4× and the Am/Cm stream by ~ 20×. In fact, the neutron rate from the Case #4 glass is only 1.6× lower than that for the DB glass. Adding the Am/Cm stream makes a significant increase in the neutron dose rate from the glass. The Case #2 glass has a dose rate similar to that for glass containing SB3 with the Pu/Gd added.

**Table 35.** Calculated Neutron Dose Rate for Three Blending Scenarios of Sludge Batch 3 (SB3)/Frit 320 Glass at 37.5 Waste Percent Loading, for Sludge Batch 2 (SB2) Glass, and for DB Glass and Relative Rates Compared to that for the Baseline Case #1 (in mrem/h at canister surface)

| Dose Rate | Case #1 | Case # 2 | Case # 4 | SB2 Glass | DB Glass[a] |
|---|---|---|---|---|---|
| Mrem/h | 13 | 31 | 259 | 29 | 420 |
| Rate Rel. to #1 | 1.00 | 2.38 | 19.9 | 2.23 | 32.3 |
| (a) See Baxter (1988). | | | | | |

### 7.4 Potential Impact on Alpha Radiation Effects on SB3 Glass

Alpha radiation has the potential to affect glass properties over thousands of years because it causes atomic displacements in the glass as well as produces helium atoms that either diffuse from the glass or remain at vacancies in the glass (Weber et al. 1997). Alpha radiation also causes ionizations in the glass as well as does the gamma and beta radiation. However, these ionizations are not as significant in possibly affecting the properties of the glass (Weber et al. 1997). Adding the Am/Cm and Pu/Gd waste streams to the SB3 glass will increase the amount of alpha radiation that interacts with the glass and the amount of He produced. Helium is produced as the alpha particle slows down in the glass and eventually captures two electrons. There have been many studies of the effect of alpha radiation from HLW on borosilicate glasses to very large doses (Weber et al. 1997). Borosilicate glasses doped with $^{244}$Cm have experienced doses of ~ 14E24 alphas per cubic meter without any deleterious effects, including He accumulation (Matzke and Vernaz 1993; Matzke 1997). Based on the isotopic content of the 37.5 wt% SB3 glasses, we have calculated the alpha dose (see Appendix F) that the SB3 glasses will experience out to 1M years. Results are shown in Table 36. Note that adding the Pu/Gd stream increases the dose by nominally 2.3× throughout the million years. Adding the Am/Cm stream increases the dose more at times less than 1000 years, but does not have a significant effect over adding the Pu/Gd stream at longer times. The highest million-year dose is 1.3E+24 alpha per cubic meter. This is ~ 10× less than that cited above; thus, adding the two additional waste streams to SB3 is not expected to have an impact on the radiation damage of the glass.

**Table 36.** Calculated Alpha Dose for Three Blending Scenarios of Sludge Batch 3 (SB3)/Frit 320 Glass at 37.5 wt% WL and Relative Doses Compared to Case #1 (presented in parentheses) (in alphas/cubic meter glass)

| Time, Years | 1.0E+01 | 1.0E+02 | 1.0E+03 | 1.0E+04 | 1.0E+06 |
|---|---|---|---|---|---|
| Case #1 | 1.04E+21 | 8.07E+21 | 3.09E+22 | 1.63E+23 | 4.96E+23 |
| Case #2 | 2.52E+21(2.4) | 1.94E+22(2.4) | 7.15E+22(2.3) | 3.77E+23(2.3) | 1.19E+24(2.4) |
| Case #4 | 6.94E+21(6.7) | 3.36E+22(4.2) | 9.23E+22(3.0) | 4.27E+23(2.6) | 1.26E+24(2.5) |

### 7.5 Potential Impact on Canister Wattage

Adding the Pu/Gd and Am/Cm streams to SB3 will increase the wattage per canister of glass because each stream puts additional radionuclides into the glass. The number of canisters of glass resulting from processing each of the blending scenarios and the watts per canister of glass have been calculated and are presented in Table 37. Details of the calculation are presented in Appendix G. This calculation assumes that the nominal weight of glass in each canister is 3900 pounds. Note that adding the Pu/Gd stream only adds one additional canister to process SB3 and

very little impact on the watts per canister. Adding the Am/Cm stream requires adding six more canisters to process SB3. This is because of adding the 9.5 kg of U to decrease the specific activity of the Am/Cm stream. The watts per canister is increased by a factor of 1.3, primarily due to the $^{244}Cm$. The final wattage of 63watts per canister is below the DB limit of 690 watts/canister (Baxter 1988).

**Table 37.** Calculated Number of Canisters of Glass and the Watts per Canister Resulting from Processing the Three Blending Scenarios of Sludge Batch 3 into (SB3)/Frit 320 Glass at 37.5 Waste Percent Loading

| | **Case #1** | **Case # 2** | **Case # 4** |
|---|---|---|---|
| Canisters Produced | 546 | 547 | 553 |
| Watts per Canister | 52 | 53 | 63 |

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# 8.0 Other Potential Issues

Based on the discussion in Sections 6.0 and 7.0, the impact of adding the Am/Cm and/or the Pu/Gd streams to SB3 on predicted properties is of minimal practical concern. Although assessments of property predictions are relatively easy and provide insight, there are other considerations that should be mentioned. These effects do not impact the predicted impacts on glass quality and/or processing (or the conclusion in this report) and, therefore, were not fully addressed under the auspices of the pertinent technical assistance request (TAR) (Patel 2002).

(1) Coal—although not associated with adding either the Am/Cm or Pu/Gd waste streams, ~ 1 to 2 wt% coal is reportedly associated with SB3. This organic poses potential processing issues. Assuming that the coal is insoluble and could be inconsistent in terms of its incorporation into the feed and/or the glass pool, the unpredictable nature or potential impact on glass REDOX may be an issue. Given the high concentration of noble metals and higher WL potentials (given implementation of the new $T_L$ model and a sludge-only frit), issues associated with metal sulfide formation, foaming, and/or melt rate may be impacted because of fluctuations in REDOX. Based on the analysis shown in Section 7.0 of this report, the noble-metals concentration is expected to be ~ 6× of that currently being processed in DWPF. Given the increased noble-metals concentration and the potential for major REDOX shifts due to the unpredictability of the coal, the use of any REDOX correlation should be re-evaluated and adjusted if necessary. The use of alternative REDOX strategies may need to be developed before processing SB3. Predicting the impact of REDOX control on melt rate (foam production) is not currently available via modeling.

(2) Cerium—Table 2 shows that there is a small relative increase in $Ce_2O_3$ with the addition of the Am/Cm waste stream. With the nominal sludge containing 0.355 wt% for Case #4, the glass will contain ~ 0.13 wt% $Ce_2O_3$ (based on a maximum WL of 37.5%). Although these concentrations appear relatively small, the thermal reduction of Ce can liberate extensive concentrations of oxygen. This phenomenon was observed in the development of the 12.7-cm (5-in.) Cylindrical Induction Melter (CIM) as the thermal reduction of cerium at elevated temperatures (> 1110°C) caused a major volume expansion. The volume expansion had a major impact on melt rates and resulted in the generation of “work arounds” to avoid its formation. Note, however, that the potential for the excess oxygen that may be liberated via cerium may be negligible compared to the off-gas issues associated with decomposition and/or REDOX reactions.

(3) Primary phase fields—During the development of the 12.7-cm (5-in.) CIM for the Am/Cm program, glass-formulation efforts were focused on the use of a lanthanide-borosilicate based glass to immobilize Am and Cm (Peeler et al. 1999). In this development effort, the primary phase field (with respect to crystallization and/or $T_L$) was found to be rare-earth silicates, alumino-silicates, or alumina, depending upon the frit composition and WL of the glass. Based on the concentration levels of the Am/Cm and/or Pu/Gd streams in SB3 (either individually [Cases #2 and #3] or coupled [Case #4]), there is no reason to believe that a shift in the primary phase would occur rendering the new $T_L$ model invalid. More specifically, it is not anticipated that the primary phase will shift to a lanthanide-based primary phase as observed when considering immobilization of Am/Cm alone (Peeler et al. 1999). Based on the expected concentrations of $Fe_2O_3$, NiO, and $Cr_2O_3$, the primary phase field should remain in the spinel–clinopyroxene phase fields.

(4) Anions—Anion concentrations (e.g., Cl, F, $PO_4$, $SO_4$) were not reported by Elder (2001 or Appendix A) or by Peters (2002). Therefore, this study did not assess the impacts of these

components. Given that the implementations of the new $T_L$ model and Frit 320 provide the opportunity to target relatively high WLs, a comparison of the anion concentrations at these higher WLs should be made relative to their single-component limits to ensure that they will not be exceeded.

(5) Oxalate—The 241-F and H Tank Farms contain an estimated 764,000 pounds of sodium oxalate, of which 660,000 pounds may be located in Tank 7.[(a)] The impact of the sodium oxalate on glass properties (such as durability), REDOX control, and processability have not been assessed in this study.

(a) Inter-Office Memorandum, A.Q. Goslen, "Estimated Sodium Oxalate in the Tank Farm", March 22, 1984.

# 9.0 Summary

Currently, DWPF is processing Sludge Batch 2 (SB2) and is projecting to initiate processing of SB3 in the spring of 2004 (WSRC 2001). In addition, the Savannah River HLW Division proposes to transfer existing excess Pu and Am/Cm materials through the Liquid Radioactive Waste Handling Facility directly to the ESPF (Elder 2001). Current blending strategies have both the Pu and Am/Cm materials being vitrified within SB3 in the DWPF.

Before committing these additional materials to ESPF and ultimately to DWPF, the SRTC was requested to assess the potential impacts on SB3 processing and product quality with the additions of both Am/Cm (Patel 2002) and Pu/Gd (Jilani 2002). Current blending strategies assume that both the Am/Cm and Pu/Gd waste streams will be blended with SB3. In case this strategy is not realized because of unforeseen issues, assessments were made in this study covering six potential blending scenarios. These scenarios will provide the basis for evaluating the impact of individual or multiple waste streams to SB3. These scenarios include:

(1) Case #1 (Baseline): SB3 (including the Tank 51 heel and sand associated with Tank 7)
(2) Case #2: SB3 baseline with only the Pu/Gd addition
(3) Case #3: SB3 baseline with only the Am/Cm addition
(4) Case #4: SB3 baseline with both Am/Cm and Pu/Gd additions
(5) Case #5: SB3 (including the Tank 51 heel—excluding Tank 7 sand)
(6) Case #6: SB3 (including the Tank 51 heel—excluding Tank 7 sand) with both Am/Cm and Pu/Gd additions.

Nominal sludge compositions and three existing frits were used as the basis for these assessments. It is assumed that the individual waste streams or sludges are essentially "compositional centroids." The blending calculations assume that individual streams will be evenly distributed or uniformly blended, resulting in a "constant" feed to the melter (once frit additions are made) and were based on weighted mass averages. More specifically, it is assumed that the individual waste streams or sludges will not constitute a "spike" in composition during processing of a limited portion of SB3. Note that the nominal compositions (and thus the assessments based upon them) do not account for any compositional sludge variation. The assessments discussed in this report were based solely on property predictions generated by PCCS models. Property measurements were not performed (experimentally) as part of this study.

However, note that two $\Delta G_P$ calculations were used. The first uses the glass durability/composition ($\Delta G_P$) model currently implemented in PCCS and used by DWPF. That model uses specific $\Delta G_{P,i}$ values reported by Jantzen et al. (1995) (typically for elements whose oxide concentrations are present at > 0.5 wt% in glass) to predict the $\Delta G_P$ for a specific SME composition which, before processing, is then compared to three SME acceptability criteria, the most restrictive of which is -12.7178 kcal/mol.

The second glass-durability calculation (referred to as the modified $\Delta G_P^*$) used in this study builds upon the PCCS version in which $\Delta G_{P,i}$ values for additional minor components tracked in this study (but either not included in the current PCCS prediction or not measured by DWPF but are associated with the prediction). For those oxides tracked in this study that are currently not included in the PCCS prediction (e.g. $AmO_2$, $Ce_2O_3$, $MoO_3$, SrO, and $PuO_2$) or not currently

measured by DWPF (e.g., $Cs_2O$, $La_2O_3$, and $ThO_2$), the appropriate $\Delta G_{P,i}$ values reported by Jantzen et al. (1995) were added to the PCCS prediction to account for the contribution. For those oxides (e.g., $Cm_2O_3$, $Eu_2O_3$, $Gd_2O_3$, $Pr_2O_3$, and $Sm_2O_3$) tracked in this study that are neither included in the PCCS prediction nor Jantzen et al. (1995), the authors used $\Delta G_{P,i}$ values associated with oxides that are thought to have a similar effect on the durability response.

Predicted glass properties and projected operating windows (i.e., WL ranges) for various blending scenarios were discussed. Comparisons were made among the various scenarios to provide a measure of the impact each waste stream has on glass quality relative to the baseline case. Glass quality is defined not only by the potential impact to durability but also by predictions regarding processability (e.g., $\eta_{1150°C}$ and $T_L$). Current PCCS (Brown and Postles 1996) property predictions (including the current $T_L$ model and viscosity models (Jantzen 1991) and the new $T_L$ model [Brown et al. 2001], which should be implemented when SB3 is processed) were used as the basis for this assessment. Note that direct comparisons can be made but should be used with caution as the WL basis may not be consistent.

The primary objective of this task was to assess the impacts of Am/Cm and/or Pu/Gd on the predicted properties of interest. A general statement can be made regarding the addition of individual and/or combined streams to SB3. These waste streams have no practical impact on predicted properties. By practical, the authors mean that although predicted properties may change for adding a particular waste stream or waste-stream combinations, the relative difference of those predictions are not of practical concern (and are perhaps not discernable if measured).

For each of the blending cases considered, the major oxides (i.e., defined in this study as those exceeding 0.5 wt% in sludge—not glass) include $Al_2O_3$, CaO, $Fe_2O_3$, MnO, $Na_2O$, $Nd_2O_3$, NiO, $SiO_2$, $U_3O_8$, and $ZrO_2$. Note that all of the major oxides are currently associated with the PCCS $\Delta G_P$ prediction. Plodinec et al. (1995) indicated that trace components (elements whose oxides are present in the glass at concentrations less than 0.5 wt%) do not have a significant impact on glass durability. Based on the projected concentrations of the added components from the $PuO_2$ and $Gd_2O_3$ waste stream to the baseline case and the conclusions drawn by Plodinec et al. (1995), one would anticipate any change to predicted properties to be a function of the minimal dilution of those oxide components forming the basis for the model predictions and/or adding components that were not associated with the baseline case (that are accounted for by the PCCS models currently used by DWPF). Regardless, changes to predictions are expected (and have been shown) to be minimal given the low total mass of this stream.

Based on model predictions, adding the Pu/Gd or the Am/Cm secondary waste streams (either individually or combined) to SB3 does not have a significant impact on glass quality or processability. Based on these assessments, there appears to be no need to expand the current PCCS $\Delta G_P$ prediction for the minor components that will be added to SB3 with the addition of the Am/Cm and Pu/Gd waste streams. In fact, the use of the current $\Delta G_P$ model is conservative as the addition each of these streams is predicted to increase durability—although of no practical differences. Again, it should be mentioned that the conclusions drawn from this assessment are based solely on the nominal sludge cases and do not account for any compositional variation in sludge.

Although the effects of adding the Am/Cm and/or Pu/Gd waste streams to SB3 are of no practical concern regarding property predictions (see Sections 5.0 and 6.0), these waste streams could impact DWPF processing with respect to increases in:

(1) Chemical hydrogen production in the SRAT and SME

(2) Radiolytic hydrogen production in the Tank Farm and the DWPF

(3) Neutron dose rate from the SB3 glasses

(4) Alpha radiation effects on the SB3 glasses.

(5) Watts per canister of glass produced.

The first two potential impacts were assessed for the sludge for blending Cases #1, #2, and #4. The last three were assessed using the maximum WL allowable for the Frit 320-based glass (37.5 wt% WL) for Cases #1, #2, and #4.

With respect to $H_2$ production in the SRAT and SME, a large change is not expected because the concentrations of noble metals remained essentially constant for the three blending scenarios. Further, based on the WCS, the concentrations of Pd, Rh, and Ru will be higher in SB3 than in SB2. On this basis, more $H_2$ may be produced in the SRAT and SME when SB3 is processed compared to SB2.

For Item 2 above, the rates for maximum $H_2$ production (radiolytic hydrogen production in the SRAT and SME processing vessels DWPF) were calculated and compared to that for the baseline Case #1 and to that calculated for SB2. It was determined that adding the Pu/Gd waste stream has little impact on the rate of $H_2$ production while adding the Am/Cm stream increases the rate by a factor of ~ 1.7. This large increase is primarily due to the large amount of total Curies of $^{244}Cm$ added from the Am/Cm stream compared to that predicted to be in SB3 baseline. The rates calculated are still well below (~ 400×) the lower of the maximum rates (Rios-Armstrong 2000) that can be tolerated in these vessels.

For Item 3 above, neutron dose rates were calculated by comparing the radionuclide contents of the SB3 glasses to the Design Based DWPF Glass (Baxter 1988). Adding the Pu/Gd stream to SB3 glass increases the neutron dose rate from 13 to 31 mrem/h while adding the Am/Cm stream increases it to 259 mrem/h. This latter value is still less than 420 mrem/h, which is the rate published for the DWPF DB glass.

To assess Item 4, the calculated alpha doses to the SB3 glasses were calculated out to 1M years. Adding the Pu/Gd stream increased the million-year dose by a factor of nominally 2.3×. Adding the Cm/Am stream had a very little effect on this dose. The million-year dose was 1.3E+24 alphas per cubic meter of glass. This is ~ 10× less than the maximum alpha doses to which borosilicate glass have been exposed with no deleterious effect on the glass.

To vitrify SB3 without adding the Pu/Gd or Am/Cm waste streams would require 546 canisters, assuming 3900 lbs/canister. Adding the Pu/Gd stream added only one additional canister while adding the Am/Cm stream increased the total cans to 553. This was primarily due to the U in that stream. The watts/canister were 52, 53, and 63 for the three respective blending scenarios—still well below the DB limit of 690 watts/canister (Baxter 1988).

Based solely on this assessment, there is no obvious reason why both Am/Cm and Pu/Gd waste streams could not be added to SB3.

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# Appendix A

## Personal Communication with H.H. Elder
## (SB3 Compositional Estimate without Tank 7 sand, Am/Cm, or Pu/Gd)

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**Herbert Elder**

To: Ned Bibler/WSRC/Srs@Srs
cc: Lawrence Lasher/BSRI/Srs@Srs, Richard Edwards/WSRC/Srs@Srs
Subject: Ned_SB3.xls

03/25/02 06:38 AM

No changes, I just added another case. See you at 0930 today.

Ned

 - Ned_SB3.xls

## Applicable portion of email attachment: Ned_SB3.xls

**This was run without the Am/Cm, which adds uranium and Pu, which adds Gd.**

Otherwise the ratio of each element to Fe stays the same. The Am/Cm activity was used but not the compounds, except for uranium poison, which was included.

| | | | | | heel radionuclide ratios | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| total slurry mass | 2424887 | | | Sludge | sludge | 6.385799 | | | | |
| total slurry vol | 566200 | kg | | Elemental | supernate | 0.605806 | | | | |
| Al | wt% | 3.521669 | Al | 9.89233 | # of batches | Tank | %Sludge in batch | %Al removed | Batch Number = 3 | |
| B | wt% | 1.59995 | 0 | 0 | 1 | 7 | 1 | 0 | Change Batch Number, DF | |
| Ba | wt% | 0.082426 | 0 | 0.231534 | 0 | 18 | 1 | 0 | | |
| Ca | wt% | 0.946596 | Ca | 2.658978 | 0 | 0 | 0 | 0 | | |
| Ce | wt% | 0.109625 | 0 | 0.307936 | 0 | 0 | 0 | 0 | | |
| Cr | wt% | 0.093121 | Cr | 0.261575 | 0 | 0 | 0 | 0 | | |
| Cs | wt% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Cu | wt% | 0.058235 | Cu | 0.163582 | 0 | 0 | 0 | 0 | | |
| Fe | wt% | 10.34984 | Fe | 29.07258 | 0 | 0 | 0 | 0 | | |
| K | wt% | 0.131446 | K | 0.36923 | WashEnd = 0.5 M $Na^+$ | | | | | |
| La | wt% | 0.063093 | 0 | 0.177227 | | | | | | |
| Li | wt% | 2.393496 | Li | 0 | NaOH conc= 19 M (for Al diss.) | | | | | |
| Mg | wt% | 0.041838 | Mg | 0.117521 | | | | | | |
| Mn | wt% | 2.044703 | Mn | 5.743547 | Heel Level = 40 inches | | | 37322.41 | | |
| Mo | wt% | 0 | 0 | 0 | | | | | | |
| Na | wt% | 8.633908 | Na | 8.148794 | Final solids= 0.16 wt% | | | | | |
| Nb | wt% | 0 | 0 | 0 | | | | | | |
| Ni | wt% | 0.464911 | Ni | 1.30593 | Heel Fraction= 0.4 0 | | | | | |
| Pb | wt% | 0.102492 | 0 | 0.287898 | | | | | | |
| Si | wt% | 22.03469 | Si | 1.012103 | Last Batch # 10 0 | | | | | |
| Th | wt% | 0.046281 | Th | 0.130003 | | | | | | |
| Ti | wt% | 0 | Ti | 0 | | | | | | |
| U | wt% | 2.890386 | U | 8.119062 | | | | | | |
| Y | wt% | 0 | 0 | 0 | | | | | | |
| Zn | wt% | 0.121459 | Zn | 0.341176 | | | | | | |
| Zr | wt% | 0.209272 | Zr | 0.587843 | | | | | | |

**Applicable portion of email attachment: Ned_SB3.xls (Continued)**

| Batch | 3 |
|---|---|

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of washes = 5 | | Tank | %Sludge in batch | %Al removed | kg/batch | | | | | | |
| Water to TF (gal) = 3205799 | | 7 | 1 | 0 | 412795.2 | | | | | | |
| Na conc= 0.5 | | 18 | 1 | 0 | 22964.65 | | | | | | |
| sludge wt% solids pre final decant = 8.453151 | | 0 | 0 | 0 | 0 | | | | | | |
| sludge glass mass(kg)= 353216.8 | | 0 | 0 | 0 | 0 | | | | | | |
| # of cans = 720.0491 | | 0 | 0 | 0 | 0 | | | | | | Kgs |
| NaOH for Al (gal) = 0 | | 0 | 0 | 0 | 0 | PHA Mass for whole | | 0 | | | |
| | | 0 | 0 | 0 | 0 | Fraction | | | | | |
| Safety stuff | % limit | | Loadings, s=sludge, p=pha, f=frit | | | Cans | | | | | |
| Inhalation dose (rem/gal) = 48688952 | 0.143625 | | s | p | f | cst | $TiO_2$ | 0 | | | |
| g shielding (mRem/h/gal) = 224.7281 | 0.093637 | | 0.284 | 0 | 0.716 | 0 | Cu | 0.000465 | YES | | |
| Watts/canister = 39.53127 | 0.085938 | | Frit 200 | | | tio2 | | | TRUE | | |
| | | | | | | 0 | | | | | |
| wt% Hg (dry) = 0.000672 | | | Heel from Batch 1 | | | | | | | | |
| Target Na molarity = 0.5 | | | 30299.33 kg | | | | | | | | |
| Na wt% dry = 6.272331 | | | WW used (gal) = 1768765 | | | space gain factor = 0.964031 | | | | | |
| Sludge mass to DWPF (kg) = 459839.9 | | | Transfer water (gal) = 1437034 | | | | | | | | |
| $Al(OH)_3$ dissolved(kg) = 0 | | | | | | | | | | | |

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# Appendix B

## Calculations of Noble Metals, Rare Earths, and Actinides Associated with SB3 (but not tracked by WCSystems) Based on $^{139}La$ Concentration, Measured $^{235}U$ Fission Yields, and 353217 kg of Calcined Solids

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| Calculation of Noble Metal Concentrations in SB3 Based on $^{139}$La and $^{235}$U Fission Yields and 353217 KG Calcined Solids | | | | |
|---|---|---|---|---|
| | | | Calcined Sludge | |
| Isotope | Fission Yield (Percent) | Mass | Calc. Conc wt% | KG IN SB3 |
| $^{139}$La | 6.6 | 139 | 1.77E-01 | 625 |
| $^{101}$Ru | 5.1 | 101 | 9.9E-02 | |
| $^{102}$Ru | 4.2 | 102 | 8.3E-02 | |
| $^{104}$Ru | 1.83 | 104 | 3.7E-02 | |
| **Total Ru** | 11.13 | | **2.2E-01** | 773 |
| $^{103}$Rh | 3.1 | 103 | 6.2E-02 | |
| **Total Rh** | | | **6.2E-02** | 218 |
| $^{105}$Pd | 0.95 | 105 | 1.9E-02 | |
| $^{106}$Pd | 0.39 | 106 | 8.0E-03 | |
| $^{107}$Pd | 0.2 | 107 | 4.1E-03 | |
| $^{108}$Pd | 0.07 | 108 | 1.5E-03 | |
| $^{110}$Pd | 0.02 | 110 | 4.2E-04 | |
| **Total Pd** | **1.63** | | **3.3E-02** | 117 |
| **Total $^{109}$Ag** | 0.031 | 109 | 6.5E-04 | 2.3 |

Equation used for the calculations:

$$(wt\%)_i = 0.177(FY_i / FY_{La})X(AM_i/139)$$

where $(wt\%)_i$ = weight percent of isotope i in the calcined sludge
$FY_i$ = measured fission yield for isotope i
$FY_{La}$ = measured fission yield for $^{139}$La = 6.6
$AM_i$ = the atomic mass of isotope i.

Fission yields taken from: General Electric Co., 1996. "Chart of the Nuclides," Fifteenth Edition, San Jose, California.

**Calculation of Rare Earth Fission Product Concentrations in SB3 Including Heel of 51. Based on wt% of $^{139}$La of 0.177 from WCS, $^{235}$U Fission Yields, and 353217 KG Calcined Oxides, Except for La and Ce, These Rare Earths Are Not Tracked by the WCS.**

| Mass # | $^{235}$U FY [a] | wt% Calcined | Element | Isotopic Total kg | | |
|---|---|---|---|---|---|---|
| 133 | 6.69 | | | Based on 353217 kg of Calcined Oxides | | |
| 134 | 6.87 | | Xe | | | |
| 135 | 6.54 | | Cs | | | |
| 136 | 6.32 | | Xe | | | |
| 137 | 6.19 | | Cs | | Element | Total kg |
| 138 | 6.71 | | Ba | | | |
| 139 | 6.4 | 1.77E-01 | La | 625.2 | La | 625.00 |
| 140 | 6.21 | 1.73E-01 | Ce | 611.0 | Ce | 1193.80 |
| 141 | 5.8 | 1.63E-01 | Pr | 574.7 | Pr | 574.73 |
| 142 | 5.84 | 1.65E-01 | Ce | 582.8 | | |
| 143 | 5.95 | 1.69E-01 | Nd | 598.0 | Nd | 2105.40 |
| 144 | 5.5 | 1.58E-01 | Nd | 556.6 | | |
| 145 | 3.93 | 1.13E-01 | Nd | 400.5 | Sm | 313.33 |
| 146 | 3 | 8.71E-02 | Nd | 307.8 | Eu | 17.0 |
| 147 | 2.25 | 6.58E-02 | Sm | 232.4 | Gd | 6.20 |
| 148 | 1.67 | 4.92E-02 | Nd | 173.7 | | |
| 149 | 1.08 | 3.20E-02 | Sm | 113.1 | Tb | 0.15 |
| 150 | 0.653 | 1.95E-02 | Nd | 68.8 | | |
| 151 | 0.417 | 1.25E-02 | Sm | 44.3 | Dy | 0.01 |
| 152 | 0.268 | 8.11E-03 | Sm | 28.6 | | |
| 153 | 0.158 | 4.81E-03 | Eu | 17.0 | Ho | 0.00 |
| 154 | 0.074 | 2.27E-03 | Sm | 8.0 | | |
| 155 | 0.032 | 9.87E-04 | Gd | 3.5 | Er | 0.00 |
| 156 | 0.0149 | 4.62E-04 | Gd | 1.6 | | |
| 157 | 0.0062 | 1.94E-04 | Gd | 0.7 | Tm | 0.00 |
| 158 | 0.0033 | 1.04E-04 | Gd | 0.4 | | |
| 159 | 0.001 | 3.16E-05 | Tb | 0.1 | Yb | 0.00 |
| 160 | 0.0003 | 9.55E-06 | Gd | 0.0 | | |
| 161 | 0.000085 | 2.72E-06 | Dy | 0.0 | Lu | 0.00 |
| 162 | 0.00002 | 6.45E-07 | Dy | 0.0 | | |

**NOTE:** Except for La and Ce, these are rare-earth fission products that are **not** tracked by the WCS. La was used to calculate all the rare earths and Ce. Elder (see Appendix A) provided a value for Ce of 0.308 wt% from the WCS. This value is close to the value calculated for total Ce of 0.338 wt% Ce. Since we are using Fe, Al, etc. from the WCS, this study used the value for Ce of 0.308 wt% from the WCS.

(a) General Electric Co. 1996. "Chart of the Nuclides," Fifteenth Edition, San Jose, California.

The equation on the previous page was used to calculate the concentrations of the specific isotopes. The total concentration for each element was calculated by summing the concentrations of those isotopes contributing to that element.

**Estimated Mass of Pu, Cm and Am in SB3 before adding the Pu/Gd and Am/Cm Waste Streams**

| Estimated Mass of Pu in Sludge Batch 3 Without Added Pu/Gd and Am/Cm | | | | | | |
|---|---|---|---|---|---|---|
| Curies of Pu Isotope | | | | | | |
| | TK 7 | TK 18 | TK 19 | Total | | |
| $^{238}$Pu | 2.43E+04 | 9.35E+02 | 7.58E+01 | 2.53E+04 | | |
| $^{239}$Pu | 3.67E+03 | 1.34E+02 | 1.08E+01 | 3.81E+03 | | |
| $^{240}$Pu | 8.76E+02 | 3.43E+01 | 2.42E+00 | 9.13E+02 | | |
| $^{241}$Pu | 7.72E+03 | 4.87E+02 | 3.41E+02 | 8.55E+03 | | |
| $^{242}$Pu | 2.82E-01 | 4.28E-02 | 4.98E-03 | 3.30E-01 | | |
| | Total Curies | Ci/g | Total Kg | Mass Isotopic Dist. (%) | wt% Pu on a Calcined Basis | Oxide Factor $PuO_2$ |
| $^{238}$Pu | 2.53E+04 | 1.71E+01 | **1.48E+00** | 2.21 | 4.43E-04 | |
| $^{239}$Pu | 3.81E+03 | 6.22E-02 | **6.13E+01** | 91.56 | 1.84E-02 | |
| $^{240}$Pu | 9.13E+02 | 2.28E-01 | **4.00E+00** | 5.98 | 1.20E-03 | |
| $^{241}$Pu | 8.55E+03 | 1.03E+02 | **8.30E-02** | 0.12 | 2.48E-05 | |
| $^{242}$Pu | 3.30E-01 | 3.82E-03 | **8.63E-02** | 0.13 | 2.58E-05 | |
| | Total | | **6.6984E+01** | 100.00 | 1.54E-02 | 1.134 |
| | Total Oxide | | **7.5960E+01** | | | |
| **Estimated Mass of Cm in Sludge Batch 3 Without Added Pu/Gd/Am/Cm** | | | | | | |
| | Total Curies | Ci/g | Total Kg | Mass Isotopic Dist. (%) | Wt% Cm on a Calcined Basis | |
| $^{244}$Cm | 2.67E+00 | 8.09E+01 | **3.30E-05** | 99.95 | 9.88E-09 | |
| $^{245}$Cm | 2.90E-06 | 1.72E-01 | **1.69E-08** | 0.05 | 5.05E-12 | |
| | Total | | **3.30E-05** | 100.00 | 7.61E-09 | |
| (a) Based of 334,000 kg of calcined solids | | | | | | |
| **Estimated Mass of U in Sludge Batch 3 Without Added Pu/Gd/Am/Cm** | | | | | | |
| | Total Curies | Ci/g | Total Kg | Mass Isotopic Dist. % | Wt% U on a Calcined Basis | |
| $^{234}$U | 0.00E+00 | 6.25E-03 | **0.00E+00** | 0.00E+00 | 0.00E+00 | |
| $^{235}$U | 4.02E-01 | 2.16E-06 | **1.86E+02** | 0.66 | 4.29E-02 | |
| $^{236}$U | 0.00E+00 | 6.47E-05 | **0.00E+00** | 0.00E+00 | 0.00E+00 | |
| $^{238}$U | 9.40E+00 | 3.36E-07 | **2.80E+04** | 99.34 | 6.45E+00 | |
| | Total | | **2.82E+04** | 100.00 | | |

| Estimated Mass of Am in Sludge Batch 3 Without Added Pu/Gd/Am/Cm | | | | | |
|---|---|---|---|---|---|
| | **TK 7** | **TK 18** | **TK 19** | **Total** | |
| Ingrown $^{241}$Am | 1.27E+03 | 4.98E+01 | 2.95E+01 | 1.35E+03 | |
| $^{241}$Am | 1.27E+04 | | | 1.27E+04 | |
| $^{242m}$Am | 16.1 | | | 1.61E+01 | |
| **$^{243}$Am is not tracked by the WCS. Its concentration will be estimated using the ratio of $^{241}$Am to $^{243}$Am measured in SB1b(a).** | | | | | |
| | **Total Curies** | **Ci/g** | **Total Kg** | **Oxide Factor** | |
| Ingrown $^{241}$Am | **1.35E+03** | **3.432** | **3.93E-01** | | |
| $^{241}$Am | **1.27E+04** | **3.432** | **3.70E+00** | | |
| $^{242m}$Am | **1.61E+01** | **9.718** | **1.66E-03** | | |
| $^{243}$Am | | | **5.42E-01** | | |
| | Total | | **4.63699E+00** | 1.132 | |
| | Total Oxide | | **5.249E+00** | | |
| **Estimate of $^{243}$Am Concentration** | | | | | |
| **Concentrations of Am isotopes in SB1b (a)** | | | | | |
| | **wt%** | | **$^{243}$Am/$^{241}$Am** | | |
| $^{241}$Am | 1.94E-04 | | 1.46E-01 | | |
| $^{243}$Am | 2.84E-05 | | | | |
| (a) Concentrations published in Fellinger and Bibler (1999). | | | | | |

## Reference

T. L. Fellinger and N.E. Bibler. 1999. *Characterization of and Waste Acceptance Radionuclides to be Reported For DWPF Macro Batch 2 (ESP 215-ESP 221)*, WSRC-RPP-99-00436, Westinghouse Savannah River Company, Aiken, South Carolina.

# Appendix C

# Compositional Estimates for Am/Cm provided by Peters (2002)

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| | | |
|---|---|---|
| Cell Dilution Factor | 1000 | Neutralization with 50 wt% NaOH and 350 g/L U solution |
| Volume in Tank, L | 11400 | |

| Raw Data Corrected for Cell Dilution | | | | | |
|---|---|---|---|---|---|
| Element | ICP-ES[(a)] ppm | g/L | Total Kg | Neutralization Solution | Total Kg After Neutralization |
| Al | 1.83 | 1.83 | 20.862 | | 20.862 |
| Cr | 0.919 | 0.919 | 10.477 | | 10.477 |
| Fe | 9.36 | 9.36 | 106.704 | | 106.704 |
| La | 1.34 | 1.34 | 15.276 | **Use La from ICP-MS** | |
| Li | 0.440 | 0.440 | 5.016 | | 5.016 |
| Mg | 0.013 | 0.013 | 0.148 | | 0.148 |
| Mn | 0.368 | 0.368 | 4.195 | | 4.195 |
| Mo | 0.045 | 0.045 | 0.513 | | 0.513 |
| Na | 1.692 | 1.692 | 19.289 | 6550 | 6569.289 |
| Ni | 0.621 | 0.621 | 7.079 | | 7.079 |
| Si | 1.273 | 1.273 | 14.512 | | 14.512 |
| Ti | 0.021 | 0.021 | 0.239 | | 0.239 |
| V | 0.045 | 0.045 | 0.513 | | 0.513 |
| Zn | 0.045 | 0.045 | 0.513 | | 0.513 |
| Zr | 0.066 | 0.066 | 0.752 | | 0.752 |
| U | 0.833 | 0.833 | 9.496 | 2870 | 2879.496 |
| **ICP-MS ppm(b), Corrected for Cell Dilution** | | | | | |
| | mg/L | Total Kg | | | Total Kg |
| $^{99}$Tc | 2.66 | 0.030 | | | 0.030 |
| Ag | 2.32 | 0.026 | | | 0.023 |
| Mo | 25.7 | 0.293 | **Use Mo from ICP-ES** | | |
| Pd | 5.06 | 0.058 | | | 0.059 |
| Rh | 2.89 | 0.033 | | | 0.032 |
| Ru | 112 | 1.277 | | | 1.254 |
| Cd | 2.39 | 0.027 | | | 0.027 |
| Sn | 0.281 | 0.003 | | | 0.003 |
| La | 1230 | 14.022 | | | 13.830 |
| Ce | 1740 | 19.836 | | | 19.410 |
| W | 0.261 | 0.003 | | | 0.003 |
| Re | 0.00 | 0.000 | | | 0.000 |
| Os | 0.00 | 0.000 | | | 0.000 |
| Ir | 0.00 | 0.000 | | | 0.000 |
| Pt | 0.00 | 0.000 | | | 0.000 |
| Au | 0.00 | 0.000 | | | 0.000 |
| Hg | 663 | 7.558 | | | 7.558 |
| Pb | 699 | 7.969 | | | 7.969 |

| All Rare Earths Below Not Reported by Peters but Calculated by Ned from ICP-MS Analysis | |
|---|---|
| Pr | 9.774 |
| Nd | 40.001 |
| Sm | 3.943 |
| Gd | 5.245 |
| Tb | 0.147 |
| Dy | 0.438 |
| Ho | 0.080 |
| Er | 0.019 |
| Tm | 0.002 |
| Yb | 0.052 |
| Lu | 0.001 |

| ICP-MS Data (ppm) | | | | | |
|---|---|---|---|---|---|
| **Mass** | | | | | |
| 232 | 0.755 | 8.607E-03 | TOTAL | Th | 8.607E-03 |
| 233 | 0 | 0.000E+00 | | | |
| 234 | 2.64 | 3.010E-02 | | | |
| 235 | 1.59 | 1.813E-02 | | | |
| 236 | 0.5 | 5.700E-03 | | | |
| 237 | 2.64 | 3.010E-02 | | | |
| 238 | 833 | 9.496E+00 | | | |
| 239 | 3.61 | 4.115E-02 | | $^{239}$Pu | 4.115E-02 |
| 240 | 125 | 1.425E+00 | | $^{240}$Pu | 1.425E+00 |
| 241 | 38.5 | 4.389E-01 | | $^{242}$Pu | 7.000E-02 |
| 242 | 6.14 | 7.000E-02 | TOTAL | Pu | 1.536E+00 |
| 243 | 770 | 8.778E+00 | | | |
| 244 | 173 | 1.972E+00 | | $^{241}$Am | 4.389E-01 |
| 245 | 9.57 | 1.091E-01 | | $^{243}$Am | 8.778E+00 |
| 246 | 7.93 | 9.040E-02 | TOTAL | Am | 9.217E+00 |
| 247 | | | | | |
| | | | | $^{244}$Cm | 1.972E+00 |
| | | | | $^{245}$Cm | 1.091E-01 |
| | | | | $^{246}$Cm | 9.040E-02 |
| | | | TOTAL | Cm | 2.172E+00 |

(a) D. P. Lambert and T. P. Peters, WSRC-RP-2001-00740, Rev 0
(b) T. B. Peters et al. WSRC-TR-2002-00029 (Appendix 5)

# Appendix D

# Calculations of Radiolytic $H_2$ Production for the Various Waste Streams from the Total Radioactive Decay Watts in the Streams and Type of Radiation

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| Estimation of Impact on Radiolytic $H_2$ Production of Adding Am/Cm and Pu/Gd to SB3 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Calculation of Total Wattage in SB3 Streams** | | | | | | | | |
| | **Baseline** | | | | | **Baseline** | | |
| | **SB3 Curies** | **Gd/Pu Curies** | **Am/Cm Curies** | | **Watts per Curie [(a)]** | **SB3 Watts** | **Gd/Pu Watts** | **Am/Cm Watts** |
| $^{14}C$ | 4.34E+05 | | | | 2.93E-04 | 1.27E+02 | | |
| $^{90}Sr$ | 3.81E+06 | | | | 1.16E-03 | 4.42E+03 | | |
| $^{90}Y$ | 3.81E+06 | | | | 5.44E-03 | 2.07E+04 | | |
| $^{137}Cs$ | 3.41E+05 | | 1.63E+03 | b | 1.01E-03 | 3.44E+02 | | 1.65E+00 |
| $^{137m}Ba$ | 3.23E+05 | | 1.53E+03 | b | 3.94E-03 | 1.27E+03 | | 6.03E+00 |
| $^{154}Eu$ | 1.33E+04 | | 5.83E+03 | b | 9.08E-03 | 1.21E+02 | | 5.29E+01 |
| $^{238}Pu$ | 2.53E+04 | 8.55E+03 | 2.53E+03 | b | 3.26E-02 | 8.25E+02 | 2.79E+02 | 8.25E+01 |
| $^{239}Pu$ | 3.81E+03 | 5.59E+03 | 2.56E+00 | | 3.02E-02 | 1.15E+02 | 1.69E+02 | 7.73E-02 |
| $^{240}Pu$ | 9.13E+02 | 1.98E+03 | 3.25E+02 | | 3.06E-02 | 2.79E+01 | 6.06E+01 | 9.92E+00 |
| $^{241}Pu$ | 8.55E+03 | 6.18E+04 | 1.13E+02 | b | 3.20E-05 | 2.74E-01 | 1.98E+00 | 3.62E-03 |
| $^{242}Pu$ | 3.30E-01 | 7.64E-01 | 2.67E-01 | | 2.90E-02 | 9.56E-03 | 2.22E-02 | 7.75E-03 |
| Ingrown $^{241}Am$ | 1.35E+03 | | | | 3.28E-02 | 4.43E+01 | | |
| $^{241}Am$ | 1.27E+04 | | 1.51E+03 | | 3.28E-02 | 4.17E+02 | | 4.94E+01 |
| $^{242m}Am$ | 1.61E+01 | | 2.08E+01 | b | 4.05E-04 | 6.52E-03 | | 8.42E-03 |
| $^{243}Am$ | 1.86E+03 | | 1.74E+04 | | 3.15E-02 | 5.86E+01 | | 5.48E+01 |
| $^{244}Cm$ | 2.67E+00 | | 1.60E+05 | | 3.44E-02 | 9.18E-02 | | 5.49E+03 |
| $^{245}Cm$ | 2.90E-06 | | 1.87E+01 | | 3.33E-02 | 9.66E-08 | | 6.24E-01 |
| | | | | | **Total Watts** | **2.85E+04** | **5.10E+02** | **5.75E+03** |
| | | | | | | **Total Wattages per Case** | | |
| | | | | | | **Case 1** | **Case 2** | **Case 4** |
| | | | | | | 2.85E+04 | 2.90E+04 | 3.48E+04 |
| | | | | | | **Fractional Increase** | 1.02E+00 | 1.22E+00 |

(a) Specific activity taken from *Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE 1995).
(b) Value from WCS

| Calculation of Watts*G in SB3 Streams | | | | |
|---|---|---|---|---|
| **Primary Radiation Emitted** | **$G(H_2)$** | **SB3 Baseline Watts*G** | **Gd/Pu WG Pu Watts*G** | **Am/Cm 1.71E+01 Watts*G** |
| Beta | 0.45 | 5.72E+01 | | |
| Beta | 0.45 | 1.99E+03 | | |
| Beta | 0.45 | 9.33E+03 | | |
| Beta | 0.45 | 1.55E+02 | | 7.41E-01 |
| Gamma | 0.45 | 5.73E+02 | | 2.71E+00 |
| Gamma | 0.45 | 5.43E+01 | | 2.38E+01 |
| Alpha | 1.6 | 1.32E+03 | 4.46E+02 | 1.32E+02 |
| Alpha | 1.6 | 1.84E+02 | 2.70E+02 | 1.24E-01 |
| Beta | 1.6 | 4.46E+01 | 9.70E+01 | 1.59E+01 |
| Alpha | 0.45 | 1.23E-01 | 8.90E-01 | 1.63E-03 |
| Alpha | 1.6 | 1.53E-02 | 3.54E-02 | 1.24E-02 |
| Alpha | 1.6 | 7.08E+01 | | |
| Alpha | 1.6 | 6.66E+02 | | 7.91E+01 |
| Alpha | 1.6 | 1.04E-02 | | 1.35E-02 |
| Alpha | 1.6 | 9.37E+01 | | 8.77E+01 |
| Alpha | 1.6 | 1.47E-01 | | 8.78E+03 |
| Alpha | 1.6 | 1.55E-07 | | 9.98E-01 |
| **Total Watts*G** | | **1.45E+04** | **8.12E+02** | **9.12E+03** |
| | | **Total Watts*G per Case** | | |
| | | **CASE 1** | **CASE 2** | **CASE 4** |
| | | 1.45E+04 | 1.53E+04 | 2.45E+04 |
| | | **Fractional Increase** | 1.06E+00 | 1.68E+00 |

| Calculation of Total Wattage in SB2 and Values for Watts*G for Major Radionuclides in SB2. | | | | | | |
|---|---|---|---|---|---|---|
| **Total Dried Oxides in SB2 (kg)** | | | **4.37E+05[a]** | | | |
| **Typical Calcine Factor** | | | **0.853[b]** | | | |
| **Total Calcined Oxides (kg)** | | | **3.73E+05** | | | |
| **Radionuclide** | **Meas' ìCi/g (b)** | **Total Curies** | **Watts per Curie** | **Total Watts** | **G** | **Watts*G** |
| Sr-90 | 4.50E+03 | 1.68E+05 | 1.16E-03 | 1.95E+02 | 0.45 | 8.76E+01 |
| Y-90 | 4.50E+03 | 1.68E+05 | 5.44E-03 | 9.13E+02 | 0.45 | 4.11E+02 |
| Cs-137 | 2.80E+03 | 1.04E+05 | 1.01E-03 | 1.05E+02 | 0.45 | 4.74E+01 |
| Ba137m | 2.80E+03 | 1.04E+05 | 3.94E-03 | 4.11E+02 | 0.45 | 1.85E+02 |
| Eu-154 | 8.00E+00 | 2.98E+02 | 9.08E-03 | 2.71E+00 | 0.45 | 1.22E+00 |
| Pu-238 | 3.90E+01 | 1.45E+03 | 3.26E-02 | 4.74E+01 | 1.60 | 7.58E+01 |
| Pu-239 | 7.70E+00 | 2.87E+02 | 3.02E-02 | 8.67E+00 | 1.60 | 1.39E+01 |
| Pu-240 | 2.40E+00 | 8.95E+01 | 3.06E-02 | 2.73E+00 | 1.60 | 4.37E+00 |
| Pu-241 | 2.80E+01 | 1.04E+03 | 3.20E-05 | 3.34E-02 | 0.45 | 1.50E-02 |
| Am-241 | 3.30E+01 | 1.23E+03 | 3.28E-02 | 4.03E+01 | 1.60 | 6.46E+01 |
| Am-243[c] | 1.91E-02 | 7.12E-01 | 3.15E-02 | 2.24E-02 | 1.60 | 3.59E-02 |
| Cm-244 | 3.90E+01 | 1.45E+03 | 3.44E-02 | 5.00E+01 | 1.60 | 8.00E+01 |
| | | | | **Total** | | **9.71E+02** |

(a) Taken from the WSRC HLW System Plan Rev. 13 (J. W. Ray, Private Communication)
(b) Fellinger et al. 2002
(c) Am-243 has not been reported for SB2 yet. Value determined by measured ratio of Am-243 to Am-241 reported for SB1b (Fellinger and Bibler [1999]).

| **Calculation of Maximum Rates of Radiolytic $H_2$ Production** | | | | |
|---|---|---|---|---|
| Avogadro Number (molecules/mole) | | | | 6.02E+23 |
| Watts per Ev/sec (conversion factor) | | | | 1.60E-19 |
| L/mole at Standard Temperature and Pressure | | | | 22.4 |
| L/cubic foot | | | | 28.3 |
| | **CASE 1** | **CASE 2** | **CASE 4** | **SB 2** |
| **W*G** | **1.45E+04** | **1.53E+04** | **2.45E+04** | **9.71E+02** |
| L/h | **1.21E+02** | **1.28E+02** | **2.05E+02** | **8.12E+00** |
| cubic feet/h | **4.29E+00** | **4.53E+00** | **7.23E+00** | **2.87E-01** |
| Moles/h | **5.42E+00** | **5.73E+00** | **9.13E+00** | **3.62E-01** |
| Grams/h | **1.08E+01** | **1.15E+01** | **1.83E+01** | **7.25E-01** |
| Lbs/h | **2.39E-02** | **2.52E-02** | **4.02E-02** | **1.60E-03** |
| **Calculation of Rates of Radiolytic $H_2$ Production Per Batch** | | | | |
| Number of Canisters | | | | 553 |
| Canisters per Batch | | | | 8 |
| Number of Batches | | | | 69 |
| | **CASE 1** | **CASE 2** | **CASE 4** | **SB 2** |
| L/h | **1.76E+00** | **1.86E+00** | **2.96E+00** | **1.18E-01** |
| cubic feet/h | **6.22E-02** | **6.57E-02** | **1.05E-01** | **4.16E-03** |
| Moles/h | **7.86E-02** | **8.30E-02** | **1.32E-01** | **5.25E-03** |
| Grams/h | **1.57E-01** | **1.66E-01** | **2.65E-01** | **1.05E-02** |
| Lbs/h | **3.46E-04** | **3.66E-04** | **5.83E-04** | **2.31E-05** |
| | **1.00** | **1.06** | **1.68** | **0.067** |

## References

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U. S. Department of Energy (DOE). 1995. *Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics,* DOE/RW-0006, Rev. 11, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

# Appendix E

# Calculation of Neutron Dose Rates from a Canister of SB3 Glass for the Three Blending Scenarios and an Estimation of the Neutron Dose Rate from SB2 Glass

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## Case #1: Baseline SB3

**Calculation of Neutron Dose Rate to Case 1 Glass with Highest WL Frit 320 Glass at 37.5 wt% WL**

| Oxide | wt% in Glass | Elemental Factor | Element | wt% in Glass |
|---|---|---|---|---|
| $Cm_2O_3$ | 3.74E-09 | 0.857 | Cm | 3.21E-09 |
| $AmO_2$ | 5.42E-04 | 0.884 | Am | 4.79E-04 |
| $PuO_2$ | 7.85E-03 | 0.882 | Pu | 6.92E-03 |

**Determining Isotopic Fraction of $^{243}Am$**

| | Elemental kg in Case 4 Sludge | Isotopic Percent |
|---|---|---|
| $^{241}Am$ | 4.39E-01 | 4.76E+00 |
| $^{243}Am$ | 8.78E+00 | 9.52E+01 |
| Sum | 9.22E+00 | 1.00E+02 |

| | Isotopic Percent for Each Element |
|---|---|
| $^{238}Pu$ | 2.33 |
| $^{239}Pu$ | 87.94 |
| $^{240}Pu$ | 10.17 |
| $^{241}Am$ | 4.76 |
| $^{243}Am$ | 95.2 |
| $^{244}Cm$ | 100 |

**Isotopic Concentrations in Case 1 Glass**

| Element | wt Percent in Glass | Curies Per Pound Glass | Specific Act. [(a)]Ci/g |
|---|---|---|---|
| $^{238}Pu$ | 1.61E-04 | 1.25E-02 | 17.12 |
| $^{239}Pu$ | 6.09E-03 | 1.72E-03 | 0.0622 |
| $^{240}Pu$ | 7.04E-04 | 7.29E-04 | 0.228 |
| $^{241}Am$ | 2.28E-05 | 3.55E-04 | 3.432 |
| $^{243}Am$ | 4.56E-04 | 4.12E-04 | 0.199 |
| $^{244}Cm$ | 3.21E-09 | 1.18E-06 | 80.9 |

| | Design Basis Glass Grams per lb | Design Basis Glass Curies per lb | Case 1Glass Curies per lb |
|---|---|---|---|
| $^{238}Pu$ | 2.34E-02 | 4.01E-01 | 1.25E-02 |
| $^{239}Pu$ | 5.61E-02 | 3.49E-03 | 1.72E-03 |
| $^{240}Pu$ | 1.03E-02 | 2.35E-03 | 7.29E-04 |
| $^{241}Am$ | 8.64E-04 | 2.97E-03 | 3.55E-04 |
| $^{243}Am$ | 7.85E-06 | 1.56E-06 | 4.12E-04 |
| $^{244}Cm$ | 3.59E-04 | 2.90E-02 | 1.18E-06 |

## Case #1: Baseline SB3

**Calculation of Neutron Dose Rate to Case 1 Glass with Highest WL Frit 320 Glass at 37.5 wt% WL**

**n/s to Calculate Neutron Dose Rate from Alpha-n Reactions**

| | Given for Design Basis Glass | Calculated for Case 1Glass |
|---|---|---|
| **$^{238}$Pu** | 7.55E+07 | 2.36E+06 |
| **$^{239}$Pu** | 6.57E+05 | 3.24E+05 |
| **$^{240}$Pu** | 4.41E+05 | 1.37E+05 |
| **$^{241}$Am** | 5.60E+05 | 6.71E+04 |
| **$^{243}$Am** | 2.94E+02 | 7.76E+04 |
| **$^{244}$Cm** | 5.47E+06 | 2.22E+02 |
| **Total** | 8.26E+07 | 2.97E+06 |

n = neutrons
s = seconds

**n/s to Calculate Neutron Dose Rate from Spontaneous Fission**

| | Given for Design Basis Glass | Calculated for Case 1Glass |
|---|---|---|
| **$^{238}$Pu** | 2.73E+05 | 8.54E+03 |
| **$^{239}$Pu** | 5.67E+00 | 2.79E+00 |
| **$^{240}$Pu** | 4.35E+04 | 1.35E+04 |
| **$^{241}$Am** | 4.15E+00 | 4.97E-01 |
| **$^{243}$Am** | 2.14E-02 | 5.65E+00 |
| **$^{244}$Cm** | 1.45E+07 | 5.88E+02 |
| **Total** | 1.48E+07 | 2.26E+04 |

**(n/s)SB3,Case 4/(n/s)Design Basis = 3.07E-02**
**Neutron Dose Rate for Canister of SB3 Case 1 Glass at Contact**
**Design Basis = 420 mrem/h**
**SB3 Glass =13 mrem/h**

**(a)** Specific Activity taken from U. S. Department of Energy, Oak Ridge National Laboratory. 1995. "Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 11, September 1995.

## CASE #2: Baseline SB3 with Pu/Gd

**Calculation of Neutron Dose Rate to Case 2 Glass with Highest WL Frit 320 Glass at 37.5 wt% WL**

| Oxide | wt% in Glass | Elemental Factor | Element | wt% in Glass |
|---|---|---|---|---|
| $Cm_2O_3$ | 3.74E-09 | 0.857 | Cm | 3.21E-09 |
| $AmO_2$ | 5.42E-04 | 0.884 | Am | 4.79E-04 |
| $PuO_2$ | 1.96E-02 | 0.882 | Pu | 1.73E-02 |

**Determining Isotopic Fraction of $^{243}$Am**

| | Elemental | |
|---|---|---|
| | kg in Case 4Sludge | Isotopic Percent |
| $^{241}$Am- | 4.39E-01 | 4.76E+00 |
| $^{243}$Am | 8.78E+00 | 9.52E+01 |
| Sum | 9.22E+00 | 1.00E+02 |

| | Isotopic Percent for each Element |
|---|---|
| $^{238}$Pu | 2.33 |
| $^{239}$Pu | 87.94 |
| $^{240}$Pu | 10.17 |
| $^{241}$Am | 4.76 |
| $^{243}$Am | 95.2 |
| $^{244}$Cm | 100 |

**Isotopic Concentrations in Case 2 Glass**

| Element | wt Percent in Glass | Curies per Pound Glass | Specific Act. [(a)]Ci/g |
|---|---|---|---|
| $^{238}$Pu | 4.03E-04 | 3.13E-02 | 17.12 |
| $^{239}$Pu | 1.52E-02 | 4.29E-03 | 0.0622 |
| $^{240}$Pu | 1.76E-03 | 1.82E-03 | 0.228 |
| $^{241}$Am | 2.28E-05 | 3.55E-04 | 3.432 |
| $^{243}$Am | 4.56E-04 | 4.12E-04 | 0.199 |
| $^{244}$Cm | 3.21E-09 | 1.18E-06 | 80.9 |

| | Design Basis Glass Grams per lb | Design Basis Glass Curies per lb | Case 2Glass Curies per lb |
|---|---|---|---|
| $^{238}$Pu | 2.34E-02 | 4.01E-01 | 3.13E-02 |
| $^{239}$Pu | 5.61E-02 | 3.49E-03 | 4.29E-03 |
| $^{240}$Pu | 1.03E-02 | 2.35E-03 | 1.82E-03 |
| $^{241}$Am | 8.64E-04 | 2.97E-03 | 3.55E-04 |
| $^{243}$Am | 7.85E-06 | 1.56E-06 | 4.12E-04 |
| $^{244}$Cm | 3.59E-04 | 2.90E-02 | 1.18E-06 |

## CASE #2: Baseline SB3 with Pu/Gd

| n/s to Calculate Neutron Dose Rate from Alpha-n Reactions | | |
|---|---|---|
| | **Given for Design Basis Glass** | **Calculated for Case 2Glass** |
| **$^{238}$Pu** | 7.55E+07 | 5.90E+06 |
| **$^{239}$Pu** | 6.57E+05 | 8.08E+05 |
| **$^{240}$Pu** | 4.41E+05 | 3.42E+05 |
| **$^{241}$Am** | 5.60E+05 | 6.71E+04 |
| **$^{243}$Am** | 2.94E+02 | 7.76E+04 |
| **$^{244}$Cm** | 5.47E+06 | 2.22E+02 |
| **Total** | 8.26E+07 | 7.20E+06 |

n = neutrons
s = seconds

| n/s to Calculate Neutron Dose Rate from Spontaneous Fission | | |
|---|---|---|
| | **Given for Design Basis Glass** | **Calculated for Case 2Glass** |
| **$^{238}$Pu** | 2.73E+05 | 2.13E+04 |
| **$^{239}$Pu** | 5.67E+00 | 6.98E+00 |
| **$^{240}$Pu** | 4.35E+04 | 3.37E+04 |
| **$^{241}$Am** | 4.15E+00 | 4.97E-01 |
| **$^{243}$Am** | 2.14E-02 | 5.65E+00 |
| **$^{244}$Cm** | 1.45E+07 | 5.88E+02 |
| **Total** | 1.48E+07 | 5.56E+04 |

**(n/s)SB3,Case 4/(n/s)Design Basis = 7.44E-02**
**Neutron Dose Rate for Canister of SB3 Case 2 Glass at Contact**
**Design Basis = 420 mrem/h**
**SB3 Glass =31 mrem/h**

**(a)** Specific activity taken from U. S. Department of Energy, Oak Ridge National Laboratory. 1995. “Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics,” DOE/RW-0006, Rev. 11, September 1995.

## CASE #4: Baseline SB3 with both Pu/Gd and Am/Cm

**Calculation of Neutron Dose Rate to Case 4 Glass with Highest WL Frit 320 Glass AT 37.5 wt% WL**

| Oxide | wt% in Glass | Elemental Factor | Element | wt% in Glass |
|---|---|---|---|---|
| $Cm_2O_3$ | 2.43E-04 | 0.857 | Cm | 2.08E-04 |
| $AmO_2$ | 1.60E-03 | 0.884 | Am | 1.41E-03 |
| $PuO_2$ | 1.95E-02 | 0.882 | Pu | 1.72E-02 |

**Determining Isotopic Fraction of $^{243}$Am**

| | Elemental kg in Case 4Sludge | Isotopic Percent |
|---|---|---|
| $^{241}$Am | 4.39E-01 | 4.76E+00 |
| $^{243}$Am | 8.78E+00 | 9.52E+01 |
| Sum | 9.22E+00 | 1.00E+02 |

| | Isotopic Percent for each Element |
|---|---|
| $^{238}$Pu | 2.33 |
| $^{239}$Pu | 87.94 |
| $^{240}$Pu | 10.17 |
| $^{241}$Am | 4.76 |
| $^{243}$Am | 95.2 |
| $^{244}$Cm | 100 |

**Isotopic Concentrations in Case 4 Glass**

| Element | wt Percent in Glass | Curies per Pound Glass | Specific Act. [(a)]Ci/g |
|---|---|---|---|
| $^{238}$Pu | 4.01E-04 | 3.11E-02 | 17.12 |
| $^{239}$Pu | 1.51E-02 | 4.27E-03 | 0.0622 |
| $^{240}$Pu | 1.75E-03 | 1.81E-03 | 0.228 |
| $^{241}$Am | 6.73E-05 | 1.05E-03 | 3.432 |
| $^{243}$Am | 1.35E-03 | 1.22E-03 | 0.199 |
| $^{244}$Cm | 2.08E-04 | 7.65E-02 | 80.9 |

| | Design Basis Glass Grams per lb | Design Basis Glass Curies per lb | Case 4Glass Curies per lb |
|---|---|---|---|
| $^{238}$Pu | 2.34E-02 | 4.01E-01 | 3.11E-02 |
| $^{239}$Pu | 5.61E-02 | 3.49E-03 | 4.27E-03 |
| $^{240}$Pu | 1.03E-02 | 2.35E-03 | 1.81E-03 |
| $^{241}$Am | 8.64E-04 | 2.97E-03 | 1.05E-03 |
| $^{243}$Am | 7.85E-06 | 1.56E-06 | 1.22E-03 |
| $^{244}$Cm | 3.59E-04 | 2.90E-02 | 7.65E-02 |

## CASE #4: Baseline SB3 with both Pu/Gd and Am/Cm

| n/s to Calculate Neutron Dose Rate from Alpha-n Reactions | | | |
|---|---|---|---|
| | **Given for Design Basis Glass** | **Calculated for Case 4Glass** | |
| **$^{238}$Pu** | 7.55E+07 | 5.87E+06 | |
| **$^{239}$Pu** | 6.57E+05 | 8.04E+05 | |
| **$^{240}$Pu** | 4.41E+05 | 3.40E+05 | |
| **$^{241}$Am** | 5.60E+05 | 1.98E+05 | |
| **$^{243}$Am** | 2.94E+02 | 2.29E+05 | |
| **$^{244}$Cm** | 5.47E+06 | 1.44E+07 | n = neutrons |
| **Total** | 8.26E+07 | 2.18E+07 | s = seconds |

| n/s to Calculate Neutron Dose Rate from Spontaneous Fission | | |
|---|---|---|
| | **Given for Design Basis Glass** | **Calculated for Case 4Glass** |
| **$^{238}$Pu** | 2.73E+05 | 2.12E+04 |
| **$^{239}$Pu** | 5.67E+00 | 6.94E+00 |
| **$^{240}$Pu** | 4.35E+04 | 3.35E+04 |
| **$^{241}$Am** | 4.15E+00 | 1.47E+00 |
| **$^{243}$Am** | 2.14E-02 | 1.67E+01 |
| **$^{244}$Cm** | 1.45E+07 | 3.82E+07 |
| **TOTAL** | 1.48E+07 | 3.82E+07 |

**(n/s)SB3,Case 4/(n/s)Design Basis = 6.17E-01**
**Neutron Dose Rate for Canister of SB3 Case 4 Glass at Contact**
**Design Basis = 420 mrem/h**
**SB3 Glass =259mrem/h**

**(a)** Specific activity taken from U. S. Department of Energy, Oak Ridge National Laboratory. 1995. “Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics,” DOE/RW-0006, Rev. 11, September 1995.

## Neutron Dose Rate for SB2 Glass

**Estimated Neutron Dose Rate for SB2 Glass**

**Calculation of Weight Percent of Pu/Am/Cm in SB2 Glass**

| | wt% in Sludge | WDF | wt% in Glass |
|---|---|---|---|
| Fe | 23.6 | 2.86 | 8.26 |
| $^{238}$Pu | 2.30E-04 | | 8.05E-05 |
| $^{239}$Pu | 0.012 | | 4.20E-03 |
| $^{240}$Pu | 0.0011 | | 3.85E-04 |
| $^{241}$Am | 9.50E-04 | | 3.33E-04 |
| $^{243}$Am | 1.40E-04 | | 4.90E-05 |
| $^{244}$Cm | 4.80E-05 | | 1.68E-05 |

(a) calc from $^{243}$Am/$^{241}$Am Ratio in SB 1B

| wt% in SB 1B | |
|---|---|
| $^{241}$Am | 1.94E-04 |
| $^{243}$Am | 2.84E-05 |

**WDF = Waste Dilution Factor = 23.6/8.26**

**Design Basis Glass from Baxter**

| | Grams per lb | Curies per lb | wt% | Ci/100 g | Specific Act. [a] Ci/g |
|---|---|---|---|---|---|
| $^{238}$Pu | 2.34E-02 | 4.01E-01 | 5.15E-03 | 8.82E-02 | 17.12 |
| $^{239}$Pu | 5.61E-02 | 3.49E-03 | 1.24E-02 | 7.69E-04 | 0.0622 |
| $^{240}$Pu | 1.03E-02 | 2.35E-03 | 2.27E-03 | 5.17E-04 | 0.228 |
| $^{241}$Am | 8.64E-04 | 2.97E-03 | 1.90E-04 | 6.53E-04 | 3.432 |
| $^{243}$Am | 7.85E-06 | 1.56E-06 | 1.73E-06 | 3.44E-07 | 0.199 |
| $^{244}$Cm | 3.59E-04 | 2.90E-02 | 7.91E-05 | 6.40E-03 | 80.9 |

**SB 2 Glass**

| Element | Curies per lb | wt% | Ci/100 g |
|---|---|---|---|
| $^{238}$Pu | 6.26E-03 | 1.42E-04 | 1.38E-03 |
| $^{239}$Pu | 1.19E-03 | 5.90E-03 | 2.61E-04 |
| $^{240}$Pu | 3.99E-04 | 3.70E-04 | 8.78E-05 |
| $^{241}$Am | 5.18E-03 | 5.44E-04 | 1.14E-03 |
| $^{243}$Am | 4.43E-05 | 5.4E-04 | 9.75E-06 |
| $^{244}$Cm | 6.17E-03 | 6.1E-09 | 1.36E-03 |

**Kg of Pu in Tank 7 after adding 17.1**

| | |
|---|---|
| $^{238}$Pu | 1.63 |
| $^{239}$Pu | 61.4 |
| $^{240}$Pu | 7.11 |
| $^{241}$Am | 4.20 |

**n/s to Calculate Neutron Dose Rate from Alpha-n Reactions**

| | Design Basis | Calc SB2 |
|---|---|---|
| $^{238}$Pu | 7.55E+07 | 1.18E+06 |
| $^{239}$Pu | 6.57E+05 | 2.23E+05 |
| $^{240}$Pu | 4.41E+05 | 7.48E+04 |
| $^{241}$Am | 5.60E+05 | 9.78E+05 |
| $^{243}$Am | 2.94E+02 | 8.33E+03 |
| $^{244}$Cm | 5.47E+06 | 1.16E+06 |
| **Total** | 8.26E+07 | 3.63E+06 |

**n/s to Calculate Neutron Dose Rate from Spontaneous Fission**

| | Design Basis | Calc SB2 |
|---|---|---|
| $^{238}$Pu | 2.73E+05 | 4.26E+03 |
| $^{239}$Pu | 5.67E+00 | 1.93E+00 |
| $^{240}$Pu | 4.35E+04 | 7.38E+03 |
| $^{241}$Am | 4.15E+00 | 7.25E+00 |
| $^{243}$Am | 2.14E-02 | 6.06E-01 |
| $^{244}$Cm | 1.45E+07 | 3.08E+06 |
| **Total** | 1.48E+07 | 3.09E+06 |

**(n/s)SB2/(n/s)Design Basis = 6.89E-02**
**Neutron Dose Rate for Canister of SB2 Glass at Contact**
**Design Basis = 420 mrem/h**
**SB2 Glass =29 mrem/h**

[a] Specific activity taken from U. S. Department of Energy, Oak Ridge National Laboratory. 1995. "Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 11, September 1995.

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# Appendix F

# Calculation of Alpha Doses to the Three Cases for SB3 with the Maximum Acceptable Waste Loading (Frit 320 Glass with 37.5 wt% Waste)

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## CASE #1: SB3 Baseline

| Calculated Alpha Dose to SB3 Glass Case 1 with 37.5% WL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Time, y | | | | | | | | | | |
| Isotope | Conc wt% | Init Conc Atoms/g Glass | Lambda [(a)] Y-1 | 1 | 10 | 50 | 100 | 200 | 300 | 500 | 1000 | 3000 | 1.00E+04 | 1.00E+05 | 1.00E+06 |
| $^{244}$Cm | 3.21E-09 | 7.92E+10 | 0.03827 | 2.98E+09 | 2.52E+10 | 6.75E+10 | 7.75E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 |
| $^{238}$Pu | 1.61E-04 | 4.07E+15 | 0.007904 | 3.21E+13 | 3.10E+14 | 1.33E+15 | 2.23E+15 | 3.24E+15 | 3.69E+15 | 4.00E+15 | 4.07E+15 | 4.07E+15 | 4.07E+15 | 4.07E+15 | 4.07E+15 |
| $^{241}$Am | 2.28E-05 | 5.70E+14 | 0.0016 | 9.11E+11 | 9.04E+12 | 4.38E+13 | 8.43E+13 | 1.56E+14 | 2.17E+14 | 3.14E+14 | 4.55E+14 | 5.65E+14 | 5.70E+14 | 5.70E+14 | 5.70E+14 |
| $^{240}$Pu | 7.04E-04 | 1.77E+16 | 1.06E-04 | 1.87E+12 | 1.87E+13 | 9.34E+13 | 1.86E+14 | 3.71E+14 | 5.53E+14 | 9.12E+14 | 1.78E+15 | 4.81E+15 | 1.15E+16 | 1.77E+16 | 1.77E+16 |
| $^{243}$Am | 4.57E-04 | 1.13E+16 | 9.39E-05 | 1.06E+12 | 1.06E+13 | 5.31E+13 | 1.06E+14 | 2.11E+14 | 3.15E+14 | 5.20E+14 | 1.02E+15 | 2.78E+15 | 6.90E+15 | 1.13E+16 | 1.13E+16 |
| $^{239}$Pu | 6.09E-03 | 1.53E+17 | 2.88E-05 | 4.42E+12 | 4.42E+13 | 2.21E+14 | 4.41E+14 | 8.81E+14 | 1.32E+15 | 2.19E+15 | 4.36E+15 | 1.27E+16 | 3.84E+16 | 1.45E+17 | 1.53E+17 |
| **Alphas per Gram** | | | | **4.03E+13** | **3.92E+14** | **1.74E+15** | **3.04E+15** | **4.85E+15** | **6.10E+15** | **7.94E+15** | **1.17E+16** | **2.49E+16** | **6.15E+16** | **1.78E+17** | **1.87E+17** |
| **Density of Glass=2.65 g/mL** | | | | | | | | | | | | | | | |
| **Alphas per Cubic Meter** | | | | **1.07E+20** | **1.04E+21** | **4.61E+21** | **8.07E+21** | **1.29E+22** | **1.62E+22** | **2.10E+22** | **3.09E+22** | **6.61E+22** | **1.63E+23** | **4.73E+23** | **4.96E+23** |

**(a)** Decay constants taken from U. S. Department of Energy, Oak Ridge National Laboratory. 1995. "Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 11, September 1995.

## Case #2: SB3 Baseline with Pu/Gd

| Calculated Alpha Dose to SB3 Glass Case 2 with 37.5% WL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Time, y | | | | | | | | | | |
| Isotope | Conc wt% | Init Conc Atoms/g Glass | Lambda [a] Y-1 | 1 | 10 | 50 | 100 | 200 | 300 | 500 | 1000 | 3000 | 1.00E+04 | 1.00E+05 | 1.00E+06 |
| $^{244}$Cm | 3.21E-09 | 7.92E+10 | 0.03827 | 2.98E+09 | 2.52E+10 | 6.75E+10 | 7.75E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 | 7.92E+10 |
| $^{238}$Pu | 4.03E-04 | 1.02E+16 | 0.007904 | 8.03E+13 | 7.75E+14 | 3.33E+15 | 5.57E+15 | 8.10E+15 | 9.25E+15 | 1.00E+16 | 1.02E+16 | 1.02E+16 | 1.02E+16 | 1.02E+16 | 1.02E+16 |
| $^{241}$Am | 2.28E-05 | 5.70E+14 | 0.0016 | 9.11E+11 | 9.04E+12 | 4.38E+13 | 8.43E+13 | 1.56E+14 | 2.17E+14 | 3.14E+14 | 4.55E+14 | 5.65E+14 | 5.70E+14 | 5.70E+14 | 5.70E+14 |
| $^{240}$Pu | 1.76E-03 | 4.42E+16 | 1.06E-04 | 4.68E+12 | 4.68E+13 | 2.33E+14 | 4.66E+14 | 9.27E+14 | 1.38E+15 | 2.28E+15 | 4.44E+15 | 1.20E+16 | 2.89E+16 | 4.42E+16 | 4.42E+16 |
| $^{243}$Am | 4.56E-04 | 1.13E+16 | 9.39E-05 | 1.06E+12 | 1.06E+13 | 5.29E+13 | 1.06E+14 | 2.10E+14 | 3.14E+14 | 5.18E+14 | 1.01E+15 | 2.77E+15 | 6.88E+15 | 1.13E+16 | 1.13E+16 |
| $^{239}$Pu | 1.52E-02 | 3.83E+17 | 2.88E-05 | 1.10E+13 | 1.10E+14 | 5.51E+14 | 1.10E+15 | 2.20E+15 | 3.30E+15 | 5.48E+15 | 1.09E+16 | 3.17E+16 | 9.59E+16 | 3.62E+17 | 3.83E+17 |
| **Alphas per Gram** | | | | **9.80E+13** | **9.52E+14** | **4.21E+15** | **7.33E+15** | **1.16E+16** | **1.45E+16** | **1.86E+16** | **2.70E+16** | **5.73E+16** | **1.42E+17** | **4.28E+17** | **4.49E+17** |
| **Density of Glass=2.65 g/mL** | | | | | | | | | | | | | | | |
| **Alphas per Cubic Meter** | | | | **2.60E+20** | **2.52E+21** | **1.12E+22** | **1.94E+22** | **3.07E+22** | **3.83E+22** | **4.93E+22** | **7.15E+22** | **1.52E+23** | **3.77E+23** | **1.13E+24** | **1.19E+24** |

**(a)** Decay constants taken from U. S. Department of Energy, Oak Ridge National Laboratory. 1995. "Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 11, September 1995.

## Case #4: SB# Baseline with both Pu/Gd and Am/Cm

| Calculated Alpha Dose to SB3 Glass Case 4 with 37.5% WL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Isotope** | **Conc wt%** | **Init Conc Atoms/g Glass** | **Lambda [a] Y-1** | **Time, y** | | | | | | | | | | |
| | | | | **1** | **10** | **50** | **100** | **200** | **300** | **500** | **1000** | **5000** | **1.00E+04** | **1.00E+05** | **1.00E+06** |
| **$^{244}$Cm** | 2.08E-04 | 5.13E+15 | 0.03827 | 1.93E+14 | 1.63E+15 | 4.38E+15 | 5.02E+15 | 5.13E+15 | 5.13E+15 | 5.13E+15 | 5.13E+15 | 5.13E+15 | 5.13E+15 | 5.13E+15 | 5.13E+15 |
| **$^{238}$Pu** | 4.01E-04 | 1.01E+16 | 0.007904 | 7.99E+13 | 7.71E+14 | 3.31E+15 | 5.54E+15 | 8.06E+15 | 9.20E+15 | 9.95E+15 | 1.01E+16 | 1.01E+16 | 1.01E+16 | 1.01E+16 | 1.01E+16 |
| **$^{241}$Am** | 6.73E-05 | 1.68E+15 | 0.0016 | 2.69E+12 | 2.67E+13 | 1.29E+14 | 2.49E+14 | 4.61E+14 | 6.41E+14 | 9.26E+14 | 1.34E+15 | 1.68E+15 | 1.68E+15 | 1.68E+15 | 1.68E+15 |
| **$^{240}$Pu** | 1.75E-03 | 4.39E+16 | 1.06E-04 | 4.66E+12 | 4.65E+13 | 2.32E+14 | 4.63E+14 | 9.21E+14 | 1.37E+15 | 2.27E+15 | 4.42E+15 | 1.81E+16 | 2.87E+16 | 4.39E+16 | 4.39E+16 |
| **$^{243}$Am** | 1.35E-03 | 3.35E+16 | 9.39E-05 | 3.14E+12 | 3.14E+13 | 1.57E+14 | 3.13E+14 | 6.23E+14 | 9.29E+14 | 1.53E+15 | 3.00E+15 | 1.25E+16 | 2.04E+16 | 3.35E+16 | 3.35E+16 |
| **$^{239}$Pu** | 1.51E-02 | 3.81E+17 | 2.88E-05 | 1.10E+13 | 1.10E+14 | 5.48E+14 | 1.09E+15 | 2.19E+15 | 3.27E+15 | 5.44E+15 | 1.08E+16 | 5.10E+16 | 9.52E+16 | 3.59E+17 | 3.81E+17 |
| | | | **Time** | **1** | **10** | **50** | **100** | **200** | **300** | **500** | **1000** | **5000** | **1.00E+04** | **1.00E+05** | **1.00E+06** |
| | | | **Alphas per Gram** | **2.94E+14** | **2.62E+15** | **8.76E+15** | **1.27E+16** | **1.74E+16** | **2.06E+16** | **2.53E+16** | **3.48E+16** | **9.86E+16** | **1.61E+17** | **4.54E+17** | **4.75E+17** |
| | | | **Density of Glass = 2.65 g/mL** | | | | | | | | | | | | |
| | | | **Alphas per Cubic Meter** | **7.79E+20** | **6.94E+21** | **2.32E+22** | **3.36E+22** | **4.61E+22** | **5.45E+22** | **6.69E+22** | **9.23E+22** | **2.61E+23** | **4.27E+23** | **1.20E+24** | **1.26E+24** |

**(a)** Decay constants taken from U. S. Department of Energy, Oak Ridge National Laboratory. 1995. "Integrated Data Base Report - 1994: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 11, September 1995.

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# Appendix G

# Calculation of Number of Canisters and Watts per Canister for SB3 Glass with the Maximum Acceptable Waste Loading (Frit 320 Glass with 37.5 wt% Waste)

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**CALCULATION OF WATTS PER CANISTER FOR THREE CASES OF SB3 WASTE LOADING WITH HIGHEST WASTE LOADING - FRIT 320 WITH 37.5% WASTE OXIDES**

**CALCULATION OF TOTAL WATTAGE IN SB3 STREAMS**

| | SB3 BASELINE Curies | Pu/Gd Curies | Am/Cm Curies | | Watts per Curie | SB3 BASELINE WATTS | Pu/Gd WATTS | Am/Cm WATTS |
|---|---|---|---|---|---|---|---|---|
| C-14 | 4.34E+05 | | | | 2.93E-04 | 1.27E+02 | | |
| Sr-90 | 3.81E+06 | | | | 1.16E-03 | 4.42E+03 | | |
| Y-90 | 3.81E+06 | | | | 5.44E-03 | 2.07E+04 | | |
| Cs-137 | 3.41E+05 | | 1.63E+03 | a | 1.01E-03 | 3.44E+02 | | 1.65E+00 |
| Ba137m | 3.23E+05 | | 1.53E+03 | a | 3.94E-03 | 1.27E+03 | | 6.03E+00 |
| Eu-154 | 1.33E+04 | | 5.83E+03 | a | 9.08E-03 | 1.21E+02 | | 5.29E+01 |
| Pu-238 | 2.53E+04 | 8.55E+03 | 2.53E+03 | a | 3.26E-02 | 8.25E+02 | 2.79E+02 | 8.25E+01 |
| Pu-239 | 3.81E+03 | 5.59E+03 | 2.56E+00 | | 3.02E-02 | 1.15E+02 | 1.69E+02 | 7.73E-02 |
| Pu-240 | 9.13E+02 | 1.98E+03 | 3.25E+02 | | 3.06E-02 | 2.79E+01 | 6.06E+01 | 9.92E+00 |
| Pu-241 | 8.55E+03 | 6.18E+04 | 1.13E+02 | a | 3.20E-05 | 2.74E-01 | 1.98E+00 | 3.62E-03 |
| Pu-242 | 3.30E-01 | 7.64E-01 | 2.67E-01 | | 2.90E-02 | 9.56E-03 | 2.22E-02 | 7.75E-03 |
| Ingrown Am-241 | 1.35E+03 | | | | 3.28E-02 | 4.43E+01 | | |
| Am-241 | 1.27E+04 | | 1.51E+03 | | 3.28E-02 | 4.17E+02 | | 4.94E+01 |
| Am-242m | 1.61E+01 | | 2.08E+01 | a | 4.05E-04 | 6.52E-03 | | 8.42E-03 |
| Am-243 | 1.86E+03 | | 1.74E+03 | | 3.15E-02 | 5.86E+01 | | 5.48E+01 |
| Cm-244 | 2.67E+00 | | 1.60E+05 | | 3.44E-02 | 9.18E-02 | | 5.49E+03 |
| Cm-245 | 2.90E-06 | | 1.87E+01 | | 3.33E-02 | 9.66E-08 | | 6.24E-01 |
| a Value from WCS | | | **TOTAL WATTS** | | | **2.85E+04** | **5.10E+02** | **5.75E+03** |

| **TOTAL WATTAGES PER CASE** | | |
|---|---|---|
| CASE 1 | CASE 2 | CASE 4 |
| 2.85E+04 | 2.90E+04 | 3.48E+04 |

| | | |
|---|---|---|
| **FRACTIONAL INCREASE** | 1.02E+00 | 1.22E+00 |

| | | | |
|---|---|---|---|
| **TOTAL MASS OF SLUDGE OXIDES IN THREE CASES, KG** | 3.628E+05 | 3.631E+05 | 3.67E+05 |
| **WASTE LOADING IN GLASS** | 37.5 wt% | | |
| **TOTAL MASS OF GLASS OXIDES IN THREE CASES, KG** | 9.675E+05 | 9.683E+05 | 9.787E+05 |

**GLASS/CAN** 3900 LB **1770.6** **KG**

| | **CASE 1** | **CASE 2** | **CASE 3** |
|---|---|---|---|
| **TOTAL CANS** | **546** | **547** | **553** |
| **WATTS/CAN** | **5.22E+01** | **5.30E+01** | **6.29E+01** |

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**SRS Distribution**

P.C. Suggs, 704-3N
B.L. Lewis, 704-S
R.E. Edwards, 704-3N
W.D. Kerley, 704-S
J.F. Ortaldo, 704-S
J.E. Occhipinti, 704-27S
M.A. Rios-Armstrong, 704-27S
J.W. Ray, 704-S
H.H. Elder, 704-3N
E.W. Holtzscheiter, 773-A
R.H. Spires, 773-A
S.L. Marra, 999-W
D.A. Crowley, 773-43A
R.C. Tuckfield, 773-42A
D.F. Bickford, 999-W
J.R. Harbour, 773-43A
C.M. Jantzen, 773-A
N.E. Bibler, 773-A
F.R. Graham, 773-A
D.R. Best, 773-41A
K.G. Brown, 773-42A
A.D. Cozzi, 999-W
W.E. Daniel, 999-W
T.B. Edwards, 773-42A
T.L. Fellinger, 773-A
J.C. George, 773-43A
C.C. Herman, 773-43A
T.M. Jones, 999-W
D.C. Koopman, 773-43A
T.H. Lorier, 999-W
D.H. Miller, 786-1A
D.K. Peeler, 999-W
M.E. Smith, 773-43A
M.E. Stone, 999-W
T.K. Snyder, 773-42A
D.C. Witt, 999-W
VT QA File