Immobilization Technology Section
Savannah River Technology Center
Westinghouse Savannah River Company

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REDUCTION OF CONSTRAINTS

Technical Status Report on the Applicability of the Homogeneity Constraint for Sludge-Only Processing (U)

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Executive Summary

The objective of this task is to develop the fundamental technical data needed to relax or eliminate the homogeneity measurement uncertainty requirement ***for projected sludge-only processing*** as long as the following criteria are satisfied:

Criterion (1)

- use the alumina constraint as currently implemented in the Defense Waste Processing Facility's (DWPF) Product Composition Control System (PCCS) ($Al_2O_3 \geq 3$ wt%) **and** add a sum of alkali[(a)] constraint with an upper limit of 19.3 wt% ($\Sigma M_2O < 19.3$ wt%)

or

Criterion (2)

- adjust the lower limit on the alumina constraint to 4 wt% ($Al_2O_3 \geq 4.0$ wt%).

In this report, initial assessments (via computational evaluations relative to acceptable property limits) are made as to whether the homogeneity constraint has the potential to restrict composition regions of projected sludge-only processing. The compositional region covered by this study included five individual waste types and two specific sludge batches (SB3 and SB4)—the latter of which defines sludge-only processing based on Revision 12 of the high-level waste (HLW) System Plan (WSRC 2001).

Three primary outcomes result from this study:

(1) an initial screening assessment (Phase 1) has been performed using centroid-based sludge compositions computed from bounding waste types and/or blended sludges

(2) the definition of 33 glass compositions to experimentally support initial screening observations

(3) the Phase 2 assessment of SB3 and SB4 glasses using centroid and extreme sludge compositions coupled with Frits 200, 165, and 320 over a nominal waste loading (WL) range.

Numerous comparisons could be made with respect to the Phase 1 and Phase 2 assessments. In light of the task objective, general observations regarding homogeneity and the projected operational window are bulleted below.

- Homogeneity for SB3 and SB4 is challenged over the nominal WL interval of interest for Frit 200, Frit 165, and Frit 320. Challenges to this constraint become more frequent as the outer layer (OL) extreme vertexes (EVs) are assessed or as lower WLs are considered.
- Homogeneity becomes less of an issue as WLs are increased or if one transitions from Frit 200 to either Frit 165 or Frit 320. There is some indication that the use of Frit 320 reduces the likelihood of challenging the homogeneity constraint. However, the use of Frit 320 or Frit 165 does challenge durability predictions more often than the Frit 200-based glasses.

(a) Alkali included in this sum are Na_2O, Li_2O, Cs_2O, and K_2O. However, for sludge-only processing neither Cs_2O nor K_2O is introduced at significant concentrations so the sum of alkali is based solely on Na_2O and Li_2O.

- Implementation of the new liquidus temperature (T_L) model almost always increases the projected composition operational window size for SB3 and SB4 regardless of frit selection. Given that higher WLs would be targeted, homogeneity (as previously mentioned) becomes less of an issue.
- The use of Frit 200 for SB3 and SB4 is typically restricted by T_L predictions.
- The use of Frit 165 or Frit 320 with SB3 or SB4 increases the upper WL limit achievable (relative to Frit 200).
- Viscosity and durability become restrictive for certain frit/sludge combinations.

It is not the intent of this assessment to select a baseline frit for SB3 and/or SB4. However, the three frits considered are the primary candidates from the established or existing frits; therefore, this assessment will be beneficial in the frit-selection decision. The selection of a baseline frit should be made in light of all the constraints—not just homogeneity—in terms of its potential impact to the overall integrated process using a systems approach. However, based on this initial assessment, it appears that Frit 320 is a potential candidate (although likely not optimized) for projected sludge-only processing relative to Frit 200 or Frit 165. Challenges to homogeneity appear to be less frequent (even at lower WLs), and higher WLs appear to be achievable with Frit 320 (regardless of the T_L model being used). It must be recognized that Frit 320 was developed specifically for SB2 to enhance the melt rate without any prior consideration of using this frit for SB3 and/or SB4. Therefore, any statements about Frit 320 being an "optimized" frit for SB3 and/or SB4 or the fact that it should be used as the "generic sludge-only frit" should not be made or should be made within the correct context. It should also be noted that the assessments in this report are based strictly on Property Acceptability Region (PAR) limits.

In the process of selecting a nominal frit for each SB or for sludge-only processing, a balanced approach must be taken, and all constraints either predicted by models or non-predictable (e.g. melt rate) must be considered. The systems approach mandates that tradeoffs must be considered for glass-formulation development to be successful. This assessment is the initial step in this process for the projected sludge-only flowsheet.

In summary, the question may be asked "Can the homogeneity constraint be eliminated unconditionally for sludge-only processing?" The short answer is "no", given the current state of knowledge. However, based on the assessments provided in this study, there is strong evidence that the homogeneity constraint could be eliminated (or the constraint not challenged) if DWPF were to transition to either Frit 165 or Frit 320 (which are frits developed for sludge-only processing or a specific sludge-only flowsheet) and implement the new T_L model. Implementing the new T_L model allows for higher WLs to be targeted, which makes challenging homogeneity a non-issue. It is recommended that this assessment be supported with experimental data to confirm these general observations. If it is shown that the homogeneity constraint cannot be unconditionally eliminated, then a path parallel to that used by Edwards and Brown (1998) for macrobatch 2 (MB2) is still a viable option.

References

Edwards, T. B., and K. G. Brown. 1998. *Evaluating the Glasses Batched for the Tank 42 Variability Study (U)*, SRT-SCS-98-017, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Westinghouse Savannah River Company (WSRC). 2001. Savannah River Site High Level Waste System Plan (HLW), HLW-2001-00040, Revision 12, Aiken, South Carolina.

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Acronyms

ASTM	American Society for Testing and Materials
clc	centerline cooled
CPES	Chemical Process Evaluation System
CVS	composition variation study
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
EV	extreme vertex
HHF	H modified high heat feed
HLF	H modified low heat feed
HLW	high-level waste
HM	H modified
HMF	H modified mixed fresh
IDMS	integrated DWPF melter system
IL	inner layer
MA	mixed acid
MAR	Measurement Acceptability Region
MB	macrobatch
MFT	Melter Feed Tank
OL	outer layer
PAR	Property Acceptability Region
PCCS	Product Composition Control System
PCT	Product Consistency Test
PF	peroxide fusion
PHF	PUREX high heat feed
PLF	PUREX low heat feed
PNNL	Pacific Northwest National Laboratory
PMF	PUREX mixed feed
PUREX	plutonium uranium extraction
PX	PUREX
QA	quality assurance
RC	reduction of constraints

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
THERMO™	Thermodynamic Hydration Energy Reaction Model
TTR	technical task request
$\eta_{1150°C}$	melt viscosity at 1150°C
WCP	waste compliance plan
WL	waste loading

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1.0 Introduction

Approximately 130 million liters of high-level radioactive waste 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. The glass is poured into stainless steel canisters that will eventually be disposed on in a permanent, geological repository.

The Product Composition Control System (PCCS) is used to determine the acceptability of each batch of DWPF melter feed in the Slurry Mix Evaporator (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. An SME batch is deemed acceptable if its sample-composition measurements lead to acceptable property predictions after accounting for modeling, measurement, and analytic 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).

A minimum of three (homogeneity, Al_2O_3, and frit) PCCS constraints supports the prediction of the glass durability from a given SME batch. The Savannah River Technology Center (SRTC) is reviewing all of the pertinent constraints associated with durability. The purpose of this review is twofold: 1) revisit these constraints in light of the additional knowledge gained since the beginning of radioactive operations at DWPF and 2) identify any supplemental studies needed to complement this knowledge so that redundant or overly conservative constraints can be eliminated, relaxed and/or replaced by more appropriate constraints.

One of the specific PCCS constraints currently being evaluated is the homogeneity constraint that is used to discriminate compositions that are likely to result in phase-separated glasses from compositions that are likely to be homogeneous. In this context, phase separation refers to the development of amorphous or glass-in-glass phase separation, not to crystallization. The homogeneity constraint is a linear function of terms representing sludge and frit. This function was obtained from a discriminate analysis of 110 glasses (88 homogeneous and 22 phase-separated) in sludge versus frit-composition space (Brown and Edwards (1995), Jantzen et. al. (1995). Jantzen and Brown (2000)). The technical basis for implementing a phase-separation discriminator into PCCS was the fact that durability of phase-separated glasses is unpredictable.

For a given SME batch, the PCCS is used to determine acceptability; it is initially used to ensure processability and durability of the final product. Because the decision regarding acceptability is based on underlying models (e.g., liquidus temperature [T_L], durability, and viscosity) used by PCCS as well as single-component concentration constraints (e.g., Al_2O_3 and Cr_2O_3), waste loadings (WLs) are usually limited by one of the model predictions (taking into account associated uncertainties).[a] For example, application of the homogeneity constraint at the Measurement Acceptability Region (MAR) limit for macrobatch 2 (MB2) eliminated much of the potential composition region from the DWPF window of operability (Edwards and Brown 1998). This issue was identified during a variability study for MB2 that was conducted by the SRTC.

(a) Waste loadings are typically limited by one of the model predictions since their uncertainty (both measured and predicted) will likely be much larger than that of an individual component.

Edwards and Brown (1998) and Edwards (1999) reported the results from that study. A similar study was performed for Macrobatch 3 (MB3) as reported by Peeler et al. (2000).

The MB2 study, supplemented by an evaluation of an existing property-composition database, led to the formation of two new options for PCCS: a new limit for the alumina constraint or the introduction of a new sum of alkali constraint coupled with the existing Al_2O_3 constraint ($\geq$ 3 wt%).[(a)] The latter of these options allowed DWPF to relax the homogeneity constraint from a measured acceptance criterion to a property acceptance criterion for MB2 without changing the existing Al_2O_3 limit. The technical basis developed by Edwards and Brown (1998) for relaxing the homogeneity constraint to the Property Acceptability Region (PAR) coupled with implementing one of the proposed equivalent criteria provided compositional flexibility (e.g., it increased the composition operational window) for MB2 operations without compromising product quality. Edwards and Brown (1998) provide a more detailed discussion for the MB2 technical basis.

The technical basis for the aforementioned MB2 decision is briefly discussed in this report to establish a technical baseline for potentially eliminating the homogeneity constraint for sludge-only processing via application of the criteria associated with Al_2O_3 and/or the sum of alkali metal oxides. Elimination of the homogeneity constraint for sludge-only processing (as currently defined by Revision 12 of the high-level waste (HLW) System Plan [WSRC 2001]) is the objective of the current task (TTR 2001).

As noted above, application of the homogeneity constraint at the MAR had a significant (negative) impact on the compositional operational window for MB2 (Tank 42). To address this issue, Edwards and Brown (1998) hypothesized that the application of the homogeneity constraint could be reduced to the PAR, given the implementation of one of two criteria:

Criterion (1)

- use the alumina constraint as currently implemented in PCCS ($Al_2O_3 \geq 3$ wt%) **and** add a sum of alkali[(b)] constraint with an upper limit of 19.3 wt% ($\Sigma M_2O <$ 19.3 wt%)

OR

Criterion (2)

- adjust the lower limit on the alumina constraint to 4 wt% ($Al_2O_3 \geq 4.0$ wt%).

This hypothesis was based on the fact that Al_2O_3 is known to suppress the formation of amorphous phase separation in borosilicate glasses (Volf 1974; Jantzen et al. 1995; Jantzen and Brown 2000; Hrma et al. 1994) and that sufficient quantities of Al_2O_3 have a positive impact on durability (usually independent of any homogeneity classification). It is also well known that relatively high quantities of alkali metal oxides typically result in a reduction in durability for borosilicate glasses (Volf 1974; Jantzen et al. 1995). It should be noted that durable (as defined by the Product Consistency Test [PCT] [ASTM 1997]) simulated waste glasses have been produced with alkali concentrations exceeding 20 wt% (Kim et al, 1995; Muller et al. 2001; Feng

(a) Jantzen, et al. (1995; see Figure 32) delineated a compositional difference between homogeneous and phase-separated glasses when examined in the Al_2O_3-B_2O_3-ΣM_2O-Fe_2O_3 quaternary. This analysis indicated that the phase-separated glasses are low in Al_2O_3 relative to homogeneous glasses.

(b) Alkalis included in this sum are Na_2O, Li_2O, Cs_2O, and K_2O.

et al. 1996; Vienna et al. 2001; Ebert and Wolf 2000; Hrma et al. 2001). Criterion (1) constrains the glass composition in a durability region where the strong bases to weak acids are balanced in the leachate (Jantzen et al. 1995). Criterion (2) does not impose an upper alkali constraint, given that Al_2O_3 concentrations are ≥ 4.0 wt%. It is important to note that either criterion should only be applied over the compositional envelopes evaluated, and it might be necessary to impose an upper alkali constraint in certain glass-composition spaces.

Figure 1.1 shows the impact of Al_2O_3 and the ΣM_2O on the durability for the glasses used to define the discriminator and the MB2 (Tank 42) variability study glasses. Glasses observed to be phase separated are labeled with the common logarithm of the normalized PCT (ASTM 1997) results (log NL [B] in g/L) as is the environmental assessment (EA) glass (log NL [B] = 1.22). Glasses with high PCT leach values (> 1.0 in log space)[a] are located in the high alkali/low alumina quadrant (lower right) of the figure. Edwards and Brown (1998) also noted that the current PCCS constraint for Al_2O_3 (≥ 3.0 wt%) is not sufficient to avoid compositions that may be near the homogeneity PAR that have unacceptable PCT values. The latter is shown by the presence of glasses with log NL [B] > 1.0 above the Al_2O_3 = 3.0 wt% limit (as denoted by the horizontal dashed line). However, the data from the MB2 (Tank 42) variability study suggest that implementing either Criterion (1) or Criterion (2) (as discussed above) would increase the assurance of producing a durable product from Tank 42 material.

Therefore, by relaxing the homogeneity constraint (to the PAR) and imposing one of the two equivalent criteria, the operational window for MB2 was increased dramatically.[b] It should also be noted that the upper limit on the sum of alkali (ΣM_2O = 19.3 wt%) and the lower limit on Al_2O_3 (≥ 3 wt%) was defined by the homogeneous WCP PUREX (PX) glass (with label of 0.45 in Figure 1.1).

Before recommending this potential change to DWPF, Edwards and Brown (1998) evaluated these potential criteria from a larger, existing database (> 1300 data points) to gain a better understanding of the relationship between the alumina and the sum of alkali and the leaching behavior. This evaluation tested the application of one of the equivalent criteria over a larger compositional window and provided some measure of confidence for their application. The database (at that time) consisted of the data used for:

- Thermodynamic Hydration Energy Reaction Model (THERMO™) model development and validation (Jantzen et al. 1995),
- the sludge-only processing glasses of the Tank 51 variability study (Peeler 1996a, Peeler 1996b),
- two pour-stream samples from Macrobatch 1 (Edwards 1997),
- the Pacific Northwest National Laboratory (PNNL) Composition Variation Study (CVS) glasses (Hrma et al. 1994), and
- the glasses from the Tank 42 variability study (Edwards and Brown 1998; Edwards 1999).[c]

(a) A value of log NL [B] > 1.0 is used as a conservative metric relative to a lower bound for EA leaching whose mean is approximately 1.22 (Jantzen et al. 1993).
(b) It should be noted that the homogeneity PAR was still required for MB2 because the data used to develop these constraints were from quenched glasses. The effect of kinetics (i.e., slow thermal cool down) was not included, and the impact on durability was not known.
(c) Over 3900 triplicate analyses (whose logarithms were averaged for each glass sample tested) formed the extensive database.

It should be noted that the majority of the property-composition data in the database were based on glasses that had been quenched from the melt temperature, although a significant number of the data were collected from canisters poured from the Integrated DWPF Melter System (IDMS).

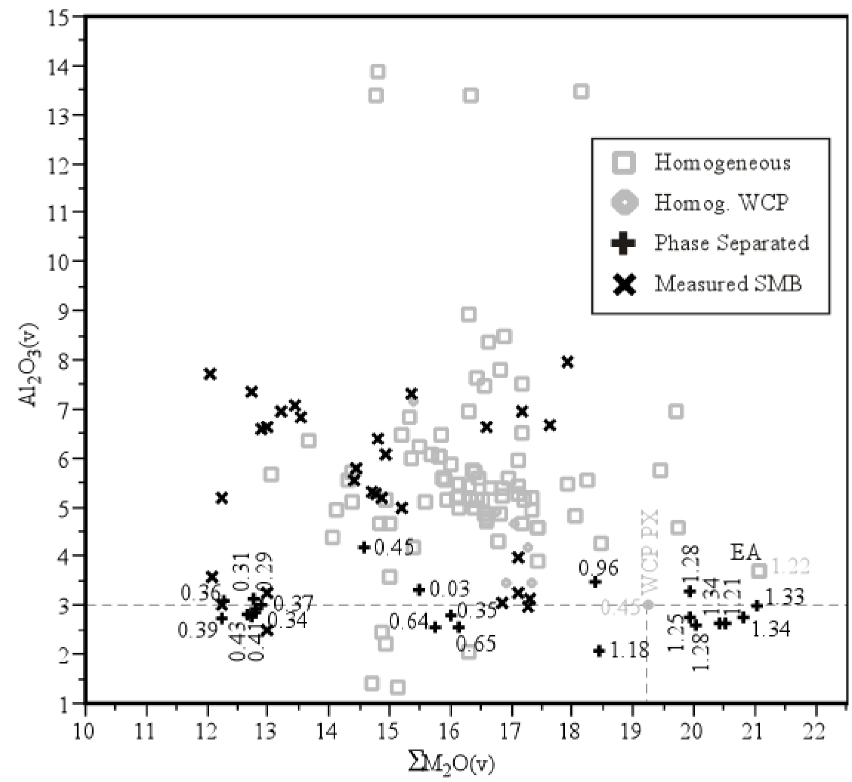

Figure 1.1. Al_2O_3 (wt%) Versus ΣM_2O (wt%) for the Glasses Used to Define the Discriminator and the MB2 (Tank 42) Variability Study Glasses (from Edwards and Brown [1998] where the $\Sigma M_2O = Na_2O + Li_2O + Cs_2O + K_2O$ wt%)

Figure 1.2 provides a plot of alumina versus ΣM_2O (wt%) content for the glasses in the compiled database. Figure 1.3 shows the data for only those glasses having log NL [B] > 1.0. When applying either of the proposed criteria (in conjunction with relaxing the homogeneity constraint to the PAR), all but six glasses would be eliminated from potential processing. As noted by Edwards and Brown (1998), these six glasses were outside the feasible composition range for glasses expected to be produced during the processing of MB2. More specifically, these glasses contained either low concentrations of Fe_2O_3 (< 2.5 wt%) or high concentrations of B_2O_3 (> 19.6 wt%). All other glasses that were evaluated within the composition region of interest with Al_2O_3 exceeding 3 wt% and the ΣM_2O less than 19.3 wt% provide PCT results for boron significantly better than those for the EA standard glass (Jantzen et al. 1993). The data also indicated that if the lower limit for Al_2O_3 were increased to 4.0 wt%, there was not a need to add an upper sum of alkali constraint (over the composition range tested) to avoid glasses that may leach as poorly as EA.

Based on analysis of the compiled database, Edwards and Brown (1998) determined that the imposition of the measurement uncertainty requirement on the homogeneity constraint (necessary to ensure reliable durability prediction) unnecessarily restricted DWPF operation for expected MB2 glass compositions. These data indicated that it was possible to relax the homogeneity measurement uncertainty requirement (to the PAR) for MB2 as long as Criterion (1) or Criterion (2) were satisfied. As noted by Edwards and Brown (1998), measurement uncertainty (at the 95% confidence limit) should be applied to the new alumina constraint and/or the coupled alumina and alkali constraint, if used.[a]

These recommendations were transmitted to and implemented by DWPF for MB2. Radioactive glasses produced at DWPF have been analyzed and have been found to be consistent with the results discussed above (Fellinger and Bibler 2000). The analysis by Edwards and Brown (1998) led to a larger compositional window for MB2 without compromising product quality.

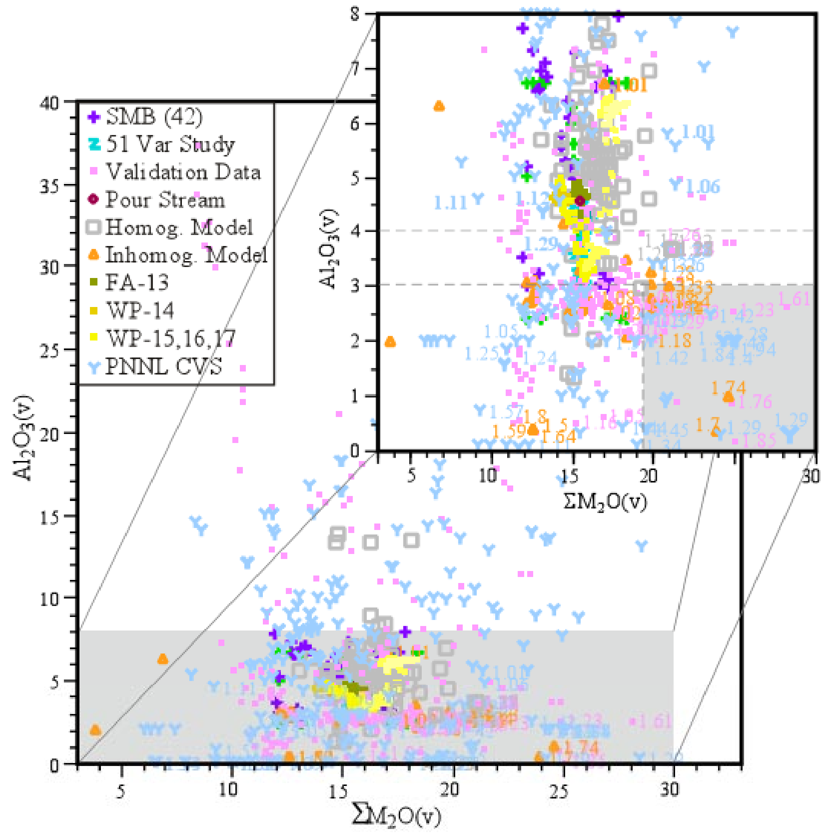

Figure 1.2. Al_2O_3 (wt%) Versus ΣM_2O (wt%) for the Existing Database (from Edwards and Brown [1998] where the $\Sigma M_2O = Na_2O + Li_2O + Cs_2O + K_2O$ wt%)

(a) The application of these two constraints applies only to the MB2 compositional envelope evaluated, which was based on a pool of candidate glasses for each sludge type: Tank 40 only and a blend of Tank 8 and Tank 40. More specifically, these constraints should not be applied to glasses outside this envelope, such as high B_2O_3 glasses.

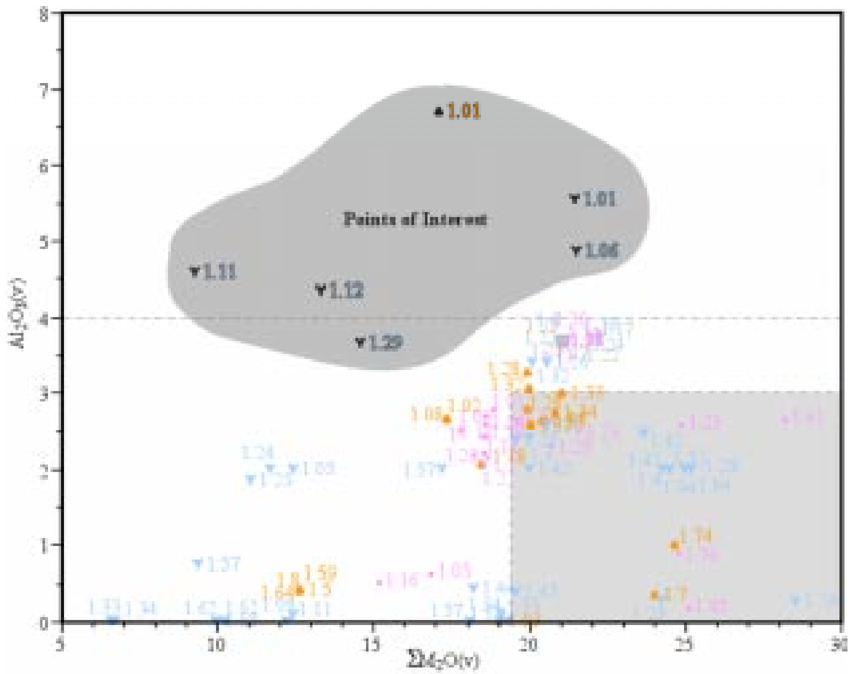

Figure 1.3. Al_2O_3 (wt%) Versus ΣM_2O (wt%) for Glasses with Log NL [B] > 1 (g/L) (from Edwards and Brown [1998] where the $\Sigma M_2O = Na_2O + Li_2O + Cs_2O + K_2O$ wt%)

Given the effectiveness of the application of the constraints associated with homogeneity for MB2 and the inherent limitations of the application of the homogeneity discriminator for MB3, an investigation into the application of these constraints to MB3 was performed (Peeler et al. 2000). The objective of that research was to provide the technical bases to relax the homogeneity measurement uncertainty requirement for MB3. To accomplish that objective, glass compositions were selected from a pool of candidate glasses (for each sludge type: Tank 40 only and a blend of Tank 8 and Tank 40) developed as part of the MB3 variability study (Harbour et al. 2000). The systematic glass-selection process was focused specifically to support the reduction of constraints (RC) objective, which allowed for the examination of the conservatism in the homogeneity constraint. More specifically, all 24 MB3 glasses selected (based on the use of Frit 200) were predicted to be outside the homogeneity PAR, based upon the current homogeneity constraint using the targeted compositions of the selected glasses.

The PCT was performed on each glass to assess the chemical durability (for both quenched and centerline cooled [clc] versions). Peeler et al. (2000) reported that all Frit 200-based MB3 glasses (regardless of thermal history) had log NL [B] < 1.0 g/L. The PCT data indicated that as the Al_2O_3 concentration approached the lower limit of 3.0 wt% (in glass) and the sum of alkali content increased (up to ~20 wt%), the glasses tended to have higher release values (or lower durability). Again, it is noted that all the MB3 glasses were significantly more durable than EA as defined by the PCT.

The performance of the homogeneity constraint for the compositions tested for both the MB2 and MB3 glasses provided strong evidence that the imposition of the measurement uncertainty for this constraint unnecessarily restricts the DWPF operational window. Based on the results reported by Peeler et al. (2000), the technical bases to relax the homogeneity measurement uncertainty requirement for MB3 were established—consistent with the approach taken by Edwards and Brown (1998) for MB2.

Given the effectiveness of applying the supporting criteria associated with homogeneity for MB2 and MB3, and the potential limitations of the application of the homogeneity discriminator for projected "sludge-only" glasses (prediction may unnecessarily limit WLs), an investigation into the application of these criteria is warranted. In this report, an assessment of five individual (or bounding) waste types and the projected blends for sludge batch 2 and sludge batch 3 is made with regard to the potential limitation of the homogeneity constraint on sludge-only processing. The sludge-only composition region was defined based on five independent (and bounding) waste types and the projected sludge-only processing blending strategies as referenced in Revision 12 of the HLW System Plan (WSRC 2001). Frits used in this assessment to develop glass compositional envelopes (when coupled with waste or sludge compositions) included Frits 200, 165 and 320.[a] Glass compositions within this region were assessed (at the PAR) using the current PCCS models, including both the existing and newly developed T_L models, to support the use of a relaxed homogeneity constraint (to the PAR) coupled with application of one of the supporting criteria.

(a) It should be noted that Frit 200 was developed for "coupled" operations (Jantzen 1988). Frit 165 was developed to support the generic "sludge-only" flowsheet while Frit 320 was developed (Peeler et al. 2001b) specifically for MB3 (a sludge-only flowhseet).

2.0 Objective Statement

The overall objective of this task is to develop the fundamental technical data to eliminate the homogeneity measurement uncertainty requirement ***for projected sludge-only processing*** as long as the following criteria are satisfied:

Criterion (1)

- use the alumina constraint as currently implemented in PCCS ($Al_2O_3 \geq 3$ wt%) **and** add a sum of alkali[(a)] constraint with an upper limit of 19.3 wt% ($\Sigma M_2O <$ 19.3 wt%),

or

Criterion (2)

- adjust the lower limit on the alumina constraint to 4 wt% ($Al_2O_3 \geq 4.0$ wt%).

In this report, initial assessments (via computational evaluations relative to acceptable property limits) are made as to whether the homogeneity constraint has the potential to limit projected sludge-only processing. The composition region covered by this study includes five individual waste-stream types and two specific sludge batches (sludge batch 3 and sludge batch 4—hereafter referred to as SB3 and SB4, respectively) as defined in the HLW Waste System Plan (WSRC 2001) coupled with Frits 200, 165, and 320. The intended outcomes of this study are threefold:

(1) perform an initial screening assessment for homogeneity using centroid-based bounding waste and/or blending sludge compositions

(2) develop a pool of candidate glasses from which a subset can be selected and experimentally tested

(3) perform a second assessment of SB3 and SB4 composition regions incorporating potential sludge variation and its likely impact on projected operational windows for DWPF.

If it is shown that the homogeneity constraint cannot be unconditionally eliminated, then a path parallel to that used by Edwards and Brown (1998) for MB2 is still a viable option. This work has been prepared to address technical issues discussed in Technical Task Request HLW/DWPF/TTR-01-0002, Rev. 0 (TTR 2001) and in accordance with the Task and Technical quality assurance (QA) Plan (Peeler et al. 2001a).

(a) Alkalis included in this sum are Na_2O, Li_2O, Cs_2O, and K_2O. However, for sludge-only processing, neither Cs_2O nor K_2O is introduced at significant concentrations, so the sum of alkali is based solely on Na_2O and Li_2O.

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3.0 Definition of Bounding Waste Types

The purpose of this section is to provide five "basic" sludge compositions[(a)] that describe the remainder of expected sludge-only operations in DWPF. This is based upon Revision 12 of the HLW System Plan (WSRC 2001) and the WCSystem.xls (dated 4/17/2000) and WCSludge.xls (dated 4/17/2000) Excel® files containing the historic information concerning transfers and compositions in the 51 waste tanks. This task will be carried out in two steps. The first involves examining the sludge compositions that have been estimated from the historic information in WCSystem.xls and WCSludge.xls versus the corresponding compositions measured in DWPF to see if adjustments appear necessary to the historic projections. Then the feeds from the tanks expected for the remainder of sludge-only operation will be segregated into the "basic" sludge types (e.g., H Modified High Heat Fresh [HHF] Feed, (PUREX) Low Heat Fresh [PLF] Feed, PUREX Mixed Fresh [PMF] Feed, etc.). These will be maintained in WCSludge.xls and then adjusted if found necessary. These basic types will then be used to examine the applicability of the homogeneity constraint for the remainder of DWPF sludge-only operation.

3.1 Historic Versus Measured Sludge Information for Tank 51 (SB1a)

Essentially, two sludge batches (SB1a and SB1b) have been processed through DWPF to date. The first sludge batch (SB1a) was comprised of Tank 51 material. According to WCSludge.xls, the transfer history for Tank 51 before its becoming feed material for DWPF is:

Tank 51 (SB1a) Transfer Summary:

- No transfers from 221 to Tank 51
- 5 transfers from Tank 18 to Tank 51 from 7/86 through 8/87
- **Tank 18 Transfer Summary**
  - 31 (PLF) transfers from 221 to Tank 18 from 8/59 through 3/77
  - 11 transfers from Tank 17 to Tank 18 from 12/79 through 6/81
  - 1 transfer from Tank 17 to Tank 18 in 4/97
  - **Tank 17 Transfer Summary**
    - 111 (PLF) transfers from 221 to Tank 17 from 5/61 through 9/77
    - 11 transfers from Tank 17 to Tank 18 from 12/79 through 6/81
    - 1 transfer from Tank 17 to Tank 18 in 4/97
  - 5 transfers from Tank 18 to Tank 42 from 9/86 to 11/86
  - 7 transfers from Tank 18 to Tank 40 from 10/86 to 1/87
  - 5 transfers from Tank 18 to Tank 51 from 7/86 to 8/87
- Transfer from Tank 21 to Tank 51 in 9/86
- **Tank 21 Transfer Summary**
  - 30 (H modified low heat feed [HLF]) transfers from 221 to Tank 21 from 4/76 through 5/81
  - 1 transfer from Tank 16 to Tank 21 in 11/79

(a) These five compositions will be combined with three frits at three sludge loadings to provide 45 glasses for further study.

  - Tank 16 Transfer Summary
- 24 (15 H modified mixed fresh [HMF] feed and 9 HLF) transfers from 221 to Tank 16 from 5/59 through 2/70
- 4 transfers to Tank 15 from 12/78 through 3/79
- 1 transfer from Tank 16 to Tank 21 in 11/79
  - 1 transfer from Tank 22 to Tank 21 in 9/86
  - Tank 22 Transfer Summary
- 46 (HLF) transfers from 221 to Tank 22 from 7/74 through 10/80
- 1 transfer from Tank 22 to Tank 51 in 7/86
- 1 transfer from Tank 22 to Tank 21 in 9/86
- 1 transfer from Tank 22 to Tank 40 in 9/86
  - 2 transfers from Tank 21 to Tank 42 in 9/86
  - 1 transfer from Tank 21 to Tank 51 in 9/86
- Transfer from Tank 22 to Tank 51 in 7/86
- **Tank 22 Transfer Summary**
  - See above
- *Transfer from Tank 51 to DWPF begun in 9/96*

Therefore, the Tank 51 (SB1a) sludge feed consisted of Fresh (F) Low (L) Heat PUREX (P) and H Modified (H) type feeds from various tanks where XYZ indicates HM or PUREX, Low or High Heat, and Age, respectively. Inventories of both the sludge and supernate fractions of the Tank 51 material are maintained in WCSludge.xls and WCSystem.xls, respectively. For the sludge fraction, the inventory in WCSludge.xls can be converted to those cations and corresponding oxides important to the prediction of glass quality and processing behavior as indicated in Table 3.1.

Similar projections can be made for the supernate fraction for Tank 51 as illustrated in Table 3.2. The sludge slurry that has been processed through DWPF was some unknown combination of the streams represented in Tables 3.1 and 3.2. It will be determined if the historic information and that measured for the Tank 51 sludge are consistent.

Table 3.1. Conversion of Tank 51 Sludge Inventory to Oxide Concentrations

Tank 51											
Source	**kg**		**kg-moles**	**kg**	**cation/Fe**	**Fe/cation**		**kg-moles**	**kg**	**oxide%**	**cat%**
AgOH	813.4	Ag	6.51	702.6	1.11E-02	90.0	AgO	6.51	806.8	0.50%	0.44%
$Al(OH)_3$	41970.1	Al	538.05	14517.5	2.30E-01	4.4	Al_2O_3	269.03	27430.2	17.08%	9.04%
$BaSO_4$	757.5	Ba	3.25	445.7	7.05E-03	141.9	BaO	3.25	497.7	0.31%	0.28%
$Ca_3(PO_4)_2$	435.6	Ca	160.46	6431.1	1.02E-01	9.8	CaO	160.46	8998.2	5.35%	3.82%
CaC_2O_4	2.8										
$CaCO_3$	13552.7										
CaF_2	761.9										
$CaSO_4$	1505.2										
$Ce(OH)_3$	1124.6	Ce	5.88	824.4	1.30E-02	76.7	CeO_2	5.88	1012.7	0.63%	0.51%
$Co(OH)_3$	58.3	Co	0.53	31.2	4.94E-04	2025.4	CoO	0.53	39.7	0.02%	0.02%
$Cr(OH)_3$	1022.5	Cr	9.93	516.1	8.16E-03	122.5	Cr_2O_3	4.96	754.3	0.47%	0.32%
$Cu(OH)_2$	550.4	Cu	5.64	358.5	5.67E-03	176.4	CuO	5.64	448.8	0.28%	0.22%
$Fe(OH)_3$	121025.4	Fe	1132.46	63244.7	1.00E+00	1.0	Fe_2O_3	566.23	90422.8	56.32%	39.39%
HgO	747.7	Hg	3.45	692.5	1.09E-02	91.3	HgO	3.45	747.7	0.47%	0.43%
KNO_3	2030.7	K	20.08	785.4	1.24E-02	80.5	K_2O	10.04	946.0	0.59%	0.49%
$La(OH)_3$	578.4	La	3.05	423.0	6.69E-03	149.5	La_2O_3	1.52	496.1	0.31%	0.26%
$Mg(OH)_2$	640.4	Mg	10.98	266.9	4.22E-03	236.9	MgO	10.98	442.6	0.28%	0.17%
MnO_2	4196.4	Mn	48.27	2651.8	4.19E-02	23.8	MnO	48.27	3424.1	2.13%	1.65%
Na_2SO_4	0.4	Na	418.12	9612.6	1.52E-01	6.6	Na_2O	209.06	12957.5	8.07%	5.99%
Na_3PO_4	0.0										
NaCl	5091.2										
NaF	0.3										
NaI	86.4										
$NaNO_3$	3651.6										
NaOH	11497.5										
$Ni(OH)_2$	0.0	Ni	0.00	0.0	0.00E+00	-	NiO	0.00	0.0	0.00%	0.00%
$PbCO_3$	17.8	Pb	3.40	704.9	1.11E-02	89.7	PbO	3.40	759.3	0.47%	0.44%
$PbSO_4$	1011.5										

Tank 51											
Source	**kg**		**kg-moles**	**kg**	**cation/Fe**	**Fe/cation**		**kg-moles**	**kg**	**oxide%**	**cat%**
$Pr(OH)_3$	543.6	Pr	2.83	399.1	6.31E-03	158.5	Pr_2O_3	3.33	1099.1	0.68%	0.25%
RuO_2	1541.6	Ru	11.59	1170.9	1.85E-02	54.0	RuO_2	11.59	1541.6	0.96%	0.73%
SiO_2	4265.0	Si	70.98	1993.6	3.15E-02	31.7	SiO_2	70.98	4265.0	2.66%	1.24%
$SrCO_3$	267.1	Sr	1.81	158.5	2.51E-03	399.0	SrO	1.81	187.5	0.12%	0.10%
ThO_2	0.1	Th	0.00	0.1	1.59E-06	628744.7	ThO_2	0.00	0.1	0.00%	0.00%
TiO_2	0.0	Ti	0.00	0.0	0.00E+00	-	TiO_2	0.00	0.0	0.00%	0.00%
$UO_2(OH)_2$	8765.9	U	28.83	6862.7	1.09E-01	9.2	U_3O_8	9.61	8092.8	5.04%	4.27%
$Zn(OH)_2$	1067.8	Zn	10.74	702.3	1.11E-02	90.1	ZnO	10.74	874.2	0.54%	0.44%
$ZrO(OH)_2$	1961.2	Zr	13.89	1266.7	2.00E-02	49.9	ZrO_2	13.89	1711.0	1.07%	0.79%
Int. Zeolite	0.0	P	2.81	87.0	1.38E-03	726.9	P_2O_5	1.40	199.4	0.12%	0.05%
Total	231594.1		2513.55	114849.8				1432.58	168155.1	100.00%	68.30%

Table 3.2. Conversion of Tank 51 Supernate Inventory to Cation Masses

Tank	**kg**	**kg-moles**		**kg**
Ag (kg)	0.18	0.00	Ag	0.18
Al (kg)	0.00	0.00	Al	543.12
$Al(OH)_4$ (kg)	1831.34	20.13		
As (kg)	53.86	0.72	As	53.86
B (kg)	0.00	0.00	B	0.00
Ba (kg)	0.00	0.00	Ba	0.00
Benzene (kg)	0.00			
Ca (kg)	3.61	0.09	Ca	3.61
Cd (kg)	0.00	0.00	Cd	0.00
Cl (kg)	23.92	0.67		
Co (kg)	0.41	0.01	Co	0.41
Cr (kg)	609.45	11.72	Cr	609.45
Cs (kg)	0.72	0.01	Cs	0.72
Cu (kg)	0.00	0.00	Cu	0.00
CO_3 (kg)	4626.74			
C_2O_4 (kg)	1102.78			
Fe (kg)	0.02	0.00	Fe	0.02
F (kg)	43.94			
Hg (kg)	110.87	0.55	Hg	110.87
Sample K (kg)	97.97	2.51	K	97.97
K Check (kg)	89.30			
Mg (kg)	0.20	0.01	Mg	0.20
Mn (kg)	0.17	0.00	Mn	0.17
Mo (kg)	0.00			
Na (kg)	61190.25	2661.63	Na	61190.25
Nd (kg)	47.36	0.33	Nd	47.36
Ni (kg)	0.76	0.01	Ni	0.76
NO_2 (kg)	10641.13			
NO_3 (kg)	7768.48			
O/A (kg)				
OH (kg)	1639.09			
Pb (kg)	0.00	0.00	Pb	0.00
Pu (kg)	0.00	0.00	Pu	0.00
PO_4 (kg)	57.66	0.61	P	18.81
Ru (kg)	4.78	0.05	Ru	4.78
Se (kg)	787.25	9.97	Se	787.25
Si (kg)	0.00	0.00	Si	0.00
Sr (kg)	20.44	0.23	Sr	20.44
SO_4 (kg)	1018.34			
Ti (kg)	0.00	0.00	Ti	0.00
TPB (kg)	0.00			
U (kg)	0.00	0.00	U	0.00
Zn (kg)	53.32	0.82	Zn	53.32
Zr (kg)	0.22	0.00	Zr	0.22

Before processing the Tank 51 material, the information (based upon measurements) in Table 3.3 was available from a number of sources. Note that the ratios of the concentration of the major insoluble component, namely Fe, to those of the various other major insoluble cations (e.g., Ca, Mn, etc.) from sludge remained reasonably invariant for the sample information in Table 3.3. The large variation in the ratios for cations such as Na or Mg are due to washing or the presence of these cations in the frit added to make melter feed from the sludge.

However, the Tank 51 (SB1a) material has been processed in DWPF and, therefore, sample information exists concerning all the batches of Tank 51 (or SB1a) material processed through DWPF. This sample information (for the median SB1a results) is summarized in Table 3.4a for the Sludge Receipt and Adjustment Tank (SRAT) and 3.4b for the melter feed (i.e., SME and the Melter Feed Tank [MFT]).(a) Median values were selected because 1) there were many outlying values and 2) medians tend to be insensitive to outliers and processing differences (that were apparent in the DWPF measurement information). A couple of observations can be made concerning the DWPF SB1a sample information:

- The SME and MFT Fe/Al and Fe/Cr ratios were generally smaller than those in both the measured DWPF SRAT information and the pre-processing information.
- The DWPF SRAT measurements provide higher Fe/Na ratios than were found in the pre-processing information for washed sludge.

However, the purpose is to attempt to relate the measured compositions from processing the SB1a material in DWPF to the compositions that can be projected from the historic information in WCSludge.xls and WCSystem.xls. As indicated above, these files contain information concerning the sludge and supernate fractions in Tank 51; however, it is not known exactly what fraction of the supernate was transferred to DWPF with the sludge as slurry. Thus, a range of possible fractions (“fract”) of supernate solids (to cover a broad range of Fe/Na) were tested as illustrated in Table 3.5.

(a) The terms “Init” and “Final” denote which set of data the measurements represent. Before DWPF Batch 44 (or the “Init” phase), the Mixed Acid (MA) and Peroxide Fusion (PF) analyses are not provided, only the data selected by DWPF.

Table 3.3. Summary of Measured Tank 51 Information Available Prior to Processing in DWPF

	Sludge 2xWashed, CPES[(a)]		Sludge Unwashed[(b)]		Sludge Washed, Measured[(c)]		SRAT Sludge-Only[(c)]		SME Sludge-Only[(c)]		Tank 51H Sludge Feed[(d)]	
	wt%	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**
Al	6.904	4.3	5.4	4.3	6.36	4.1	5.8	3.9	2.29	4.0	6.39	3.8
Ca	2.761	10.6	2.2	10.6	2.39	10.8	2.16	10.5	0.87	10.5	2.38	10.3
Cr	0.1715	171.4	0.13	180.0	0.19	135.8	0.18	126.1	0.196	46.4	0.17	144.7
Cu	0.02507	1172.7	0.02	1170.0	0.038	678.9	0.027	840.7	0.25	36.4	0.03	820.0
Fe	29.4	**1.0**	23.4	**1.0**	25.8	**1.0**	22.7	**1.0**	9.1	**1.0**	24.6	**1.0**
K	0.1085	271.0	0.07	334.3	NM	NM	0.058	391.4	0.03	303.3	0.05	492.0
Mg	1.378	21.3	1.1	21.3	1.2	21.5	1.05	21.6	*1.18*	7.7	1.16	21.2
Mn	3.075	9.6	2.45	9.6	2.61	9.9	2.4	9.5	0.899	10.1	2.53	9.7
Na	10.05	2.9	14.5	*1.6*	9.4	*2.7*	9.5	2.4	*9.6*	*0.9*	8.74	2.8
Ni	0.2925	100.5	0.23	101.7	0.33	78.2	0.28	81.1	0.16	56.9	0.26	94.6
Pb	0.1305	225.3	NM	NM	NM	NM	0.09	252.2	0.05	182.0	NM	NM
Ru	0.007141	4117.1	0.005	4680.0	NM	NM	NM	NM	NM	NM	0.0026	9461.5

[a] A.S. Choi, HLW Flowsheet Material Balance for WPF RAD Operation with Tank 51 Sludge and ITP Cycle 1 Precipitate, WSRC-TR-95-0019, Westinghouse Savannah River Company, Aiken, SC.

[b] M.S. Hay, Estimated Batch 1 Sludge Insoluble Solids Composition Based on the Analysis of ESP Baselining Test Samples From Tank 51 (U), SRT-LWP-94-086, Westinghouse Savannah River Company, Aiken, SC.

[c] D. Ferrara, Shielded Celss Batch 1 – Sludge-Only Campaign with Tank 51 Sludge and Frit 200, WSRC-TR-95-0481, Rev. 0, Westinghouse Savannah River Company, Aiken, SC.

[d] M.S. Hay and N.E. Bibler, The Characterization of Tank 51H Sludge Feed for DWPF and Comparison to ESP Process Requirements, WRSC-RP-95-1048, Westinghouse Savannah River Company, Aiken, SC.

	Sludge		Sludge		Sludge		SRAT		SME		Tank 51H	
	2xWashed, CPES[(a)]		Unwashed[(b)]		Washed, Measured[(c)]		Sludge-Only[(c)]		Sludge-Only[(c)]		Sludge Feed[(d)]	
	wt%	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**	**wt%**	**Fe/cation**
Si	0.7456	39.4	0.59	39.7	0.6	43.0	0.65	34.9	*23.2*	0.4	0.63	39.0
Th	0.0392	750.0	NM	NM	NM	NM	0.19	119.5	0.06	151.7	NM	NM
Ti	0.0418	703.3	0.03	780.0	0.016	1612.5	0.012	1891.7	0.021	433.3	0.02	1230.0
U	2.648	11.1	2.11	11.1	3.21	8.0	NM	NM	NM	NM	3.42	7.2
Zr	6.91E-05	425531.9	NM	NM	NM	NM	0.007	3242.9	0.08	113.8	NM	NM

NM = Not measured

Table 3.4a. Summary of Measured DWPF SB1a SRAT Information

	SRAT Receipt		SRAT Product	
	Median		Median	
	wt%	Fe/cation	wt%	Fe/cation
Al	6.794	3.9	6.283	3.8
Ca	2.529	10.4	2.036	11.6
Cr	0.175	150.2	0.163	145.3
Cu	0.283	92.6	0.024	1003.0
Fe	26.236	**1.0**	23.653	**1.0**
K	0.037	702.0	0.040	588.9
Mg	1.274	20.6	0.964	24.5
Mn	2.769	9.5	2.472	9.6
Na	6.063	4.3	6.978	3.4
Ni	0.293	89.4	0.270	87.6
Si	0.741	35.4	0.671	35.2
Ti	0.014	1846.5	0.013	1775.1
U	2.856	9.2	2.678	8.8
Zr	0.017	1505.6	0.014	1709.9

Table 3.4b. Summary of Measured DWPF SB1a Melter Feed (i.e., SME and MFT) Information

Init SME Product			Final SME Product			Final SME Product			Init MFT Product			Final MFT Product			Final MFT Product		
	Median			MA Median*			PF Median*			Median			MA Median*			PF Median*	
	wt%	Fe/		wt%	Fe/		wt%	Fe/		wt%	Fe/		wt%	Fe/		wt%	Fe/
Al	2.353	3.6	**Al**	2.494	3.4	**Al**	2.455	3.3	**Al**	2.380	3.5	**Al**	2.511	3.4	**Al**	2.479	3.4
B	2.704	3.1	**B**	-	-	**B**	2.622	3.1	**B**	2.720	3.1	**B**	-	-	**B**	2.659	3.1
Ca	0.808	10.5	**Ca**	0.901	9.4	**Ca**	0.833	9.8	**Ca**	0.842	9.9	**Ca**	0.875	9.7	**Ca**	0.800	10.4
Cr	0.070	120.7	**Cr**	0.067	126.3	**Cr**	0.069	117.8	**Cr**	0.072	116.6	**Cr**	0.066	128.8	**Cr**	0.069	121.3
Cu	0.321	26.4	**Cu**	0.012	727.2	**Cu**	0.013	645.1	**Cu**	0.332	25.1	**Cu**	0.012	725.3	**Cu**	0.013	637.9
Fe	8.477	**1.0**	**Fe**	8.423	**1.0**	**Fe**	8.171	**1.0**	**Fe**	8.336	**1.0**	**Fe**	8.510	**1.0**	**Fe**	8.346	**1.0**
K	0.086	99.0	**K**	0.152	55.3	**K**	0.115	71.1	**K**	0.094	88.8	**K**	0.147	58.0	**K**	0.121	68.7
Li	1.707	5.0	**Li**	1.661	5.1	**Li**	1.613	5.1	**Li**	1.734	4.8	**Li**	1.668	5.1	**Li**	1.632	5.1
Mg	1.281	6.6	**Mg**	1.284	6.6	**Mg**	1.256	6.5	**Mg**	1.272	6.6	**Mg**	1.292	6.6	**Mg**	1.255	6.7
Mn	0.829	10.2	**Mn**	0.862	9.8	**Mn**	0.825	9.9	**Mn**	0.826	10.1	**Mn**	0.852	10.0	**Mn**	0.833	10.0
Na	8.841	1.0	**Na**	8.804	1.0	**Na**			**Na**	8.956	0.9	**Na**	8.847	1.0	**Na**		
Ni	0.107	79.2	**Ni**	0.100	84.6	**Ni**	0.104	78.4	**Ni**	0.106	78.8	**Ni**	0.105	81.0	**Ni**	0.103	80.8
Si	23.194	0.4	**Si**	22.869	0.4	**Si**	24.446	0.3	**Si**	23.620	0.4	**Si**	22.887	0.4	**Si**	24.586	0.3
Ti	0.020	434.7	**Ti**	0.021	398.9	**Ti**	0.019	439.7	**Ti**	0.016	537.8	**Ti**	0.023	373.0	**Ti**	0.018	457.3
U	1.074	7.9	**U**	1.100	7.7	**U**			**U**	1.058	7.9	**U**	1.126	7.6	**U**		
Zr	0.016	546.9	**Zr**	0.053	160.2	**Zr**			**Zr**	0.013	658.1	**Zr**	0.052	162.8	**Zr**		

* Mixed Acid (MA) and Peroxide Fusion (PF)

Table 3.5. Historic SB1a Compositions as a Function of Supernate Loading

	mass Fe/cation					
fract	0	0.05	0.1	0.15	0.2	0.25
Al	4.4	4.3	4.3	4.3	4.3	4.3
Ca	9.8	9.8	9.8	9.8	9.8	9.8
Cr	122.5	115.7	109.6	104.1	99.1	94.6
Cu	176.4	176.4	176.4	176.4	176.4	176.4
Fe	1.0	1.0	1.0	1.0	1.0	1.0
K	80.5	80.0	79.5	79.1	78.6	78.1
Mg	236.9	236.9	236.9	236.9	236.9	236.9
Mn	23.8	23.8	23.8	23.8	23.8	23.8
Na	6.6	5.0	4.0	3.4	2.9	2.5
Ni	-	1655435.3	827717.6	551811.8	413858.8	331087.1
Si	31.7	31.7	31.7	31.7	31.7	31.7
Ti	-	-	-	-	-	-
U	9.2	9.2	9.2	9.2	9.2	9.2
Zr	49.9	49.9	49.9	49.9	49.9	49.9

When the range of compositions computed in Table 3.5 are compared to the measured values for SB1a sludge, it is apparent that:

- The Fe/Al ratio is significantly higher in projections than in measurements for all but the original, unwashed (and hence also Chemical Process Evaluation System (CPES)) values, which may indicate that more Al is soluble than projected and/or that the Fe is higher in projections than in the slurry transferred to DWPF.
- The Fe/Ca ratio is comparable in projections to that obtained from measurements of the sludge feed.
- The Fe/Cr ratio appears lower in projections than in the measured feed to DWPF, but the Cr is a minor component that is present in both soluble and insoluble forms; therefore, no reasonable conclusions can be drawn from the above information.
- The Cu concentrations appear to be specious, which may be a result of being at or below the detection limit for the measurements.
- There may be an indication that the Fe fed to DWPF may be lower, in general, than projected, based upon tank histories.
- The Fe/K ratio appears lower in projections than in the measured feed to DWPF, but the K is a minor component that is present in both soluble and insoluble forms. Therefore, no reasonable conclusions can be drawn from the above information (although the ratios from the projections appear fairly consistent with those from the vitrified analyses on the Tank 51 material).
- The Fe/Mg ratios in projections are higher by almost an order of magnitude than those in the feeds to DWPF. It has recently been determined that slag and crushed crucibles rich in MgO were periodically fed to the waste tanks from canyon separations and, therefore, it is likely that there is more Mg in the waste tanks than the projections account for, and there may be less Fe than accounted for.

- The Fe/Mn ratios appear to be higher by more than a factor of 2 than those in the melter feed processed in DWPF, which may be attributable to more Mn and/or less Fe in the actual feed than accounted for in projections.
- No conclusions concerning the Na can be made as the tests were “designed” to cover the ranges found, based upon measurement.
- Projections indicate that there should be almost no Ni in the tanks, whereas, measurements indicate that measurable quantities are present. However, most of these are likely fairly close to detection limits; therefore, no definitive conclusions can be made.
- The Fe/Si ratios appear to be slightly lower in projections versus the melter feed processed in DWPF. This is the first indication that the Fe might not necessarily be lower, in general, in the material processed in DWPF versus that in projections.
- The Fe/U ratios appear to be somewhat higher in projections than in the melter feed processed in DWPF, indicating that there is more U and/or less Fe in the actual sludge than in the projections made using WCSludge.xls and WCSystem.xls information.
- The Zr concentrations appear to be specious, which may be a result of being at or below the detection limit for the measurements.

3.2 Historic Versus Measured Sludge Information for Tank 42 (SB1b)

A similar analysis can be made on the Tank 42 (or SB1b) material. The transfer history for Tank 42 (before feeding to DWPF) indicates that, ignoring the Tank 51 heel, the Tank 42 (or SB1b) sludge consists of Fresh (F) Low (L) Heat PUREX (P) and Low, Mixed (M), and High (H) Heat HM (H) type feeds from various tanks. However, the Tank 51 heel material consists of Fresh (F) Low (L) Heat PUREX (P) and HM (H) type feeds. Inventories of both the sludge and supernate fractions of the Tank 42 material are maintained in WCSludge.xls and WCSystem.xls, respectively. For the sludge fraction, the inventory can be converted to those cations and oxides important to glass quality as was done for the SB1a material in Tables 3.1 and 3.2. The Tank 42 slurry feed to DWPF will be some combination of sludge and supernate streams (and the remaining Tank 51 heel).

In fact, much of the SB1b material has been processed through DWPF, and a summary of the DWPF measurements for this material is provided in Table 3.6. Median values were again selected, as they tend to be insensitive to outliers and processing differences. The measurement information will be compared to that projected from various combinations of the historic Tank 42 sludge and supernate information. This information does not provide the fraction of the supernate that was transferred to DWPF with the sludge as slurry. Because of this, a range of possible fractions of supernate solids (to cover the ratio of Fe/Na) was tested as illustrated in Table 3.7.

Table 3.6. Summary of Measured DWPF SB1b Melter Feed Information

	SRAT Product Median			SME Product MA Median*			SME Product PF Median*			MFT Product MA Median*			MFT Product PF Median*	
	wt%	**Fe/cation**		**wt%**	**Fe/cation**		**wt%**	**Fe/cation**		**wt%**	**Fe/cation**		**wt%**	**Fe/cation**
Al	7.618	2.7	**Al**	3.150	2.5	**Al**	3.151	2.4	**Al**	3.024	2.4	**Al**	2.959	2.4
B	0.010	2050.5	**B**	-	-	**B**	2.514	*3.1*	**B**	-	-	**B**	2.600	*2.8*
Ca	2.325	8.8	**Ca**	0.953	8.1	**Ca**	0.928	8.3	**Ca**	0.878	8.3	**Ca**	0.845	8.5
Cr	0.134	153.4	**Cr**	0.058	134.3	**Cr**	0.060	128.5	**Cr**	0.057	127.9	**Cr**	0.059	121.7
Cu	0.035	594.4	**Cu**	0.015	535.7	**Cu**	0.016	477.5	**Cu**	0.015	502.1	**Cu**	0.015	487.6
Fe	20.505	**1.0**	**Fe**	7.768	**1.0**	**Fe**	7.679	**1.0**	**Fe**	7.323	**1.0**	**Fe**	7.192	**1.0**
K	0.123	167.0	**K**	0.170	45.6	**K**	0.151	50.8	**K**	0.189	38.7	**K**	0.154	46.7
Li	0.009	2321.3	**Li**	1.591	*4.9*	**Li**	1.559	*4.9*	**Li**	1.663	*4.4*	**Li**	1.614	*4.5*
Mg	1.115	18.4	**Mg**	1.247	*6.2*	**Mg**	1.226	*6.3*	**Mg**	1.257	*5.8*	**Mg**	1.215	*5.9*
Mn	3.190	6.4	**Mn**	1.192	6.5	**Mn**	1.172	6.6	**Mn**	1.069	6.8	**Mn**	1.038	6.9
Na	6.987	2.9	**Na**	8.258	*0.9*	**Na**			**Na**	8.006	*0.9*	**Na**		
Ni	0.317	64.7	**Ni**	0.128	60.6	**Ni**	0.125	61.4	**Ni**	0.120	61.2	**Ni**	0.118	61.1
Si	1.411	14.5	**Si**	23.066	*0.3*	**Si**	24.665	*0.3*	**Si**	23.429	*0.3*	**Si**	25.505	*0.3*
Ti	0.017	1183.0	**Ti**	0.047	166.4	**Ti**	0.036	213.9	**Ti**	0.059	123.8	**Ti**	0.035	207.0
U	2.698	7.6	**U**	1.102	7.0	**U**			**U**	1.054	6.9	**U**		
Zr	0.058	356.4	**Zr**	0.082	94.5	**Zr**			**Zr**	0.079	92.4	**Zr**		

* Mixed Acid (MA) and Peroxide Fusion (PF)

Table 3.7. Historic SB1b Compositions as a Function of Supernate Loading

	Fe/cation		
fract	0	0.01	0.02
Al	2.6	2.6	2.6
Ca	10.3	10.3	10.3
Cr	124.2	118.1	112.4
Cu	207.3	200.3	193.7
Fe	1.0	1.0	1.0
K	92.2	82.4	74.5
Mg	153.7	153.7	153.7
Mn	16.7	16.7	16.7
Na	6.4	3.3	2.2
Ni	8828.7	8723.1	8619.9
Si	20.6	20.6	20.6
Ti	-	-	-
U	12.2	12.2	12.2
Zr	50.9	50.9	50.9

When compared to the results from the measured values for SB1b sludge, it is apparent that:

- The projected Fe/Al ratio may be slightly higher than in the melter feed processed in DWPF. In the Tank 51 material, this difference was larger.
- The projected Fe/Ca ratio is slightly higher than that obtained from measurements of the sludge fed to DWPF. This is the same as found for the Tank 51 material.
- The Fe/Cr ratio appears slightly lower in projections than in the measured feed to DWPF, but the Cr is a minor component that is present in both soluble and insoluble forms; consequently, no reasonable conclusions can be drawn from the above information.
- The Cu concentrations appear to be less than half of that obtained from the measurements of the material processing in DWPF; however, this is a minor component and no meaningful conclusions can likely be drawn from this information.
- There may be an indication that the Fe fed to DWPF may be lower, in general, than projected, based upon tank histories.
- The K is a minor component that is present in both soluble and insoluble forms, and hence no reasonable conclusions can be drawn from the above information.
- The Fe/Mg ratios in projections are higher by more than a factor of 8 than those in the feeds processed in DWPF. It has recently been determined that slag and crushed crucibles rich in MgO were periodically fed to the waste tanks from canyon separations and, therefore, it is likely that there is more Mg in the waste tanks than the projections account for, and there may be less Fe than accounted for.
- The Fe/Mn ratios appear to be higher by a factor of more than 2.5 than those in the material processed in DWPF, which may be attributable to more Mn and/or less Fe in the actual feed than accounted for in projections.
- No conclusions concerning the Na can be made as the tests were “designed” to cover the ranges found, based upon measurement.

- Projections indicate that there should be almost no Ni in the tanks, whereas, measurements indicate that measurable quantities may be present. However, most of these are likely fairly close to detection limits, and thus no definitive conclusions can be made.
- The Fe/Si ratios appear to be higher in projections versus the material processed in DWPF, which is different than in the Tank 51 material.
- The projected Fe/U ratios appear to be almost twice that in the material processed in DWPF, indicating that there is more U and/or less Fe in the actual sludge than in the projections made using WCSludge.xls and WCSystem.xls information.
- The Zr concentrations appear to be specious, which may be a result of being at or below the detection limit for the measurements.

3.3 Historic Versus Measured Sludge Information for Tank 40 (SB2)

A similar analysis can be made on the Tank 40 (or SB2) material. The transfer history for Tank 40 indicates that this material is comprised of Fresh Low Heat HM and PUREX plus the contribution from Tank 42 (which, as indicated above, consists of Fresh (F) Low (L) Heat PUREX (P) and Low, Mixed (M), and High (H) Heat HM (H) type feeds from various tanks). Tank 8 material was then transferred to Tank 40 to comprise the sludge in Tank 40 that became SB2. The Tank 8 material was comprised of Fresh (F) Low (L), Medium (M), and High (H) Heat PUREX feeds. However, there are only a handful of analyses on the actual sludge (and none in the DWPF), and, therefore, the Tank 40 information will not be used for subsequent analysis. A cursory look at the data does not indicate any major differences between the conclusions drawn from the SB1a and SB1b examinations.

3.4 Summary of Measured versus Projected Sludge Information

Because most insoluble species were indexed to the $Fe(OH)_3$ in WCSludge.xls, balances on $Fe(OH)_3$ for the Tank 51 (or SB1a) and Tank 42 (or SB1b) information provide estimates for the distributions of sludge types in these two sludge batches. These are provided in Tables 3.8a and 3.8b. Therefore, each of these sludge feeds to DWPF was comprised primarily of PLF and HLF type feeds. Summaries of the ratios of Fe to the cation concentrations for these sludge batches are provided in Tables 3.9a and 3.9b.

Table 3.8a. Approximate SB1a Waste Type Distributions Based upon $Fe(OH)_3$

	Source(s)	$Fe(OH)_3$ (kg)	%
Tank 51	16–18, 21, and 22	121025.4	100.00
PLF*	17 and 18	108440.6	89.60
HLF**	16, 21, and 22	12565.3	10.38
HMF***	16	18.1	0.01
HHF****	21	1.3	0.00

Table 3.8b. Approximate SB1b Waste Type Distributions Based upon $Fe(OH)_3$

	Source(s)	$Fe(OH)_3$ (kg)	%
Tank 42	15-18, 21, and 22	115068.9	100.00
PLF*	17 and 18	77350.9	67.22
HLF**	15, 16, 21, and 22	28573.3	24.83
HMF***	15 and 16	4475.0	3.89
HHF****	15 and 21	4670.6	4.06

* PLF – PX/Low Heat/Fresh Sludge
** HLF – HM/Low Heat/Fresh Sludge
*** HMF – HM/Mixed Heat/Fresh Sludge
**** HHF – HM/High Heat/Fresh Sludge

Table 3.9a. Summary Ratios of Fe to Other Cations for SB1a

51	SRAT		SME	SME Final		MFT	MFT Final			Tank 51 Sludge	
	Receipt	Product	Init	MA	PF	Init	MA	PF		Min	Max
Al	3.9	3.8	3.6	3.4	3.3	3.5	3.4	3.4	Al	4.3	4.3
B			*3.1*		*3.1*	*3.1*		*3.1*	*B*		
Ca	10.4	11.6	10.5	9.4	9.8	9.9	9.7	10.4	Ca	9.8	9.8
Cr	150.2	145.3	120.7	126.3	117.8	116.6	128.8	121.3	Cr	104.1	115.7
Cu	92.6	1003	26.4	727.2	645.1	25.1	725.3	637.9	Cu	176.4	176.4
Fe	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	Fe	1.0	1.0
K	702	588.9	99.0	55.3	71.1	88.8	58.0	68.7	K	79.1	80.0
Li			*5*	*5.1*	*5.1*	*4.8*	*5.1*	*5.1*	*Li*		
Mg	20.6	24.5	*6.6*	*6.6*	*6.5*	*6.6*	*6.6*	*6.7*	Mg	236.9	236.9
Mn	9.5	9.6	10.2	9.8	9.9	10.1	10.0	10.0	Mn	23.8	23.8
Na	4.3	3.4	*1.0*	*1.0*		*0.9*	*1.0*		Na	3.4	5.0
Ni	89.4	87.6	79.2	84.6	78.4	78.8	81.0	80.8	Ni	551811.8	1655435.3
Si	35.4	35.2	*0.4*	*0.4*	*0.3*	*0.4*	*0.4*	*0.3*	*Si*	31.7	31.7
Ti	1846.5	1775.1	434.7	398.9	439.7	537.8	373.0	457.3	Ti	-	-
U	9.2	8.8	7.9	7.7		7.9	7.6		U	9.2	9.2
Zr	1505.6	1709.9	546.9	160.2		658.1	162.8		Zr	49.9	49.9

Table 3.9b. Summary Ratios of Fe to Other Cations for SB1b

42	SRAT	SME Product		MFT Product			Tank 42 Sludge	
	Product	MA	PF	MA	PF		Min	Max
Al	2.7	2.5	2.4	2.4	2.4	Al	2.6	2.6
B	2050.5		*3.1*		*2.8*	B		
Ca	8.8	8.1	8.3	8.3	8.5	Ca	10.3	10.3
Cr	153.4	134.3	128.5	127.9	121.7	Cr	112.4	118.1
Cu	594.4	535.7	477.5	502.1	487.6	Cu	193.7	200.3
Fe	1.0	1.0	1.0	1.0	1.0	Fe	1.0	1.0
K	167.0	45.6	50.8	38.7	46.7	K	74.5	82.4
Li	2321.3	*4.9*	*4.9*	*4.4*	*4.5*	Li		
Mg	18.4	*6.2*	*6.3*	*5.8*	*5.9*	Mg	153.7	153.7
Mn	6.4	6.5	6.6	6.8	6.9	Mn	16.7	16.7
Na	2.9	*0.9*		*0.9*		Na	2.2	3.3
Ni	64.7	60.6	61.4	61.2	61.1	Ni	8619.9	8723.1
Si	14.5	*0.3*	*0.3*	*0.3*	*0.3*	Si	20.6	20.6
Ti	1183.0	166.4	213.9	123.8	207.0	Ti	-	-
U	7.6	7.0		6.9		U	12.2	12.2
Zr	356.4	94.5		92.4		Zr	50.9	50.9

In general, the following conclusions can be drawn concerning the SB1a and SB1b sludge types:

- There are no systematic trends in the Al data that may have to do with the ages of the various sludges and levels of washing.
- The projected Fe/Ca ratios are close to those measured in DWPF and from sludge samples.
- Cr is a minor constituent; however, the projected ratio appears to be a little lower than that measured in DWPF.
- Cu is a minor constituent; however, the projected Fe/Cu ratio appears to be consistently less than half of that measured in DWPF.
- There are indications that the projected Fe in these two sludge types may be (absolutely) higher than that measured in DWPF.
- K is a minor constituent, and no conclusions can be drawn from the information available.
- The projected Fe/Mg ratios are much higher than that measured in DWPF (neglecting those ratios on melter-feed data).
- The projected Fe/Mn ratios are more than 2 times that measured in DWPF.
- No conclusions can be drawn from the Na data.
- Ni is a minor constituent, and no conclusions can be drawn from these data except for the fact that the projected Fe/Ni ratios appear much higher than those measured in DWPF.
- Si is a minor constituent; however, the projected Fe/Si ratios appear to be in reasonable agreement with those measured in DWPF.
- Ti is a minor constituent, and no conclusions can be drawn from the information available.
- The projected Fe/U ratios are higher than those measured in DWPF.

- Zr is a minor constituent, and no conclusions can be drawn from the information available.

3.5 The Basic Insoluble Sludge Types in WCSludge.xls

The information for SB1a and SB1b can also be compared to that provided in WCSludge.xls for the basic sludge types that are supposed to comprise the insoluble fractions of the sludge to be fed to DWPF. This information is summarized in Table 3.10. As indicated in Tables 3.8a and 3.8b, the first two sludge batches (SB1a and SB1b) were expected to be comprised of over 90% PLF and HLF types of feeds. Tables 3.11a and 3.11b summarize the comparable information for the SB1a and SB1b sludge batches, respectively.

Table 3.10. Summary of the Basic Sludge Types

Fe/	HH	HL	HM	PH	PL	PM
Al	0.2	3.4	0.3	11.3	5.2	6.4
Ca	7.5	13.2	8.8	20.2	9.6	11.7
Cr	46.2	305.6	66.3	73.3	114.6	95.9
Cu	165.7	917.0	233.9	251.3	161.3	184.1
Fe	1.0	1.0	1.0	1.0	1.0	1.0
K	61.8	343.8	87.2	263.9	74.0	98.5
Mg	47.4	91.7	57.2	104.2	290.4	179.4
Mn	3.2	3.2	3.2	3.3	9.4	5.8
Na	2.8	9.4	3.7	7.5	6.4	6.7
Ni	8.3	56.1	11.9	6.9	11.5	9.4
Si	2.4	-	3.8	56.5	28.5	34.4
Ti	-	-	-	-	-	-
U	5.4	6.5	5.8	3.0	4.1	3.6
Zr	32.3	68.8	39.8	66.0	48.4	53.3

Table 3.11a. Summary of SB1a Sludge Information

51	DWPF Info				Projected Sludge				Basic Types	
	Min	Max			Min	Max			PL	HL
Al	3.3	3.9		Al	4.3	4.3		Al	5.2	3.4
Ca	9.4	11.6		Ca	9.8	9.8		Ca	9.6	13.2
Cr	116.6	150.2		Cr	104.1	115.7		Cr	114.6	305.6
Cu	25.1	1003.0		Cu	176.4	176.4		Cu	161.3	917.0
Fe	1.0	1.0		Fe	1.0	1.0		Fe	1.0	1.0
K	55.3	702.0		K	79.1	80.0		K	74.0	343.8
Mg	20.6	24.5		Mg	236.9	236.9		Mg	290.4	91.7
Mn	9.5	10.2		Mn	23.8	23.8		Mn	9.4	3.2
Na	3.4	4.3		Na	3.4	5.0		Na	6.4	9.4
Ni	78.4	89.4		Ni	551811.8	1655435.3		Ni	11.5	56.1
Si	35.2	35.4		*Si*	31.7	31.7		Si	28.5	-
Ti	373.0	1846.5		Ti	-	-		Ti	-	-
U	7.6	9.2		U	9.2	9.2		U	4.1	6.5
Zr	160.2	1709.9		Zr	49.9	49.9		Zr	48.4	68.8

Table 3.11b. Summary of SB1b Sludge Information

42	DWPF Info			Projected Sludge			Basic Types	
	Min	Max		Min	Max		PL	HL
Al	2.4	2.7	Al	2.6	2.6	Al	5.2	3.4
Ca	8.1	8.8	Ca	10.3	10.3	Ca	9.6	13.2
Cr	121.7	153.4	Cr	112.4	118.1	Cr	114.6	305.6
Cu	477.5	594.4	Cu	193.7	200.3	Cu	161.3	917.0
Fe	1.0	1.0	Fe	1.0	1.0	Fe	1.0	1.0
K	38.7	167.0	K	74.5	82.4	K	74.0	343.8
Mg	18.4	18.4	Mg	153.7	153.7	Mg	290.4	91.7
Mn	6.4	6.9	Mn	16.7	16.7	Mn	9.4	3.2
Na	2.9	2.9	Na	2.2	3.3	Na	6.4	9.4
Ni	60.6	64.7	Ni	8619.9	8723.1	Ni	11.5	56.1
Si	14.5	14.5	Si	20.6	20.6	Si	28.5	-
Ti	123.8	1183.0	Ti	-	-	Ti	-	-
U	6.9	7.6	U	12.2	12.2	U	4.1	6.5
Zr	92.4	356.4	Zr	50.9	50.9	Zr	48.4	68.8

It appears that the sludge compositions measured in DWPF are not similar to those that can be computed in WCSludge.xls and WCSystem.xls; however, the measured compositions do not appear to be greatly different from those that could be made from the basic sludge types (with the possible exceptions of perhaps the Al, Mg, and U for the major components). This would appear to be an inconsistency as the WCSludge.xls and WCSystem.xls balances use the basic types as inputs; however, the manner in which the calculations are performed are not quite as straightforward as computing the tank compositions as linear combinations of the basic sludge types.

In WCSludge.xls, the type, volume transferred, and quantities of Th, U isotopes, Np^{237}, Pu isotopes, $Fe(OH)_3$, MnO_2, $NaAlO_2$, and $Ni(OH)_2$ are provided for each transfer to a given tank. The quantities of Th, U, Np, Pu, Fe, Mn, Al, and Ni are computed from these input values (the quantities of Na transferred to the tanks are not). The concentrations for the radioactive species (other than those enumerated above) are computed from specific Ci/gal ratios for the given basic types, and those for the non-radioactive species (other than those listed above) are computed from specific sludge compound/$Fe(OH)_3$ ratios. In part, this may explain why the projected sludge compositions do not necessarily agree with those computed from the basic sludge types and, hopefully, the compositions measured in DWPF with those projected in WCSludge.xls and WCSystem.xls. Another complication is that a number of transfers to the vessels were described in terms of only fission products and water, fission products with $NaAlO_2$, or water. Constituents such as Ca, Cr, Mg, etc. are only considered transferred to a vessel if there is a corresponding transfer of $Fe(OH)_3$ to that vessel.

From the information above, the manner in which projections are made for system planning does not appear to reflect what has been processed in DWPF. The issue then becomes how to adjust the projections for the rest of sludge-only operation to better represent what might be processed in DWPF in the future.

3.6 Sludge Batches 3 (SB3) and 4 (SB4)

This task involves selecting five sludge compositions that represent the remaining sludge-only operations (SB3 and SB4) in DWPF. These five sludge compositions will be combined with different frits at three WLs (25, 30, and 35%) for a total of 45 glasses. The basic information concerning SB3 and SB4 is provided in Table 3.12.

Table 3.12. Blending Strategy for SB3 and SB4 (WSRC 2001)

Tanks	SB3 (%)	SB4 (%)
7	70	30
18	70	30
19	70	30
11	0	100

From the information in WCSludge.xls, approximately 70% of the SB3 material will be transferred to the unknown heel remaining in Tank 51 (from SB1a, SB1b, and SB2 processing) to produce SB3 for DWPF. Transfers from Tanks 18 and 19 were made according to the WCSludge.xls file to produce Tank 7 material, of which 70% will be transferred to Tank 51 to produce SB3. Note that unlike the previous sludge batches fed to DWPF, the material in Tank 7 will be comprised of only PLF, PMF, and PUREX high heat feed (PHF)-type feeds. No HM type feeds (apart from that material remaining in the Tank 51 heel) will be part of SB3. The SB4 material was assumed to be comprised of the remaining 30% of the Tank 7 material (after Tank 18 and 19 additions) plus the contents of Tank 11.

3.6.1 SB3 Examination

From an $Fe(OH)_3$ balance using the information in WCSludge.xls, the SB3 sludge (before transfer to Tank 11 and minus the Tank 51 heel) was approximately distributed among the basic waste types as indicated in Table 3.13. More than 85% of the SB3 material is comprised of PLF type feed, and over 11% is comprised of Mixed PX feed, which according to WCSludge.xls is 50% PLF. Therefore, the SB3 material may be comprised of more than 90% PLF type feed (based upon an approximate $Fe(OH)_3$ balance). It should be reasonable to assume that the measured information for the first two sludge batches (SB1a and SB1b) to be processed in DWPF would provide information pertinent to SB3.

Table 3.13. Approximate SB3 Waste Type Distributions Based upon $Fe(OH)_3$

	Source(s)	$Fe(OH)_3$ (kg)	%
Tank 7	221, 1–3, and 17–19	183540.6	100.00
PLF	221, 1, and 17–19	156996.9	85.54
PMF	1–3	20971.6	11.43
PHF	1	5572.0	3.04

As before, material balances can be performed using the information in WCSludge.xls and WCSystem.xls to define projected SB3 compositions. These projected compositions are provided in Table 3.14 as a function of the SB3 supernate loading. This information for SB3, which is supposed to be comprised of PLF, PMF, and PHF sludge types, can be compared to that for the basic sludge types provided in Table 3.10. Because the Tank 51 (or SB1a) material, which has already been processed through DWPF, was also comprised of approximately 90% PLF type feed, it is reasonable to also compare the SB3 projections to both the SB1a projections and DWPF measurements; this is done in Table 3.15. Note that the SB3 projections are, in general, like those for the SB1a material. The corresponding information for SB4 must be examined before defining a set of five sludge compositions for the RC task.

Table 3.14. Projected SB3 Compositions as a Function of Supernate Loading

	Fe/cation					
fract	0	0.02	0.04	0.06	0.08	0.1
Al	3.0	2.9	2.9	2.8	2.8	2.7
Ca	9.9	9.9	9.9	9.9	9.9	9.9
Cr	110.3	108.0	105.7	103.6	101.6	99.6
Cu	165.5	163.8	162.2	160.7	159.1	157.6
Fe	1.0	1.0	1.0	1.0	1.0	1.0
K	77.9	71.5	66.1	61.5	57.4	53.9
Mg	258.1	258.1	258.1	258.1	258.1	258.1
Mn	4.8	4.8	4.8	4.8	4.8	4.8
Na	6.4	4.5	3.4	2.8	2.3	2.0
Ni	20.8	20.8	20.8	20.8	20.8	20.8
Si	17.8	17.8	17.8	17.8	17.8	17.8
Ti	-	-	-	-	-	-
U	3.4	3.4	3.4	3.4	3.4	3.4
Zr	49.3	49.3	49.3	49.3	49.3	49.3

Table 3.15. Comparison of SB1a and SB3 Compositions

	DWPF SB1a			Projected SB3 Sludge			Basic Types	
	Min	**Max**		**Min**	**Max**		**PL**	**HL**
Al	3.3	3.9	Al	4.3	4.3	Al	5.2	3.4
Ca	9.4	11.6	Ca	9.8	9.8	Ca	9.6	13.2
Cr	116.6	150.2	Cr	104.1	115.7	Cr	114.6	305.6
Cu	25.1	1003.0	Cu	176.4	176.4	Cu	161.3	917.0
Fe	1.0	1.0	Fe	1.0	1.0	Fe	1.0	1.0
K	55.3	702.0	K	79.1	80.0	K	74.0	343.8
Mg	20.6	24.5	Mg	236.9	236.9	Mg	290.4	91.7
Mn	9.5	10.2	Mn	23.8	23.8	Mn	9.4	3.2
Na	3.4	4.3	Na	3.4	5.0	Na	6.4	9.4
Ni	78.4	89.4	Ni	551811.8	1655435.3	Ni	11.5	56.1
Si	35.2	35.4	Si	31.7	31.7	Si	28.5	-
Ti	373.0	1846.5	Ti	-	-	Ti	-	-
U	7.6	9.2	U	9.2	9.2	U	4.1	6.5
Zr	160.2	1709.9	Zr	49.9	49.9	Zr	48.4	68.8

3.6.2 SB4 EXAMINATION

From an approximate $Fe(OH)_3$ balance using the information in WCSludge.xls, more than half of the SB4 sludge (minus any Tank 40 or Tank 51 heel material) is comprised of PLF-type feed, and over 7% is comprised of Mixed PX feed, which, according to WCSludge.xls, is 50% PLF. The

SB4 material may be comprised of almost 60% PLF-type feed, based upon the approximate $Fe(OH)_3$ balance illustrated in Table 3.16. Thus, it should be reasonable to assume that the measured information for the first two DWPF sludge batches (and especially SB1b) to be processed in DWPF would provide information pertinent to SB4.

Table 3.16. Approximate SB4 Waste Type Distributions based upon $Fe(OH)_3$

	Source(s)	$Fe(OH)_3$ (kg)	%
Tank 11	221, 1–3, 7, and 17–19	87243.6	100.00
PLF	221 and 7	47099.1	53.99
PMF	1–3	6291.5	7.21
PHF	1	1671.6	1.92
HLF	221	16382.2	18.78
HMF	221	1226.4	1.41
HHF	221	14572.9	16.70

As before, material balances can be performed using the information in WCSludge.xls and WCSystem.xls to define projected SB4 compositions. These projected compositions are provided in Table 3.17 as a function of the SB4 supernate loading. This information for SB4, which is supposed to be comprised of PLF, HLF, and HHF sludge types, can be compared to that for the basic sludge types provided in Table 3.10. Because the Tank 42 (or SB1b) material, much of which has already been processed through DWPF, was also comprised of primarily PLF and HLF type feeds, it is reasonable to also compare the SB4 projections to both the SB1b projections and DWPF measurements; this is done in Table 3.18. As indicated in Table 3.18, the SB4 results do not correspond as well to those from SB1b as those from SB3 corresponded to SB1a. Therefore, it appears that there is no simple manner in which to define bounding compositions for the rest of the sludge-only operation.

Table 3.17. Historic SB4 Compositions as a Function of Supernate Loading

	Fe/cation					
fract	0	0.01	0.02	0.03	0.04	0.05
Al	1.6	1.6	1.5	1.5	1.5	1.5
Ca	9.8	9.8	9.8	9.8	9.8	9.8
Cr	98.4	97.8	97.3	96.7	96.2	95.6
Cu	196.6	196.1	195.7	195.3	194.9	194.5
Fe	1.0	1.0	1.0	1.0	1.0	1.0
K	86.8	85.4	84.1	82.8	81.5	80.3
Mg	121.0	121.0	121.0	121.0	121.0	121.0
Mn	5.4	5.4	5.4	5.4	5.4	5.4
Na	5.5	4.1	3.3	2.8	2.4	2.1
Ni	27.1	27.1	27.1	27.1	27.1	27.1
Si	9.3	9.3	9.3	9.3	9.3	9.3
Ti	-	-	-	-	-	-
U	5.3	5.3	5.3	5.3	5.3	5.3
Zr	47.5	47.5	47.5	47.5	47.5	47.5

Table 3.18. Comparison of SB1b and SB4 Compositions

	SB1b			Projected SB4 Sludge			Basic Types	
	Min	Max		Min	Max		PL	HL
Al	2.4	2.7	Al	2.6	2.6	Al	5.2	3.4
Ca	8.1	8.8	Ca	10.3	10.3	Ca	56.5	-
Cr	121.7	153.4	Cr	112.4	118.1	Cr	114.6	305.6
Cu	477.5	594.4	Cu	193.7	200.3	Cu	161.3	917.0
Fe	1.0	1.0	Fe	1.0	1.0	Fe	1.0	1.0
K	38.7	167.0	K	74.5	82.4	K	74.0	343.8
Mg	18.4	18.4	Mg	153.7	153.7	Mg	290.4	91.7
Mn	6.4	6.9	Mn	16.7	16.7	Mn	9.4	3.2
Na	2.9	2.9	Na	2.2	3.3	Na	6.4	9.4
Ni	60.6	64.7	Ni	8619.9	8723.1	Ni	11.5	56.1
Si	14.5	14.5	Si	20.6	20.6	Si	28.5	-
Ti	123.8	1183.0	Ti	-	-	Ti	-	-
U	6.9	7.6	U	12.2	12.2	U	4.1	6.5
Zr	92.4	356.4	Zr	50.9	50.9	Zr	48.4	68.8

3.7 General Considerations

In a desire to be as bounding as possible, it can be shown that the SB3 and SB4 sludge feeds will be comprised of sludge material in the following order:

$$PLF >> HLF > HHF > PHF$$

when decomposing the mixed types into high and low activity fractions. It is also likely that the importance of each sludge type to the remaining sludge-only operation is also ordered in a similar manner. For example, the most likely fifth candidate for consideration would be a PMF-type feed for a number of reasons, including:

- PX types have the lowest Al concentration so are likely the most important in terms of potential phase separation and durability
- PX types are highest in Fe and therefore are most likely to crystallize.

It is reasonable to define five compositions (PLF, PMF, PHF, HLF, and HHF) to bound the various sludge compositions expected in remaining DWPF sludge-only operations.

As given in WCSludge.xls, the basic information for these five sludge types is provided in Table 3.10. The measurements made in DWPF for the SB1a and SB1b feeds are assumed to be most informative concerning these feeds and are summarized in Table 3.19. From the information in Table 3.19, the following can be discerned:

- The projected Fe/Al ratio is slightly higher than that obtained from the measured DWPF information.
- The projected Fe/Ca ratio is reasonably close to that obtained from the measured DWPF information.

- The projected Fe/Cr ratio may be slightly lower than that obtained from the measured DWPF information.
- The projected Fe/Mg ratio is as much as an order of magnitude higher than that obtained from the measured DWPF information.
- The projected Fe/Mn ratio is as much as 2 to 3 times higher than that obtained from the measured DWPF information.
- The Fe/Na ratios cannot be discussed because of how these values were computed.
- The projected Fe/Ni ratios approximate zero, and those obtained from the DWPF measurements appear above the detection limit (albeit very small).
- The projected Fe/Si ratios are proximate to those obtained from the measured DWPF information (although they may be as much as 1.5 times bigger).
- The projected Fe/U ratios may be larger than those measured in DWPF by a factor of up to 1.6 times.
- The other components (e.g., Cu, K, Ti, and Zr), which have minor concentrations in all the sludge types, will be included as part of an "Others" term, which has already been defined for the Tank 40/Frit 320 Variability Study (Brown et al. 2001). The minor components will be added in concentrations, based upon that study.

Table 3.19. SB1a and SB1b Measurement Summaries

	Tank 51 (SB1a)						Tank 42 (SB1b)			
	DWPF Info			Projected Sludge			DWPF Info			Projected Sludge	
	Min	Max		Min	Max		Min	Max		Min	Max
Al	3.3	3.9	Al	4.3	4.3	Al	2.4	2.7	Al	2.6	2.6
Ca	9.4	11.6	Ca	9.8	9.8	Ca	8.1	8.8	Ca	10.3	10.3
Cr	116.6	150.2	Cr	104.1	115.7	Cr	121.7	153.4	Cr	112.4	118.1
Cu	25.1	1003.0	Cu	176.4	176.4	Cu	477.5	594.4	Cu	193.7	200.3
Fe	1.0	1.0	Fe	1.0	1.0	Fe	1.0	1.0	Fe	1.0	1.0
K	55.3	702.0	K	79.1	80.0	K	38.7	167.0	K	74.5	82.4
Mg	20.6	24.5	Mg	236.9	236.9	Mg	18.4	18.4	Mg	153.7	153.7
Mn	9.5	10.2	Mn	23.8	23.8	Mn	6.4	6.9	Mn	16.7	16.7
Na	3.4	4.3	Na	3.4	5.0	Na	2.9	2.9	Na	2.2	3.3
Ni	78.4	89.4	Ni	551811.8	1655435.3	Ni	60.6	64.7	Ni	8619.9	8723.1
Si	35.2	35.4	Si	31.7	31.7	Si	14.5	14.5	Si	20.6	20.6
Ti	373.0	1846.5	Ti	-	-	Ti	123.8	1183.0	Ti	-	-
U	7.6	9.2	U	9.2	9.2	U	6.9	7.6	U	12.2	12.2
Zr	160.2	1709.9	Zr	49.9	49.9	Zr	92.4	356.4	Zr	50.9	50.9

So how does one project the relevant PLF, PMF, PHF, HLF, and HHF concentrations to which the above SB3 and SB4 information applies? One way to do this is to aggregate the various transfers that comprise the SB3 and SB4 material by sludge type; this is done in Table 3.20 where the "Balance" columns were computed from a material balance on the transfer information given in WCSludge.xls, and the "Basic" columns are those for the given, basic sludge types as provided in Table 3.10. As a check, note that the concentrations for those cations that are unique relative to the $Fe(OH)_3$ concentration are identical in the above information; however, there is quite a difference in the ratios of Fe to Al, Mn, Ni, and U. However, the above information can be used to define ranges of ratios of Fe to the major cations to be studied in the RC task. This assumes that the measured SB1a information is most relevant to the PLF, PMF, and PHF types, and the SB1b measurements are most relevant to the HLF and HHF types.

Table 3.20. Aggregated Transfer Information for SB3 and SB4

	PLF		PMF		PHF		HLF		HHF	
Fe/	**Balance**	**Basic**	**Balance**	**Basic**	**Balance**	**Basic**	**Balance**	**Basic**	**Balance**	**Basic**
Al	2.5	5.2	13.2	6.4	4.1	11.3	32.6	3.4	0.4	0.2
Ca	9.6	9.6	11.7	11.7	20.2	20.2	13.2	13.2	7.5	7.5
Cr	114.6	114.6	95.9	95.9	73.3	73.3	305.6	305.6	46.2	46.2
Fe	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mg	290.4	290.4	179.4	179.4	104.2	104.2	91.7	91.7	47.4	47.4
Mn	14.2	9.4	0.9	5.8	1.8	3.3	-	3.2	3.3	3.2
Na	6.4	6.4	6.7	6.7	7.5	7.5	9.4	9.4	2.8	2.8
Ni	-	11.5	4.4	9.4	1.4	6.9	-	56.1	25.3	8.3
Si	28.5	28.5	34.4	34.4	56.5	56.5	-	-	2.4	2.4
U	3.7	4.1	3.0	3.6	1.1	3.0	2260.5	6.5	380.6	5.4

Note that the maxima and minima from the above tables relate to the lower and upper bounds, respectively, of the composition ranges to be tested for the RC Study. These minima and maxima will be adjusted using the measured DWPF information so that the main concerns for durability and other relevant constraints are tested. For example, low Al is a concern for durability as this may translate into a condition where the Al_2O_3 in glass is sufficiently low as to allow amorphous phase separation in glass. Cations such as Cr, Mg, Mn, Ni, etc. that promote crystalline formation will also be considered to the extent possible.

For example, consider the PLF feed type and the relevant Tank 51 (SB1a) information provided in Table 3.21. Assuming there is useful information in both the ratios obtained from the WCSludge.xls material balance and the basic sludge types, adjustments can be made to the minima and maxima from these based upon the Tank 51 measured versus projected information. For example, the Fe to Al ratio can be adjusted by the factor obtained from this information; however, the maximum is set to 5.2 from the “Basic” information because 1) it is assumed that this information has some relevance and 2) this maximum translates into the minimum Al_2O_3 in glass, which is of concern. This logic applies to many of the ratios where adjustments are made, and the extrema are selected from the adjusted and original “Balance” and “Basic” information. One exception is the Fe to Na ratio that cannot be determined as it depends upon the relative fraction of some unknown supernate per some unit sludge and will be bounded below. The Fe to Ni information is also highly suspect and, therefore, the maximum from the Tank 51 information will be used. Similar analyses provide the following proposed extrema for the five basic sludge types provided in Table 3.22.

Table 3.21. Adjusting the PLF Information Based upon Tank 51 Results

	PLF		Tank 51 Info		Projected Tank 51		Adjustments		Adjusted PLF		Proposed PLF	
Fe/	Balance	Basic	Min	Max	Min	Max	Min (%)	Max (%)	Min	Max	Min	Max
Al	2.5	5.2	3.3	3.9	4.3	4.3	76.7	90.7	2.0	4.7	2.0	5.2
Ca	9.6	9.6	9.4	11.6	9.8	9.8	95.9	118.4	9.2	11.3	9.2	11.3
Cr	114.6	114.6	116.6	150.2	104.1	115.7	112.0	129.8	128.4	148.8	114.6	148.8
Fe	1.0	1.0	1.0	1.0	1.0	1.0	---	---	---	---	---	---
Mg	290.4	290.4	20.6	24.5	236.9	236.9	8.7	10.3	25.3	30.0	25.3	290.4
Mn	14.2	9.4	9.5	10.2	23.8	23.8	39.9	42.9	3.8	6.1	3.8	14.2
Na	6.4	6.4	3.4	4.3	3.4	5.0	100.0	86.0	6.4	6.4	---	---
Ni	-	11.5	78.4	89.4	5.52E+05	1.66E+06	0.0	0.0	0.0	-	11.5	89.4
Si	28.5	28.5	35.2	35.4	31.7	31.7	111.0	111.7	31.6	31.8	28.5	31.8
U	3.7	4.1	7.6	9.2	9.2	9.2	82.6	100.0	3.1	4.1	3.1	4.1

Table 3.22. Proposed Sludge Regions for the RC Study

	Proposed PLF		Proposed PMF		Proposed PHF		Proposed HLF		Proposed HHF	
Fe/	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Al	2.0	5.2	4.9	13.2	3.1	11.3	3.1	32.6	0.2	0.5
Ca	9.2	11.3	11.2	13.8	19.3	23.9	10.4	13.2	5.9	7.5
Cr	114.6	148.8	95.9	124.5	73.3	95.2	305.6	397.0	46.2	60.1
Fe	---	---	---	---	---	---	---	---	---	---
Mg	25.3	290.4	15.6	179.4	9.1	104.2	11.0	91.7	5.7	47.4
Mn	3.8	14.2	0.3	5.8	0.7	3.3	3.2	6.9	1.2	3.3
Na	---	---	---	---	---	---	---	---	---	---
Ni	11.5	89.4	4.4	89.4	1.4	89.4	56.1	64.7	0.1	25.3
Si	28.5	31.8	34.4	38.4	56.5	63.1	14.5	14.5	1.7	2.4
U	3.1	4.1	2.5	3.6	0.9	3.0	3.7	1408.2	3.1	380.6

The information in Table 3.22 indicates why the various tank wastes must be either blended or in some case preprocessed (e.g., Al dissolution) to provide feed to DWPF that can be processed into durable glass without harming the DWPF melter (e.g., crystallization and/or pouring problems).

To define the extrema in sludge composition space, the concentrations of Fe must be known for the various sludge types represented in Table 3.22. This information can be obtained from the basic information contained in WCSludge.xls and the various material balances representing the individual sludge types that will be processed in SB3 and SB4; the resulting Fe concentrations are provided in Table 3.23. The desired composition ranges, provided in Table 3.24, for the basic sludge types were obtained from the Fe concentrations from Table 3.23. The various Fe to other cation ratios were obtained from Table 3.22 where the Na values were computed to span the range of 6 to 9% Na in sludge on a total solids basis (assuming a calcine factor of between 0.75 and 0.80 g of oxides per gram of sludge solids). The equivalent oxide ranges are provided in Table 3.25.

Table 3.23. Iron Concentrations by Waste Type

	g Fe per 100 g Sludge Oxides				
Type	**PLF (%)**	**PMF (%)**	**PHF (%)**	**HLF (%)**	**HHF (%)**
Balance	31.17	23.22	19.49	50.13	11.72
Basic	33.97	33.63	33.01	32.48	7.69

Table 3.24. Basic Sludge Type Cation Composition Ranges for the RC Study

	Proposed PLF		Proposed PMF		Proposed PHF		Proposed HLF		Proposed HHF	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Al	5.97	17.42	1.76	6.83	1.73	10.53	1.00	16.11	16.76	55.36
Ca	2.76	3.71	1.68	3.00	0.82	1.71	2.46	4.83	1.03	1.99
Cr	0.21	0.30	0.19	0.35	0.20	0.45	0.08	0.16	0.13	0.25
Fe	31.17	33.97	23.22	33.63	19.49	33.01	32.48	50.13	7.69	11.72
Mg	0.11	1.35	0.13	2.16	0.19	3.64	0.35	4.57	0.16	2.07
Mn	2.19	9.03	4.04	96.31	5.88	46.07	10.11	15.60	6.21	9.48
Na	7.50	12.00	7.50	12.00	7.50	12.00	7.50	12.00	7.50	12.00
Ni	0.35	2.96	0.26	7.61	0.22	24.19	0.50	0.89	0.30	200.84
Si	0.98	1.19	0.61	0.98	0.31	0.58	2.24	3.46	3.16	6.85
U	7.58	11.06	6.40	13.35	6.58	36.18	0.02	13.59	0.02	3.82

Table 3.25. Basic Sludge Type Oxide Composition Ranges for the RC Study

	Proposed PLF		Proposed PMF		Proposed PHF		Proposed HLF		Proposed HHF	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Al_2O_3	11.28	32.91	3.32	12.91	3.27	19.90	1.88	30.44	31.67	104.60
CaO	3.86	5.19	2.35	4.20	1.14	2.39	3.45	6.76	1.44	2.79
Cr_2O_3	0.31	0.43	0.27	0.51	0.30	0.66	0.12	0.24	0.19	0.37
Fe_2O_3	44.57	48.57	33.20	48.08	27.87	47.19	46.44	71.67	10.99	16.76
MgO	0.18	2.23	0.21	3.58	0.31	6.04	0.59	7.57	0.27	3.43
MnO	2.83	11.66	5.21	124.36	7.59	59.49	13.05	20.15	8.02	12.24
Na_2O	10.11	16.18	10.11	16.18	10.11	16.18	10.11	16.18	10.11	16.18
NiO	0.44	3.76	0.33	9.68	0.28	30.78	0.64	1.14	0.39	255.59
SiO_2	2.10	2.55	1.29	2.09	0.66	1.25	4.79	7.40	6.77	14.66
U_3O_8	8.93	13.04	7.55	15.75	7.75	42.67	0.03	16.02	0.02	4.50

From the above information, it is apparent that at least three (PMF, PHF, and HLF) of these types can never satisfy the lower Al_2O_3 constraint of at least 3% in glass over their complete ranges. Furthermore, it is likely that Al dissolution must be performed on feeds of the HHF type or blending strategies used to account for the minimum Al_2O_3 limit. Also glasses that are comprised of 100% NiO and/or MnO are unreasonable. Therefore, the ranges defined exceed what can be reliably processed in DWPF to produce acceptable glass. Each type will be considered separately to define reasonable ranges for the RC Study.

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4.0 Definition of Extreme Vertices and SB3/SB4 Glass Composition Regions

To meet programmatic objectives (as described in Section 2.0), a dual (yet integrated) approach was taken in an effort to bound the sludge-only processing compositional envelope and the potential impacts of the homogeneity constraint within these composition regions. The initial approach identifies and uses five individual waste stream types in an attempt to bound the effects of the homogeneity constraint for sludge-only processing. In terms of program objectives, if the homogeneity constraint can be eliminated based on these individual streams, then eliminating this constraint for combinations or blends of these streams should be relatively straightforward. The second approach is more focused on the projected blending strategies for SB3 and SB4 as defined by Revision 12 of the HLW System Plan (WSRC 2001).

The objective of this section is to develop a set of glasses that can be evaluated in terms of predicted properties as they compare to various process and product performance constraints. The primary objective is the assessment of homogeneity over the composition region defined by the dual approach. The assessment will also include other process and product performance related properties, given that models are available and predicted properties are easily calculated. Again, this assessment will provide an initial basis for evaluating the homogeneity constraint for sludge-only processing. This process is the initial step in developing the technical basis from which the application of Criterion (1) or Criterion (2) could be implemented while relaxing or eliminating the homogeneity constraint for sludge-only operations. This assessment will ultimately provide an initial pool of candidate glasses from which experimental evaluations can be made to challenge the homogeneity constraint within (or bounding) the projected sludge-only processing region.

In Section 4.1, compositional bounds (in terms of oxide wt%) for five individual (unblended and bounding) waste types and projected SB3 and SB4 compositions are defined. In Section 4.2, extreme vertices and centroid compositions for each basic waste type and sludge batch are calculated. Section 4.3 summarizes the three frit compositions used to develop representative glass compositions for each waste type and sludge batch. In Section 4.4, the PAR limits are defined from which assessments of acceptability are made. Sixty-nine centroid-based glass compositions are presented in Section 4.5 representing a range of WLs. In Section 4.6, a high-level assessment of each frit-based system is provided with respect to the acceptability criteria defined in Section 4.4. Although the primary focus is on the homogeneity constraint, model predictions are easily performed for other properties, making assessments on the projected operational window another area of interest.

4.1 Definition of Basic Waste Types and Projected Sludge Batches

Table 4.1 summarizes the information discussed in Section 3.0, which provides bounding intervals for oxide concentrations corresponding to an individual or basic waste type. The concentrations can be used to determine the contribution of each waste component to the final glass composition. For example, a glass generated by processing PLF sludge at a 30 wt% WL would have a minimum of 0.30 x 11.28 = 3.384 wt% Al_2O_3.

Table 4.1. Bounding Oxide Intervals for Select Waste Types (wt%)

	PLF		PMF		PHF		HLF		HHF	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Al_2O_3	11.28	32.91	3.32	12.91	3.27	19.90	1.88	30.44	31.67	104.60
CaO	3.86	5.19	2.35	4.20	1.14	2.39	3.45	6.76	1.44	2.79
Cr_2O_3	0.31	0.43	0.27	0.51	0.30	0.66	0.12	0.24	0.19	0.37
Fe_2O_3	44.57	48.57	33.20	48.08	27.87	47.19	46.44	71.67	10.99	16.76
MgO	0.18	2.23	0.21	3.58	0.31	6.04	0.59	7.57	0.27	3.43
MnO	2.83	11.66	5.21	124.36	7.59	59.49	13.05	20.15	8.02	12.24
Na_2O	10.11	16.18	10.11	16.18	10.11	16.18	10.11	16.18	10.11	16.18
NiO	0.44	3.76	0.33	9.68	0.28	30.78	0.64	1.14	0.39	255.59
SiO_2	2.10	2.55	1.29	2.09	0.66	1.25	4.79	7.40	6.77	14.66
U_3O_8	8.93	13.04	7.55	15.75	7.75	42.67	0.03	16.02	0.02	4.50

From the information in Table 4.1, it is apparent that at least three waste types (PMF, PHF, and HLF) will challenge the lower Al_2O_3 constraint ($\geq$ 3% in glass) over typical WL ranges (e.g., 20 to 35 wt%). More specifically, given the low Al_2O_3 concentrations for the PMF, PHF, and HLF waste streams, one would have to approach (or exceed in the case of the HLF stream) 100% WL to meet this single component constraint. Also, wastes that are comprised of 100% NiO (HHF), Al_2O_3 (HHF), and/or MnO (PMF) are unreasonable, and assessments using these bounding cases should be viewed accordingly. Furthermore, it is likely that Al dissolution will be performed on select feeds (e.g., the HHF type) or that blending strategies will be considered in the processing of waste streams comprised of one or more of the basic waste types to mitigate such issues. Specifically, the blends anticipated (WSRC 2001) that define SB3 and SB4 are of interest for this study since these batches are to be processed during DWPF's sludge-only operation. Although the individual waste types were assessed in this study to bound sludge-only processing, the primary focus concerns the assessment of the homogeneity constraint for sludge-only processing for SB3 and SB4.

Table 4.2 provides the proportions of the basic waste types that define the blends for SB3 and SB4. Note that there are two rows in this table for SB4. The first shows a small contribution (1.4%) from the HMF waste type for this sludge batch. However, because the HMF waste stream is merely a combination of the HLF and HHF, its small contribution was ignored in this study by re-normalizing the contribution to SB4 from the other five basic waste types. The resulting contributions to SB4 are provided in the last row of Table 4.2.

Table 4.2. Basic Waste Type Blends Defining SB3 and SB4

Sludge Batch	PLF	PMF	PHF	HLF	HHF	HMF
SB3	0.8553	0.1143	0.0304	-	-	-
SB4	0.5399	0.0721	0.0192	0.1878	0.1670	0.0140
SB4	0.5476	0.0731	0.0195	0.1905	0.1694	-

Using the information from Table 4.1 and Table 4.2, the bounding intervals for the composition of SB3 and SB4 were developed, and they are provided in Table 4.3.

Table 4.3. Bounding Oxide Intervals for SB3 and SB4 (in wt%)

	SB3		SB4	
Oxide	**Min**	**Max**	**Min**	**Max**
Al_2O_3	10.13	30.23	9.51	34.01
CaO	3.61	4.99	3.21	4.96
Cr_2O_3	0.31	0.45	0.25	0.39
Fe_2O_3	42.77	48.48	38.09	47.52
MgO	0.19	2.50	0.28	3.62
MnO	3.25	17.46	5.92	17.09
Na_2O	10.11	16.18	10.11	16.18
NiO	0.42	5.26	0.46	3.89
SiO_2	1.96	2.46	3.32	5.47
U_3O_8	8.74	14.03	5.60	12.79

The Cr_2O_3 concentrations are shaded in Table 4.1 and Table 4.3 to indicate that this oxide is only a minor component of each of the basic waste types and projected sludge batches. To capture its contribution to the final composition of the glass but in keeping with its role as a minor component, the Cr_2O_3 was included as part of an "Others" component in each individual waste type and for SB3 and SB4. The composition of this "Others" was developed as part of the glass selection effort for the SB2/Frit 320 variability study (Brown et al. (2001)) and is provided in Table 4.4.

Table 4.4. Oxide Ranges for Sludge "Others"

	Grams/100 g Sludge Oxides		%Oxide in "Others"
	Minimum	**Maximum**	**Mean**
B_2O_3	3.25E-02	4.28E-02	1.32
BaO	4.20E-02	5.80E-02	1.74
CdO	1.67E-01	2.21E-01	6.79
CoO	2.10E-02	3.51E-02	0.94
Cr_2O_3	2.23E-01	5.19E-01	11.75
CuO	6.42E-02	1.01E-01	2.80
La_2O_3	4.70E-02	7.19E-02	2.03
Li_2O	1.61E-01	2.13E-01	6.55
ThO_2	4.09E-02	6.15E-02	1.75
RuO_2	6.98E-02	9.54E-02	2.88
MoO_3	8.08E-03	1.11E-02	0.33
P_2O_5	7.54E-01	2.16E+00	44.60
PbO	1.10E-01	1.56E-01	4.61
SnO_2	1.87E-02	4.50E-02	1.00
SrO	2.45E-02	3.42E-02	1.02
TiO_2	3.14E-02	4.59E-02	1.33
V_2O_5	3.18E-02	4.59E-02	1.34
ZnO	6.88E-02	1.03E-01	2.94
ZrO_2	9.65E-02	1.55E-01	4.26
SUM	2.01	4.17	100.00

The interval from 2.01 wt% to 4.17 wt% for "Others" was used for each of the individual or basic waste types and for SB3 and SB4 to bound its likely composition. This leads to Table 4.5, which defines these bounding compositional regions.

Table 4.5. Final Bounding Oxide Intervals for Select Waste Types and Sludge Batches

	OXIDE										
Waste	**i**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Type	**Oxide**	**Al_2O_3**	**CaO**	**Fe_2O_3**	**MgO**	**MnO**	**Na_2O**	**NiO**	**SiO_2**	**U_3O_8**	**Others**
PLF	Min	11.28	3.86	44.57	0.18	2.83	10.11	0.44	2.1	8.93	2.01
	Max	32.91	5.19	48.57	2.23	11.66	16.18	3.76	2.55	13.04	4.17
PMF	Min	3.32	2.35	33.2	0.21	5.21	10.11	0.33	1.29	7.55	2.01
	Max	12.91	4.2	48.08	3.58	124.36	16.18	9.68	2.09	15.75	4.17
PHF	Min	3.27	1.14	27.87	0.31	7.59	10.11	0.28	0.66	7.75	2.01
	Max	19.9	2.39	47.19	6.04	59.49	16.18	30.78	1.25	42.67	4.17
HLF	Min	1.88	3.45	46.44	0.59	13.05	10.11	0.64	4.79	0.03	2.01
	Max	30.44	6.76	71.67	7.57	20.15	16.18	1.14	7.4	16.02	4.17
HHF	Min	31.67	1.44	10.99	0.27	8.02	10.11	0.39	6.77	0.02	2.01
	Max	104.6	2.79	16.76	3.43	12.24	16.18	255.59	14.66	4.5	4.17
SB3	Min	10.13	3.61	42.77	0.19	3.25	10.11	0.42	1.96	8.74	2.01
	Max	30.23	4.99	48.48	2.50	17.46	16.18	5.26	2.46	14.03	4.17
SB4	Min	9.51	3.21	38.09	0.28	5.92	10.11	0.46	3.32	5.60	2.01
	Max	34.01	4.96	47.52	3.62	17.09	16.18	3.89	5.47	12.79	4.17

4.2 Definition of Extreme Vertices and Centroid Compositions

An actual sludge composition from any one of the individual waste types or sludge batches would be a mixture of the ten components indicated in Table 4.5. Thus, if x_i represents the concentration (as a mass fraction) of the i^{th} component (i = 1 for Al_2O_3, 2 for CaO, …, 10 for "Others") for such a sludge composition, then

$$\sum_{i=1}^{10} x_i = 1 \quad \text{and} \quad l_i \le x_i \le u_i \quad \text{for i =1, 2, …10} \qquad (1)$$

where l_i is the corresponding minimum (min) value and u_i is the maximum (max) value (both expressed as mass fractions) in Table 4.5. The statistical aspects of designing studies and modeling responses over regions such as that defined by the set of Equations (1) have been investigated (see, for example, Cornell [1990]). An approach for generating compositions along the boundary of the region defined by Equation (1) is to compute the extreme vertices (EVs) for the region. Algorithms for carrying out these computations are commercially available, and one such algorithm is available as part of JMP® Version 4.0 from SAS Institute, Inc. (SAS 2000).

JMP was used to generate the set of EVs for the composition region of each of the basic waste types and projected sludge batches of Table 4.5. Table 4.6 provides a summary of the number of EVs generated using JMP for each waste type or sludge batch.

Table 4.6. Number of Extreme Vertices for Select Waste Types and Projected Sludge Batches

Waste-Type	PLF	PMF	PHF	HLF	HHF	SB3	SB4
# of EVs	664	796	544	378	652	606	724

A representative composition of glasses that could be generated by the vitrification of each of the individual waste types or sludge batches was determined. This was done to gain an initial foothold on their likely properties (both process and product performance). Representative compositions for each waste type or sludge batch were computed by averaging all of the EVs (SAS 2000) for that waste type or batch. This results in an EV centroid for each waste type or sludge batch. Table 4.7 provides the centroids computed from the EVs summarized in Table 4.6. (It should be noted that JMP forced the upper limits for Al_2O_3, MnO, and NiO to be 100% [although shown as greater than 100% in Tables 4.1 and 4.5]). The centroid compositions were used as representatives of the various waste types and sludge batches in the initial assessment or paper study (see Sections 4.5 and 4.6). As previously stated, the primary objective of this initial assessment (sometimes referred to as the Phase 1 paper study) was to evaluate the homogeneity constraint and its potential to impact the size of the operational window for sludge-only processing. It is recognized that this initial assessment uses or is based on single (centroid) waste compositions. In Section 6.0, a second assessment (referred to as the Phase 2 paper study) is performed in which potential sludge variation is accounted for. Given models are readily available for these assessments; discussions of other process and product performance properties are also provided as warranted given they can provide additional insight into the projected operational window. It should be noted that the assessments discussed in this report were based solely on property predictions generated by PCCS models used by the DWPF. Property measurements were not performed (experimentally) as part of this study.

Table 4.7. Centroids for the EVs of the Waste Types and Sludge Batches

Oxide	HHF	HLF	PHF	PLF	PMF	SB3	SB4
Al_2O_3	43.87	3.22	8.90	12.52	8.16	11.80	11.55
CaO	2.09	4.90	1.75	4.49	3.27	4.28	4.05
Fe_2O_3	13.50	47.85	34.40	46.26	41.27	45.26	41.83
MgO	1.74	3.46	2.89	1.12	1.89	1.30	1.82
MnO	9.93	15.97	11.35	5.23	10.65	5.74	9.90
Na_2O	12.74	12.73	12.83	12.51	13.21	12.77	12.84
NiO	1.07	0.89	8.39	1.88	5.07	2.56	2.04
SiO_2	9.99	5.96	0.95	2.32	1.69	2.21	4.35
U_3O_8	2.04	2.02	15.47	10.66	11.71	11.05	8.58
Others	3.02	2.99	3.06	3.00	3.08	3.04	3.04

4.3 Frit Compositions

Table 4.8 summarizes the three frits that were considered in this study. 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 $N\text{-}s/m^2$ (or Pa-s) as possible, with a liquidus temperature 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 has been used to process MB1, MB1b, and MB2 (sludge-only feeds). It is anticipated that Frit 200 will be used during the transition to and in the early processing stages of SB2 (or MB3). However, Lambert et al. (2001) have recommended that DWPF use Frit 320 for SB2 to improve melt rate without compromising either processing or product performance properties. Peeler et al. (2001b) provide details of the development of Frit 320 for SB2. Although specifically developed for SB2 melt-rate improvements, inclusion of Frit 320 in this study will provide an initial assessment of its potential use for the projected sludge-only batches. Assuming that Frit 320 is a viable candidate for SB3 and SB4, this may provide DWPF the opportunity to use this frit instead of transitioning back to Frit 200 or developing and implementing a new frit for SB3 or SB4.

Table 4.8. 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

4.4 Property Acceptance Region Limits Used for Assessments

As mentioned in Section 1.0, PCCS is used to determine the acceptability of each batch of DWPF melter feed in the SME. This control 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. 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 durabilty (PCT response), viscosity, T_L (using both the existing and newly developed models), homogeneity, and Al_2O_3 and alkali concentrations. The definition of acceptable properties for this assessment were based on PAR limit values (see Table 4.9) for the respective properties. It should be noted that the PAR limit set for assessing the new T_L model was conservatively set at 1010°C (consistent with that used by Brown et al. [2001]).[a] It is anticipated that the PAR limits for the new model will not be this restrictive (in

(a) Preliminary information regarding the new T_L model was used to assist in the evaluation of glass compositions in this study. Details of the model form used in this report are provided in K.G. Brown, C.M. Jantzen, and G. Ritzhaupt, "Relating Liquidus Temperature to Composition for Defense Waste Processing Facility (DWPF) Process Control," WSRC-TR-2001-00520, October 25, 2001. The PAR for this relationship is composition-dependent but has been conservatively set at 1010°C. The full impact of this new T_L model on the DWPF operating window is still being assessed, so no attempt was made in this study to incorporate the actual PAR determinations for the new model.

terms of limiting the projected compositional operating window). Therefore, in the assessment discussions that follow, when the new T_L model imposes on or 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 1010°C PAR limit.

Table 4.9. PAR Limits for Various Properties

Property	PAR Limit
T_L (existing)	< 1024.95°C
T_L (new)	< 1010°C
Homogeneity	> 210.92
ΔG_P (durability)	> -12.7178
$\eta_{1150°C}$ (melt viscosity)	21.5–105.4 Poise
Al_2O_3	≥ 3.0 wt% (in glass)
Σalkali	< 19.3 wt% (in glass)

Again, the primary objective of this study is to assess the impact of the homogeneity constraint within a compositional region that bounds that expected for sludge-only processing. For this assessment, a glass is classified as "acceptable" (within the projected operational window and a potential candidate for further testing) if it satisfies all of the constraints (listed in Table 4.9). There are two exceptions to this latter statement:

- To meet programmatic objectives, glasses that meet all of the constraints with the exception of homogeneity will be considered viable candidates for fabrication and testing (i.e., to assess or challenge the homogeneity constraint).
- Glasses that meet one (or both) of the T_L constraints will also be considered as potential candidates. For example, a glass that is deemed acceptable by the new model (given the conservative 1010°C PAR limit) but fails the existing model is considered a viable candidate—and vice versa. Only those glasses that fail both T_L models are deemed unacceptable and are excluded from further consideration. Allowing glasses that satisfy the new T_L model while failing the existing T_L model induces some risk as this implies that implementation of the new T_L model into DWPF will occur and that the new model is applicable over the entire composition range.

It should be noted that the acceptance criteria used in this study are at the PAR; not the more restrictive MAR limits. These "acceptance" criteria were used to screen the pool of candidate glasses to establish glasses for experimental evaluation (see Section 5.0) to challenge the homogeneity constraint. Although experimental evaluation of this set of glasses is currently being performed, the results (e.g., chemical composition and PCT response) are not reported in this document. A separate document will be issued summarizing these results.

4.5 Defining the 69 Centroid-Based Glasses

The EV centroids (see Table 4.7) and the three primary frits of interest (see Table 4.8) were initially combined at nominal WLs of 25, 30, and 35 wt%, and the PCCS models of interest were used to predict process and product properties for the resulting glass compositions. Using this approach, an initial set of 63 compositions (7 centroids x 3 frits x 3 loadings = 63 glass compositions) was developed and ultimately evaluated in terms of "acceptance." Based on an initial assessment, the WLs of various frit and waste-type combinations were modified beyond the nominal WLs so that combinations would be "acceptable" for further study. For some combinations of frit and basic waste types (within the nominal WL of interest), no "acceptable" projected processing window was identified. Therefore, WL adjustments were made to provide some information worthy of discussion. In addition, each of the SB3 and SB4 centroids was combined with each of the three frits (165, 200, and 320) at WLs beyond 35 wt% to expand the range of validity for the study results for these two blended sludge types. This was a result of certain combinations not being restricted at 35 wt% WL—making the evaluation of higher WLs of primary interest. This extension added six compositions to the paper study, leading to a total of 69 centroid-based glasses, that were evaluated as part of the Phase 1 assessment.

Table 4.10 summarizes the 69 glasses and their predicted properties. The column identified as "DWPF PAR Operating Window" represents the comparison of the predicted property versus the PAR limits as shown in Table 4.9. For example, the "DWPF PAR Operating Window" nomenclature for Glass #1 (based on Frit 165, the basic HHF waste stream and the EV centroid at 15% WL) indicates "Durable, Visc., T_L, Not Homo, 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 existing liquidus temperature model (T_L), the new liquidus temperature model (New T_L), the Al_2O_3 lower limit, and sum of alkali. However, this glass challenges the homogeneity constraint (as noted by "Not Homo"). Based on the acceptance criteria established in Section 4.4, this glass is a viable candidate for further assessment (either via a more detailed paper study or experimental evaluation).

As another example, consider Glass #27 (based on Frit 200, the HLF waste stream, and the EV centroid at a WL of 35%). The "DWPF PAR Operating Window" nomenclature for this glass indicates "Durable, Visc., Not T_L, Homo, New T_L, Not 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, homogeneity, the new T_L model, and sum of alkali. This glass is predicted to have a T_L > 1024.95°C based on the existing T_L model. (Note that the new T_L model does not constrain this glass even with the more conservative 1010°C limit imposed.) Even though this glass passes the 1010°C constraint associated with the new T_L model, it still would not be considered processable as the Al_2O_3 concentration is < 3.0 wt%. Even at a 35 wt% WL, the Al_2O_3 concentration in glass is below the 3% lower limit and was, therefore, considered "unacceptable" and is not a potential candidate for further study. It should be noted that assessing glasses with lower than 3% Al_2O_3 is not viewed as an unworthy task (quite the opposite). However, using this constraint is a mechanism to help bound or control the number of glasses being used in this assessment and ultimately selected for experimental study (see Section 6.0).

Glasses that are considered as "unacceptable" based on a comparison of predicted properties and the established acceptance criteria are shown in red (and italicized) in Table 4.10. The predicted property (or properties) that result in this classification is (are) also shown in red (and italicized).

Table 4.10. Phase 1 Assessment of Centroid-Based Glasses: Projections of DWPF's PAR Operating Window

Glass	DWPF PAR Operating Window	Frit-Sludge	% Loading
1	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	165-HHF	15
2	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	165-HHF	20
3	Durable; *Not Visc*; T_L; Not Homo; New T_L; Al_2O_3; alkali	165-HHF	22.5
4	*Not Durable*; Visc; T_L; Not Homo; New T_L; *Not* Al_2O_3; alkali	165-HLF	22.5
5	*Not Durable*; Visc; T_L; Homo; New T_L; *Not* Al_2O_3; alkali	165-HLF	30
6	*Not Durable; Not Visc*; Not T_L; Homo; New T_L; *Not* Al_2O_3; alkali	165-HLF	35
7	Durable; Visc; T_L ; Not Homo; Not New T_L; Al_2O_3; alkali	165-PHF	35
8	Durable; Visc; *Not* T_L; Not Homo; *Not New* T_L; Al_2O_3; alkali	165-PHF	37.5
9	Durable; *Not Visc; Not* T_L; Not Homo; *Not New* T_L; Al_2O_3; alkali	165-PHF	40
10	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	165-PLF	25
11	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	165-PLF	30
12	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	165-PLF	35
13	*Not Durable*; Visc; T_L; Not Homo; New T_L; *Not* Al_2O_3; alkali	165-PMF	25
14	Durable; *Not Visc*; Not T_L; Homo; New T_L; *Not* Al_2O_3; alkali	165-PMF	35
15	Durable; *Not Visc*; *Not* T_L; Homo; *Not New* T_L; Al_2O_3; alkali	165-PMF	37.5
16	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	165-SB3	27.5
17	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	165-SB3	30
18	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	165-SB3	35
19	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	165-SB4	27.5
20	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	165-SB4	30
21	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	165-SB4	35
22	Durable; *Not Visc*; T_L; Not Homo; New T_L; Al_2O_3; alkali	200-HHF	15
23	Durable; *Not Visc*; T_L; Homo; New T_L; Al_2O_3; alkali	200-HHF	25
24	Durable; *Not Visc*; T_L; Homo; New T_L; Al_2O_3; alkali	200-HHF	30
25	Durable; Visc; T_L; Not Homo; New T_L; *Not* Al_2O_3; alkali	200-HLF	25
26	Durable; Visc; T_L; Homo; New T_L; *Not* Al_2O_3; alkali	200-HLF	30
27	Durable; Visc; Not T_L; Homo; New T_L; *Not* Al_2O_3; alkali	200-HLF	35
28	Durable; Visc; T_L; Homo; New T_L; *Not* Al_2O_3; alkali	200-PHF	33
29	Durable; Visc; T_L; Not Homo; Not New T_L; Al_2O_3; alkali	200-PHF	35
30	Durable; Visc; *Not* T_L; Not Homo; *Not New* T_L; Al_2O_3; alkali	200-PHF	37.5
31	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	200-PLF	25
32	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	200-PLF	30
33	Durable; Visc; *Not* T_L; Homo; *Not New* T_L; Al_2O_3; alkali	200-PLF	35
34	Durable; Visc; *Not* T_L; Homo; *Not New* T_L; *Not* Al_2O_3; alkali	200-PMF	36.5
35	Durable; Visc; *Not* T_L; Homo; *Not New* T_L; Al_2O_3; alkali	200-PMF	37
36	Durable; Visc; *Not* T_L; Homo; *Not New* T_L; Al_2O_3; alkali	200-PMF	37.5
37	Durable; Visc; T_L ; Homo; New T_L; Al_2O_3; alkali	200-SB3	27.5
38	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	200-SB3	30
39	Durable; Visc; *Not* T_L; Homo; *Not New* T_L; Al_2O_3; alkali	200-SB3	32.5
40	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	200-SB4	30
41	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	200-SB4	32.5
42	Durable; Visc; *Not* T_L; Homo; *Not New* T_L; Al_2O_3; alkali	200-SB4	35

Glass	DWPF PAR Operating Window	Frit-Sludge	% Loading
43	Durable; *Not Visc*; T_L; Not Homo; New T_L; Al_2O_3; alkali	320-HHF	15
44	Durable; *Not Visc*; T_L; Homo; New T_L; Al_2O_3; alkali	320-HHF	30
45	Durable; *Not Visc*; T_L; Homo; New T_L; Al_2O_3; alkali	320-HHF	37.5
46	Durable; *Not Visc*; *Not T_L*; Homo; *Not New T_L*; *Not Al_2O_3*; alkali	320-HLF	90
47	*Not Durable*; Visc; T_L; Homo; New T_L; *Not Al_2O_3*; alkali	320-HLF	30
48	*Not Durable*; *Not Visc*; Not T_L; Homo; New T_L; *Not Al_2O_3*; alkali	320-HLF	37.5
49	Durable; Visc; T_L; Not Homo; Not New T_L; Al_2O_3; alkali	320-PHF	35
50	Durable; Visc; *Not T_L*; Not Homo; *Not New T_L*; Al_2O_3; alkali	320-PHF	37.5
51	Durable; Visc; *Not T_L*; Not Homo; *Not New T_L*; Al_2O_3; alkali	320-PHF	40
52	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	320-PLF	25
53	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	320-PLF	30
54	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	320-PLF	35
55	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	320-PMF	37.5
56	Durable; *Not Visc*; *Not T_L*; Homo; *Not New T_L*; Al_2O_3; alkali	320-PMF	40
57	Durable; *Not Visc; Not T_L*; Homo; *Not New T_L*; Al_2O_3; alkali	320-PMF	40
58	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	320-SB3	27.5
59	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	320-SB3	30
60	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	320-SB3	35
61	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	320-SB4	27.5
62	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	320-SB4	30
63	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	320-SB4	35
64	Durable; *Not Visc*; *Not T_L*; Homo; *Not New T_L*; Al_2O_3; alkali	165-SB3	37.5
65	Durable; Visc; *Not T_L*; Homo; *Not New T_L*; Al_2O_3; alkali	200-SB3	37.5
66	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	320-SB3	37.5
67	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	165-SB4	37.5
68	Durable; Visc; *Not T_L*; Homo; *Not New T_L*; Al_2O_3; alkali	200-SB4	37.5
69	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	320-SB4	40

4.6 Phase 1 Assessment: Centroid-Based Glasses

Numerous comparisons can be made for the 69 centroid-based glasses listed in Table 4.10. A general description of the major observations is provided in the following sections for these glasses. Sections 4.6.1, 4.6.2, and 4.6.3 discuss each of the waste types and sludge batches based on Frit 165, Frit 200, and Frit 320, respectively, in terms of processing issues and projected compositional windows. It is recognized that this initial assessment uses or is based on single (centroid) waste compositions. In Section 6.0, a second assessment (referred to as the Phase 2 paper study) was performed in which potential sludge variation is accounted for.

4.6.1 Frit 165-Based Glasses

HHF Waste Type

As shown in Table 4.7, the centroid composition of the HHF waste type has an Al_2O_3 concentration of 43.87 wt%. Given this relatively high Al_2O_3 concentration, during the assessment of predicted properties, WLs had to be reduced to approximately 20% (or lower) to satisfy the melt viscosity ($\eta_{1150°C}$) constraint. If Al_2O_3 dissolution were considered, WLs could potentially increase, assuming that no other constraint becomes active.[(a)] Blending this waste type with wastes characterized by lower Al_2O_3 concentrations (e.g., HLF) would also be beneficial. Homogeneity is challenged over the WL range of 15 to 22.5 wt%.

HLF Waste Type
The most crucial characteristic of this particular waste type is the extremely low Al_2O_3 concentration (3.22 wt%). Given the current lower Al_2O_3 requirement of 3.0 wt%, a WL of approximately 100% would be required. Since 100% WLs are infeasible or impractical, blending this bounding waste type to acceptable levels is required. For the three HLF-based glasses listed in Table 4.10, WLs ranging from 22.5 to 35 wt% are shown. Over this WL range, not only is the lower Al_2O_3 limit not met, but homogeneity is challenged, and durability also restricts acceptability. Although not shown in Table 4.10, viscosity and T_L (using the existing model) predictions restrict acceptance at WLs of 37.5% and higher.

PHF Waste Type
As with the HLF waste type discussed above, the Al_2O_3 concentration in the centroid PHF waste type is relatively low (8.9 wt%). This again challenges the lower Al_2O_3 constraint until WLs of at least 34 wt% are targeted when coupled with Frit 165. As WL is incrementally increased from 34 to 35 wt%, the new T_L model fails, but given that the existing T_L model prediction is acceptable, this glass is considered acceptable for further evaluation. The fact that homogeneity is challenged at 25% WL makes this glass even more interesting given programmatic objectives. At 36 wt% WL, both T_L models fail, providing a small (but existing) operational window for this nominal waste type (centroid) from 34 to 35 wt%. Again, it should be mentioned that the use of the 1010°C limit for the new T_L model may overly restrict an acceptable glass. In terms of homogeneity, for WLs ranging from 35 to 40 wt%, homogeneity is challenged for the PHF centroid/Frit 165 combinations.

PLF Waste Type
Model assessment of the PLF centroid coupled with Frit 165 results in acceptable glasses (all PAR limits listed in Table 4.9 are met) being produced over the nominal WL range of interest (25 to 35 wt%). It should be noted that the existing T_L model fails at 30 and 35% WL, but these glasses are still considered acceptable given the new T_L model predictions. Processing this waste type (unblended) would require implementing the new T_L model at the higher WLs. Homogeneity is not challenged for this centroid waste type/frit combination over the WL range evaluated.

PMF Waste Type
The low Al_2O_3 concentration in the PMF centroid (8.16 wt%) restricts the potential to process this waste type over the nominal WL range of interest (25 to 35 wt%). Waste loadings of at least 37 wt% would be required to meet the single component Al_2O_3 constraint. At WLs above 37 wt%, both T_L model predictions restrict processing rendering essentially no processing window for this particular nominal waste type. Blending would be required for this waste type.

SB3 Waste Type
Assessing the SB3 coupled with Frit 165 yields a fairly large projected operating window of 25.5 to 37 wt% WL. At 25 wt% WL, the low Al_2O_3 limit is not satisfied pushing WLs higher. At 30- and 35 wt% WL, implementing the new T_L model would be required as the existing T_L model

(a) It should be noted that the impact of Al dissolution was not formally addressed as a part of this paper study.

predicts an unacceptable processing situation. Although a full paper study will be performed, it should be noted that the centroid SB3 composition with Frit 165 does not challenge homogeneity over this WL range.

As previously discussed, glasses labeled 64 to 69 (see Table 4.10) were based on the SB3 and SB4 EV centroids combined with each of the three frits (165, 200, and 320) at WLs beyond 35%. This expanded the range of validity for the study results for these two blended sludge types. For Glass #64 (Frit 165, SB3 centroid at 37.5 wt% WL), predictions of T_L using both models fail as well as predictions of viscosity. Viscosity prediction of this higher waste loaded glass is 19.9 Poise (at 1150°C), falling below the lower acceptance limit as listed in Table 4.9.

SB4 Waste Type
From Table 4.7, the centroid composition of SB4 is very similar to that of SB3 (with slight differences in the U_3O_8 and Fe_2O_3 concentrations). Given that, similar trends in the projected operational window are expected. As with SB3, assessment over the nominal WL range of interest indicates acceptable glasses from 26 to 35 wt%. It should be noted that the existing T_L model fails at 35 wt% WL, requiring implementation of the new T_L model to ensure processability at the higher WLs. Based on the assessment at higher WL (see Glass # 67), WLs of at least 37.5 wt% are achievable given implementation of the new T_L model. In fact, further assessments to determine the upper WL limit indicate that 38.5% WL would be acceptable. However, at 39%, both T_L model predictions and viscosity fail. Homogeneity is not challenged over the WL range of 28 to 38.5 wt% with this centroid-based SB4 glass and Frit 165.

4.6.2 FRIT 200-BASED GLASSES

HHF Waste Type
As previously discussed, the centroid composition of the HHF waste type has an Al_2O_3 concentration of 43.87 wt%. Even when lowering the WL to 15%, predicted viscosity values exceed the upper PAR limit for the Frit 200-based glasses. If Al_2O_3 dissolution were considered, WL could potentially increase, assuming that no other constraint becomes active. Blending this waste type with waste streams characterized by lower Al_2O_3 concentrations (e.g., HLF) would also be beneficial.

HLF Waste Type
The most crucial characteristic of this particular waste type is the extremely low Al_2O_3 concentration (3.22 wt%). Given the current lower Al_2O_3 requirement of 3.0 wt%, a WL of approximately 100% would be required (regardless of being coupled with Frit 200, 165, or 320—as these frits do not contain Al_2O_3). Since 100% WLs are infeasible or impractical, blending this bounding waste type to acceptable levels is required. Another option to address this lower Al_2O_3 limit would be to develop new frit compositions with higher concentrations of Al_2O_3. Given that these are bounding waste types, that option is not considered feasible at this point.

PHF Waste Type
As with the HLF waste type discussed above, the Al_2O_3 concentration in the centroid PHF waste type is relatively low (8.9 wt%). This again challenges the lower Al_2O_3 constraint until WLs of at least 34 wt% are targeted when coupled with any of the frits being considered. As WL is incrementally increased from 34 to 35 wt%, both homogeneity and the new T_L model prediction would limit processing. At 36 wt% WL, both T_L models fail, based on model predictions resulting in a small (but existing 34 to 35 wt%) operational window for this nominal waste type

(centroid) at the PAR, assuming that the existing T_L model was used. It should be mentioned that the use of the 1010°C limit for the new T_L model may overly restrict an acceptable glass.

PLF Waste Type
Assessing the PLF coupled with Frit 200 results in acceptable property predictions over the WL range of 25 to 30 wt%. At 30% WL, the existing T_L model fails, so implementing the new model would be required to expand this potential operational window. At WLs above 32.5 wt%, both T_L models fail (even though, as indicated above, a conservative PAR limit is used for the new T_L model). Note that homogeneity is not challenged for this nominal waste type with Frit 200 over the nominal WL range.

PMF Waste Type
An operational window does not exist for this nominal waste type when coupled with Frit 200. The low Al_2O_3 concentration of the waste (coupled with the fact that Frit 200 has no Al_2O_3), makes it impossible to meet the lower Al_2O_3 limit of 3% at WLs at or below 36.5%. However, at 36.5 wt% WL and above, both T_L models fail.

SB3 Waste Type
Assessing the SB3 centroid with Frit 200 yields a predicted operational window between 26 and 30.5 wt% WL. In transitioning from 29 to 30 wt% WL, the existing T_L model fails while the new T_L model is satisfied. At 31 wt% WL, both T_L models fail (even though a conservative PAR limit is used for the new T_L model). At WLs below 26 wt%, the lower Al_2O_3 limit is not met due to the relatively low concentration of Al_2O_3 in the centroid waste type and given that there is no Al_2O_3 contribution from the frit. Homogeneity is not challenged within this particular system over the WL range of interest.

SB4 Waste Type
Assessing the SB4 centroid composition with Frit 200 yields processable glasses over the WL range of 26 to 33 wt%. As with the SB3 composition, glasses from WLs less than 26 wt% do not satisfy the lower Al_2O_3 constraint. At 32.5% WL, the existing T_L model fails, indicating that implementing the new model would enhance the projected processing region. At 35% WL, both T_L models fail (even though a conservative PAR limit is used for the new T_L model). Homogeneity is not challenged with the Frit 200/SB4 EV centroid composition over the WL range of interest.

4.6.3 FRIT 320-BASED GLASSES

HHF Waste Type
As previously discussed, the centroid composition of the HHF waste type has an Al_2O_3 concentration of 43.87 wt%. The impact of this high Al_2O_3 waste type restricts the use of Frit 320 over the WL range from 15 to 37.5 wt% as the $\eta_{1150°C}$ constraint is not satisfied (e.g., predictions exceed the upper viscosity limit as listed in Table 4.9). If Al_2O_3 dissolution were considered, WLs could potentially increase, assuming that no other constraint becomes active. Blending this waste type with waste streams characterized by lower Al_2O_3 concentrations (e.g., HLF) would also be beneficial. If one were to ignore the negative impacts of viscosity, over WLs between 15 and 23%, the homogeneity constraint would be challenged, but it becomes non-constraining at higher WLs.

HLF Waste Type
The most crucial characteristic of this particular waste type is the extremely low Al_2O_3 concentration (3.22 wt%). Given the current lower Al_2O_3 requirement of 3.0 wt%, a WL of approximately 100% would be required (regardless of being coupled with Frit 200, 165, or 320—as these frits do not contain Al_2O_3). As shown in Table 4.10, a 90% WL case yields an unacceptable glass for several properties, one of which is Al_2O_3. Since 100% WLs are infeasible or impractical, blending this bounding waste type to acceptable levels is required.

PHF Waste Type
As with the HLF waste type discussed in Sections 4.6.1 and 4.6.2, the Al_2O_3 concentration of the PHF centroid is relatively low (8.9 wt%). This again challenges the lower Al_2O_3 constraint at lower WLs (below 34 wt%). At WLs from 34 to 40 wt%, homogeneity is challenged for this centroid PHF waste type. At 34 wt% WL and higher, the new T_L model fails (all other predicted properties being acceptable). If the existing T_L model were used, a very small operational window (34 to 36.5%) exists for this nominal waste type (centroid) at the PAR. Again, it should be mentioned that the use of the conservative 1010°C PAR limit for the new T_L model may unnecessarily reject an acceptable glass.

PLF Waste Type
When coupled with Frit 320, the PLF centroid results in acceptable glasses over the nominal WL range of interest (25 to 35 wt%). At 30% WL, the existing T_L model fails, so implementing the new model would be required to increase the operational window (based on this single centroid composition) to the 35 wt% level. Note that homogeneity is not challenged for this centroid waste-type composition over the nominal WL range.

PMF Waste Type
The low Al_2O_3 concentration of the waste (coupled with the fact that Frit 320 has no Al_2O_3) makes it impossible to meet the minimum lower Al_2O_3 limit of 3% at WLs below 37%. Although the lower Al_2O_3 constraint is satisfied at 37% WL, the existing T_L model PAR limit is exceeded. At 38.5 wt% WL, both T_L models fail while at 39%, the WL viscosity is also violated.

SB3 Waste Type
Assessing the SB3 centroid with Frit 320 over the nominal WL range (25 to 35 wt%) yields acceptable glasses at WLs of 26 wt% and above. At WLs below 26 wt%, the lower Al_2O_3 constraint is not met due to the relatively low concentration of Al_2O_3 in the centroid waste type and given that there is no Al_2O_3 contribution from the frit. In transitioning from 31 to 32 wt% WL, only the existing T_L model fails. Again implementing the new T_L model would allow WLs to range from 26 to 35 wt%. Assessments at higher WLs indicate that WLs up to 37.5 wt% are processable (where this upper WL is defined by Glass # 66). Homogeneity is not challenged over the WL range of interest.

SB4 Waste Type
As with the SB3 centroid, assessing the SB4 centroid with Frit 320 over the nominal WL range (25 to 35 wt%) yields acceptable glasses at WLs of 26 wt% and above. At WLs below 26 wt%, the lower Al_2O_3 constraint is not met due to the relatively low concentration of Al_2O_3 in the centroid waste type and given that there is no Al_2O_3 contribution from the frit. In transitioning from 31 to 32 wt% WL, only the existing T_L model fails. Again implementing the new T_L model would allow WLs to range from 26 to 35 wt%. Assessment at higher WLs indicates that WLs up to 40 wt% are achievable given implementation of the new T_L model (where Glass #69 defines the upper limit). Homogeneity is not challenged over the WL range of interest.

5.0 Selection of 33 Glass Compositions for Experimental Evaluation

Although the primary focus of this report is the assessments with respect to homogeneity and the projected operational windows, the definition of the 69 centroid composition provides a pool of candidate glasses from which a subset was selected for actual fabrication and testing. Experimental evaluation of these glasses will provide the initial foundation from which the determination as to whether the homogeneity constraint can be eliminated (or relaxed) for projected sludge-only processing can be made.

The selection process was based solely on the criteria established in Section 4.4. Thirty-three (as shown in Table 5.1) of the sixty-nine centroid-based glasses met the criteria established to support programmatic objectives. Experimental assessments will parallel those used in previous studies (Edwards and Brown [1998] and Peeler et al. [2000]) to assess the homogeneity constraint. More specifically, durability of both quenched and centerline-cooled glasses will be evaluated via the PCT. It should be noted that a separate report will be issued that summarizes the experimental results.

Table 5.1. Candidate Sludge-Only Glasses (in mass fraction)

Glass ID	DWPF PAR Operating Window	Loading (%)	Frit	Al_2O_3	B_2O_3	CaO	Fe_2O_3	Li_2O	MgO	MnO	Na_2O	NiO	SiO_2	U_3O_8	ZrO_2	Others
rc-25	Durable; Visc; Not T_L; Homo; New T_L ; Al_2O_3; alkali	35	165	0.04382	0.06514	0.01571	0.16191	0.04619	0.01042	0.01832	0.12829	0.00659	0.45012	0.03733	0.00695	0.0097
rc-26	Durable; Visc; Not T_L; Homo; New T_L ; Al_2O_3; alkali	35	165	0.04130	0.06514	0.01497	0.15843	0.04620	0.01103	0.02009	0.12918	0.00897	0.44972	0.03867	0.00695	0.0098
rc-27	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	27.5	165	0.03177	0.07261	0.01114	0.11504	0.05130	0.01225	0.02721	0.12955	0.00561	0.50496	0.02359	0.00761	0.0077
rc-28	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	30	165	0.03466	0.07012	0.01216	0.12550	0.04960	0.01246	0.02969	0.12951	0.00612	0.48904	0.02573	0.00739	0.0084
rc-29	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	30	165	0.03756	0.07012	0.01346	0.13878	0.04959	0.01036	0.01570	0.12853	0.00565	0.48296	0.03199	0.00738	0.0083
rc-30	Durable; Visc; T_L; Not Homo; Not New T_L; Al_2O_3; alkali	35	165	0.03115	0.06514	0.00613	0.12040	0.04620	0.01663	0.03973	0.12939	0.02938	0.44534	0.05414	0.00696	0.0099
rc-31	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	20	165	0.08774	0.08008	0.00419	0.02699	0.05640	0.01148	0.01986	0.12949	0.00215	0.56399	0.00409	0.00826	0.0056
rc-32	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	35	165	0.04044	0.06514	0.01418	0.14642	0.04620	0.01287	0.03463	0.12943	0.00714	0.45722	0.03002	0.00695	0.0098
rc-33	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	37.5	165	0.04333	0.06265	0.01519	0.15687	0.04450	0.01307	0.03711	0.12939	0.00765	0.44130	0.03217	0.00674	0.0105
rc-34	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	30	165	0.03540	0.07012	0.01283	0.13579	0.04960	0.01089	0.01722	0.12930	0.00768	0.48262	0.03314	0.00739	0.0084
rc-35	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	27.5	165	0.03245	0.07261	0.01176	0.12448	0.05130	0.01081	0.01578	0.12935	0.00704	0.49907	0.03038	0.00761	0.0077
rc-36	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	15	165	0.06581	0.08506	0.00314	0.02024	0.05980	0.01111	0.01489	0.12961	0.00161	0.59299	0.00307	0.00869	0.0042
rc-37	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	25	165	0.03130	0.07510	0.01122	0.11565	0.05299	0.01030	0.01309	0.12878	0.00471	0.51580	0.02666	0.00782	0.0069
rc-38	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	30	200	0.03540	0.08412	0.01283	0.13579	0.03560	0.01789	0.01722	0.11530	0.00768	0.49662	0.03314	0.00039	0.0084
rc-39	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	30	200	0.03466	0.08412	0.01216	0.12550	0.03560	0.01946	0.02969	0.11551	0.00612	0.50304	0.02573	0.00039	0.0084
rc-40	Durable; Visc; T_L; Not Homo; Not New T_L; Al_2O_3; alkali	35	200	0.03115	0.07814	0.00613	0.12040	0.03320	0.02313	0.03973	0.11639	0.02938	0.45834	0.05414	0.00046	0.0099
rc-41	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	25	200	0.03130	0.09010	0.01122	0.11565	0.03799	0.01780	0.01309	0.11378	0.00471	0.53080	0.02666	0.00032	0.0069
rc-42	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	30	200	0.03756	0.08412	0.01346	0.13878	0.03559	0.01736	0.01570	0.11453	0.00565	0.49696	0.03199	0.00038	0.0083
rc-43	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	32.5	200	0.03755	0.08113	0.01317	0.13596	0.03440	0.01941	0.03216	0.11597	0.00663	0.48663	0.02788	0.00042	0.0091

Glass ID	DWPF PAR Operating Window	Loading (%)	Frit	Al_2O_3	B_2O_3	CaO	Fe_2O_3	Li_2O	MgO	MnO	Na_2O	NiO	SiO_2	U_3O_8	ZrO_2	Others
rc-44	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	27.5	200	0.03245	0.08711	0.01176	0.12448	0.03680	0.01806	0.01578	0.11485	0.00704	0.51357	0.03038	0.00036	0.0077
rc-45	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	35	320	0.04130	0.05214	0.01497	0.15843	0.05270	0.00453	0.02009	0.12268	0.00897	0.47572	0.03867	0.00045	0.0098
rc-46	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	37.5	320	0.03060	0.05015	0.01227	0.15478	0.05076	0.00707	0.03993	0.12455	0.01902	0.45633	0.04389	0.00049	0.0106
rc-47	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	35	320	0.04382	0.05214	0.01571	0.16191	0.05269	0.00392	0.01832	0.12179	0.00659	0.47612	0.03733	0.00045	0.0097
rc-48	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	37.5	320	0.04425	0.05015	0.01604	0.16974	0.05075	0.00486	0.02152	0.12287	0.00961	0.45827	0.04143	0.00049	0.0105
rc-49	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	30	320	0.03466	0.05612	0.01216	0.12550	0.05660	0.00546	0.02969	0.12251	0.00612	0.51704	0.02573	0.00039	0.0084
rc-50	Durable; Visc; T_L; Not Homo; Not New T_L; Al_2O_3; alkali	35	320	0.03115	0.05214	0.00613	0.12040	0.05270	0.01013	0.03973	0.12289	0.02938	0.47134	0.05414	0.00046	0.0099
rc-51	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	27.5	320	0.03177	0.05811	0.01114	0.11504	0.05855	0.00500	0.02721	0.12230	0.00561	0.53396	0.02359	0.00036	0.0077
rc-52	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	25	320	0.03130	0.06010	0.01122	0.11565	0.06049	0.00280	0.01309	0.12128	0.00471	0.54580	0.02666	0.00032	0.0069
rc-53	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	40	320	0.04622	0.04816	0.01621	0.16733	0.04880	0.00728	0.03958	0.12335	0.00817	0.44939	0.03431	0.00052	0.0112
rc-54	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	30	320	0.03756	0.05612	0.01346	0.13878	0.05659	0.00336	0.01570	0.12153	0.00565	0.51096	0.03199	0.00038	0.0083
rc-55	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	35	320	0.04044	0.05214	0.01418	0.14642	0.05270	0.00637	0.03463	0.12293	0.00714	0.48322	0.03002	0.00045	0.0098
rc-56	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	27.5	320	0.03245	0.05811	0.01176	0.12448	0.05855	0.00356	0.01578	0.12210	0.00704	0.52807	0.03038	0.00036	0.0077
rc-57	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	30	320	0.03540	0.05612	0.01283	0.13579	0.05660	0.00389	0.01722	0.12230	0.00768	0.51062	0.03314	0.00039	0.0084

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6.0 Phase 2 Assessment: Sludge Variation

An initial assessment (Phase 1) of the processing windows for the individual waste types and sludge batch centroids was performed in Section 4.6. Although valuable in terms of providing guidance concerning the constraints that may restrict projected processing windows for various sludge/frit combinations, one must realize that the waste compositions were essentially fixed (i.e., centroids derived from extreme vertices). It should be noted that the individual waste types and sludge batches do not overwhelmingly challenge the homogeneity constraint (based on the centroid compositions). However, the single component limit for Al_2O_3 (a key component used for relaxing the homogeneity constraint for MB2 and MB3) is frequently challenged for individual waste-type centroids (e.g., PMF, PHF, and HLF), providing a technical basis for blending.

Given the primary objective of this task and the fact that homogeneity was infrequently challenged by the centroid compositions, the focus of this section will be solely on the projected sludge-only blends for SB3 and SB4 (WSRC 2001). To gain additional insight into the likely process and product characteristics of the glass anticipated from the vitrification of SB3 and SB4, a second paper study (referred to as Phase 2) was conducted that focused on these two blended sludges. The primary focus will be on the homogeneity constraint but, as previously stated, given that other property predictions are readily available and easily calculated, an assessment of the projected processing windows and other property constraints will also be provided as warranted. In the Phase 2 assessment, three frits (200, 165, and 320) were once again considered. As previously mentioned, the primary differences between Phase 1 and Phase 2 were twofold: (1) Phase 2 was used to evaluate the impact of the likely variation in the sludge in terms of challenging the homogeneity constraint and the resulting process operational window and (2) Phase 2 will only focus on SB3 and SB4.

In Section 6.1, inner layer, outer layer, and ring compositions are defined for SB3 and SB4 from which the Phase 2 assessment is based. In Section 6.2, SB3 and SB4 are assessed in terms of challenging homogeneity and defining projected processing windows, based on potential sludge variation over a nominal WL range.

6.1 Definition of Inner Layer, Outer Layer, and Ring Compositions

The initial set of compositions used to represent each of the blended sludges was the set of EVs presented in Section 4.2. These EVs are referred to as the outer layer (OL) EVs of the composition regions of interest. (And in a similar fashion, the centroid computed from these EVs is referred to as the OL centroid.) An inner layer (IL) region was defined for SB3 and SB4 by moving in 20% of the range for the OL interval. The resulting oxide intervals for the IL are provided (along with the OL intervals) for SB3 and SB4 in Table 6.1.

The IL information in Table 6.1 was used as input to JMPs mixture-design algorithms to generate a corresponding set of IL EVs for both SB3 and SB4. In addition, the centroid for each IL was determined. These sludge compositions were added to the EVs and centroids for the SB3 and SB4 OLs to form a set of sludge compositions for the Phase 2 paper study. These sludge compositions were combined with the three frits at nominal WLs of 25, 30, and 35 wt% to generate glass compositions.

Table 6.1. Oxide Intervals for the Inner Layer and Outer Layer of SB3 and SB4 Regions

	SB3 OL		SB3 IL		SB4 OL		SB4 IL	
Oxide	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Al_2O_3	10.13	30.23	14.15	26.21	9.51	34.01	14.41	29.11
CaO	3.61	4.99	3.89	4.71	3.21	4.96	3.56	4.61
Fe_2O_3	42.77	48.48	43.91	47.34	38.09	47.52	39.98	45.63
MgO	0.19	2.50	0.65	2.04	0.28	3.62	0.95	2.95
MnO	3.25	17.46	6.09	14.62	5.92	17.09	8.15	14.86
Na_2O	10.11	16.18	11.32	14.97	10.11	16.18	11.32	14.97
NiO	0.42	5.26	1.39	4.29	0.46	3.89	1.15	3.20
SiO_2	1.96	2.46	2.06	2.36	3.32	5.47	3.75	5.04
U_3O_8	8.74	14.03	9.80	12.97	5.60	12.79	7.04	11.35
Others	2.01	4.17	2.44	3.74	2.01	4.17	2.44	3.74

The development of the IL and OL EV-based glasses provides the opportunity to assess homogeneity over the projected (and hopefully bounding) sludge-only composition region. There was an attempt to produce a third layer by moving in 20% of the range from the IL interval for each oxide. However, due to the bounding nature of these intervals, the resulting region was not feasible (i.e., no compositions in the resulting region satisfied the set of Equation [1]). Therefore, to provide additional insight, a third set of glasses from which this assessment could be made was computed. This third set is referred to as a "ring" on which glasses were defined for both SB3 and SB4 composition regions. The rings were generated from the SB3 and SB4 OL centroids by defining a sludge region (e.g., the ring), which was ±5% around the nominal compositions for the centroids. These rings are defined by the oxide intervals given in Table 6.2. Assessing this ±5% ring around the OL centroids would provide additional information regarding the homogeneity constraint and the projected processing windows for each sludge batch.

Given the development of IL, OL, and ring composition regions, assessments in terms of the robustness of a particular frit-based system can be made. If the results of a particular assessment indicate that the processing window is not restricted over the OL, IL, ring or centroid-based compositions, this would be an ideal case (i.e., large operating window with maximum flexibility). More likely, as one transitions from the centroid to the ±5% ring, to the IL EVs, and ultimately to the OL EVs in sludge space, one would anticipate challenging more constraints as the composition regions explored become more extreme testing the flexibility of the particular frit/sludge combinations. Conversely, as one moves closer to the centroid composition, a suggestion of the robustness of the particular system should be indicated by a positive assessment of all properties resulting in an acceptable processing window. Figures 6.1 and 6.2 present a 2-dimensional view of the relationship among the centroids, rings, IL EVs and OL EVs for SB3 and SB4, respectively.

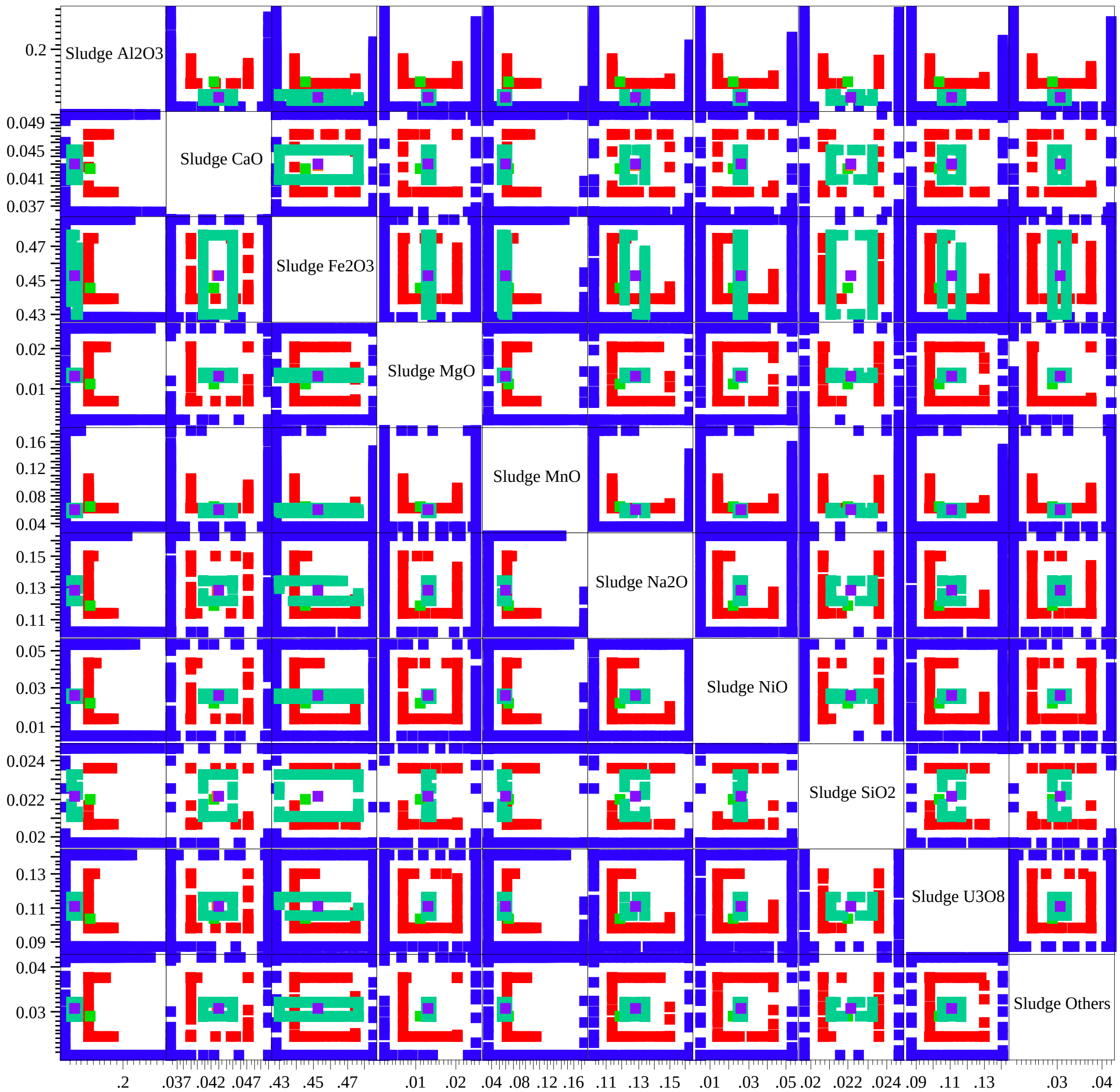

Figure 6.1. Scatterplot Matrix Showing 2-Dimensional View of the Relationship Among the Centroids, Rings, IL EVs, and OL EVS for SB3

Figure 6.2. Scatterplot Matrix Showing 2-Dimensional View of the Relationship Among the Centroids, Rings, IL EVs and OL EVS for SB4

The use of these various layers will provide some indication of the projected operational window size and may lead to the selection of a particular frit (although not optimized in terms of composition) for each SB. Although it should be recognized that quantitative assessments regarding the size of the projected operating window are difficult to make given the uncertainty in sludge composition projections (e.g., recognizing previous differences between process history and actual sludge-sample analysis—although hopefully bounded in this study). This suggests that negative assessments observed (especially in OL EV composition space) may be indicative of sludge combinations that may never be realized during actual SB3 or SB4 processing and should be viewed accordingly.

Table 6.2. Oxide Intervals for the SB3 and SB4 Sludge Rings

	SB3 Ring		SB4 Ring	
Oxide	**Min**	**Max**	**Min**	**Max**
Al_2O_3	11.21	12.39	10.97	12.13
CaO	4.07	4.49	3.85	4.25
Fe_2O_3	43.00	47.52	39.74	43.92
MgO	1.24	1.37	1.73	1.91
MnO	5.45	6.03	9.41	10.4
Na_2O	12.13	13.41	12.2	13.48
NiO	2.43	2.69	1.94	2.14
SiO_2	2.10	2.32	4.13	4.57
U_3O_8	10.50	11.60	8.15	9.01
Others	2.89	3.19	2.89	3.19

Once again, JMP was used to generate the set of EVs for each of the regions, and subsequently, the centroids for these regions were generated from the EVs. These sludge compositions were combined with the three frits at WLs of 25, 30, and 35 wt% to generate additional glass compositions for the Phase 2 paper study.

Exhibit A.1 through Exhibit A.3 (see Appendix A) provide the details of these evaluations of the IL and OL EV glasses by WL. The evaluation of the ±5% ring-based glasses by WL is provided in Exhibit A.4 through Exhibit A.6. These exhibits summarize the contingency analysis indicating or categorizing glasses, based on the acceptance criteria established in Table 4.9. It should be noted that the following section will use these data, but the tables shown are presented in a slightly different format—although there is technically no difference between the two presentations.

As in the assessment of the centroid-based glasses (see Section 5.0), PCCS models were used to predict process and product properties for these glasses, and these predictions were assessed against the PAR limits of Table 4.9. Properties assessed included durability, viscosity, T_L (using both the existing and newly developed models), homogeneity, and Al_2O_3 and sum of alkali concentrations. It should be noted that the PAR limit for assessing the new T_L model was still conservatively set at 1010°C. It is anticipated that the PAR limits for the new model will not be this restrictive (in terms of limiting the potential compositional operating window). Therefore, upon review of the assessments to follow, when the new T_L model prediction is "failed," one must remember this conservatively set PAR limit. More specifically, failing this constraint (as currently defined in Table 4.9) does not necessarily mean it would be an unacceptable glass once the appropriate PAR is used to make this assessment.

Again, the primary objective of the Phase 2 study is to assess the frequency of SB3 and SB4 to challenge the homogeneity constraint within a bounding composition region. The acceptance criteria defined in Section 4.4 were used to assess the projected operational windows for both SB3 and SB4. For a glass to be classified as "acceptable," it must satisfy all of the constraints listed in Table 4.9 with two exceptions:

- To meet programmatic objectives, glasses that satisfy all of the PAR constraints with the exception of homogeneity will be considered as potential candidates for additional study (e.g., fabrication and testing).
- Glasses that meet one (or both) of the T_L constraints will also be considered as potential candidates. For example, a glass that is deemed acceptable by the new model (given the conservative 1010°C PAR limit) but fails the existing model is considered a viable candidate. Only those glasses that fail both T_L models are deemed unacceptable and are excluded from further consideration. Allowing glasses that satisfy the new T_L model to fail the existing T_L model does introduce some risk as this implies that implementing the new T_L model into DWPF will occur and that the new model is applicable over the entire composition range.

It should be noted that glasses classified as acceptable in the Phase 2 assessment were not considered as candidates for experimental evaluation. This is not because they are considered as not providing valuable information to meet programmatic objectives, but solely due to timing. The experimental study was initiated (based on the assessment of the centroid compositions defined in Section 4.2 and the resulting pool of candidate glasses) before developing the Phase 2 paper study. It should be noted that the result of the Phase 2 assessment will provide a pool of candidate glasses to further assess the impact of the homogeneity constraint on sludge-only processing (which will take into account potential sludge-variation). An additional experimental assessment should be performed to address the sludge-variation issue.

6.2 Assessing SB3

Exhibits A.1 to A.3 (in Appendix A) provide detailed information regarding property predictions for the SB3 IL, OL, and ring EVs and centroid compositions. It should be noted that numerous comparisons could be made based on the results presented in Appendix A. The intent of the following discussion is to highlight those observations associated with the homogeneity constraint (including Al_2O_3 and the sum of alkali). The propensity of each sludge batch/frit system to challenge this constraint and its potential to restrict the processing region for future sludge batches, based on the HLW System Plan (WSRC 2001), is the focus. Other technical issues (e.g., impacts on T_L, durability, or viscosity) will be discussed as warranted. It should be recognized that Frit 320 was not developed as a "generic" sludge-only frit but specifically to improve the melt rate for SB2 (Peeler et al. 2001b). Coupling Frit 320 with SB3 and SB4 provides an opportunity to assess the potential advantages or disadvantages of this frit relative to Frit 200 or Frit 165.

The information presented in Appendix A is summarized in Sections 6.2 and 6.3 in a slightly different format. For example, information presented in Table 6.1 includes the sludge type, WL, frit, "DWPF PAR Operating Window," and "N Rows." The sludge type indicates either SB3 (in Section 6.2) or SB4 (in Section 6.3) with IL and OL EVs and centroid compositions. As previously discussed, the column identified as "DWPF PAR Operating Window" represents the comparison of the predicted property versus the PAR limits as shown in Table 4.9. For example, the "DWPF PAR Operating Window" nomenclature for SB3 IL centroid with Frit 320 at 35 wt% WL (see Table 6.3, last row) indicates "Durable, Visc, Not T_L, Homo, New T_L, Al_2O_3, and alkali." This nomenclature indicates that this particular group of compositions satisfies the PAR limits (based on predictions using target compositions) for durability, viscosity, New T_L, homogeneity, the Al_2O_3 lower limit, and the sum of alkali. This glass fails the existing T_L model, indicating that the T_L prediction exceeds the 1024.95°C constraint. The "N Rows" value of "1" indicates that one glass falls within this category, that single glass being the IL centroid composition of SB3 at 35 wt% WL using Frit 320.

6.2.1 INNER LAYER (IL) CENTROIDS

Table 6.3 summarizes the assessment of the SB3 IL centroid with Frits 165, 200, and 320 over the nominal WL range. In terms of homogeneity, this constraint is not challenged for this centroid composition when coupled with any frit over the nominal WL range of 25 to 35 wt%. Assessing the inner layer centroid with Frits 165 and 200 suggests that for glasses at WLs of 30 wt% or greater, the current T_L model predictions exceed the acceptable PAR limit of 1024.95°C. Implementing the new T_L model would be required to process these higher WL centroid-based glasses with Frits 165 or 200. However, even with implementation of the new T_L model, predictions indicate that the 35 wt% WL would also be restricted for the Frit 200-based glasses. Again, it should be mentioned that the use of the 1010°C limit for the new T_L model may overly restrict the Frit 200-based centroid. The three Frit 320-based centroid glasses (25, 30, and 35 wt% WL) all appear to be acceptable, based on the criteria established in Section 4.4. Implementing the new T_L model would be required with the Frit 320-based centroid glass at 35 wt% WL.

For each frit, viscosity and durability for this particular centroid waste stream are not restrictive over the WL range of interest. It should also be noted that the Al_2O_3 lower limit and the sum of alkali constraints for these combinations are not restrictive. Therefore, if one were to eliminate the homogeneity constraint in favor of application of the equivalent constraints on Al_2O_3 and the sum of alkali, then the compositional operating window would not be restricted by Al_2O_3 or sum of alkali.

Although frit comparisons can and have been made, one should not select the application of a specific frit based solely on this centroid composition recognizing that this assessment does not account for any variation in the sludge. Once the assessment of the centroids and EVs for the IL, OL, and rings have been discussed, then one may attempt to make such a judgement.

Table 6.3. SB3 IL Centroid with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB3 IL - centroid	25	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	25	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	35	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB3 IL - centroid	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1

6.2.2 INNER LAYER EXTREME VERTICES

As one transitions from the SB3 IL centroid to the IL EVs (and ultimately to the OL EVs) in sludge space, one would anticipate challenging more constraints as the composition regions explored become more extreme, testing the flexibility of the particular frit/sludge combinations. This assessment provides some indication of the projected operational window size and may lead to the selection of a particular frit (although not optimized in terms of composition) for each SB.

Table 6.4 summarizes the assessment of the SB3 IL EVs with Frits 165, 200, and 320 over the nominal WL of interest. Use of the inner layer SB3 EVs when coupled with either Frit 200 or 165 at 25 wt% WL challenges the current homogeneity constraint. Use of Frit 320 with the IL EVs suggests that the homogeneity constraint is not challenged. This would suggest that Frit 320 has a potential advantage for this particular program (i.e., eliminating the homogeneity constraint for sludge-only processing). This latter statement is made based solely on the current task objective and does not consider other process or product-performance issues. One should not make such a judgement or conclusion until the assessment is complete (remember this is only the IL EVs for SB3), and it should be recognized that other properties or processing criteria may drive the frit-selection process.

At 25 wt% WL, only homogeneity is challenged; all other property predictions are acceptable, based on the criteria established in Section 4.4. The existing T_L model for the SB3 IL EVs becomes restrictive at 30 wt% WL for all of the Frit 200-based glasses and a portion of the Frit 165-based glasses. For the Frit 165-based glasses, implementing the new T_L model would allow the processing of all SB3 IL EVs up to 30 wt% WL. Implementing the new T_L model would only partially open up the processing window for the Frit 200-based IL EVs. At 35 wt% WL, all of the Frit 200 and the majority of the Frit 165-based glasses are not processable as both T_L model predictions exceed their respective PAR limits. Liquidus temperature predictions do not impose any restrictions on the use of Frit 320 at 25 and only partial restrictions (with the existing T_L model) at 30 wt% WL. At 35% WL, the majority of the Frit 320-based IL EV glasses are acceptable (based on the new T_L model). It should be noted that viscosity, durability, Al_2O_3, and alkali are not restrictive over the nominal WL range of interest for any of the three frits with the SB3 IL EVs.

Based on this assessment, implementing the new T_L model appears to provide the opportunity to access a potentially larger SB3 composition region without imposing restrictions. The use of either Frit 165 or 320 also allows for a larger processing window to be accessed without compromising process or product performance properties (based on predictions). Given the fact that higher WLs can be realized (> 25 wt%), the issue of homogeneity for this set of glasses is not challenged. Frit 320 appears to provide a more robust processing window (based on predictions) for the SB3 IL EVs composition region regardless of the decision to implement the new T_L model.

Table 6.4. SB3 IL EVs with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB3 IL	25	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	148
SB3 IL	25	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	38
SB3 IL	25	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	148
SB3 IL	25	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	38
SB3 IL	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	186
SB3 IL	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	186
SB3 IL	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	127
SB3 IL	30	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	59
SB3 IL	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	149
SB3 IL	30	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	37
SB3 IL	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	102
SB3 IL	35	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	84
SB3 IL	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	186
SB3 IL	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	137
SB3 IL	35	320	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	49

6.2.3 OUTER LAYER CENTROIDS

Table 6.5 summarizes the assessment of the nine OL centroid-based glasses when coupled with Frits 165, 200, and 320 over the nominal WL range of interest. Homogeneity is challenged by combining Frits 165 or 200 with the SB3 OL centroid at a 25% WL. At WLs of 30% or higher, homogeneity is not an issue for these two frits when coupled with the OL centroid. It should be mentioned that the exact WL for which homogeneity transitions between being (25 wt%) and not being (30 wt%) an issue was not evaluated. The use of Frit 320 with the SB3 OL centroid does not challenge homogeneity over the nominal WL range. Again, this suggests that an alternative approach to reduce the potentially negative impacts of homogeneity for SB3 would be to transition to Frit 320. This latter statement is based on the centroid compositions with obvious violations of homogeneity being projected in the OL EV composition region for Frit 320 (see next section). Therefore, assessing glasses within this composition region that challenge homogeneity must be completed before making any judgement on the use of a particular frit in terms of minimizing the impact of the homogeneity constraint for sludge-only processing.

One of the most interesting issues regarding the SB3 OL centroid projections is the fact that at 25 wt% WL, all three frits fail the lower Al_2O_3 constraint. Even though SB3 OL centroid/Frit 320 does not challenge homogeneity, this glass would be restricted from DWPF processing, based solely on the Al_2O_3 concentration being lower than 3.0 wt%. Given no Al_2O_3 in the frits being assessed, the only way to meet this limit is to increase WL. (Another option would be to develop a frit containing Al_2O_3, but given that higher WLs may be attainable with the existing frits, this option is not necessary at this time.) As WL is increased, Al_2O_3 is not restrictive, but the T_L constraints become active. Liquidus temperature predictions using the existing model exceeded the acceptable PAR limit of 1024.95°C with both Frit 165 and Frit 200 at WLs at and above 30 wt%. For Frit 320, predictions from the existing T_L model would allow the 30 wt% glass to be processed while restricting the 35 wt% WL glass. Implementing the new T_L model increases (based on model predictions) the projected processing window for the SB3 OL centroid for all three frits. The only predicted restriction is when Frit 200 is coupled with the OL centroid at 35 wt% WL (based on the conservative 1010°C PAR limit being used). It should be noted that the upper WL limit bounded by the new T_L model prediction was not assessed for the Frit 165- or Frit 320-based glasses. Based on model predictions, durability and viscosity do not restrict any of the nine SB3 OL centroid-based glasses from being processed.

Table 6.5. SB3 OL Centroid with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB3 OL - centroid	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB3 OL - centroid	25	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB3 OL - centroid	25	320	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	1
SB3 OL - centroid	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 OL - centroid	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 OL - centroid	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 OL - centroid	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 OL - centroid	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB3 OL - centroid	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1

6.2.4 OUTER LAYER EXTREME VERTICES

General observations using the outer-layer SB3 EVs include challenges of the homogeneity constraint, durability, viscosity, T_L, and Al_2O_3 as shown in Table 6.6. As expected, as one pushes toward the extremes in waste-composition space, property predictions are more frequently challenged. The homogeneity constraint is challenged with all three frits when coupled with certain SB3 OL EV wastes. Challenges to homogeneity are restricted to WLs of 25 wt% or less, which is consistent with previous challenges with other sludge/frit systems (homogeneity challenged at the lower WLs).

One of the more interesting assessments for the SB3 OL EVs is that of the Al_2O_3 concentration. For combinations of SB3 OL EV and frit whose Al_2O_3 concentration in glass are not ≥ 3.0 wt%, a "Not Al_2O_3" is displayed in Table 6.6. Failure to meet this lower Al_2O_3 constraint results in a non-processable glass for DWPF. This is the case for certain SB3 OL EVs at 25 wt% WL for all three frits. This is a result of the relatively low Al_2O_3 contribution in the sludge and the fact that the three frits being used contain no Al_2O_3. So unless an alternative frit is developed that contains Al_2O_3, there are potential scenarios in SB3 composition space that may limit processability, based on this lower Al_2O_3 limit (even if the homogeneity constraint were eliminated for sludge-only processing). However, these regions (as well as homogeneity) are limited to 25 wt% as Al_2O_3 is not an issue for any of the SB3 OL EV compositions at 30 wt% or greater (refer to Table 6.6). Therefore, as higher WLs were targeted for this composition region to address the lower Al_2O_3 limit, homogeneity became a non-issue.

Other interesting features at 25 wt% include limited challenges to durability (based on model predictions) and T_L. Assessing the "DWPF PAR Operating Window" and "N Rows" (or number of glasses falling into a particular category) columns indicates that of the glasses projected when Frit 165 is coupled with S3 OL EV compositions, approximately 40 glasses are predicted to be non-durable. For the Frit 320-based glasses, only 7 have been identified that are predicted to be non-durable. Further assessment indicates that these glasses also have low Al_2O_3 concentrations and are predicted to be inhomogeneous (for the most part). Future testing should consider these glasses as potential candidates to challenge the homogeneity constraint (and the lower Al_2O_3 limit) for sludge-only processing. It should be noted that durability is not an issue for the Frit 200-based glasses.

Liquidus temperature restrictions at 25 wt% WL are limited to the use of Frit 200 and predictions using the new T_L model with the conservative 1010°C PAR limit. Given the need to target higher WLs (to address the low Al_2O_3 issue), T_L predictions become the most active or restrictive property. Both the existing and new T_L models are challenged for certain compositional combinations at WLs of 30 and 35 wt%. Based on the assessment of the "N Rows" column, the existing T_L model becomes more of a limitation than does the new T_L model, especially when Frits 165 or 320 are used. At 30 wt% WL, implementing the new T_L model and using Frit 165 limits the processing of approximately 80 glasses, while the use of Frit 320 limits only 7. The majority of the Frit 200-based glasses at 30% WL would be restricted regardless of which T_L model was used for predicting.

At 35 wt% WL, the existing T_L model restricts the processing of all SB3 OL EV glasses. Implementing the new T_L would therefore increase the projected operational window and provide a more robust processing window to handle potential sludge variation (regardless of frit selection). Given implementation of the new T_L model, processing would still be restricted for certain combinations of the SB3 OL EVs with all three frits. Based on an assessment of the number of glasses falling into this category, it appears that the use of Frit 320 would be less restrictive followed by Frit 165 and then Frit 200. Therefore, T_L restrictions become less of an issue with implementing the new T_L model and are perhaps less restrictive with Frit 320 at higher WLs.

Unlike the SB3 IL EVs, durability (based on model prediction) becomes a limiting constraint for certain combinations of the SB3 OL EVs with both Frit 165 and Frit 320 over the entire WL range evaluated. This suggests that there are combinations in the OL EV composition space that are predicted to lead to non-durable glasses. Given the capability to assess the number of glasses falling into this category, the use of Frit 165 leads to a non-durable prediction for 41, 21, and 16 glasses at 25, 30, and 35 wt% WL, respectively. Frit 320 leads to non-durable predictions for 7, 4, and 2 glasses. Although the potential to produce a non-durable product with either Frit 165 or Frit 320 exists (based on predictions), it must be remembered that these glasses are based on OL EVs, and these compositions may not actually materialize. Viscosity also becomes an issue for both Frit 165 and Frit 320 for certain glasses at 35 wt% WL (e.g., challenging the lower $\eta_{1150°C}$ limit as defined in Table 4.9). It should be noted that the Frit 200-based SB3 OL EV glasses do not challenge durability or viscosity over the nominal WL range of interest.

6.2.5 RING CENTROIDS

Assessment of the nine SB3 ring-based centroids is summarized in Table 6.7. The assessment indicates that homogeneity is challenged with the use of Frit 200 and Frit 165 at 25 wt% WL. At higher WLs or with the use of Frit 320 (over the WL range of 25 to 35 wt%), homogeneity is not challenged. At 25 wt% WL, the Al_2O_3 lower limit of 3 wt% is not met, requiring higher WLs to be processed. It should be noted that although the lower Al_2O_3 limit is not met for the three 25 wt% WL glasses, all three are predicted to be durable. Therefore, if one were to challenge the lower Al_2O_3 constraint and examine the possibility of a new lower bound, there is the potential to open the operating window. Although this is an option, it is not considered practical given that higher WLs are achievable.

As in previous assessments, as WL is increased, the T_L typically becomes the limiting constraint. For the SB3 ring centroid composition, this also applies. At 25 wt% WL, both the existing and new T_L models are not limiting (although low Al_2O_3 is). As WL increases to 30 wt%, T_L becomes the limiting constraint with the existing T_L model for Frit 165 and Frit 200. Implementing the new T_L model does not restrict processing the SB3 ring centroid at 30 wt% WL for any of the frits evaluated. At 35 wt% WL, implementing the new T_L model is required as the predictions using the existing model exceed the 1024.95°C PAR limit. Predictions using the conservative 1010°C PAR limit with the new T_L model indicate that the Frit 165- and Frit 320-based ring centroids would be acceptable. Predictions using the new T_L model for Frit 200 at 35 wt% WL indicate that this glass would not be processable. Durability and viscosity are not challenged in the SB3 ring centroid composition region over the WL range of interest.

Table 6.6. SB3 OL EVs with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB3 OL	25	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	122
SB3 OL	25	165	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	163
SB3 OL	25	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	22
SB3 OL	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	258
SB3 OL	25	165	Not Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	1
SB3 OL	25	165	Not Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	40
SB3 OL	25	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	98
SB3 OL	25	200	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	150
SB3 OL	25	200	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	24
SB3 OL	25	200	Durable; Visc; T_L; Homo; Not New T_L; Not Al_2O_3; alkali	14
SB3 OL	25	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	21
SB3 OL	25	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	293
SB3 OL	25	200	Durable; Visc; T_L; Not Homo; Not New T_L; Al_2O_3; alkali	1
SB3 OL	25	200	Durable; Visc; T_L; Not Homo; Not New T_L; Not Al_2O_3; alkali	5
SB3 OL	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	137
SB3 OL	25	320	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	231
SB3 OL	25	320	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	7
SB3 OL	25	320	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	224
SB3 OL	25	320	Not Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	7
SB3 OL	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	207
SB3 OL	30	165	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	13
SB3 OL	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	295
SB3 OL	30	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	70
SB3 OL	30	165	Not Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	21
SB3 OL	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	173
SB3 OL	30	200	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	114
SB3 OL	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	181
SB3 OL	30	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	138
SB3 OL	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	321

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB3 OL	30	320	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	5
SB3 OL	30	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	274
SB3 OL	30	320	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	2
SB3 OL	30	320	Not Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	4
SB3 OL	35	165	Durable; Not Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	156
SB3 OL	35	165	Durable; Not Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	76
SB3 OL	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	165
SB3 OL	35	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	193
SB3 OL	35	165	Not Durable; Not Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	16
SB3 OL	35	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	203
SB3 OL	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	403
SB3 OL	35	320	Durable; Not Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	42
SB3 OL	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	385
SB3 OL	35	320	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	177
SB3 OL	35	320	Not Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	2

Table 6.7. SB3 Ring Centroids with Frits 200, 165, and 320 as a Function of WL

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB3 Ring Centroid	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB3 Ring Centroid	25	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB3 Ring Centroid	25	320	Durable; Visc; T_L; Homo; New T_L ; Not Al_2O_3; alkali	1
SB3 Ring Centroid	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 Ring Centroid	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 Ring Centroid	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 Ring Centroid	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB3 Ring Centroid	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB3 Ring Centroid	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1

6.2.6 RING EXTREME VERTICES

Table 6.8 summarizes the assessment of the SB3 ring EVs for Frits 165, 200, and 320 over the nominal WL range of interest. The homogeneity constraint is challenged by certain combinations of sludge compositions with all three frits of interest at 25 wt% WL. As with the SB3 ring centroid, Al_2O_3 concentration is also a limiting constraint as the majority of the EV-based glasses have Al_2O_3 concentrations less than 3 wt%—thereby restricting processing, based on current acceptance constraints. As WLs increase to 30 and 35 wt%, both homogeneity and Al_2O_3 are not challenged, and T_L becomes the restricting constraint. At the 25 wt% WL, neither T_L model restricts the projected processing window. As WLs reach 30 wt%, the existing T_L model restricts processing of almost all Frit 165- and Frit 200-based SB3 EVs glasses. The existing T_L model restricts some of the Frit 320-based glasses, but based on this assessment, over two-thirds of these glasses are still processable. Implementing the new T_L model would only restrict processing with Frit 200 (over some combinations) at 30 wt% WL. At 35 wt% WL, the existing T_L model completely restricts the processing of any SB3 EV with any of the frits of interest, requiring implementation of the new T_L model. The new T_L model provides operational windows for the Frit 165 (partial window) and Frit 320 (no restrictions projected) based SB3 EVs at 35 wt% WL. The Frit 200-based SB3 EV glasses at 35 wt% WL are still not processable even with the new T_L model.

Durability and viscosity are not restrictive over the nominal WL range (25 to 35 wt%) for any of the frits of interest with one exception: at 35 wt% WL, some of the Frit 165-based glasses challenge the lower $\eta_{1150°C}$ limit. This latter constraint further collapses the projected processing window for the Frit 165-based glasses, making Frit 320 a potentially more viable selection.

6.3 Assessing SB4

6.3.1 INNER LAYER CENTROIDS

Table 6.9 summarizes the assessment of the SB4 IL centroid glasses. The homogeneity constraint is challenged when the IL centroid is coupled with Frit 165 and Frit 200 at 25 wt% WL. Homogeneity is not an issue for these two frits at higher WLs. Homogeneity is not challenged for the Frit 320-based glasses over the entire WL range of interest.

Assessing the inner layer centroid coupled with all three frits at 30 wt% WL indicates no restrictions, based on property predictions. At 35 wt% WL, implementing the new T_L model is required as the predictions using the existing model exceed the 1024.95°C PAR limit. Predictions using the conservative 1010°C PAR limit with the new T_L model indicate that the Frit 165- and Frit 320-based IL centroids are acceptable.

The durability, viscosity, Al_2O_3, and sum of alkali do not restrict any of the nine SB4 IL centroid-based glasses.

Table 6.8. SB3 Ring EVs with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit ID	DWPF PAR Operating Window	N Rows
SB3 Ring	25	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	96
SB3 Ring	25	165	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	146
SB3 Ring	25	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	213
SB3 Ring	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	161
SB3 Ring	25	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	96
SB3 Ring	25	200	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	146
SB3 Ring	25	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	213
SB3 Ring	25	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	161
SB3 Ring	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	292
SB3 Ring	25	320	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	298
SB3 Ring	25	320	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	17
SB3 Ring	25	320	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	9
SB3 Ring	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	69
SB3 Ring	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	547
SB3 Ring	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	219
SB3 Ring	30	200	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	4
SB3 Ring	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	275
SB3 Ring	30	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	118
SB3 Ring	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	466
SB3 Ring	30	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	150
SB3 Ring	35	165	Durable; Not Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	50
SB3 Ring	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	322
SB3 Ring	35	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	244
SB3 Ring	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	616
SB3 Ring	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	616

Table 6.9. SB4 IL Centroid with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 IL - centroid	25	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	25	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB4 IL - centroid	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1

6.3.2 INNER LAYER EXTREME VERTICES

Assessment of the SB4 IL EVs is summarized in Table 6.10. The homogeneity constraint is challenged at 25 wt% WL for certain combinations of the SB4 IL with all three frits of interest. Again, challenging the homogeneity constraint at lower WLs has been previously observed in other studies. As WL is increased to 30 wt% and above, homogeneity becomes a non-constraining property prediction.

The only other processing prediction that challenges or actually restricts the projected processing window for the SB4 IL EVs is T_L. Partial processing restrictions result when using the existing T_L model at 30 wt% WL or all three frits. In fact, implementing the new T_L model is required at 35 wt% WL as T_L predictions using the existing model exceed the 1024.95°C PAR limit in all cases. Implementing the new T_L model allows (based on model predictions) processing of all combinations of the SB4 IL EVs to at least 30 wt% with Frits 165 and 320 without any restrictions imposed. Certain combinations using Frit 165 or Frit 320 are restricted at the 35 wt% level. All other predicted properties are within the acceptable PAR limits as defined in Table 4.9.

6.3.3 OUTER LAYER CENTROIDS

Table 6.11 summarizes the property assessments for the SB4 OL centroid-based glasses over the nominal WL range. The homogeneity constraint is challenged when the SB4 OL centroid is combined with all three frits at 25 wt% WL. As with the SB3 OL centroid, one of the most interesting issues regarding the SB4 OL centroid projections is the fact that in the case of 25 wt% WL, all three frits not only "fail" the homogeneity criteria, but also do not pass the lower Al_2O_3 constraint. Therefore, even if the homogeneity constraint were eliminated for sludge-only processing, these glasses would be restricted from DWPF processing, based on the lower Al_2O_3 constraint. Given no Al_2O_3 in the frits being assessed, the only way to meet this limit is to increase WL.

As WL is increased, the T_L constraints become active in the sense that T_L predictions using the existing model exceed the acceptable PAR limit of 1024.95°C with all three frits at 35 wt% WL. Implementing the new T_L model appears to open up the processing window for the SB4 OL centroid for Frits 165 and 320 at 35 wt%, but use of Frit 200 is still restricted to WLs of 30 wt% or less even with the new T_L model. Viscosity and durability are not restrictive for these centroid-based glasses over the nominal WL range of interest.

6.3.4 OUTER LAYER EXTREME VERTICES

As one transitions from the centroids to the IL EVs, and ultimately to the OL EVs in sludge space, one would anticipate challenging more constraints as the composition regions explored become more extreme and begin to test the flexibility of the particular frit/sludge combinations. This is actually the case as several properties are not satisfied for the SB4 OL EVs as shown in Table 6.12.

Table 6.10. SB4 IL EVs with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 IL	25	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	74
SB4 IL	25	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	244
SB4 IL	25	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	74
SB4 IL	25	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	244
SB4 IL	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	138
SB4 IL	25	320	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	180
SB4 IL	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	270
SB4 IL	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	48
SB4 IL	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	222
SB4 IL	30	200	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	61
SB4 IL	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	33
SB4 IL	30	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	2
SB4 IL	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	298
SB4 IL	30	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	20
SB4 IL	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	247
SB4 IL	35	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	71
SB4 IL	35	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	51
SB4 IL	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	267
SB4 IL	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	308
SB4 IL	35	320	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	10

Table 6.11. SB4 OL Centroids with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 OL - centroid	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB4 OL - centroid	25	200d	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB4 OL - centroid	25	320	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB4 OL - centroid	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 OL - centroid	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 OL - centroid	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 OL - centroid	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 OL - centroid	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB4 OL - centroid	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1

Table 6.12. SB4 OL EVs with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 OL	25	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	94
SB4 OL	25	165	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	83
SB4 OL	25	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	75
SB4 OL	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	259
SB4 OL	25	165	Not Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	15
SB4 OL	25	165	Not Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	5
SB4 OL	25	165	Not Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	193
SB4 OL	25	200	Durable; Not Visc; T_L; Homo; New T_L; Al_2O_3; alkali	16
SB4 OL	25	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	75
SB4 OL	25	200	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	98
SB4 OL	25	200	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	3
SB4 OL	25	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	80
SB4 OL	25	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	452
SB4 OL	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	112
SB4 OL	25	320	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	191
SB4 OL	25	320	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	60
SB4 OL	25	320	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	269
SB4 OL	25	320	Not Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	2
SB4 OL	25	320	Not Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	90
SB4 OL	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	108
SB4 OL	30	165	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	39
SB4 OL	30	165	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	8
SB4 OL	30	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	23
SB4 OL	30	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	122
SB4 OL	30	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	57
SB4 OL	30	165	Durable; Visc; Not T_L; Homo; New T_L; Not Al_2O_3; alkali	204
SB4 OL	30	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	6

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 OL	30	165	Not Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	3
SB4 OL	30	165	Not Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	7
SB4 OL	30	165	Not Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	6
SB4 OL	30	165	Not Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	137
SB4 OL	30	165	Not Durable; Visc; Not T_L; Homo; New T_L; Not Al_2O_3; alkali	4
SB4 OL	30	200	Durable; Not Visc; T_L; Homo; New T_L; Al_2O_3; alkali	3
SB4 OL	30	200	Durable; Not Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	2
SB4 OL	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	82
SB4 OL	30	200	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	46
SB4 OL	30	200	Durable; Visc; T_L; Homo; Not New T_L; Al_2O_3; alkali	41
SB4 OL	30	200	Durable; Visc; T_L; Homo; Not New T_L; Not Al_2O_3; alkali	12
SB4 OL	30	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	27
SB4 OL	30	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	251
SB4 OL	30	200	Durable; Visc; T_L; Not Homo; Not New T_L; Al_2O_3; alkali	2
SB4 OL	30	200	Durable; Visc; T_L; Not Homo; Not New T_L; Not Al_2O_3; alkali	8
SB4 OL	30	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	28
SB4 OL	30	200	Durable; Visc; Not T_L; Homo; New T_L; Not Al_2O_3; alkali	144
SB4 OL	30	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	26
SB4 OL	30	200	Durable; Visc; Not T_L; Homo; Not New T_L; Not Al_2O_3; alkali	52
SB4 OL	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	141
SB4 OL	30	320	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	187
SB4 OL	30	320	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	15
SB4 OL	30	320	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	151
SB4 OL	30	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	49
SB4 OL	30	320	Durable; Visc; Not T_L; Homo; New T_L; Not Al_2O_3; alkali	94
SB4 OL	30	320	Not Durable; Visc; T_L ; Homo; New T_L; Al_2O_3; alkali	4
SB4 OL	30	320	Not Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	20
SB4 OL	30	320	Not Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	2
SB4 OL	30	320	Not Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	61
SB4 OL	35	165	Durable; Not Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	111
SB4 OL	35	165	Durable; Not Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	8

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 OL	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	314
SB4 OL	35	165	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	150
SB4 OL	35	165	Durable; Visc; Not T_L; Not Homo; New T_L; Al_2O_3; alkali	17
SB4 OL	35	165	Durable; Visc; Not T_L; Not Homo; Not New T_L; Al_2O_3; alkali	1
SB4 OL	35	165	Not Durable; Not Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	59
SB4 OL	35	165	Not Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	64
SB4 OL	35	200	Durable; Not Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB4 OL	35	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	310
SB4 OL	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	395
SB4 OL	35	200	Durable; Visc; Not T_L; Not Homo; New T_L; Al_2O_3; alkali	12
SB4 OL	35	200	Durable; Visc; Not T_L; Not Homo; Not New T_L; Al_2O_3; alkali	6
SB4 OL	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	562
SB4 OL	35	320	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	78
SB4 OL	35	320	Not Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	84

For Frit 165 and Frit 200, the homogeneity constraint is challenged over the entire WL range of interest (25 to 35 wt%) for select combinations of frit and SB4 OL EVs. With Frit 320, homogeneity is challenged at the 25 and 30 wt% levels but is not an issue at 35 wt% WL. One of the most interesting issues regarding the SB4 OL EV glasses is the fact that at 25 and 30 wt% WL, all three frits could potentially produce glasses that would not pass the lower Al_2O_3 constraint of ≥ 3 wt% (in glass). This is slightly different from the assessment of the SB3 OL EVs where, at WLs at and exceeding 30 wt%, Al_2O_3 was not an issue. Therefore, even if the homogeneity constraint were eliminated for sludge-only processing, some of these EV glasses would be restricted from DWPF processing based on this lower Al_2O_3 constraint. Given no Al_2O_3 in the frits being assessed, the only way to meet this limit is to increase WL, which may be more feasible pending implementing the new T_L model (as discussed below).

In terms of T_L predictions, restrictions are imposed, based on predictions using the existing T_L model, only at WLs of 30 and 35 wt%. All three frits have some composition region that exceeds the 1024.95°C PAR limit for the existing T_L model at 30 and 35 wt% WL. All glasses at 25 wt% WL are acceptable, based on the existing T_L model predictions. If one were to implement the new T_L model, at 25 wt% WL, there is a slight restriction (three glasses based on the 1010°C conservative PAR limit) on the composition region associated with Frit 200-based glasses. This provides some incentive to consider either Frit 165 or Frit 320 as a potential baseline frit. It should be noted that neither Frit 165 nor Frit 320 was specifically developed for SB3 or SB4, and there may be alternative frits that could “optimize” both process and product performance properties. The Frit 165-based SB4 OL EV glasses are somewhat restricted in terms of T_L at the 30 and 35 wt% level using the new T_L model. As for Frit 320 OL EV-based glasses, restrictions are limited to the 35 wt% level with the new T_L model. All Frit 320-based glasses at 30 wt% WL are acceptable, based on T_L predictions using the new model.

As with the SB3 OL EVs, other property predictions (besides homogeneity, Al_2O_3, and T_L) impose restrictions on the projected processing envelope due to larger compositional variation. Predictions of durability limit potential compositional combinations for Frit 165 and Frit 320 over the full WL range of interest (25 to 35 wt%). Use of Frit 200 does not impose durability restrictions over the entire region of interest.

Viscosity also becomes a limitation for select Frit 165- and Frit 200-based SB4 OL EV glasses. Glasses failing this constraint exceed the 105.4 Poise limit. Select (and limited) Frit 200-based glasses are predicted to be limited over the entire 25 to 35 wt% WL range, while Frit 165 glasses (again select and limited) could potentially be limited only at the 35 wt% level. Glasses projected within the Frit 320 region appear to be acceptable from a viscosity perspective over the entire WL range.

6.3.5 RING CENTROIDS

Table 6.13 summarizes the property predictions of the SB4 ring centroid-based glasses over the nominal WL range. The homogeneity and lower Al_2O_3 constraints are challenged at 25 wt% WL for all three frits. At higher WLs, both homogeneity and Al_2O_3 are no longer restrictions. Restrictions in terms of T_L predictions are not encountered until WLs of 35 wt% are targeted. At 35 wt% WL, the existing T_L model prohibits processing of the SB4 ring centroid with any of the frits evaluated. Implementing the new T_L model provides a projected processing window for the Frit 165- and Frit 320-based SB4 ring centroid glasses, but it still restricts processing the Frit 200-

based glasses. Durability and viscosity are not limiting over the 25 to 35 wt% WL range based on predictions.

6.3.6 RING EXTREME VERTICES

The assessment of the SB4 ring EVs is summarized in Table 6.14. At 25 wt% WL, the homogeneity constraint is challenged by all Frit 165- and Frit 200-based glasses. For the Frit 320-based glasses at 25 wt% WL, there is an indication that use of this frit stretches the composition region in a direction that minimizes the negative impact of homogeneity. Specifically, although the majority of Frit 320-based glasses at 25 wt% WL are predicted to be inhomogeneous, a limited number of glasses are "acceptable" in terms of this predicted property.

As WLs are incrementally increased to 30 wt% and above, homogeneity is not challenged for any of the three frits evaluated (and the lower Al_2O_3 limit is not an issue). As with the SB3 ring EVs, the Al_2O_3 concentration is also a limiting constraint at 25 wt% WL as the majority of the EV-based glasses have Al_2O_3 concentrations less than 3 wt%—thereby restricting processing, based on current acceptance constraints. As WLs increase to 30 and 35 wt%, the lower Al_2O_3 constraint does not restrict the projected processing window as defined by the EVs evaluated.

At 25 and 30 wt% WL, neither T_L model restricts the projected processing window. As WLs reach 35 wt%, the existing T_L model restricts all Frit 165-, Frit 200-, and Frit 320-based SB4 ring EV glasses from being processed. Given this, implementing the new T_L model would be required to process Frit 165- or Frit 320-based glasses at the higher WLs. At 35 wt% WL, the Frit 200-based glasses are still not processable given the 1010°C PAR limit. All SB4 ring EVs evaluated appear processable with Frit 165 or Frit 320 at 30 and 35 wt% WL. Higher WLs were not evaluated for the SB4 ring EVs. Durability and viscosity are not restrictive over the nominal 25- to 35 wt% WL range.

Table 6.13. SB4 Ring Centroids with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 Ring Centroid	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB4 Ring Centroid	25	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB4 Ring Centroid	25	320	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	1
SB4 Ring Centroid	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 Ring Centroid	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 Ring Centroid	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 Ring Centroid	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1
SB4 Ring Centroid	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	1
SB4 Ring Centroid	35	320	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	1

Table 6.14. SB4 Ring EVs with Frits 200, 165, and 320

Sludge Type	Waste Loading (%)	Frit	DWPF PAR Operating Window	N Rows
SB4 Ring	25	165	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	317
SB4 Ring	25	165	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	348
SB4 Ring	25	200	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	317
SB4 Ring	25	200	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	348
SB4 Ring	25	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	2
SB4 Ring	25	320	Durable; Visc; T_L; Homo; New T_L; Not Al_2O_3; alkali	2
SB4 Ring	25	320	Durable; Visc; T_L; Not Homo; New T_L; Al_2O_3; alkali	315
SB4 Ring	25	320	Durable; Visc; T_L; Not Homo; New T_L; Not Al_2O_3; alkali	346
SB4 Ring	30	165	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	665
SB4 Ring	30	200	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	665
SB4 Ring	30	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	665
SB4 Ring	35	165	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	665
SB4 Ring	35	200	Durable; Visc; Not T_L; Homo; New T_L; Al_2O_3; alkali	22
SB4 Ring	35	200	Durable; Visc; Not T_L; Homo; Not New T_L; Al_2O_3; alkali	643
SB4 Ring	35	320	Durable; Visc; T_L; Homo; New T_L; Al_2O_3; alkali	665

7.0 Summary

The objective of this task is to develop the fundamental technical data to relax or eliminate the homogeneity measurement uncertainty requirement ***for projected sludge-only processing*** as long as the following criteria are satisfied:

Criterion (1)

- use the alumina constraint as currently implemented in DWPF's PCCS ($Al_2O_3 \geq 3$ wt%) **and** add a sum of alkali[(a)] constraint with an upper limit of 19.3 wt% ($\Sigma M_2O < 19.3$ wt%),

or

Criterion (2)

- adjust the lower limit on the alumina constraint to 4 wt% ($Al_2O_3 \geq 4.0$ wt%).

In this report, initial assessments (via computational evaluations relative to acceptable property limits) are made as to whether the homogeneity constraint has the potential to restrict composition regions of projected sludge-only processing. The composition region covered by this study included five individual or basic waste types and two specific sludge batches (SB3 and SB4)—the latter of which defines sludge-only processing, based on Revision 12 of the HLW Waste System Plan (WSRC 2001).

Three primary outcomes result from this study:

(1) An initial screening assessment (Phase 1) has been performed using centroid-based sludge compositions computed from bounding waste types and/or blended sludges.

(2) Thirty-three glass compositions have been defined to experimentally support initial screening observations.

(3) The Phase 2 assessment of SB3 and SB4 glasses using centroid and extreme sludge compositions within an inner layer, outer layer and ring layer was completed.

These three areas are summarized below.

Phase 1 Assessment: Centroid-Based Glasses

Five "basic" sludge types and projections of SB3 and SB4 were used to develop composition bounds for the Phase 1 assessment. The basic sludge types were based on examining the sludge compositions that have been estimated from the historic information versus the corresponding compositions measured in DWPF (where adjustments were made to the historic projections as needed to develop a bounding envelope). Feeds from the tanks expected for the remainder of sludge-only operation were developed, based on projected blends of the "basic" sludge types

(a) Alkalis included in this sum are Na_2O, Li_2O, Cs_2O, and K_2O. However, for sludge-only processing, neither Cs_2O nor K_2O is introduced at significant concentrations, so the sum of alkali is based solely on Na_2O and Li_2O.

(e.g., H Modified High Heat Fresh (HHF) Feed, PUREX Low Heat Fresh (PLF) Feed, PUREX Mixed Fresh (PMF) Feed, etc.).

Extreme vertices and centroid compositions for each basic waste type and sludge batch were calculated, which formed the basis of the Phase 1 assessment. The waste and sludge centroids were coupled with Frits 165, 200, and 320 over a nominal WL range (e.g., 25, 30, and 35 wt%) to develop a pool of glass compositions for this assessment. Assessments were made, based on established "acceptability" criteria (at the PAR) on 69 centroid-based glasses. Although the primary focus is on the homogeneity constraint, model predictions were easily performed for other properties making assessments on the projected operational window another area of interest.

It should be noted that the individual waste types and sludge batches do not overwhelmingly challenge the homogeneity constraint (based on the centroid compositions). However, the single component limit for Al_2O_3 (a key component used for relaxing the homogeneity constraint for MB2 and MB3) is frequently challenged for individual waste-type centroids (e.g., PMF, PHF, and HLF), providing a technical basis for blending.

For the five basic sludge types, the Al_2O_3 concentration was a recurring limitation as some streams contained too much Al_2O_3 (typically challenging upper viscosity limits) or not enough Al_2O_3 (resulting in failures to meet the lower Al_2O_3 limit of 3 wt%). For example, the high concentration of Al_2O_3 in the HHF centroid-based waste type drove WLs to a relatively low level to achieve an acceptable viscosity prediction. The low Al_2O_3 concentrations represented by the HLF centroid-based wastes resulted in minimum WLs that were impractical (e.g., 100%). For the PHF waste type, a minimum of 34 wt% was required to meet the lower Al_2O_3 constraint. At slightly higher WLs (e.g., 36 wt%), both T_L model predictions were unacceptable, rendering a very small projected operating window. It is recognized that using the conservative 1010°C PAR limit for the new T_L model may overly restrict this projected operating window. In the case of the PMF waste type, there was no projected operating window given the low Al_2O_3 concentrations. For the PLF waste type, processing over the nominal WL range (25 to 35 wt%) results in acceptable glasses when Frit 165 or Frit 320 are used. The use of Frit 200 limits processing to 32 wt% or less as T_L predictions become unacceptable for both T_L models, given the associated PAR limits.

Blending strategies for these basic waste types are crucial given the Al_2O_3 issues with the majority of the basic waste types. It is recognized that Al_2O_3 dissolution could help to resolve this issue for the HHF waste type (high Al_2O_3), but overall (and probably of no surprise) blending would be beneficial. It should be noted that homogeneity is infrequently challenged within these basic waste-type operating regions.

Probably of more direct interest is the assessment of SB3 and SB4, given that blending strategies have been defined (WSRC 2001). Given the objectives of this task, the most important observation for the SB3 and SB4 centroid-based compositions is that homogeneity is not challenged when coupled with any of the frits evaluated over the projected operational windows. However, the selection of a frit appears to influence the size of the operational window. First consider SB3 with Frits 165, 200, and 320. Based on model predictions and the use of the "established acceptability criteria" (see Table 4.9), the use of Frit 200 appears to be most restrictive in terms of the projected operational window size (i.e., an acceptable window being projected between 26 to 30.5 wt% WL). At higher WLs, both T_L model predictions become unacceptable. The use of Frit 165 pushes the upper acceptable WL to 35 wt%, assuming that the new T_L model is implemented. Assessing Frit 320 and the SB3 centroid indicates that WLs of

37.5 wt% are achievable (again given implementation of the new T_L model). It must be mentioned that the use of the conservative 1010°C PAR limit for the new T_L model may overly restrict the projected processing windows.

For the SB4 centroid glasses, the same general trends are observed. Homogeneity is not challenged over the projected operational windows regardless of frit selection. However, the size of the window is influenced by frit selection. The use of Frit 200 limited WLs to 33 wt%, while the use of Frit 165 and Frit 320 yielded upper WL limits of 38.5 wt% and 40 wt%, respectively, given implementation of the new T_L model.

Although comparisons have been made, the selection of or decision to use a particular frit for SB3 and/or SB4 should not be made, based on the Phase 1 assessment alone. The Phase 1 assessments were based on centroid compositions that did not take into account any potential variation in sludge.

Pool Of Candidate Centroid-Based Glasses
Upon completion of the Phase 1 assessment, a pool of candidate glasses was available from which glasses could be (and were) selected to experimentally support these assessments. Thirty-three glasses satisfied the "acceptability criteria" that were established specifically for this study. Although the Phase 1 assessment of these centroid-based glasses rarely challenged homogeneity, five glasses were selected (covering the three frits of interest) that were predicted to be inhomogeneous. The objective of this experimental study is to challenge the homogeneity constraint for sludge-only processing by monitoring the durability responses for both quenched and clc glasses within this composition region. The results of this experimental study are not presented in this report. A subsequent report will be issued.

Phase 2 Assessment: Impact of Sludge Variation
The Phase 1 assessment of the five basic sludge types indicated that blending strategies would be beneficial (or required in some cases) to process the majority of these waste types. The Phase 2 assessment therefore focused solely on SB3 and SB4 and their potential sludge variation and its likely impact on projected operational windows. It must be recognized that likely composition variation was accounted for, based on estimates from historic information versus the corresponding compositions measured in DWPF. Adjustments were made to the historic projections as needed to develop a bounding envelope. Any conclusions from this study are based on the fact that the assumptions and information used to bound this compositional envelope will ultimately bound SB3 and SB4 compositions once blending strategies are implemented and analyses are received.

The initial set of compositions used to represent each of the blended sludges was the set of OL extreme vertices. An IL region was defined for SB3 and SB4 by moving in 20% of the range for the OL interval. In addition, IL and OL centroids were determined for both sludge batches. These sludge compositions were combined with the three frits at nominal WLs of 25, 30, and 35 wt% to generate candidate glass compositions on which the Phase 2 assessment was based.

The development of the IL and OL EV-based glasses provided the opportunity to assess homogeneity over the projected sludge-only composition region. To provide additional insight, a third set of glasses from which this assessment could be made was computed. This third set is referred to as a "ring" on which glasses were defined for both SB3 and SB4 composition regions. The rings were generated from the SB3 and SB4 OL centroids by defining a sludge region (e.g., the ring), which was ±5% around the nominal compositions for the centroids. Assessing this ±5% ring around the OL centroids provided additional information regarding the homogeneity constraint and the projected processing windows for each sludge batch.

Given the development of IL, OL, and ring composition regions, assessments in terms of the robustness of a particular frit-based system were made. Although an ideal case (i.e., the results of a particular assessment indicate that the processing window is not restricted over the OL, IL, ring or centroid-based compositions) was not found, definite trends were observed. As expected, as one transitions from the centroid to the ±5% ring, to the IL EVs, and ultimately to the OL EVs in sludge space, one challenges more constraints as the glass composition regions explored become more extreme, testing the flexibility of the particular frit/sludge combinations.

Numerous comparisons could be made with respect to the Phase 2 assessment. In light of the task objective, general observations regarding homogeneity and the projected operational window are bulletized below.

- Homogeneity for SB3 and SB4 is challenged over the nominal WL interval of interest for all three frits. Challenges to this constraint become more frequent as the OL EVs are assessed or as lower WLs are considered.
- Homogeneity becomes less of an issue as WLs are increased or if one transitions from Frit 200 to either Frit 165 or Frit 320. There is some indication that the use of Frit 320 reduces the likelihood of challenging the homogeneity constraint. However, the use of Frit 320 and 165 challenge durability predictions more often than the Frit 200-based glasses.
- Implementation of the new T_L model almost always increases the projected operational window size for SB3 and SB4 regardless of frit selection. Given that higher WLs would be targeted, homogeneity (as previously mentioned) becomes less of an issue.
- The use of Frit 200 for SB3 and SB4 is typically restricted by T_L predictions.
- The use of Frit 165 or Frit 320 with SB3 or SB4 increases the upper WL limits achievable (relative to Frit 200).
- Viscosity and durability become restrictive for certain frit/sludge combinations.

It is not the intent of this assessment to select a baseline frit for SB3 and/or SB4. However, these are the primary candidates from the established or extant frits; therefore, this assessment will be beneficial in the frit-selection decision. The selection of a baseline frit should be made in light of all the constraints—not just homogeneity—in terms of its potential impact to the overall integrated process using a systems approach (Jantzen 1986). However, based on this initial assessment, it appears that Frit 320 is a potential candidate (although likely not optimized) for projected sludge-only processing with operational windows generally larger than either Frit 200 or Frit 165. Challenges to homogeneity appear to be less frequent (even at lower WLs), and higher WLs appear to be achievable with this frit (regardless of the T_L model being used). It must be recognized that this particular frit was developed specifically for SB2 to enhance melt rate without any prior consideration of using this frit for SB3 and SB4. Therefore, any statements about Frit 320 being an “optimized” frit for SB3 and/or SB4 or the fact that is should be used as the “generic sludge-only frit” should not be made or should be made within the correct context.

As one looks to select a primary frit for each SB or for sludge-only processing, a balanced approach must be taken, and all constraints either predicted by models or non-predictable (e.g.

melt rate) must be considered. The systems approach mandates that tradeoffs must be considered for glass-formulation development to be successful. This assessment is the initial step in this process for the projected sludge-only flowsheet.

In summary, one may ask the question "Can the homogeneity constraint be eliminated unconditionally for sludge-only processing?" The short answer is "no," given the current state of knowledge. However, based on the assessments provided in this study, there is strong evidence that the homogeneity constraint could be eliminated (or the constraint not challenged) if DWPF were to transition to either Frit 165 or Frit 320 (which are frits developed for sludge-only processing) and implement the new T_L model. Implementing the new T_L model allows for higher WLs to be targeted, which makes challenging homogeneity less of an issue. It is recommended that this assessment be supported with experimental data to confirm these general observations. If it is shown that the homogeneity constraint cannot be unconditionally eliminated, then a path parallel to that used by Edwards and Brown (1998) for MB2 is still a viable option.

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8.0 Future/Ongoing Work

The following is a list of activities that are currently in progress to support the general observations from this assessment. The EM-40 or EM-50 activities that are currently planned that may have an impact on this task are also provided.

Current Task:

(1) Phase 1 experimental evaluation.
Thirty-three of the sixty-nine centroid-based glasses met the criteria established to support programmatic objectives. Experimental assessments will parallel those used in previous studies (Edwards and Brown [1998] and Peeler, et al. [2000]) to assess the applicability of the homogeneity constraint. More specifically, durability of both quenched and clc glasses will be evaluated via the PCT. It should be noted that a separate report will be issued that summarizes the experimental results.

Planned Tasks:

(1) Phase 2 experimental evaluation.

One outcome of the Phase 2 assessment was a large pool of candidate glasses from which one could potentially select to address specific objectives. Based on the results of the Phase 1 experimental studies, a Phase 2 experimental program will be initiated to support the overall objective to eliminate the homogeneity constraint for sludge-only processing. The primary difference between the Phase 1 and Phase 2 experimental studies will be the selection of glasses that expand the composition regions for SB3 and SB4 (i.e., glasses developed, based on potential sludge composition variations).

(2) Assessment of the current durability model.

Currently, there is an EM-50 task (Tanks Focus Area Task Technical Plan #SR16WT31) to assess the current durability model in terms of minimizing any negative impacts to the projected composition regions. This task is primarily a result of the glass-formulation efforts to increase the melt rate for SB2 from which Frit 320 was developed and recommended. Although Frit 320 was shown to improve the melt rate under the testing protocol used, an alternative frit (Frit 304) actually melted faster (Peeler et al. 2001b). This frit was not recommended by SRTC, given that prediction of durability indicated that this was an unacceptable glass. However, when experimental assessments of durability (via the PCT) were made, both quenched and clc glasses (based on Frit 304) were acceptable in terms of the measured B, Li, and Na releases (all being less than 2 g/L). Assuming the durability model can be revised based on new data generated after its development, the new model may open up a composition region of interest to DWPF for sludge-only processing.

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Appendix A

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Exhibit A.1: Waste Loading at 25%

Count Total % Col % Row %	Durable; Not Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Not Al2O3; alkali	Not Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	
165-SB3 IL	0	148	0	0	0	38	0	0	0	0	0	0	186
	0.00	2.68	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	3.37
	0.00	10.50	0.00	0.00	0.00	3.76	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	79.57	0.00	0.00	0.00	20.43	0.00	0.00	0.00	0.00	0.00	0.00	
165-SB3 IL - centroid	0	1	0	0	0	0	0	0	0	0	0	0	1
	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
165-SB3 OL	0	122	163	0	0	22	258	0	0	1	0	40	606
	0.00	2.21	2.96	0.00	0.00	0.40	4.68	0.00	0.00	0.02	0.00	0.73	10.99
	0.00	8.65	17.78	0.00	0.00	2.18	14.66	0.00	0.00	6.25	0.00	12.12	
	0.00	20.13	26.90	0.00	0.00	3.63	42.57	0.00	0.00	0.17	0.00	6.60	
165-SB3 OL - centroid	0	0	0	0	0	0	1	0	0	0	0	0	1
	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
165-SB4 IL	0	74	0	0	0	244	0	0	0	0	0	0	318
	0.00	1.34	0.00	0.00	0.00	4.43	0.00	0.00	0.00	0.00	0.00	0.00	5.77
	0.00	5.25	0.00	0.00	0.00	24.13	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	23.27	0.00	0.00	0.00	76.73	0.00	0.00	0.00	0.00	0.00	0.00	
165-SB4 IL - centroid	0	0	0	0	0	1	0	0	0	0	0	0	1
	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	
165-SB4 OL	0	94	83	0	0	75	259	0	0	15	5	193	724
	0.00	1.70	1.51	0.00	0.00	1.36	4.70	0.00	0.00	0.27	0.09	3.50	13.13
	0.00	6.67	9.05	0.00	0.00	7.42	14.72	0.00	0.00	93.75	71.43	58.48	
	0.00	12.98	11.46	0.00	0.00	10.36	35.77	0.00	0.00	2.07	0.69	26.66	
165-SB4 OL - centroid	0	0	0	0	0	0	1	0	0	0	0	0	1
	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
200-SB3 IL	0	148	0	0	0	38	0	0	0	0	0	0	186
	0.00	2.68	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	3.37
	0.00	10.50	0.00	0.00	0.00	3.76	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	79.57	0.00	0.00	0.00	20.43	0.00	0.00	0.00	0.00	0.00	0.00	
200-SB3 IL - centroid	0	1	0	0	0	0	0	0	0	0	0	0	1
	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
200-SB3 OL	0	98	150	24	14	21	293	1	5	0	0	0	606
	0.00	1.78	2.72	0.44	0.25	0.38	5.31	0.02	0.09	0.00	0.00	0.00	10.99

Count Total % Col % Row %	Durable; Not Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Not Al2O3; alkali	Not Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	
	0.00	6.95	16.36	88.89	100.00	2.08	16.65	100.00	100.00	0.00	0.00	0.00	
	0.00	16.17	24.75	3.96	2.31	3.47	48.35	0.17	0.83	0.00	0.00	0.00	
200-SB3 OL - centroid	0	0	0	0	0	0	1	0	0	0	0	0	1
	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
200-SB4 IL	0	74	0	0	0	244	0	0	0	0	0	0	318
	0.00	1.34	0.00	0.00	0.00	4.43	0.00	0.00	0.00	0.00	0.00	0.00	5.77
	0.00	5.25	0.00	0.00	0.00	24.13	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	23.27	0.00	0.00	0.00	76.73	0.00	0.00	0.00	0.00	0.00	0.00	
200-SB4 IL - centroid	0	0	0	0	0	1	0	0	0	0	0	0	1
	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	
200-SB4 OL	16	75	98	3	0	80	452	0	0	0	0	0	724
	0.29	1.36	1.78	0.05	0.00	1.45	8.20	0.00	0.00	0.00	0.00	0.00	13.13
	100.00	5.32	10.69	11.11	0.00	7.91	25.68	0.00	0.00	0.00	0.00	0.00	
	2.21	10.36	13.54	0.41	0.00	11.05	62.43	0.00	0.00	0.00	0.00	0.00	
200-SB4 OL - centroid	0	0	0	0	0	0	1	0	0	0	0	0	1
	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
320-SB3 IL	0	186	0	0	0	0	0	0	0	0	0	0	186
	0.00	3.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.37
	0.00	13.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
320-SB3 IL - centroid	0	1	0	0	0	0	0	0	0	0	0	0	1
	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
320-SB3 OL	0	137	231	0	0	7	224	0	0	0	0	7	606
	0.00	2.48	4.19	0.00	0.00	0.13	4.06	0.00	0.00	0.00	0.00	0.13	10.99
	0.00	9.72	25.19	0.00	0.00	0.69	12.73	0.00	0.00	0.00	0.00	2.12	
	0.00	22.61	38.12	0.00	0.00	1.16	36.96	0.00	0.00	0.00	0.00	1.16	
320-SB3 OL - centroid	0	0	1	0	0	0	0	0	0	0	0	0	1
	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
320-SB4 IL	0	138	0	0	0	180	0	0	0	0	0	0	318
	0.00	2.50	0.00	0.00	0.00	3.26	0.00	0.00	0.00	0.00	0.00	0.00	5.77
	0.00	9.79	0.00	0.00	0.00	17.80	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	43.40	0.00	0.00	0.00	56.60	0.00	0.00	0.00	0.00	0.00	0.00	
320-SB4 IL - centroid	0	1	0	0	0	0	0	0	0	0	0	0	1
	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
320-SB4 OL	0	112	191	0	0	60	269	0	0	0	2	90	724

Count Total % Col % Row %	Durable; Not Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Not Al2O3; alkali	Not Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	
	0.00 0.00 0.00	2.03 7.94 15.47	3.46 20.83 26.38	0.00 0.00 0.00	0.00 0.00 0.00	1.09 5.93 8.29	4.88 15.28 37.15	0.00 0.00 0.00	0.00 0.00 0.00	0.00 0.00 0.00	0.04 28.57 0.28	1.63 27.27 12.43	13.13
320-SB4 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.06 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
	16 0.29	1410 25.57	917 16.63	27 0.49	14 0.25	1011 18.34	1760 31.92	1 0.02	5 0.09	16 0.29	7 0.13	330 5.98	5514

Exhibit A.2: Waste Loading at 30%

Count Total % Col % Row %	Durable; Not Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Not Al2O3; alkali	Not Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; Not TL; Homo; New TL ; Not Al2O3; alkali	
165-SB3 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	186 3.37 13.89 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	186 3.37
165-SB3 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.07 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
165-SB3 OL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	207 3.75 10.46 34.16	0 0.00 0.00 0.00	13 0.24 5.37 2.15	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	295 5.35 22.03 48.68	0 0.00 0.00 0.00	70 1.27 23.10 11.55	0 0.00 0.00 0.00	21 0.38 65.63 3.47	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	606 10.99
165-SB3 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.07 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
165-SB4 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	270 4.90 13.64 84.91	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	48 0.87 3.58 15.09	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	318 5.77
165-SB4 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
165-SB4 OL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	108 1.96 5.46 14.92	39 0.71 14.34 5.39	8 0.15 3.31 1.10	0 0.00 0.00 0.00	23 0.42 35.38 3.18	122 2.21 23.28 16.85	0 0.00 0.00 0.00	0 0.00 0.00 0.00	57 1.03 4.26 7.87	204 3.70 46.15 28.18	6 0.11 1.98 0.83	0 0.00 0.00 0.00	3 0.05 9.38 0.41	7 0.13 25.93 0.97	6 0.11 75.00 0.83	137 2.48 69.19 18.92	4 0.07 100.00 0.55	724 13.13
165-SB4 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
200-SB3 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	127 2.30 9.48 68.28	0 0.00 0.00 0.00	59 1.07 19.47 31.72	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	186 3.37
200-SB3 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.07 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02

Count Total % Col % Row %	Durable; Not Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Not Al2O3; alkali	Not Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; Not TL; Homo; New TL ; Not Al2O3; alkali	
200-SB3 OL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	173 3.14 8.74 28.55	0 0.00 0.00 0.00	114 2.07 47.11 18.81	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	181 3.28 13.52 29.87	0 0.00 0.00 0.00	138 2.50 45.54 22.77	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	606 10.99
200-SB3 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.07 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
200-SB4 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	222 4.03 11.22 69.81	0 0.00 0.00 0.00	61 1.11 25.21 19.18	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	33 0.60 2.46 10.38	0 0.00 0.00 0.00	2 0.04 0.66 0.63	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	318 5.77
200-SB4 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
200-SB4 OL	3 0.05 100.00 0.41	2 0.04 100.00 0.28	82 1.49 4.14 11.33	46 0.83 16.91 6.35	41 0.74 16.94 5.66	12 0.22 100.00 1.66	27 0.49 41.54 3.73	251 4.55 47.90 34.67	2 0.04 100.00 0.28	8 0.15 100.00 1.10	28 0.51 2.09 3.87	144 2.61 32.58 19.89	26 0.47 8.58 3.59	52 0.94 100.00 7.18	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	724 13.13
200-SB4 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB3 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	149 2.70 7.53 80.11	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	37 0.67 2.76 19.89	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	186 3.37
320-SB3 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB3 OL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	321 5.82 16.22 52.97	0 0.00 0.00 0.00	5 0.09 2.07 0.83	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	274 4.97 20.46 45.21	0 0.00 0.00 0.00	2 0.04 0.66 0.33	0 0.00 0.00 0.00	4 0.07 12.50 0.66	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	606 10.99
320-SB3 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB4 IL	0 0.00 0.00	0 0.00 0.00	298 5.40 15.06	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	20 0.36 1.49	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	318 5.77

Count Total % Col % Row %	Durable; Not Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; Not New TL; Not Al2O3; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Not Al2O3; alkali	Not Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	Not Durable; Visc; Not TL; Homo; New TL ; Not Al2O3; alkali	
	0.00	0.00	93.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
320-SB4 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB4 OL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	141 2.56 7.12 19.48	187 3.39 68.75 25.83	0 0.00 0.00 0.00	0 0.00 0.00 0.00	15 0.27 23.08 2.07	151 2.74 28.82 20.86	0 0.00 0.00 0.00	0 0.00 0.00 0.00	49 0.89 3.66 6.77	94 1.70 21.27 12.98	0 0.00 0.00 0.00	0 0.00 0.00 0.00	4 0.07 12.50 0.55	20 0.36 74.07 2.76	2 0.04 25.00 0.28	61 1.11 30.81 8.43	0 0.00 0.00 0.00	724 13.13
320-SB4 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
	3 0.05	2 0.04	1979 35.89	272 4.93	242 4.39	12 0.22	65 1.18	524 9.50	2 0.04	8 0.15	1339 24.28	442 8.02	303 5.50	52 0.94	32 0.58	27 0.49	8 0.15	198 3.59	4 0.07	5514

Exhibit A.3: Waste Loading at 35%

Count Total % Col % Row %	Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Not Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Not Homo; Not New TL; Al2O3 ; alkali	Not Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	
165-SB3 IL	0	0	102	84	0	0	0	0	186
	0.00	0.00	1.85	1.52	0.00	0.00	0.00	0.00	3.37
	0.00	0.00	3.65	4.06	0.00	0.00	0.00	0.00	
	0.00	0.00	54.84	45.16	0.00	0.00	0.00	0.00	
165-SB3 IL - centroid	0	0	0	1	0	0	0	0	1
	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	
165-SB3 OL	156	76	165	193	0	0	16	0	606
	2.83	1.38	2.99	3.50	0.00	0.00	0.29	0.00	10.99
	50.49	89.41	5.91	9.33	0.00	0.00	21.33	0.00	
	25.74	12.54	27.23	31.85	0.00	0.00	2.64	0.00	
165-SB3 OL - centroid	0	0	1	0	0	0	0	0	1
	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
165-SB4 IL	0	0	247	71	0	0	0	0	318
	0.00	0.00	4.48	1.29	0.00	0.00	0.00	0.00	5.77
	0.00	0.00	8.85	3.43	0.00	0.00	0.00	0.00	
	0.00	0.00	77.67	22.33	0.00	0.00	0.00	0.00	
165-SB4 IL - centroid	0	0	1	0	0	0	0	0	1
	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
165-SB4 OL	111	8	314	150	17	1	59	64	724
	2.01	0.15	5.69	2.72	0.31	0.02	1.07	1.16	13.13
	35.92	9.41	11.25	7.25	58.62	14.29	78.67	42.67	
	15.33	1.10	43.37	20.72	2.35	0.14	8.15	8.84	
165-SB4 OL - centroid	0	0	1	0	0	0	0	0	1
	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
200-SB3 IL	0	0	0	186	0	0	0	0	186
	0.00	0.00	0.00	3.37	0.00	0.00	0.00	0.00	3.37
	0.00	0.00	0.00	8.99	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	
200-SB3 IL - centroid	0	0	0	1	0	0	0	0	1
	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	
200-SB3 OL	0	0	203	403	0	0	0	0	606
	0.00	0.00	3.68	7.31	0.00	0.00	0.00	0.00	10.99
	0.00	0.00	7.27	19.49	0.00	0.00	0.00	0.00	
	0.00	0.00	33.50	66.50	0.00	0.00	0.00	0.00	

Count Total % Col % Row %	Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Not Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Not Homo; Not New TL; Al2O3 ; alkali	Not Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	
200-SB3 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
200-SB4 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	51 0.92 1.83 16.04	267 4.84 12.91 83.96	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	318 5.77
200-SB4 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
200-SB4 OL	0 0.00 0.00 0.00	1 0.02 1.18 0.14	310 5.62 11.11 42.82	395 7.16 19.10 54.56	12 0.22 41.38 1.66	6 0.11 85.71 0.83	0 0.00 0.00 0.00	0 0.00 0.00 0.00	724 13.13
200-SB4 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.05 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB3 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	137 2.48 4.91 73.66	49 0.89 2.37 26.34	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	186 3.37
320-SB3 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB3 OL	42 0.76 13.59 6.93	0 0.00 0.00 0.00	385 6.98 13.79 63.53	177 3.21 8.56 29.21	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	2 0.04 1.33 0.33	606 10.99
320-SB3 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB4 IL	0 0.00 0.00 0.00	0 0.00 0.00 0.00	308 5.59 11.04 96.86	10 0.18 0.48 3.14	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	318 5.77
320-SB4 IL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
320-SB4 OL	0 0.00 0.00	0 0.00 0.00	562 10.19 20.14	78 1.41 3.77	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	84 1.52 56.00	724 13.13

Count Total % Col % Row %	Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Not Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Not Homo; Not New TL; Al2O3 ; alkali	Not Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Not Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	
	0.00	0.00	77.62	10.77	0.00	0.00	0.00	11.60	
320-SB4 OL - centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.02
	309 5.60	85 1.54	2791 50.62	2068 37.50	29 0.53	7 0.13	75 1.36	150 2.72	5514

Exhibit A.4: Ring EVs at 25% Waste Loading

Sludge Loading (%)=25
Contingency Analysis of Satisfies PAR By Category

Contingency Table
Category By Satisfies PAR

Count Total % Col % Row %	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; New TL ; Not Al2O3; alkali	Durable; Visc; TL ; Not Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Not Homo; New TL ; Not Al2O3; alkali	
165-SB3 Ring	96 2.49 19.75 15.58	146 3.79 24.62 23.70	213 5.53 15.30 34.58	161 4.18 11.68 26.14	616 16.00
165-SB3 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.07 100.00	1 0.03
165-SB4 Ring	0 0.00 0.00 0.00	0 0.00 0.00 0.00	317 8.24 22.77 47.67	348 9.04 25.25 52.33	665 17.28
165-SB4 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.07 100.00	1 0.03
200-SB3 Ring	96 2.49 19.75 15.58	146 3.79 24.62 23.70	213 5.53 15.30 34.58	161 4.18 11.68 26.14	616 16.00
200-SB3 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.07 100.00	1 0.03
200-SB4 Ring	0 0.00 0.00 0.00	0 0.00 0.00 0.00	317 8.24 22.77 47.67	348 9.04 25.25 52.33	665 17.28
200-SB4 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.07 100.00	1 0.03
320-SB3 Ring	292 7.59 60.08 47.40	298 7.74 50.25 48.38	17 0.44 1.22 2.76	9 0.23 0.65 1.46	616 16.00
320-SB3 Ring Centroid	0 0.00 0.00 0.00	1 0.03 0.17 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03
320-SB4 Ring	2 0.05 0.41 0.30	2 0.05 0.34 0.30	315 8.18 22.63 47.37	346 8.99 25.11 52.03	665 17.28
320-SB4 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.07 100.00	1 0.03
	486 12.63	593 15.41	1392 36.17	1378 35.80	3849

Exhibit A.5: Ring EVs at 30% Waste Loading

Sludge Loading (%)=30
Contingency Analysis of Satisfies PAR By Category
Contingency Table

Category By Satisfies PAR

Count Total % Col % Row %	Durable; Visc; TL ; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; TL ; Homo; Not New TL; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	
165-SB3 Ring	69 1.79 2.51 11.20	0 0.00 0.00 0.00	547 14.21 56.16 88.80	0 0.00 0.00 0.00	616 16.00
165-SB3 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.10 100.00	0 0.00 0.00 0.00	1 0.03
165-SB4 Ring	665 17.28 24.16 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	665 17.28
165-SB4 Ring Centroid	1 0.03 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03
200-SB3 Ring	219 5.69 7.95 35.55	4 0.10 100.00 0.65	275 7.14 28.23 44.64	118 3.07 100.00 19.16	616 16.00
200-SB3 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.10 100.00	0 0.00 0.00 0.00	1 0.03
200-SB4 Ring	665 17.28 24.16 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	665 17.28
200-SB4 Ring Centroid	1 0.03 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03
320-SB3 Ring	466 12.11 16.93 75.65	0 0.00 0.00 0.00	150 3.90 15.40 24.35	0 0.00 0.00 0.00	616 16.00
320-SB3 Ring Centroid	1 0.03 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03
320-SB4 Ring	665 17.28 24.16 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	665 17.28
320-SB4 Ring Centroid	1 0.03 0.04 100.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03
	2753 71.53	4 0.10	974 25.31	118 3.07	3849

Exhibit A.4: Ring EVs at 35% Waste Loading

Sludge Loading (%)=35

DataTable=Sludge Loading (%)=35,Sludge Loading (%)=35

Contingency Analysis of Satisfies PAR By Category

Contingency Table

Category By Satisfies PAR

Count Total % Col % Row %	Durable; Not Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; New TL ; Al2O3 ; alkali	Durable; Visc; Not TL; Homo; Not New TL; Al2O3 ; alkali	
165-SB3 Ring	50 1.30 100.00 8.12	322 8.37 14.04 52.27	244 6.34 16.21 39.61	616 16.00
165-SB3 Ring Centroid	0 0.00 0.00 0.00	1 0.03 0.04 100.00	0 0.00 0.00 0.00	1 0.03
165-SB4 Ring	0 0.00 0.00 0.00	665 17.28 28.99 100.00	0 0.00 0.00 0.00	665 17.28
165-SB4 Ring Centroid	0 0.00 0.00 0.00	1 0.03 0.04 100.00	0 0.00 0.00 0.00	1 0.03
200-SB3 Ring	0 0.00 0.00 0.00	0 0.00 0.00 0.00	616 16.00 40.93 100.00	616 16.00
200-SB3 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.07 100.00	1 0.03
200-SB4 Ring	0 0.00 0.00 0.00	22 0.57 0.96 3.31	643 16.71 42.72 96.69	665 17.28
200-SB4 Ring Centroid	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 0.03 0.07 100.00	1 0.03
320-SB3 Ring	0 0.00 0.00 0.00	616 16.00 26.85 100.00	0 0.00 0.00 0.00	616 16.00
320-SB3 Ring Centroid	0 0.00 0.00 0.00	1 0.03 0.04 100.00	0 0.00 0.00 0.00	1 0.03
320-SB4 Ring	0 0.00 0.00 0.00	665 17.28 28.99 100.00	0 0.00 0.00 0.00	665 17.28
320-SB4 Ring Centroid	0 0.00 0.00 0.00	1 0.03 0.04 100.00	0 0.00 0.00 0.00	1 0.03
	50 1.30	2294 59.60	1505 39.10	3849

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SRS Distribution

J.P. Morin, 703-H
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
R.C. Tuckfield, 773-42A
D.A. Crowley, 773-43A
D.F. Bickford, 999-W
C.M. Jantzen, 773-A
N.E. Bibler, 773-A
T.K. Snyder, 773-42A
J. J. Connelly, 773-41A
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
J.C. George, 773-43A
C.C. Herman, 773-43A
T.M. Jones, 999-W
D. Koopman, 773-43A
T.H. Lorier, 999-W
D.H. Miller, 786-1A
D.K. Peeler, 999-W
I.A. Reamer, 773-A
M.E. Smith, 773-43A
M.E. Stone, 999-W
D.C. Witt, 999-W
R.J. Workman, 999-W
Records (4)
VT QA File

TFA Distribution

B.J. Williams, PNNL (8)
T.P. Pietrok, DOE-RL
Kurt Gerdes, DOE-HQ
P.C. Suggs, DOE-SR (704-3N)
T.M. Brouns, PNNL
B.A. Carteret, PNNL
L.M. Peurrung, PNNL
J.D. Vienna, PNNL (5)
J.H. Westsik, PNNL