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Frit Recommendation for Sludge Batch 9 Coupled Operation with the Salt Waste Processing Facility

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T.B. Edwards

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Savannah River National Laboratory™

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EXECUTIVE SUMMARY

Prior to the processing of Sludge Batch 9 (SB9) with Frit 803 at the Defense Waste Processing Facility (DWPF), assessments and experimental glass work were completed to support SB9 coupled processing with streams from the Actinide Removal Process (ARP) and Modular Caustic Side Solvent Extraction Unit (MCU). This previous work did not address coupled processing with streams from the Salt Waste Processing Facility (SWPF) because the Product Composition Control System (PCCS) models limited the TiO_2 concentration in glass to 2 weight percent (wt.%). These high activity streams from SWPF include monosodium titanate (MST) and sludge solids from the Sludge Solids Receipt Tank (SSRT) as well as Cs-containing strip effluent (SE). The SWPF streams are expected to reach TiO_2 concentrations in glass greater than 2 wt.% based on an MST strike of 0.4 g MST/L of salt solution. Therefore, revisions to the models contained in PCCS were completed to allow the evaluation of glasses containing greater than 2 wt.% TiO_2, but less than 6 wt.%.

Since the initial SB9 qualification for ARP-MCU coupled operation, additional Tank 40 analyses have been completed, which served as the basis for an updated projection of the SB9 blend composition in Tank 40. This projection will be used to support SB9 coupled operation with SWPF in 2019. Savannah River Remediation (SRR) has requested that the Savannah River National Laboratory (SRNL) select a second frit to optimize SB9 coupled operation with SWPF. The selected frit would provide operational flexibility by allowing an acceptable waste loading (WL) to be targeted while maintaining an operating window of at least ± 4 percentage points around this target.

The objective of this study was to select a second frit based on a paper-study utilizing Measurement Acceptance Region (MAR) assessments with DWPF PCCS. To support these assessments, SRNL developed a new method for rigorous and directed optimization of frit compositions, which allowed for rapid screening and an assessment of a large array of candidate frits, and the ability to simultaneously satisfy the following single and double MST strike operating scenarios.

- Case 1: Single strike operation, with aluminum, and no entrained insoluble sludge solids. This case represents the baseline.
- Case 2: Single strike operation, no aluminum, and no entrained insoluble sludge solids. Per SRR-WSR-2018-00025, more conservative cases were developed where the aluminum in the SSRT stream was set to 0 mg/L.
- Case 3: Single strike operation, with aluminum, and 1200 mg/L of entrained insoluble sludge solids, which were assumed to be SB9 sludge solids.
- Case 4: Double strike operation, with aluminum, and no entrained insoluble sludge solids.
- Case 5: Double strike operation, no aluminum, and no entrained insoluble sludge solids.

All cases were evaluated with both 5200 and 5700 gallons of Tank 40 sludge slurry per Sludge Receipt and Adjustment Tank (SRAT) batch. Frit optimization was focused on the scenarios containing 12,800 gallons of SE based on the BOBCalix solvent per SRAT batch. Once candidate frits were identified, subsequent MAR assessments were conducted to confirm viability of the operating scenarios with SE based on the Next Generation Solvent (NGS).

Using these inputs, a viable alternative to Frit 803 was identified, which would enable DWPF to process under all cases; however, processing would be limited to a target waste loading (WL) near 30%. It was noted throughout the MAR assessment process that the compositional shift of Case #3 with 1200 mg/L of entrained insoluble sludge solids had a significant impact on the outcome of the frit optimization process. Based on discussions with SRR, modifications to Case #3 would be considered if the selection of a different frit would enable processing at higher WL. Thus, SRNL recommended that frit optimization be performed with the entrained insoluble sludge solids concentration in Case #3 set to 600 mg/L to lessen its impact.

Based on these MAR assessment results, Frit 625 is recommended for processing SB9 coupled with streams from SWPF based on Cases #1, 2, 4, and 5, and Case #3 set to 600 mg/L of entrained insoluble solids. The composition of Frit 625 in wt.% is $1Al_2O_3$-$8B_2O_3$-$7Li_2O$-$6Na_2O$-$78SiO_2$. This optimized frit simultaneously meets SRR's acceptability criteria for operational flexibility for single and double strike operating scenarios. Frit 625 generally has an operating window of at least 9 percentage points and demonstrates the ability to maximize salt waste throughput. A target waste loading of 36% is achievable for the baseline (single strike) case. The viability of Frit 625 has also been confirmed for SB9 coupled with the ARP-MCU flowsheet if the need arises to transition from Frit 803 before SWPF startup.

There is a risk that the entrained insoluble solids content for a Salt Batch could be different in composition or higher in concentration than the 600 mg/L evaluated in this assessment. Documentation of this risk will occur in the next revision of Y-RAR-G-00022 (ID number 503). Reduced washing of the SSRT stream could be a potential risk mitigation strategy for higher than expected entrained insoluble sludge solids for SB9 coupled operation with SWPF and Frit 625.

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LIST OF ABBREVIATIONS

ARP	Actinide Removal Process
DWPF	Defense Waste Processing Facility
EVs	extreme vertices
MAR	Measurement Acceptance Region
MCU	Modular Caustic Side Solvent Extraction Unit
MST	monosodium titanate
NGS	Next Generation Solvent
PCCS	Product Composition Control System
PS	Production Support
SB	Sludge Batch
SE	strip effluent
SME	Slurry Mix Evaporator
SRAT	Sludge Receipt and Adjustment Tank
SRNL	Savannah River National Laboratory
SRR	Savannah River Remediation
SSRT	Sludge Solids Receipt Tank
SWPF	Salt Waste Processing Facility
TTQAP	Task Technical and Quality Assurance Plan
TTR	Technical Task Request
WL	waste loading
wt.%	weight percent

1.0 Introduction

Prior to the processing of Sludge Batch 9 (SB9) with Frit 803 at the Defense Waste Processing Facility (DWPF), assessments and experimental glass work were completed to support SB9 coupled processing with streams from the Actinide Removal Process (ARP) and Modular Caustic Side Solvent Extraction Unit (MCU).[1-5] This previous work did not address coupled processing with streams from the Salt Waste Processing Facility (SWPF) because the Product Composition Control System (PCCS) models limited the TiO_2 concentration in glass to 2 weight percent (wt.%).[6] These high activity streams from SWPF include monosodium titanate (MST) and sludge solids from the Sludge Solids Receipt Tank (SSRT) as well as Cs-containing strip effluent (SE). The SWPF streams are expected to reach TiO_2 concentrations in glass greater than 2 wt.% based on an MST strike of 0.4 g MST/L of salt solution. Therefore, revisions to the models contained in PCCS were completed to allow the evaluation of glasses containing greater than 2 wt.% TiO_2, but less than 6 wt.%.[7]

Since the initial SB9 qualification for ARP-MCU coupled operation, additional Tank 40 analyses have been completed, which served as the basis for an updated projection[8] of the SB9 blend composition in Tank 40. This projection will be used to support upcoming SB9 coupled operation with SWPF in 2019. Savannah River Remediation (SRR) has requested that the Savannah River National Laboratory (SRNL) select a second frit to optimize SB9 coupled operation with SWPF. The selected frit would provide operational flexibility by allowing an acceptable waste loading (WL) to be targeted while maintaining an operating window of at least ± 4 percentage points around this target.[9]

The objective of this study was to select a second frit based on a paper-study by utilizing Measurement Acceptance Region (MAR) assessments with DWPF PCCS.[7] Note that this assessment only addresses the impact of SWPF operations on glass properties; Chemical Process Cell processing is not included in the evaluation.

2.0 Quality Assurance

This work was requested via a Technical Task Request (TTR)[9] and directed by a Task Technical and Quality Assurance Plan.[10] The functional classification of this task is Production Support (PS). This task is not waste form affecting and does not need to follow the quality assurance requirements of RW-0333P.[11] Microsoft Excel and JMP® Pro Version 11.2.1[12,13] were used to support this work. Given the PS designation, the use of the Level D software package (JMP® Pro Version 11.2.1) is compliant. Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60.[14] This document, including all calculations, was reviewed by a Design Check. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.[15]

3.0 Inputs and Assumptions

An updated SB9 Tank 40 blend projection on a calcine basis was received from SRR.[8] The elemental concentrations were converted to oxides and normalized to 100 wt.% as shown in Table 3-1. Based on the guidance and assumptions provided by SRR,[8,16] SRNL performed subsequent calculations to estimate compositions of SE[17] and the SSRT effluent stream for the following five cases:[18]

- Case 1: Single MST strike operation, with aluminum, and no entrained insoluble sludge solids. This case represents the baseline.
- Case 2: Single MST strike operation, no aluminum,[a,8] and no entrained insoluble sludge solids.

[a] Per SRR-WSE-2018-00025, more conservative cases were developed where the aluminum in the SSRT effluent stream was set to 0 mg/L.

- Case 3: Single MST strike operation, with aluminum, and 1200 mg/L of entrained insoluble sludge solids, which were assumed to be SB9 sludge solids.
- Case 4: Double MST strike operation (i.e., two sequential contacting of waste in SWPF with 0.4 g MST/L of waste in each), with aluminum, and no entrained insoluble sludge solids.
- Case 5: Double MST strike operation, no aluminum,[a] and no entrained insoluble sludge solids.

Table 3-1. Normalized SB9 Tank 40 Blend Projection

Oxide	Concentration (wt.%)	Oxide	Concentration (wt.%)
Al_2O_3	17.50	**MnO**	9.42
B_2O_3	0.06	**Na_2O**	24.40
BaO	0.10	**NiO**	2.02
CaO	1.86	**PbO**	0.05
Ce_2O_3	0.16	**SO_4^{2-}**	1.02
Cr_2O_3	0.15	**SiO_2**	3.80
CuO	0.09	**ThO_2**	1.25
Fe_2O_3	32.11	**TiO_2**	0.05
K_2O	0.13	**U_3O_8**	4.99
La_2O_3	0.06	**ZnO**	0.05
Li_2O	0.15	**ZrO_2**	0.08
MgO	0.50		

Other pertinent inputs from SRR-WSE-2018-00025 include:

- 0.7M Na (total Na) wash endpoint for the SSRT stream
- DWPF receives 5200 or 5700 gallons of sludge slurry from Tank 40 per Sludge Receipt and Adjustment Tank (SRAT) batch
- DWPF receives 12,800 gallons of SE per SRAT batch based on either the baseline BOBCalix C6 solvent[b] or the Next Generation Solvent (NGS)[c]
- Frit must be able to accommodate 2800 gallons of the SSRT effluent stream (MST/SS) per SRAT batch for single strike operation and 4200 gallons for double strike operation

4.0 Methodology for the Variation Stage MAR assessments

The approach taken for the Variation Stage MAR assessments[19] was to evaluate how robust Frit 803 and alternative frit compositions were relative to expected variation in the composition of the SB9 SRAT material and the uncertainty in targeting the desired waste loading (WL). These uncertainties take effect as DWPF (i) conducts the blending process[d] to target the desired WL for the next Slurry Mix Evaporator (SME) batch, and (ii) subsequently judges the new SME batch for MAR acceptability via the PCCS process, which is driven by the analysis of samples of the new SME batch.

Cases #1-3 (single strike operation) were evaluated at 2400-3600 gallons of MST/SS and Cases #4-5 (double strike operation) were evaluated at 3800-4200 gallons of MST/SS in increments of 400 gallons. Compositional variation (±) was applied to SRAT compositions representing each volume addition of the MST/SS stream to account for likely, but not necessarily bounding, differences that may be seen in the material that is transferred from Tank 40 and SWPF into the SRAT during the processing of SB9. The

[b] BOBCalixC6 is calix[4]arene-bis(tert-octylbenzo-crown-6) , which uses a nitric acid strip solution.
[c] NGS contains the extractant MaxCalix (1,3-alt-25,27-bis(3,7- dimethyloctyl-1-oxy)calix[4]arene-benzocrown-6), which uses a boric acid strip solution.
[d] Combining SRAT material with frit and the heel of the SME.

compositional variation for the individually-tracked oxides was represented by the larger of 0.5 wt.% or 7.5% of the nominal concentration. Those oxides not tracked individually were grouped into an "Others" component.[e] The resulting SRAT oxide intervals are summarized in Table 4-1 through Table 4-4, which represent the minimum and maximum oxide concentrations for the various cases of MST/SS and SE additions. Extreme vertices (EVs) were generated using JMP®[12] for the SB9 SRAT composition at each volume of the MST/SS evaluated in these assessments.

Table 4-1. SRAT Oxide Intervals (wt.%) for 5700 Gallons of Tank 40 per SRAT Batch (BOBCalix)

Oxide	Case 1	Case 2	Case 3 (1200 mg/L)	Case 4	Case 5
Al_2O_3	13.67-16.59	12.97-16.02	16.38-19.25	12.89-15.23	12.19-14.48
CaO	0.98-2.07	0.99-2.08	1.19-2.22	0.89-1.92	0.90-1.93
Cs_2O	1.00-2.10	1.01-2.11	0.58-1.75	0.91-1.94	0.92-1.95
Fe_2O_3	23.59-29.21	23.80-29.40	27.22-32.08	22.16-26.34	22.36-26.56
MnO	6.92-8.57	6.98-8.63	8.65-10.11	6.50-7.73	6.56-7.79
Na_2O	25.22-30.57	25.37-30.84	18.88-22.91	25.70-30.16	25.91-30.43
NiO	1.10-2.21	1.12-2.22	1.08-2.17	1.01-2.04	1.02-2.05
SiO_2	2.52-3.72	2.55-3.74	3.26-4.28	2.34-3.40	2.36-3.42
ThO_2	0.49-1.56	0.50-1.56	0.60-1.63	0.43-1.45	0.44-1.46
TiO_2	5.87-9.61	5.91-9.70	4.48-6.92	11.17-14.03	11.26-14.15
U_3O_8	3.46-4.72	3.50-4.75	3.94-5.03	3.22-4.31	3.26-4.34
Others	1.81-2.91	1.83-2.92	2.07-3.09	1.68-2.71	1.70-2.73

Table 4-2. SRAT Oxide Intervals (wt.%) for 5200 Gallons of Tank 40 per SRAT Batch (BOBCalix)

Oxide	Case 1	Case 2	Case 3 (1200 mg/L)	Case 4	Case 5
Al_2O_3	13.48-16.42	12.73-15.80	16.40-19.27	12.66-14.98	11.90-14.16
CaO	0.95-2.05	0.96-2.06	1.18-2.21	0.85-1.89	0.87-1.90
Cs_2O	1.11-2.23	1.13-2.24	0.63-1.83	1.01-2.05	1.02-2.06
Fe_2O_3	23.13-28.79	23.35-28.98	27.09-31.93	21.63-25.76	21.84-25.98
MnO	6.79-8.45	6.85-8.50	8.65-10.11	6.35-7.56	6.41-7.62
Na_2O	25.43-30.89	25.60-31.19	18.68-22.70	25.92-30.43	26.15-30.72
NiO	1.07-2.18	1.09-2.20	1.05-2.14	0.97-2.01	0.98-2.02
SiO_2	2.46-3.67	2.49-3.69	3.26-4.28	2.27-3.34	2.29-3.36
ThO_2	0.47-1.54	0.48-1.55	0.60-1.62	0.41-1.43	0.42-1.44
TiO_2	6.36-10.33	6.40-10.43	4.78-7.26	11.97-15.01	12.08-15.15
U_3O_8	3.39-4.66	3.42-4.69	3.91-5.00	3.13-4.22	3.17-4.26
Others	1.78-2.89	1.81-2.91	2.07-3.09	1.65-2.68	1.67-2.70

[e] The "Others" components include BaO, Ce_2O_3, Cr_2O_3, CuO, K_2O, La_2O_3, Li_2O, MgO, PbO, SO_4^{2-}, ZnO, and ZrO_2. B_2O_3 is only considered as an "Others" component for BOBCalix cases.

Table 4-3. SRAT Oxide Intervals (wt.%) for 5700 Gallons of Tank 40 per SRAT Batch (NGS)

Oxide	Case 1	Case 2	Case 3 (1200 mg/L)	Case 4	Case 5
Al_2O_3	13.59-16.49	12.89-15.92	16.30-19.16	12.82-15.15	12.12-14.39
B_2O_3	0.16-1.20	0.16-1.20	0-1.05	0.12-1.13	0.12-1.14
CaO	0.97-2.06	0.98-2.07	1.18-2.21	0.88-1.91	0.89-1.92
Cs_2O	0.99-2.09	1.00-2.10	0.57-1.74	0.90-1.93	0.91-1.95
Fe_2O_3	23.45-29.03	23.65-29.21	27.10-31.92	22.03-26.19	22.23-26.40
MnO	6.88-8.52	6.94-8.57	8.61-10.07	6.47-7.68	6.52-7.75
Na_2O	25.05-30.38	25.21-30.65	18.80-22.79	25.55-29.99	25.76-30.25
NiO	1.09-2.20	1.11-2.21	1.07-2.16	1.00-2.03	1.01-2.04
SiO_2	2.50-3.70	2.53-3.72	3.24-4.26	2.32-3.38	2.34-3.41
ThO_2	0.49-1.55	0.49-1.56	0.60-1.62	0.43-1.45	0.44-1.46
TiO_2	5.83-9.56	5.87-9.64	4.45-6.89	11.11-13.95	11.20-14.07
U_3O_8	3.44-4.70	3.47-4.72	3.92-5.01	3.20-4.29	3.24-4.32
Others	1.74-2.84	1.76-2.85	2.02-3.03	1.62-2.65	1.63-2.67

Table 4-4. SRAT Oxide Intervals (wt.%) for 5200 Gallons of Tank 40 per SRAT Batch (NGS)

Oxide	Case 1	Case 2	Case 3 (1200 mg/L)	Case 4	Case 5
Al_2O_3	13.39-16.30	12.64-15.69	16.31-19.18	12.59-14.88	11.83-14.07
B_2O_3	0.20-1.25	0.21-1.26	0-1.08	0.16-1.17	0.16-1.18
CaO	0.94-2.04	0.95-2.05	1.17-2.20	0.84-1.88	0.86-1.89
Cs_2O	1.10-2.21	1.12-2.23	0.63-1.82	1.00-2.04	1.01-2.05
Fe_2O_3	22.98-28.59	23.20-28.78	26.96-31.76	21.50-25.59	21.70-25.82
MnO	6.74-8.39	6.81-8.44	8.60-10.06	6.31-7.51	6.37-7.58
Na_2O	25.25-30.69	25.42-30.98	18.60-22.58	25.76-30.25	25.98-30.53
NiO	1.06-2.17	1.08-2.18	1.05-2.14	0.96-2.00	0.98-2.01
SiO_2	2.44-3.65	2.47-3.67	3.24-4.26	2.25-3.32	2.28-3.34
ThO_2	0.47-1.53	0.48-1.54	0.59-1.62	0.40-1.43	0.41-1.43
TiO_2	6.31-10.26	6.36-10.36	4.75-7.23	11.90-14.91	12.00-15.06
U_3O_8	3.36-4.63	3.40-4.66	3.89-4.98	3.11-4.20	3.15-4.23
Others	1.72-2.82	1.74-2.84	2.02-3.03	1.59-2.62	1.61-2.64

To support these assessments, SRNL developed a new method for rigorous and directed optimization of frit compositions, which allowed for rapid screening and an assessment of a large array of candidate frits, and the ability to simultaneously satisfy the operating scenarios represented by Cases #1-5. For each of the scenarios represented by Table 4-1 through Table 4-4, all the EVs for Cases #1-5 were combined with Frit 803 and a large array of frits covering the Al_2O_3-B_2O_3-Li_2O-Na_2O-SiO_2 region at WLs in the interval of 24 – 42%. Each of the resulting glass compositions was evaluated against the PCCS MAR criteria to determine whether the composition would pass the SME acceptability process. An overall operating window of at least 9 percentage across Cases #1-5 simultaneously was the primary success metric used to select an alternative frit for SB9 coupled processing with SWPF.

Frit optimization was focused on the scenarios containing 12,800 gallons of SE based on the BOBCalix solvent per SRAT batch. Once candidate frits were identified, subsequent MAR assessments were conducted to confirm viability of the operating scenarios with SE based on NGS.

5.0 Variation State MAR Assessment Results

5.1 Frit Optimization with Case #3 Set to 1200 mg/L of Entrained Insoluble Sludge Solids

Table 5-1 provides the results of the Frit 803 Variation Stage MAR assessments for 5700 gallons of Tank 40 per SRAT batch (BOBCalix solvent). TiO_2 and Na_2O concentrations (wt.%) in the SRAT are provided for reference. Consider Case #1 in Table 5-1 as an example for the interpretation of the information provided. When 2400 gallons of MST/SS are present, the nominal Na_2O and TiO_2 concentrations in the SRAT are 27.26 wt.% and 6.37 wt.%, respectively. The operating window (WL interval over which all EVs pass the SME acceptability process) is 30-40% WL (shaded green). At 24% WL, the limiting constraint is high viscosity (shaded yellow), and at 26-29% WL, at least one of the limiting constraints is Al_2O_3, Al_2O_3/TiO_2 or R_2O (shaded red). At 2800 gallons of MST/SS per SRAT batch, the nominal Na_2O and TiO_2 concentrations in the SRAT are increased to 27.67 wt.% and 7.26 wt.%, respectively. The operating window slightly narrows to 30-39% WL, and at 40% WL, the limiting constraint is low viscosity.

Frit 803 has limited viability for SB9-SWPF coupled processing since the operating window for Frit 803 is less than 9-percentage points during double strike operation. The overall operating window across all five cases is 35-37% WL (3 percentage points). Due to the similarities in the results for the remaining scenarios (5200 gallons of Tank 40 per SRAT batch and NGS), a summary is provided in Appendix Table A-1 and Table A-2. Double strike operation, at TiO_2 concentrations greater than 2 wt.%, is limited at WLs lower than 35% due to an insufficient concentration of Al_2O_3 in the glass (≤ 4 wt.%), thus failing a PCCS constraint.

To alleviate the Al_2O_3 deficiency constraints at lower waste loading, the frit composition was subsequently optimized to contain Al_2O_3. As shown in Table 5-2, the optimized frit (Frit A)[f] simultaneously satisfies the operating window requirement of 9 percentage points for all five cases. The overall operating window across all five cases is 25-34% WL (10 percentage points), which is also observed for 5200 gallons of Tank 40 per SRAT batch and NGS (see Appendix Table A-1 and Table A-2).

[f] Frit A: $2Al_2O_3 – 9B_2O_3 – 8Li_2O – 6Na_2O – 75SiO_2$ (wt.%)

Table 5-1. MAR Assessment Results for 5700 Gallons of Tank 40 per SRAT Batch and Frit 803 (BOBCalix)

Case	Case 1 Single Strike With Al_2O_3 Without SS				Case 2 Single Strike Without Al_2O_3 Without SS				Case 3 (1200 mg/L) Single Strike With Al_2O_3 With SS				Case 4 Double Strike With Al_2O_3 Without SS		Case 5 Double Strike Without Al_2O_3 Without SS	
MST/SS Addition (gallons)	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	3800	4200	3800	4200
SRAT Na_2O	27.26	27.67	28.06	28.43	27.43	27.87	28.28	28.69	21.31	20.98	20.68	20.41	27.78	28.05	28.01	28.30
SRAT TiO_2	6.37	7.26	8.12	8.94	6.41	7.31	8.19	9.02	4.98	5.51	5.98	6.42	12.08	13.05	12.18	13.16
Frit 803																
%WL, 24	hv	hv			hv				hv	hv	hv	hv				
25									hv	hv	hv	hv				
26									hv	hv	hv	hv				
27									hv	hv	hv	hv				
28									hv	hv	hv	hv				
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39								lv					lv	lv	lv	lv
40		lv	lv	lv		lv	lv	lv					lv	lv	lv	lv

No limiting constraints
Limiting constraints is viscosity (hv= high viscosity and lv = low viscosity)
Limiting constraint is liquidus temperature (TL)
At least one of the limiting constraints is Al_2O_3, Al_2O_3/TiO_2, or R_2O
- Al_2O_3 or R_2O = alumina/sum of alkali issue
- Al_2O_3/TiO_2 = TiO_2 > (2 wt.% minus measurement uncertainty) and Al_2O_3 < (4 wt.% minus measurement uncertainty)

Table 5-2. MAR Assessment Results for 5700 Gallons of Tank 40 per SRAT Batch and Frit A (BOBCalix)

Case	Case 1 Single Strike With Al_2O_3 Without SS				Case 2 Single Strike Without Al_2O_3 Without SS				Case 3 (1200 mg/L) Single Strike With Al_2O_3 With SS				Case 4 Double Strike With Al_2O_3 Without SS		Case 5 Double Strike Without Al_2O_3 Without SS	
MST/SS Addition (gallons)	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	3800	4200	3800	4200
SRAT Na_2O	27.26	27.67	28.06	28.43	27.43	27.87	28.28	28.69	21.31	20.98	20.68	20.41	27.78	28.05	28.01	28.30
SRAT TiO_2	6.37	7.26	8.12	8.94	6.41	7.31	8.19	9.02	4.98	5.51	5.98	6.42	12.08	13.05	12.18	13.16
Frit A																
%WL, 24												hv				
25																
26																
27																
28																
29																
30																
31																
32																
33																
34																
35														lv	lv	lv
36				lv			lv	lv					lv	lv	lv	lv
37	lv	lv	lv	lv	lv	lv	lv	lv					lv	lv	lv	lv
38	lv	lv	lv	lv	lv	lv	lv	lv					lv	lv	lv	lv
39	lv	lv	lv	lv	lv	lv	lv	lv					lv	lv	lv	lv
40	lv	lv	lv	lv	lv	lv	lv	lv					lv	lv	lv	lv

No limiting constraints
Limiting constraints is viscosity (hv= high viscosity and lv = low viscosity)
Limiting constraint is liquidus temperature (TL)
At least one of the limiting constraints is Al_2O_3, Al_2O_3/TiO_2, or R_2O
- Al_2O_3 or R_2O = alumina/sum of alkali issue
- Al_2O_3/TiO_2 = TiO_2 > (2 wt.% minus measurement uncertainty) and Al_2O_3 < (4 wt.% minus measurement uncertainty)

5.2 Frit Optimization with Case #3 Set to 600 mg/L of Entrained Insoluble Sludge Solids

Frit A is a viable alternative to Frit 803 and enables DWPF to process under all cases; however, processing would be limited to a target WL near 30%. It was noted throughout the MAR assessment process that the compositional shift of Case #3 had a significant impact on the outcome of the frit optimization process. As shown in Table 5-1 and Table 5-2, the average Na_2O concentration in the SRAT is 28 wt.% for Cases #1, 2, 4, and 5, whereas Case #3 is 21 wt.%. Based on discussions with SRR,[16] modifications to Case #3 would be considered if the selection of a different frit would enable processing at higher WL. Thus, SRNL recommended that frit optimization be performed with the entrained insoluble sludge solids concentration in Case #3 set to 600 mg/L to lessen its impact. The SSRT stream composition used in the MAR assessment is shown in Table 5-3.

Table 5-3. Case #3 SSRT Composition with the Entrained Insoluble Solids Set to 600 mg/L

Oxide	Concentration (wt.%)
Al_2O_3	15.63
CaO	1.15
Ce_2O_3	0.17
Cs_2O	0.01
Fe_2O_3	20.31
K_2O	0.24
MgO	0.29
MnO	7.37
Na_2O (total)	22.44
NiO	0.78
P_2O_5	0.37
SO_4^{2-}	1.34
SiO_2	2.95
ThO_2	0.71
TiO_2	23.34
U_3O_8	2.91
Total Oxides (g/L)	96.71

As shown in Table 5-4, Frit 625[g] was optimized for all five cases where Case #3 was set at 600 mg/L of entrained insoluble sludge solids in the SSRT stream instead of 1200 mg/L. For comparison, the results for Frit 625 at zero gallons of MST/SS and Case #3 with 1200 mg/L of entrained insoluble sludge solids are also shown. Frit 625 provides a higher WL target than Frit A and generally satisfies the operating window requirement of 9 percentage points for all five cases for each of the scenarios (5200/5700 gallons of Tank 40 per SRAT batch and BOBCalix/NGS). The overall operating window across all five cases (excluding 0 gallons of MST/SS and Case #3 with 1200 mg/L of entrained insoluble solids) is 29-38% WL, which provides a higher WL target than Frit A. A summary of the results for the remaining scenarios are shown in Appendix Table A-3 and Table A-4. Slight differences are present in some of the operating windows for a specific volume increment of MST/SS.

There is a risk that the entrained insoluble solids content for a Salt Batch could be different in composition or higher in concentration than the 600 mg/L evaluated in this assessment. Documentation of this risk will occur in the next revision of Y-RAR-G-00022 (ID number 503).[20]

[g] Frit 625: $1Al_2O_3 – 8B_2O_3 – 7Li_2O – 6Na_2O – 78SiO_2$ (wt.%)

Table 5-4. MAR Assessment Results for 5700 Gallons of Tank 40 per SRAT Batch and Frit 625 (BOBCalix)

Case	Sludge and SE	Case 1 Single Strike With Al_2O_3 Without SS				Case 2 Single Strike Without Al_2O_3 Without SS				Case 3 (600 mg/L) Single Strike With Al_2O_3 With SS				Case 3 (1200 mg/L) Single Strike With Al_2O_3 With SS				Case 4 Double Strike With Al_2O_3 Without SS		Case 5 Double Strike Without Al_2O_3 Without SS	
MST/SS Addition (gallons)	0	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	3800	4200	3800	4200
SRAT Na_2O (wt.%)	24.38	27.26	27.67	28.06	28.43	27.43	27.87	28.28	28.69	23.92	23.86	23.81	23.76	21.31	20.98	20.68	20.41	27.78	28.05	28.01	28.30
SRAT TiO_2 (wt.%)	0.05	6.37	7.26	8.12	8.94	6.41	7.31	8.19	9.02	5.59	6.26	6.89	7.47	4.98	5.51	5.98	6.42	12.08	13.05	12.18	13.16
Frit 625																					
%WL, 24	hv	hv	hv			hv	hv			hv	hv	hv	hv	hv	hv	hv	hv				
25	hv	hv	hv			hv				hv	hv	hv	hv	hv	hv	hv	hv				
26	hv									hv	hv	hv	hv	hv	hv	hv	hv				
27	hv									hv	hv	hv	hv	hv	hv	hv	hv				
28	hv									hv	hv	hv	hv	hv	hv	hv	hv				
29	hv													hv	hv	hv	hv				
30														hv	hv	hv	hv				
31														hv	hv	hv	hv				
32															hv	hv	hv				
33																					
34																					
35																					
36																					
37																					
38																					
39																			lv	lv	lv
40					lv			lv	lv									lv	lv	lv	lv
41			lv	lv	lv	lv	lv	lv	lv									lv	lv	lv	
42		lv	lv	lv	lv	lv	lv	lv	lv									lv		lv	

No limiting constraints

Limiting constraints is viscosity (hv= high viscosity and lv = low viscosity)

Limiting constraint is liquidus temperature (TL) or viscosity and TL.

At least one of the limiting constraints is Al_2O_3/TiO_2.
- Al_2O_3/TiO_2 = TiO_2 > (2 wt.% minus measurement uncertainty) and Al_2O_3 < (4 wt.% minus measurement uncertainty)

At least one of the limiting constraints is max Ti
- Max Ti = TiO2 > (6 wt.% minus measurement uncertainty)

5.3 Evaluation of Case #3 at Higher SSRT Stream Na Wash Endpoints

As shown Table 5-4, the operating window for Frit 625 for Case #3 with 1200 mg/L of entrained insoluble solids) is less than the desired 9 percentage point operating window primarily due to the low Na_2O concentration in the SRAT. To determine whether the operating window could be recovered, this case was evaluated using the following higher SSRT stream Na wash endpoints than the nominal[18] 0.7M (total Na):

- 1.25M Na wash endpoint, which was selected so that the Na_2O concentration in the SRAT nominally matches Case #3 set at 600 mg/L of entrained insoluble sludge solids
- 2.14M Na wash endpoint, which was selected so that the Na_2O concentration in the SRAT nominally matches the baseline case with no entrained insoluble sludge solids

The SSRT stream compositions used in the MAR assessments are shown in Table 5-5. This evaluation assumed that the entrained insoluble solids are SB9 solids.

Table 5-5. Case #3 SSRT Compositions at Higher SSRT Stream Na Wash Endpoints with the Entrained Insoluble Solids Set to 1200 mg/L

Oxide	Concentration (wt.%)	
	1.25M SSRT Stream Na Wash Endpoint	2.14M SSRT Stream Na Wash Endpoint
Al_2O_3	18.17	17.04
CaO	1.34	1.13
Ce_2O_3	0.19	0.16
Cs_2O	0.01	0.02
Fe_2O_3	23.64	19.85
K_2O	0.28	0.43
MgO	0.33	0.28
MnO	8.58	7.20
Na_2O	23.32	33.54
NiO	0.91	0.76
P_2O_5	0.43	0.36
SO_4^{2-}	1.56	1.41
SiO_2	3.43	2.88
ThO_2	0.83	0.70
TiO_2	13.58	11.40
U_3O_8	3.38	2.84
Total Oxides (g/L)	166.2	197.9

Table 5-6 shows a comparison of the MAR assessment results for the 0.7M, 1.25M, and 2.14M SSRT stream Na wash endpoints. Reduced washing of the SSRT stream does increase the operating window for Frit 625, which could be a potential risk mitigation strategy for higher than expected entrained insoluble sludge solids. Impacts to Chemical Process Cell processing would need to be evaluated.

Table 5-6. MAR Assessment Results for Various SSRT Stream Na Wash Endpoints at 5700 Gallons of Tank 40 per SRAT Batch and Frit 625 (BOBCalix)

Case	Case 3 (1200 mg/L) Single Strike With Al_2O_3 and SS											
SSRT Na Wash Endpoint	0.7M				1.25M				2.14M			
MST/SS Addition (gallons)	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600
SRAT Na_2O (wt.%)	21.31	20.98	20.68	20.41	24.01	23.97	23.94	23.91	27.95	28.29	28.59	28.86
SRAT TiO_2 (wt.%)	4.98	5.51	5.98	6.42	4.77	5.26	5.69	6.08	4.47	4.90	5.27	5.60
Frit 625												
%WL, 24	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv
25	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv
26	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv
27	hv	hv	hv	hv	hv	hv	hv	hv				
28	hv	hv	hv	hv	hv	hv	hv	hv				
29	hv	hv	hv	hv	hv	hv	hv	hv				
30	hv	hv	hv	hv								
31	hv	hv	hv	hv								
32		hv	hv	hv								
33												
34												
35												
36												
37												
38												
39												
40												
41												
42									lv	lv	lv	lv

No limiting constraints
Limiting constraints is viscosity (hv= high viscosity and lv = low viscosity)
Limiting constraint is liquidus temperature (TL).

5.4 Evaluation of Frit 625 with the SB9 Coupled with ARP-MCU Flowsheet

To further confirm the viability of Frit 625 for SB9 processing, a MAR assessment was performed for SB9 coupled with the ARP stream to enable transition from Frit 803 before SWPF startup. The assumptions used for these calculations include:

- DWPF receives 5700 gallons of sludge slurry from Tank 40 per SRAT batch[8]
- DWPF receives 12,800 gallons of SE per SRAT batch[8] with a maximum strip solution concentration of 0.0125M boric acid[21]
- ARP product additions (without MST)[22] per SRAT batch in increments of ~0.8 wt.% Na_2O up to ~7 wt.% above the nominal projection value

Table 5-7 provides the results of the MAR assessments with Frit 625, and for comparison, the results for Frit 803 are also shown. The operating window for Frit 625 is at least 9 percentage throughout the expected compositional region expected for ARP stream additions. From a glass property perspective, there are no issues with transitioning to Frit 625 during SB9 coupled processing with ARP-MCU should the need arise.

Table 5-7. MAR Assessment Results for SB9 Coupled Processing with ARP-MCU

SRAT Na_2O (wt.%)	24.40 no ARP	25.20	25.98	26.75	27.50	28.23	28.95	29.65	30.34	31.02	31.68
Frit 625											
%WL, 24	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv	hv
25	hv	hv	hv	hv	hv	hv	hv	hv	hv		
26	hv	hv	hv	hv	hv	hv	hv				
27	hv	hv	hv	hv	hv						
28	hv	hv	hv	hv							
29	hv	hv									
30	hv										
31											
32											
33											
34											
35											
36											
37											
38											
39											
40										lv	
41								lv	lv		
42						lv	lv	lv			
Frit 803											
%WL, 24	hv	hv	hv	hv	hv	hv	hv	hv	hv		
25	hv	hv	hv	hv	hv	hv	hv				
26	hv	hv	hv	hv	hv						
27	hv	hv	hv								
28	hv	hv									
29											
30											
31											
32											
33											
34											
35											
36											
37											
38											
39											
40											
41											
42						lv					

No limiting constraints
Limiting constraints is viscosity (hv= high viscosity and lv = low viscosity)
Limiting constraint is liquidus temperature (TL).
Limiting constraint is R_2O.
- R_2O = alumina/sum of alkali issue
At least one of the limiting constraints is durability (ΔG_p)

6.0 Conclusions

Based on these MAR assessment results, Frit 625 is recommended for processing SB9 coupled with SWPF streams. This optimized frit simultaneously meets SRR's acceptability criteria for operational flexibility for single and double strike operating scenarios. Frit 625 generally has an operating window of at least 9 percentage points and demonstrates the ability to maximize salt waste throughput. A target WL of 36% is achievable for the baseline (single strike) case. The viability of Frit 625 has also been confirmed for SB9 coupled with the ARP-MCU flowsheet should the need arise to transition from Frit 803.

There is a risk that the entrained insoluble solids content for a Salt Batch could be different in composition or higher in concentration than the 600 mg/L evaluated in this assessment. Documentation of this risk will occur in the next revision of Y-RAR-G-00022 (ID number 503).[20] Reduced washing of the SSRT stream could be a potential risk mitigation strategy for higher than expected entrained insoluble sludge solids for SB9 coupled operation with SWPF and Frit 625.

7.0 Future Work

In support of the SB9 coupled operation with SWPF, these remaining tasks will be completed:

- Frit 625 fabrication and viscosity testing to verify that a frit vendor will not have any manufacturing issues
- Assessments and potential experiments related to the variability study, sulfate solubility limit, and bounding glass density used for fissile mass loading calculations

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Appendix A. Operating Window Summaries

Table A-1. Operating Window Summary for 5200 and 5700 Gallons of Tank 40 per SRAT Batch (BOBCalix)

Case	Case #1 Single Strike With Al_2O_3 Without SS				Case #2 Single Strike Without Al_2O_3 Without SS				Case #3 (1200 mg/L) Single Strike With Al_2O_3 With SS				Case #4 Double Strike With Al_2O_3 Without SS		Case #5 Double Strike Without Al_2O_3 Without SS		Overall Window
MST/SS Addition (gallons)	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	3800	4200	3800	4200	
5700 Gallons of Tank 40 per SRAT Batch (BobCalix)																	
SRAT Na_2O (wt.%)	27.26	27.67	28.06	28.43	27.43	27.87	28.28	28.69	21.31	20.98	20.68	20.41	27.78	28.05	28.01	28.30	
SRAT TiO_2 (wt.%)	6.37	7.26	8.12	8.94	6.41	7.31	8.19	9.02	4.98	5.51	5.98	6.42	12.08	13.05	12.18	13.16	
Frit A																	
min %WL	24	24	24	24	24	24	24	24	24	24	24	25	24	24	24	24	**25**
max %WL	36	36	36	35	36	36	35	35	36	36	36	35	35	34	34	34	**34**
Frit 803																	
min %WL	30	30	31	31	31	31	32	33	31	31	32	32	32	33	34	35	**35**
max %WL	40	39	39	39	40	39	39	38	38	38	38	37	38	38	38	37	**37**
5200 Gallons of Tank 40 per SRAT Batch (BobCalix)																	
SRAT Na_2O (wt.%)	27.49	27.93	28.34	28.74	27.68	28.14	28.59	29.01	21.12	20.78	20.47	20.2	28.02	28.31	28.27	28.58	
SRAT TiO_2 (wt.%)	6.87	7.83	8.74	9.61	6.92	7.89	8.81	9.7	5.28	5.82	6.31	6.75	12.94	13.96	13.06	14.09	
Frit A																	
min %WL	24	24	24	24	24	24	24	24	24	24	24	25	24	24	24	24	**25**
max %WL	36	36	35	35	36	35	35	34	36	36	36	35	34	34	34	34	**34**
Frit 803																	
min %WL	30	31	31	32	31	32	33	33	31	31	32	32	33	34	35	36	**36**
max %WL	40	39	39	38	39	39	38	38	38	38	37	37	38	38	37	37	**37**

Table A-2. Operating Window Summary for 5200 and 5700 Gallons of Tank 40 per SRAT Batch (NGS)

Case	Case #1 Single Strike With Al_2O_3 Without SS				Case #2 Single Strike Without Al_2O_3 Without SS				Case #3 (1200 mg/L) Single Strike With Al_2O_3 With SS				Case #4 Double Strike With Al_2O_3 Without SS		Case #5 Double Strike Without Al_2O_3 Without SS		Overall Window
MST/SS Addition (gallons)	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	3800	4200	3800	4200	
5700 Gallons of Tank 40 per SRAT Batch (NGS)																	
SRAT Na_2O (wt.%)	27.09	27.49	27.89	28.26	27.25	27.69	28.11	28.51	21.20	20.88	20.58	20.32	27.62	27.89	27.84	28.14	
SRAT TiO_2 (wt.%)	6.33	7.22	8.07	8.89	6.37	7.27	8.13	8.97	4.95	5.48	5.96	6.39	12.01	12.97	12.11	13.09	
Frit A																	
min %WL	24	24	24	24	24	24	24	24	25	25	25	25	24	24	24	24	**25**
max %WL	36	36	36	35	36	36	35	35	36	36	35	35	35	34	34	34	**34**
Frit 803																	
min %WL	30	30	31	31	31	32	32	33	31	32	32	32	33	33	34	35	**35**
max %WL	40	39	39	39	40	39	39	38	38	38	37	37	38	38	38	37	**37**
5200 Gallons of Tank 40 per SRAT Batch (NGS)																	
SRAT Na_2O (wt.%)	27.30	27.74	28.15	28.55	27.48	27.95	28.39	28.82	21.00	20.67	20.37	20.11	27.85	28.14	28.09	28.40	
SRAT TiO_2 (wt.%)	6.83	7.77	8.68	9.55	6.87	7.83	8.75	9.64	5.25	5.79	6.28	6.72	12.86	13.87	12.97	14.00	
Frit A																	
min %WL	24	24	24	24	24	24	24	24	24	24	24	25	24	24	24	24	**25**
max %WL	36	36	35	35	36	35	35	34	36	36	36	35	34	34	34	34	**34**
Frit 803																	
min %WL	30	31	31	32	31	32	33	34	31	31	32	32	33	34	35	36	**36**
max %WL	40	39	39	38	39	39	38	38	39	38	37	37	38	37	37	37	**37**

Table A-3. Operating Window Summary for Frit 625 (BOBCalix)

Case	Case #1 Single Strike With Al_2O_3 Without SS				Case #2 Single Strike Without Al_2O_3 Without SS				Case #3 (600 mg/L) Single Strike With Al_2O_3 With SS				Case #4 Double Strike With Al_2O_3 Without SS		Case #5 Double Strike Without Al_2O_3 Without SS		Overall Window
MST/SS Addition (gallons)	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	3800	4200	3800	4200	
5700 Gallons of Tank 40 per SRAT Batch (BobCalix)																	
SRAT Na_2O (wt.%)	27.26	27.67	28.06	28.43	27.43	27.87	28.28	28.69	23.92	23.86	23.81	23.76	27.78	28.05	28.01	28.30	
SRAT TiO_2 (wt.%)	6.37	7.26	8.12	8.94	6.41	7.31	8.19	9.02	5.59	6.26	6.89	7.47	12.08	13.05	12.18	13.16	
Frit 625																	
min %WL	26	26	25	26	26	26	27	27	29	29	29	29	27	27	28	29	**29**
max %WL	41	40	40	39	40	40	39	39	39	39	38	38	39	38	38	38	**38**
5200 Gallons of Tank 40 per SRAT Batch (BobCalix)																	
SRAT Na_2O (wt.%)	27.49	27.93	28.34	28.74	27.68	28.14	28.59	29.01	23.89	23.83	23.77	23.72	28.02	28.31	28.27	28.58	
SRAT TiO_2 (wt.%)	6.87	7.83	8.74	9.61	6.92	7.89	8.81	9.7	5.97	6.68	7.33	7.93	12.94	13.96	13.06	14.09	
Frit 625																	
min %WL	26	25	26	26	25	26	27	28	29	29	29	29	27	28	29	30	**30**
max %WL	40	40	39	39	40	39	39	38	39	39	38	38	38	38	38	38	**38**

Table A-4. Operating Window Summary for Frit 625 (NGS)

Case	Case #1 Single Strike With Al_2O_3 Without SS				Case #2 Single Strike Without Al_2O_3 Without SS				Case #3 (600 mg/L) Single Strike With Al_2O_3 With SS				Case #4 Double Strike With Al_2O_3 Without SS		Case #5 Double Strike Without Al_2O_3 Without SS		Overall Window
MST/SS Addition (gallons)	2400	2800	3200	3600	2400	2800	3200	3600	2400	2800	3200	3600	3800	4200	3800	4200	
5700 Gallons of Tank 40 per SRAT Batch (NGS)																	
SRAT Na_2O (wt.%)	27.09	27.49	27.89	28.26	27.25	27.69	28.11	28.51	23.78	23.73	23.69	23.64	27.62	27.89	27.84	28.14	
SRAT TiO_2 (wt.%)	6.33	7.22	8.07	8.89	6.37	7.27	8.13	8.97	5.56	6.23	6.85	7.44	12.01	12.97	12.11	13.09	
Frit 625																	
min %WL	26	26	25	26	26	26	27	27	29	29	29	29	27	27	28	29	**29**
max %WL	40	40	40	39	40	40	39	39	39	39	38	38	39	38	38	38	**38**
5200 Gallons of Tank 40 per SRAT Batch (NGS)																	
SRAT Na_2O (wt.%)	27.30	27.74	28.15	28.55	27.48	27.95	28.39	28.82	23.74	23.69	23.64	23.59	27.85	28.14	28.09	28.40	
SRAT TiO_2 (wt.%)	6.83	7.77	8.68	9.55	6.87	7.83	8.75	9.64	5.94	6.64	7.29	7.89	12.86	13.87	12.97	14.00	
Frit 625																	
min %WL	26	25	26	26	25	27	27	28	29	29	29	29	27	28	29	30	**30**
max %WL	40	40	39	39	40	39	39	38	39	39	39	38	38	38	38	37	**37**