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THE IMPACT OF FRIT 202 ON MELT RATE FOR THE SB3 FEED SYSTEM

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EXECUTIVE SUMMARY

The Defense Waste Processing Facility (DWPF) began using Frit 418 with SB3 in early 2004. Additional Frit 418 was necessary to continue running, but a significant cost savings would be achieved (~$400K) if an interim frit could be used and the purchase of Frit 418 delayed until FY05. A large quantity of Frit 202 was available and it was proposed to use this material until additional Frit 418 was obtained. A series of dry-fed tests (using the Melt Rate Furnace or MRF) and slurry fed tests (using the Slurry-Fed Melt Rate Furnace or SMRF) have been performed to investigate the effect of Frit 202 on the melt rate of the SB3 system. Initial MRF testing indicated about a 20% decrease in melt rate when substituting Frit 202 for Frit 418. More recent tests with both the MRF and SMRF have shown a 10-35% decrease in rate using Frit 202. MRF testing indicated that the addition of sodium hydroxide would mitigate a majority of the melt rate loss associated with Frit 202. When NaOH was tested in the SMRF, the quantity that could be added was limited due to total organic carbon (TOC) concerns from the additional formic acid required, to balance the hydroxide addition. SMRF testing with NaOH showed no increase in melt rate, but the NaOH addition was only 58% of that used in the dry feed test. No major processing problems were indicated when testing Frit 202, but the feed does have a greater tendency to mound than feeds using Frit 418, when tested in the SMRF. Samples taken from the top of the melter after idling overnight reveal the presence of a foamy layer of glass similar to previous runs with Frit 418.

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LIST OF ACRONYMS

ACTL	Aiken County Technology Laboratory
DWPF	Defense Waste Processing Facility
ITS	Immobilization Technology Section
LMR	Linear Melt Rate
MRF	Melt Rate Furnace
REDOX	REDuction/OXidation
SEM	Scanning electron microscopy
SB2	Sludge batch 2
SB3	Sludge batch 3
SME	Slurry Mix Evaporator
SMRF	Slurry-fed Melt Rate Furnace
SRAT	Sludge Receipt and Adjustment Tank
SRS	Savannah River Site
SRNL	Savannah River National Laboratory
TOC	Total Organic Carbon
WL	Waste Loading
WSRC	Westinghouse Savannah River Company
XRD	X-ray diffraction

1.0 INTRODUCTION

The Defense Waste Processing Facility (DWPF) began using Frit 418 with SB3 in early 2004. Additional Frit 418 was necessary to continue running, but a significant cost savings would be achieved (~$400K) if an interim frit could be used and the purchase of Frit 418 delayed until FY05. A large quantity of Frit 202 was available and it was proposed to use this material until additional Frit 418 was obtained. A series of dry-fed tests (using the Melt Rate Furnace or MRF) and slurry fed tests (using the Slurry-Fed Melt Rate Furnace or SMRF) have been performed to investigate the effect of Frit 202 on the melt rate of the SB3 system. There were two main purposes for the test. One was to compare Frit 202 with Frit 418 at 35% waste loading (WL), since earlier testing had been at higher waste loadings. This was also important since DWPF is currently targeting approximately 34-35% waste loading. The second was to determine the effect of NaOH addition on melt rate and processing parameters.

Sulfate solubility using Frit 202 was addressed in a previous study (Peeler and Edwards, 2004). Based on this previous report and the corresponding WAC limits in SO4, DWPF could not operate with waste loadings above 37 weight %. Previous testing with Frit 202 involved melt rate assessment using Frits 202, 418, and 432 at measured waste loading of 40%. This testing indicated that Frit 202 could be used but would have negative effect on melt rate (Smith et al 2003).

Additive testing was performed to determine if the anticipated melt rate reduction with Frit 202 could be regained. Based on MRF results, sodium hydroxide addition to the SRAT/SME was chosen for further SMRF testing as a possible mitigation technique for DWPF.

Tests were performed with non-radioactive, simulated SB3 material. Due to the small-scale of the test equipment and the design of the equipment, as well as the use of dry or slurry simulant feed, the behavior of the actual radioactive feed in the DWPF melter cannot be fully predicted.

2.0 EXPERIMENTAL

2.1 SRAT/SME Feed Preparation

All Sludge Receipt and Adjustment Tank (SRAT) products for the MRF runs were fabricated at the Aiken County Technology Laboratory (ACTL). All feeds made for the MRF and SMRF tests used the same simulated sludge and they all had a targeted waste loading (WL) of 35%. The sludge was made at the Clemson Environmental Technologies Laboratory. It was a mixture of 40% SB2 and 60% SB3. Trim chemicals were added to achieve the final desired composition. The SRNL Mobile Lab sample ID for the SB2/SB3 simulated sludge is 04-0241 and the average results of two samples are given below in Table 2-1.

Table 2.1 SB3 Sludge Composition for all MRF and SMRF Runs

Element	Weight % Calcined @ 1100 C		Element	Weight % Calcined @ 1100 C
Al	9.57		Mn	4.07
Ba	0.139		Na	14.05
Ca	2.37		Ni	1.06
Cr	0.153		Pb	0.01
Cu	0.157		S	0.35
Fe	28.35		Si	1.04
Gd	0.075		Zn	0.323
K	0.122		Zr	0.486
Mg	2.15			

Anion	Mg/Kg
HCO_2	< 100
NO_2	19050
NO_3	14150
SO_4	2215
C_2O_4	< 1000

Total % Solids	Insoluble % Solids	Wt% Calcined
22.6	15.4	16.3

The feed for the MRF testing was made from the same 22L run of SRAT product (FPMR 21). Additives were blended with the SRAT product prior to addition of frit. In the case of NaOH, the pH was checked before and after the NaOH addition. The pH was 7.4 prior to the addition of the ground sodium hydroxide. After the NaOH was added the pH rose to 12.8. After 4 hours without agitation, the pH was measured at 9.6. The SRAT product was then mixed with the appropriate amount of frit and dried at 110 °C overnight. The dried feed was passed through a 10 mesh screen and stored in a desiccator until ready for use. The additive quantities were chosen to bring the total alkali content with Frit 202 to the same level as that found with Frit 418. The run plans for the MRF testing are documented in SRNL inter-office memos: SRT-GPD-2004-00081 through SRT-GPD-2004-00086.

The feeds for the SMRF tests were made in the ACTL 22-L SRAT/SME (Slurry Mix Evaporator). Two 22-L runs were needed for each type of feed made. The first Frit 202 batch (FPMR 024/26) had a targeted acid stoichiometry of 155% and a 0.2 target REDOX. The waste loading was targeted at 35%. The Frit 202 batch with NaOH (FPMR 30/32) had the same targets except for REDOX which was lowered to 0.15. This was due to concerns over violating the TOC limit in DWPF caused by the extra formic acid requirement. The NaOH was added to the sludge prior to the SRAT cycle and the amount of acid was increased to account for the increased base equivalents. Maintaining the 0.2 REDOX target in the SMRF would have allowed only ~43% of the full NaOH addition that was used in the MRF. A target of 0.1 would have allowed ~75 % of the full NaOH addition, but this target was too close to REDOX values that had previously shown to have a negative effect on melt rate (Smith et al 2004). The target of 0.15 was chosen and this allowed ~58% of the full NaOH addition that was used in the MRF testing. Analyses of the SRAT and SME products used in the tests are given in Appendix A-1 and A-2. The designations for the batches are shown in Table 2.2. The calculated waste loadings for the two feeds were both above the targeted 35% (39.9 and 37.7% respectively). All waste loadings were calculated by using the normalized lithia (Li_2O) values in the Frit 202 and SME feeds tested.

Table 2.2 Sample Batch Designations for SMRF Runs

Sample ID	Process	Run #	NaOH Addition
FPMR 23	SRAT	1	No
FPMR 24	SME	1	No
FPMR 25	SRAT	2	No
FPMR 26	SME	2	No
FPMR 31	SRAT	1	Yes
FPMR 32	SME	1	Yes
FPMR 33	SRAT	2	Yes
FPMR 34	SME	2	Yes

Additional details of the various feed preparation runs are given in Savannah River National Laboratory (SRNL) notebook WSRC-NB-2004-00004. The run plan for the 22-L SRAT/SME run with Frit 202 is given in SRNL inter-office memorandum SRT-GPD-2004-00079. The run plan for the 22-L SRAT/SME run with Frit 202 and NaOH is SRNL-GPD-2004-00004.

2.2 Melt Rate Furnace Testing

The dry-fed MRF utilizes has a cylindrical inner chamber approximately 0.5 cubic feet in size, with heating coils winding around the chamber walls. The diameter of the chamber is ~7", and an insulating sleeve and a 1200 ml stainless steel beaker were inserted from the top. The tests were conducted with 6" deep stainless steel beakers inserted with the sleeve so that the beaker bottom was approximately flush with the top of the uppermost chamber coil. An insulating block was used to cover the beaker. The furnace was heated to 1150°C with the top opening covered. Once the furnace reached the setpoint, the cover was removed and the beaker containing sufficient dried, sieved material to produce 500 grams of glass was inserted. After 50 minutes, the beaker was removed from the furnace and allowed to slowly cool to room temperature. This residence time in the furnace was determined during testing in 2002 to establish a standard test time for melt rate comparison for this dry-fed furnace (Lorier et al. 2002).

The beakers are sectioned and the relative melt rate is determined by measuring the height of the glass layer in the bottom of the beaker at ¼" intervals. The average height and duration in the furnace is used to yield a relative linear melt rate number, with units of inches/hour. General observations of the sectioned beaker are also used to describe differences between runs. A volumetric estimate of melt rate is also calculated, but the linear method is the basis for comparison in this and other reports. In general, the volumetric and linear values show similar results.

The first set of MRF tests was conducted before the heating element in the furnace failed. A second set of tests was conducted to re-establish the baseline and evaluate the effect of various additives. Several candidates were considered to increase the alkali content of the feed. The test conditions selected are shown in Table 2.2.

Table 2.3 MRF Test Conditions

SB3/Frit 202 Baseline
SB3/Frit 202 with Full Sodium Nitrate/Formate Addition
SB3/Frit 202 with Half Sodium Nitrate/Formate Addition
SB3/Frit 202 with Sodium Hydroxide Addition
SB3 w/Frit 418

The quantities of the additions were based on increasing the equivalent total alkali in the Frit 202 glass to that obtained with Frit 418. Sodium hydroxide was chosen as a direct additive since it is a DWPF trim chemical and existing lines are available. The blend of sodium nitrate and sodium formate was added to SRAT product to simulate adding sodium hydroxide to the start of the SRAT cycle and increasing the amount of nitric and formic acid as required to maintain pH and REDOX targets. The test with one half of the additive amount was chosen to determine if a smaller increase in alkali would yield any significant increase in melt rate.

2.3 SMRF Testing

The SMRF was charged with a prefabricated SB3 Frit 418 glass targeting 35% waste loading. The run plan used for the SMRF tests was SRT-GPD-2004-00005 ("Run Plan for the SB3 Frit 202 Runs in the Slurry Fed Melt Rate Furnace"). The SRNL log notebook used was WSRC-NB-2003-00163. After the tests were completed, the SMRF was drained and shut down. The melt pool and vapor space set points were 1125°C and 750°C respectively. Temperatures, glass pool and vapor space heater powers, feed rate, pour rate and cold cap were all monitored during the testing. The vapor space power was capped at 87% which is the same value used in most previous runs. Feed and cold cap samples were taken periodically throughout the run. Two batches were tested in the SMRF. The first was a baseline SB3 batch with Frit 202. The second was SB3/Frit 202 with sodium hydroxide addition. The sodium hydroxide was limited to 43% of that used in the MRF as noted in section 2.1.

2.3.1 Frit 202 Test Details

The SMRF was charged with 5 kg of startup glass on 7/6/04 and heated to operating temperatures. On 7/7/04 feeding was initiated using SME product from batches FPMR 24 and 26. The feed rate gradually slowed down during the first few hours, which led to rinsing the slots of suction tube and adjusting rpm's on the agitator and feed pump. After several hours mounding of the cold cap was noticed, which nearly reached the feed tube. A picture of the mound is shown in Figure 2.1. The mound was physically knocked down and feeding was suspended to allow the cold cap to burn off. Feeding resumed after ~1.5 hours with the feed diluted to 45 weight % solids. An analysis of the feed sample (SMRF 0175) is shown in Appendix A3. The diluted feed behaved in a similar fashion to the 50 weight % solids material and mounding of the feed pile was observed. The mound was physically knocked down twice during the remainder of the testing. No pluggages of the feed line or tube were encountered during the testing of this batch of material. Thirty minutes after feeding was concluded for the day, the melt surface was observed. The surface was a dull orange with no visible mound or dry feed remaining. The feed and glass stream were both sampled during the run. About 1 hour after feeding was stopped; a cold cap sample was taken (SMRF 0177).

Figure 2.1 Mounding of Cold Cap

The next morning a top of glass sample was taken (SMRF-178). The top of the melt pool had a foamy layer ~ ½ thick. The layer was not crusty and was easy to penetrate.

2.3.2 Frit 202 With NaOH Addition Test Details

Feeding was initiated on 7/8/04 using SME product from batches FPMR 30 and 32 (50 weight % solids). After about 2 hours of feeding, the melt pool current was observed to be running at ~10 amps. This is half the normal value and indicated that one heater had failed. Since the melt pool temperature was being maintained, the test was continued. Replacement of the heater would have caused a significant delay since the melter must be drained and shut down. The melt pool cumulative power increase per 30 minutes was ~0.37kW for this run vs. ~0.40kW for the run without the NaOH. The vapor space power change per 30 minutes was ~0.85 kW for both runs. This indicated that the test conditions were similar. Mounding of the feed was observed similar to that of the previous run. The mound was physically knocked down on two occasions. Since melt rate between feed with and without NaOH showed no difference, dilution of the feed to 45% solids was not performed on this batch. Problems with the drain tube heater were encountered which required physical removal of the glass from the melter at the end of the run. A sample of the glass near the bottom of the melter was taken for analysis (SMRF 0179).

3.0 RESULTS AND DISCUSSION

3.1 MRF Tests

The results of the MRF testing with Frit 202 are shown in Table 3.1

Table 3.1 Melt Rates for SB3/Frit 202 in MRF

Test Condition	Melt Rate (in/hr)
SB3/Frit 202 Baseline	0.4
SB3/Frit 202 with Full Sodium Nitrate/Formate Addition	0.5
SB3/Frit 202 with Half Sodium Nitrate/Formate Addition	0.42
SB3/Frit 202 with Sodium Hydroxide Addition	0.55
SB3 w/Frit 418	0.60

The dry feed test indicated a marked decrease in melt rate when Frit 202 was substituted for Frit 418. This trend had been seen in earlier testing, but the absolute values for all conditions were lower than previous testing. This indicates a need for better understanding the variation between MRF when similar conditions are evaluated at different times. The blended addition of sodium nitrate and sodium formate showed improvement in melt rate as expected since the total alkali approached that of Frit 418. The run using one half of the sodium nitrate/formate addition indicated very little change. The sodium hydroxide addition had the most dramatic effect and was chosen for further study using the SMRF, but at a reduced quantity necessitated by the TOC limits.

3.2 SMRF Tests

Details of the SMRF runs are given in section 2.3. Table 3-2 summarizes the melt rates for these feeds.

Table 3.2 Melt Rates for SB3/Frit 202 in SMRF

SME Product	Weight % Solids	Melt Rate (g/min)	Run Times Used to Determine Melt Rates
SB3/Frit 202 Baseline	50	9.37	7/7/04 (0930-1200)
SB3/Frit 202 Baseline	45	11.9	7/7/04 (1430-1930)
SB3/Frit 202 w NaOH Addition	50	9.28	7/8/04 (0900 - 1330)

For the runs at 50 wt% solids, there was no significant difference in melt rate between the SB3/Frit 202 with and without NaOH addition. This is partially explained by the fact that the amount of NaOH was limited in the SMRF run compared to the MRF due to TOC limits. A previous SMRF run with the same SRAT/SME target values using Frit 418 yielded a melt rate of 14.1 g/min (Smith et al, 2004). This would indicate about a 30% decrease in melt rate when substituting Frit 202 for Frit 418. There is no comparison at 45 wt% solids since the test was ended prior to dilution of the feed.

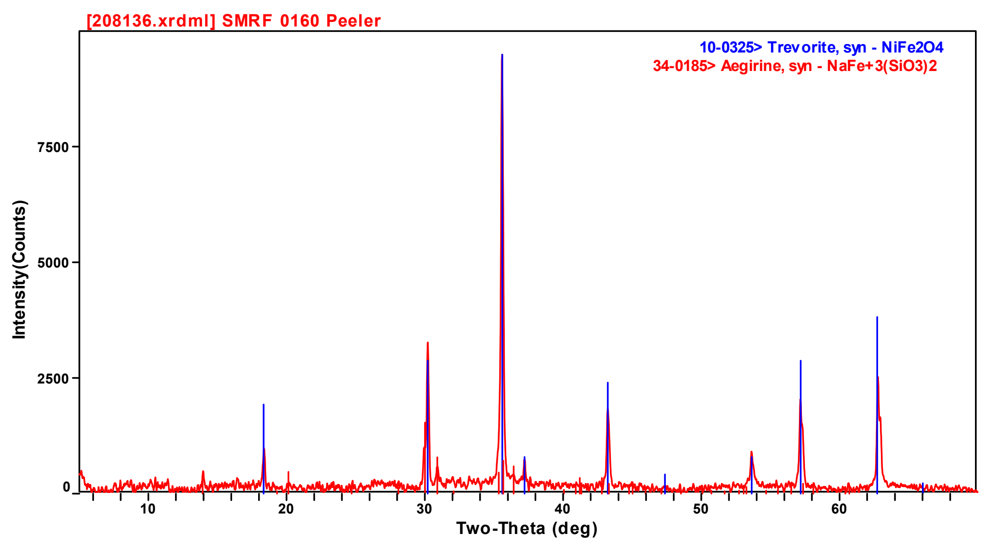
The expected gain in melt rate from increased alkali may be mitigated by the additional acid requirement to compensate for the OH addition. Previous SMRF testing has indicated that higher acid may have a negative impact on melt rate. Selection of an additive that does not require acid compensation may be a better alternative.

One additional observation, the baseline 45 weight percent solids feed had slightly higher melt rates than at 50 weight percent solids. This is contrary to previous testing that was used to evaluate stoichiometry and REDOX effect (Smith, et al, 2004). A possible explanation for this is that the mound under the feed tube was physically pushed down several times during the 45 wt% run. This led to an increase in pour rate that could be observed by the brightness of the pour stream and the recorded weight gain. It was not possible to observe a long period of time that wasn't influenced by one of these conditions. The calculated melt rate during the 50 wt% testing was not influenced by this physical removal of the mound. Generally SMRF results should be considered to be a better indicator of DWPF melt rate because small scale slurry feeding is a better test method (versus dry fed tests) for melt rate for DWPF, especially when the targeted glass composition is not being altered. In the most recent MFR and SMRF testing, both systems indicated a similar reduction in melt rate when Frit 202 is substituted for Frit 418.

3.3 SMRF Top of Glass Pool Samples

As noted in section 2.3.1 a sample of the top glass surface was taken after the melter had idled overnight. This was not possible with the NaOH addition test since the melter was emptied at the end of the run. The sample taken did exhibit foamy characteristics similar to that reported previously in runs involving Frit 418 (Smith, et al, 2004). This foamy layer can negatively impact melt rate by acting as an insulating layer between the molten glass and the cold cap. The resultant lower temperatures in the upper region of the melt pool (850 to 940 ºC as previously cited) would allow for the formation of crystalline phases. Figure 3-1 is an X ray diffraction (XRD) plot of a cold cap sample from a previous SMRF run, showing the presence of the crystalline phases trevorite ($NiFe_2O_4$) and aegerine ($NaFe^{3+}Si_2O_6$)..

Figure 3.1 XRD of Cold Cap Sample



4.0 CONCLUSIONS

A series of dry-fed tests (using the Melt Rate Furnace or MRF) and slurry fed tests (using the Slurry-Fed Melt Rate Furnace or SMRF) have been performed to investigate the effect on the melt rate when using Frit 202 as a substitute for Frit 418 with the SB3 system. In addition, tests were performed to determine if an additive could be used to regain the anticipated loss in melt rate when transitioning to a more refractory frit (less alkali) frit. The following conclusions can be made based on this work:

- Slurry feed testing indicates that melt rate would be reduced by ~ 30% when substituting Frit 202 for Frit 418 in the SB3 system.
- The combination of SB3 and Frit 202 exhibited more cold cap mounding than using Frit 418, but the material can still be processed through the system.
- The increase in melt rate from the full addition of NaOH observed in the MRF could not be verified in the SMRF. The amount of additive used in the SMRF was limited due to TOC concerns.
- SMRF top of glass pool sample taken after cold cap burn off was found to be foamy. Previous analysis of a similar layer from Frit 418 glass has shown the presence of crystalline phases trevorite and aegerine.

5.0 RECOMMENDATIONS/PATH FORWARD

- Evaluate changes in the SMRF operating conditions, such as continuous feeding, to allow processing of feeds with lower melt rate or mounding tendencies.
- Investigate reproducibility of MRF by running multiple tests with identical feeds.
- Additional testing of additives should investigate materials that do not require major adjustments to the acid strategy.

6.0 REFERENCES

Peeler, DK and TB Edwards. *Frit 202 – SB3 Sulfate Solubility Assessment*, SRT-GPD-2004-00069.

Smith, ME, TH Lorier, and TM Jones. 2003. *SMRF and MRF DWPF Melt Rate Testing for SB2/SB3 (Case 6b – 250 Canisters) (U)*, WSRC-TR-2003-00466, Westinghouse Savannah River Company, Aiken, South Carolina.

Smith, ME, DH Miller, and TL Lorier, 2004. *The Impact of Feed Preparation Acid Stoichiometry and REDOX on Melt rate for the SB3-Frit 418 System(U)*, WSRC-TR-2004-00350.

APPENDIX A – SRAT/SME ANALYSES

Sample ID	Lab ID	Al	B	Ba	Ca	Cr	Cu	Fe	Gd	K	Li	Mg	Mn	Na	Ni	P	Pb	S	Si	Ti	Zn	Zr
elemental wt%-calcined 1100C		Al	B	Ba	Ca	Cr	Cu	Fe	Gd	K	Li	Mg	Mn	Na	Ni	P	Pb	S	Si	Ti	Zn	Zr
FPMR-23 A	04-0958	9.13	<0.100	0.122	1.97	0.156	0.162	29.2	0.067	0.145	<0.100	1.82	3.68	15.7	1.03	0.06	0.011	0.404	1.07	0.024	0.328	0.409
FPMR-23 B	04-0958	9.01	<0.100	0.127	1.84	0.159	0.159	28.5	0.069	0.129	<0.100	1.85	3.92	15.8	1.07	0.07	0.01	0.412	1.11	0.024	0.332	0.448
FPMR-24 A	04-0959	3.44	1.42	0.048	0.779	0.061	0.053	10.3	0.025	0.078	1.9	1.49	1.42	8.54	0.381	0.04	0.038	0.114	24.3	0.023	0.126	0.192
FPMR-24 B	04-0959	3.43	1.42	0.047	0.758	0.059	0.053	10.4	0.024	0.084	1.9	1.44	1.43	8.49	0.373	0.04	0.038	0.11	24.6	0.022	0.121	0.182
FPMR-25 A	04-0960	8.88	<0.100	0.126	2.07	0.155	0.142	27.4	0.071	0.118	<0.100	1.99	3.88	15.3	1.06	0.057	0.009	0.428	1.11	0.024	0.328	0.432
FPMR-25 B	04-0960	8.86	<0.100	0.129	2.08	0.153	0.141	28.3	0.068	0.214	<0.100	2.02	3.96	15.3	1.03	0.058	0.009	0.438	1.19	0.023	0.326	0.43
FPMR-26 A	04-0961	3.34	1.4	0.045	0.753	0.057	0.056	10.2	0.023	0.087	1.97	1.42	1.38	8.31	0.378	0.043	0.035	0.111	25.3	0.023	0.118	0.176
FPMR-26 B	04-0961	3.27	1.41	0.046	0.726	0.057	0.052	9.92	0.023	0.071	1.96	1.49	1.37	8.13	0.361	0.032	0.037	0.109	24.6	0.023	0.122	0.179

oxide wt% - calcined 1100C		Al2O3	B2O3	BaO	CaO	Cr2O3	CuO	Fe2O3	Gd2O3	K2O	Li2O	MgO	MnO	Na2O	NiO	P2O5	PbO	SO4	SiO2	TiO2	ZnO	ZrO2	Totals	Norm Li2O
FPMR-23 A	04-0958	17.3	0	0.137	2.76	0.228	0.203	41.8	0.077	0.174	0	3.02	4.75	21.2	1.31	0.13	0.012	1.21	2.29	0.04	0.407	0.552	97.5	
FPMR-23 B	04-0958	17	0	0.142	2.58	0.232	0.199	40.8	0.079	0.155	0	3.07	5.06	21.3	1.36	0.15	0.011	1.24	2.38	0.04	0.412	0.605	96.8	
FPMR-24 A	04-0959	6.5	4.57	0.054	1.09	0.089	0.066	14.7	0.029	0.094	4.09	2.47	1.83	11.5	0.48	0.08	0.041	0.34	52	0.038	0.156	0.259	100.5	4.06
FPMR-24 B	04-0959	6.48	4.57	0.053	1.06	0.086	0.066	14.9	0.028	0.101	4.09	2.39	1.84	11.5	0.47	0.08	0.041	0.33	52.6	0.037	0.15	0.246	101.1	4.04
FPMR-25 A	04-0960	16.8	0	0.141	2.9	0.226	0.178	39.2	0.082	0.142	0	3.3	5.01	20.7	1.346	0.13	0.01	1.28	2.38	0.04	0.407	0.583	94.8	
FPMR-25 B	04-0960	16.7	0	0.144	2.91	0.223	0.176	40.5	0.078	0.257	0	3.35	5.11	20.7	1.308	0.13	0.01	1.31	2.55	0.038	0.404	0.581	96.5	
FPMR-26 A	04-0961	6.31	4.51	0.05	1.05	0.083	0.07	14.6	0.026	0.104	4.24	2.36	1.78	11.2	0.48	0.1	0.038	0.333	54.1	0.038	0.146	0.238	101.9	4.16
FPMR-26 B	04-0961	6.18	4.54	0.052	1.02	0.083	0.065	14.2	0.026	0.085	4.21	2.47	1.77	11	0.458	0.07	0.04	0.327	52.6	0.038	0.151	0.242	99.6	4.23

Anions (mg/Kg)		NO2	NO3	SO4	HCO2
FPMR-23 A	04-0958	<100	30000	1430	75600
FPMR-23 B	04-0958	<100	29100	1380	73300
FPMR-24 A	04-0959	<100	25400	1410	67000
FPMR-24 B	04-0959	<100	24500	1340	65000
FPMR-25 A	04-0960	<100	30100	1430	73800
FPMR-25 B	04-0960	<100	29800	1400	72100
FPMR-26 A	04-0961	<100	25400	1440	64900
FPMR-26 B	04-0961	<100	25800	1380	65900

Avg Norm Li2O for SB3/Frit 202	WL for SB3/Frit 202
4.12	39.9

Norm Li2O in Frit 202 (Lot 14)
6.86

Weight % Solids Calculations

Sample	Lab ID	Empty Crucible wt	Crucible Wt Wet Sample	Crucible Wt + Dry wt	Total Solids	Wet Wt	Dry Wt	Insoluble Solids	Cruc Wt+ Calcined	Wt % Calcined
FPMR-23 A	04-0958	41.7582	47.5443	43.2899	26.50%	5.7861	1.532	13.70%	42.7502	17.10%
FPMR-23 B	04-0958	44.3827	50.3134	45.9505	26.40%	5.9307	1.568	13.70%	45.3981	17.10%
FPMR-24 A	04-0959	42.3596	47.8571	45.0083	48.20%	5.4975	2.649	36.80%	44.55	39.80%
FPMR-24 B	04-0959	43.1453	48.2928	45.6335	48.30%	5.1475	2.488	37.00%	45.2053	40.00%
FPMR-25 A	04-0960	43.428	49.152	44.9344	26.30%	5.724	1.506	13.70%	44.3945	16.90%
FPMR-25 B	04-0960	44.1276	50.076	45.6972	26.40%	5.9484	1.57	13.60%	45.1349	16.90%
FPMR-26 A	04-0961	43.5925	48.5479	46.0375	49.30%	4.9554	2.445	38.20%	45.6318	41.20%
FPMR-26 B	04-0961	43.0816	48.1235	45.5747	49.40%	5.0419	2.493	38.20%	45.1603	41.20%

Sample	Lab ID	Empty Crucible wt	Crucible Wt Wet Sample	Crucible Wt + Dry wt	Uncorr	Soluble Solids		Density	pH
FPMR-23 A	04-0959	43.6846	44.8011	43.8494	14.80%	12.70%		1.22	7.43
FPMR-23 B	04-0959	45.2786	46.3936	45.4434	14.80%	12.80%			
FPMR-24 A	04-0960	42.9258	44.0863	43.1349	18.00%	11.40%		1.45	7.05
FPMR-24 B	04-0960	44.0233	45.1653	44.2291	18.00%	11.40%			
FPMR-25 A	04-0961	44.393	45.5053	44.5558	14.60%	12.60%		1.17	7.49
FPMR-25 B	04-0961	43.3323	44.4497	43.4974	14.80%	12.80%			
FPMR-26 A	04-0962	44.6744	45.8155	44.8805	18.10%	11.20%		1.44	7.16
FPMR-26 B	04-0962	44.8538	45.9892	45.06	18.20%	11.20%			

Table A1, SB3/Frit 202 - SRAT and SME Product Analytical Results

elemental wt%		Al	B	Ba	Ca	Cr	Cu	Fe	Gd	K	Li	Mg	Mn	Na	Ni	P	Pb	S	Si	Ti	Zn	Zr
calcined 1100C																						
FPMR-29B A	04-0970	8.53	<0.100	0.119	1.92	0.148	0.125	27	0.065	0.11	<0.100	1.99	3.66	18.9	0.94	0.07	0.006	0.425	1.16	0.022	0.311	0.453
FPMR-29B B	04-0970	8.46	<0.100	0.119	1.93	0.146	0.123	28	0.064	0.111	<0.100	1.97	3.69	18.4	0.95	0.06	0.005	0.42	1.24	0.022	0.31	0.451
FPMR-30B A	04-0971	3.3	1.52	0.046	0.728	0.057	0.058	10.9	0.023	0.074	1.98	1.59	1.35	9.17	0.34	0.03	0.036	0.11	23.9	0.021	0.119	0.189
FPMR-30B B	04-0971	3.3	1.54	0.046	0.729	0.057	0.06	10.7	0.025	0.07	1.98	1.51	1.34	9.21	0.34	0.03	0.036	0.101	23.5	0.021	0.119	0.186
FPMR-31B A	04-0972	8.41	<0.100	0.122	1.94	0.154	0.121	27.4	0.064	0.111	<0.100	2.01	3.92	18.6	1.01	0.07	0.006	0.433	1.01	0.023	0.328	0.447
FPMR-31B B	04-0972	8.57	<0.100	0.125	1.93	0.153	0.123	27.8	0.066	0.108	<0.100	2.03	3.73	18.9	0.953	0.066	0.005	0.437	0.998	0.023	0.318	0.461
FPMR-32B A	04-0973	3.18	1.37	0.044	0.705	0.055	0.067	10.3	0.022	0.074	2.03	1.48	1.24	9.18	0.309	0.036	0.035	0.112	24	0.023	0.113	0.179
FPMR-32B B	04-0973	3.14	1.34	0.045	0.704	0.057	0.07	10.3	0.024	0.108	2.03	1.51	1.26	9.14	0.306	0.044	0.041	0.12	24.9	0.028	0.115	0.181

oxide wt% - calcined 1100C		Al2O3	B2O3	BaO	CaO	Cr2O3	CuO	Fe2O3	Gd2O3	K2O	Li2O	MgO	MnO	Na2O	NiO	P2O5	PbO	SO4	SiO2	TiO2	ZnO	ZrO2	Totals	Norm Li2O
FPMR-29B A	04-0970	16.1	0	0.133	2.69	0.216	0.156	38.6	0.075	0.132	0	3.3	4.72	25.5	1.2	0.149	0.006	1.28	2.48	0.04	0.386	0.612	97.8	
FPMR-29B B	04-0970	16	0	0.133	2.7	0.213	0.154	40	0.074	0.133	0	3.27	4.76	24.8	1.21	0.147	0.005	1.26	2.65	0.04	0.384	0.609	98.6	
FPMR-30B A	04-0971	6.24	4.89	0.052	1.02	0.083	0.073	15.6	0.026	0.089	4.26	2.64	1.74	12.4	0.425	0.073	0.039	0.33	51.1	0.04	0.148	0.255	101.5	4.19
FPMR-30B B	04-0971	6.24	4.96	0.052	1.02	0.083	0.075	15.3	0.029	0.084	4.26	2.51	1.73	12.4	0.429	0.076	0.039	0.303	50.3	0.04	0.148	0.251	100.3	4.24
FPMR-31B A	04-0972	15.9	0	0.137	2.72	0.225	0.151	39.2	0.074	0.133	0	3.34	5.06	25.1	1.28	0.16	0.006	1.3	2.16	0.04	0.407	0.603	98	
FPMR-31B B	04-0972	16.2	0	0.14	2.7	0.223	0.154	39.8	0.076	0.13	0	3.37	4.81	25.5	1.21	0.151	0.005	1.31	2.14	0.04	0.394	0.622	98.9	
FPMR-32B A	04-0973	6.01	4.41	0.049	0.987	0.08	0.084	14.7	0.025	0.089	4.36	2.46	1.6	12.4	0.392	0.082	0.038	0.336	51.4	0.04	0.14	0.242	99.9	4.37
FPMR-32B B	04-0973	5.93	4.31	0.05	0.986	0.083	0.088	14.7	0.028	0.13	4.36	2.51	1.63	12.3	0.389	0.101	0.044	0.36	53.3	0.05	0.143	0.244	101.8	4.29

Anions (mg/Kg)		NO2	NO3	SO4	HCO2
FPMR-29B A	04-0970	<100	37000	1460	74100
FPMR-29B B	04-0970	<100	37000	1370	74100
FPMR-30B A	04-0971	<100	28800	1260	60700
FPMR-30B B	04-0971	<100	29400	1275	62500
FPMR-31B A	04-0972	<100	35900	1350	75500
FPMR-31B B	04-0972	<100	36900	1360	77800
FPMR-32B A	04-0973	<100	27500	1280	60500
FPMR-32B B	04-0973	<100	27400	1350	59900

Avg Norm Li2O for SB3/Frit 202 w/NaOH	WL for SB3/Frit 202 w/NaOH
4.27	37.7

Norm Li2O in Frit 202 (Lot 14)
6.86

Weight % Solids Calculations

Sample	Lab ID	Empty Crucible wt	Crucible Wt Wet Sample	Crucible Wt + Dry wt	Total Solids	Wet Wt	Dry Wt	Insoluble Solids	Cruc Wt+ Calcined	Wt % Calcined
FPMR-29B A	04-0970	42.4804	48.5354	44.2106	28.60%	6.055	1.73	13.90%	43.5566	17.80%
FPMR-29B B	04-0970	40.8174	46.9524	42.57	28.60%	6.135	1.753	13.80%	41.9087	17.80%
FPMR-30B A	04-0971	42.5105	48.5897	45.4005	47.50%	6.0792	2.89	35.70%	44.8774	38.90%
FPMR-30B B	04-0971	44.3817	51.1274	47.5995	47.70%	6.7457	3.218	36.00%	47.0157	39.00%
FPMR-31B A	04-0972	41.7574	47.6525	43.4415	28.60%	5.8951	1.684	13.80%	42.8041	17.80%
FPMR-31B B	04-0972	43.1869	49.327	44.9412	28.60%	6.1401	1.754	13.90%	44.2755	17.70%
FPMR-32B A	04-0973	44.0499	50.4625	47.1772	48.80%	6.4126	3.127	36.90%	46.6267	40.20%
FPMR-32B B	04-0973	43.0572	49.9433	46.4109	48.70%	6.8861	3.354	36.90%	45.8214	40.10%

Sample	Lab ID	Empty Crucible wt	Crucible Wt Wet Sample	Crucible Wt + Dry wt	Uncorr	Soluble Solids		Density	pH
FPMR-29B A	04-0970	44.3918	45.5242	44.5848	17.00%	14.70%		1.24	7.9
FPMR-29B B	04-0970	44.5749	45.7093	44.7694	17.10%	14.80%			
FPMR-30B A	04-0971	44.2965	45.4472	44.5084	18.40%	11.80%		1.45	8
FPMR-30B B	04-0971	42.5626	43.7007	42.7709	18.30%	11.70%			
FPMR-31B A	04-0972	44.4167	45.5448	44.6096	17.10%	14.70%		1.25	7.79
FPMR-31B B	04-0972	45.2782	46.4107	45.4714	17.10%	14.70%			
FPMR-32B A	04-0973	40.2289	41.3711	40.444	18.80%	11.90%		1.45	7.65
FPMR-32B B	04-0973	44.1756	45.3119	44.3884	18.70%	11.80%			

Table A2 - SB3/Frit 202 - SRAT and SME Product Analytical Results

elemental wt%-calcined 1100C		Al	B	Ba	Ca	Cr	Cu	Fe	Gd	K	Li	Mg	Mn	Na	Ni	Pb	Si	Ti	Zn	Zr
SMRF-0175 (A)	04-1043	3.37	1.52	0.046	0.685	0.068	0.052	9.82	0.025	0.069	2.04	1.52	1.26	8.4	0.356	0.037	23.4	0.023	0.136	0.183
SMRF-0175 (B)	04-1043	3.41	1.5	0.046	0.673	0.069	0.049	10.2	0.025	0.068	2.06	1.49	1.23	8.23	0.35	0.036	23.9	0.023	0.116	0.184
SMRF-0176 (A)	04-1044	3.34	1.56	0.046	0.698	0.058	0.049	9.92	0.025	0.069	2.12	1.44	1.28	8.51	0.32	0.036	23.7	0.023	0.115	0.187
SMRF-0176 (B)	04-1044	3.47	1.45	0.046	0.703	0.064	0.051	9.89	0.025	0.071	2.05	1.44	1.28	8.61	0.32	0.036	23.3	0.023	0.119	0.187
SMRF-0179 (A)	04-1045	3.17	1.23	0.041	0.64	1.19	0.051	12.9	0.021	0.057	1.89	1.29	1.41	8.01	1.46	0.032	20.4	0.023	0.142	0.163
SMRF-0179 (B)	04-1045	3.26	1.24	0.041	0.637	1.28	0.054	13.4	0.021	0.059	1.88	1.28	1.42	8.11	1.51	0.031	20.6	0.023	0.14	0.164

oxide wt% - calcined 1100C		Al2O3	B2O3	BaO	CaO	Cr2O3	CuO	Fe2O3	Gd2O3	K2O	Li2O	MgO	MnO	Na2O	NiO	PbO	SiO2	TiO2	ZnO	ZrO2	Totals
SMRF-0175 (A)	04-1043	6.37	4.89	0.052	0.959	0.099	0.065	14	0.029	0.083	4.39	2.52	1.63	11.3	0.452	0.04	50.1	0.038	0.169	0.247	97.5
SMRF-0175 (B)	04-1043	6.44	4.83	0.052	0.942	0.101	0.061	14.6	0.029	0.082	4.43	2.47	1.59	11.1	0.445	0.039	51.1	0.038	0.144	0.248	98.8
SMRF-0176 (A)	04-1044	6.31	5.02	0.052	0.977	0.085	0.061	14.2	0.029	0.083	4.56	2.39	1.65	11.5	0.406	0.039	50.7	0.038	0.143	0.252	98.5
SMRF-0176 (B)	04-1044	6.56	4.67	0.052	0.984	0.093	0.064	14.1	0.029	0.085	4.41	2.39	1.65	11.6	0.406	0.039	49.9	0.038	0.148	0.252	97.5
SMRF-0179 (A)	04-1045	5.99	3.96	0.046	0.896	1.74	0.064	18.4	0.024	0.068	4.06	2.14	1.82	10.8	1.85	0.035	43.7	0.038	0.176	0.22	96.1
SMRF-0179 (B)	04-1045	6.16	3.99	0.046	0.892	1.87	0.068	19.2	0.024	0.071	4.04	2.12	1.83	10.9	1.92	0.033	44.1	0.038	0.174	0.221	97.7

		Fe(2+)	Fe(3+)	Fe(total)	Fe(2+)/Fe(3+)	Fe(2+)/Fe(total)
EA		0.05	0.243	0.293	0.21	0.17
SMRF-0175	04-1043	0.016	0.501	0.517	0.03	0.03
		0.015	0.503	0.518	0.03	0.03
SMRF-0176	04-1044	0.108	0.444	0.552	0.24	0.2
		0.104	0.442	0.546	0.24	0.19
SMRF-0179	04-1045	0.144	0.266	0.41	0.54	0.35
		0.142	0.267	0.409	0.53	0.35

		Empty	Crucible Wt	Crucible Wt +				Insoluble	Cruc Wt+	Wt %
Sample	Lab ID	Crucible wt	Wet Sample	Dry wt	Total Solids	Wet Wt	Dry Wt	Solids	Calcined	Calcined
SMRF-0175 (A)	04-1043	44.3179	51.0321	47.3905	45.80%	6.7142	3.073	35.40%	46.8815	38.20%
SMRF-0175 (B)	04-1043	44.574	51.0317	47.5236	45.70%	6.4577	2.95	35.30%	47.0284	38.00%

		Empty	Crucible Wt	Crucible Wt +		Soluble				
Sample		Crucible wt	Wet Sample	Dry wt	Uncorr	Solids			Density	pH
SMRF-0175 (A)	04-1043	43.1437	44.2638	43.3233	16.03%	10.40%			1.37	*
SMRF-0175 (B)	04-1043	44.0244	45.1405	44.2038	16.07%	10.40%				* Ph meter broken

Table A-3. SMRF SB3 Frit 202 Feed and Glass Analytical Results