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Experimental Plan for Crystal Accumulation Studies in the WTP Melter Riser

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EXECUTIVE SUMMARY

This experimental plan defines crystal settling experiments to be in support of the U.S. Department of Energy – Office of River Protection crystal tolerant glass program. The road map for development of crystal-tolerant high level waste glasses recommends that fluid dynamic modeling be used to better understand the accumulation of crystals in the melter riser and mechanisms of removal. A full-scale version of the Hanford Waste Treatment and Immobilization Plant (WTP) melter riser constructed with transparent material will be used to provide data in support of model development. The system will also provide a platform to demonstrate mitigation or recovery strategies in off-normal events where crystal accumulation impedes melter operation. Test conditions and material properties will be chosen to provide results over a variety of parameters, which can be used to guide validation experiments with the Research Scale Melter at the Pacific Northwest National Laboratory, and that will ultimately lead to the development of a process control strategy for the full scale WTP melter.

The experiments described in this plan are divided into two phases. Bench scale tests will be used in Phase 1 (using the appropriate solid and fluid simulants to represent molten glass and spinel crystals) to verify the detection methods and analytical measurements prior to their use in a larger scale system. In Phase 2, a full scale, room temperature mockup of the WTP melter riser will be fabricated. The mockup will provide dynamic measurements of flow conditions, including resistance to pouring, as well as allow visual observation of crystal accumulation behavior.

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LIST OF ABBREVIATIONS

DOE	U.S. Department of Energy
DOE-ORP	U.S. Department of Energy – Office of River Protection
HLW	High Level Waste
INL	Idaho National Laboratory
JHCM	Joule Heated Ceramic Melters
LAW	Low Activity Waste
PNNL	Pacific Northwest National Laboratory
RSM	Research Scale Melter
SRNL	Savannah River National Laboratory
WTP	Hanford Waste Treatment and Immobilization Plant

1.0 Introduction

The U.S. Department of Energy (DOE) is building a Tank Waste Treatment and Immobilization Plant (WTP) at the Hanford Site in Washington to remediate 55 million gallons of radioactive waste that is being temporarily stored in 177 underground tanks. The low-activity waste (LAW) fraction will be partitioned from the high-level waste (HLW). Both the LAW and HLW will then be vitrified in borosilicate glass with Joule-heated ceramic melters (JHCM).[1]

Efforts are being made to significantly increase the waste loadings of glasses over the composition regions that WTP expects to process while balancing impacts to melter performance and lifetime. Recent experimental studies have significantly expanded the composition regions and waste loadings of glasses beyond the point used in project planning models. Glass formulation data have suggested that significant increases in waste loading in HLW and LAW glasses are possible over current system planning estimates.[2] Improvements in waste loading may be achieved if higher crystal content can be routinely processed in JHCM.

Historically, crystallization constraints are used in process control systems to prevent premature or catastrophic failure of JHCM through bulk devitrification or crystal accumulation and to mitigate negative impacts of crystals as glass is produced. Belsher and Meinert identified five constraints that were most influential on the estimated Hanford HLW glass volumes.[3] One of those constraints was the limit of no more than 1 vol% spinel crystals in equilibrium with the melt ($T_{1\%}$) at a temperature of 950 °C. Therefore, the DOE Office of River Protection (DOE-ORP) has initiated a program to develop an appropriate and defensible crystallization control strategy to modify or replace the current $T_{1\%}$ approach.[4,5]

A road map has been developed that describes research and development efforts needed to establish an alternative approach for crystallization control in the WTP HLW melters.[6] The basis of this alternative approach is an empirical model predicting the crystal accumulation in the WTP melt discharge riser and melter bottom as a function of glass composition, time, and temperature.[7-10] When coupled with an associated operating limit (e.g., the maximum tolerable thickness of an accumulated layer of crystals), this model could then be integrated into the process control algorithms to formulate crystal-tolerant HLW glasses targeting high waste loadings while still meeting process related limits and melter lifetime expectancies. The program aims to provide a fundamental and technically sound approach that can be implemented in WTP operation, which will allow for significant savings in mission cost and lifetime.

The road map recommends that fluid dynamic modeling be used to better understand the accumulation of crystals in the melter riser and mechanisms of removal. The melter riser is considered to be most vulnerable to the detrimental effects of spinel accumulation. A full-scale version of the WTP melter riser constructed with transparent material and operated using silicone oils with viscosities similar to those of glass with the addition of spinel crystals can be used to provide data such as the relative packing density, shear-strength, rheology of the accumulated layer, and crystal accumulation and clearing of the riser. The combination of transparency and room temperature operation will make this system simpler to use for multiple test conditions as compared to a scaled melter, which requires a significant investment of time and resources for each experimental run. The data generated will support fluid dynamic modeling underway at Idaho National Laboratory (INL) to evaluate the impact of various parameters on the accumulation and removal of crystals from the riser. This model will be designed as a tool for predicting the rate of spinel accumulation under a given set of glass composition and melter operating conditions. The model will be incorporated as an integral component of the crystal-tolerant strategy. Precipitation of spinel crystals, their mutual interaction including agglomeration, and their reaction or bonding with refractory or other crystals need to be considered when designing experiments to support this effort. It will therefore be beneficial to combine the data obtain from room temperature testing with scale melter runs in order to capture these additional effects and to validate the room temperature results. The testing platform may also be used to demonstrate mitigation or recovery strategies in off-normal events where crystal accumulation impedes melter operation.

2.0 Experimental Plan

Room temperature experiments to study the accumulation of spinels in the WTP melter riser are planned in two phases. Phase 1 will be bench scale experiments using the appropriate solid and fluid simulants (to represent molten glass and spinel crystals) will be performed to verify the detection methods and analytical measurements prior to their use in a larger scale system. In Phase 2, a full-scale mockup of the discharge port which includes 30° slant section, vertical section (riser), and horizontal section (pour spout) will be designed and tested at room temperature under static and prototypic flow conditions (based on planned WTP HLW facility glass pouring rates of about 1075 pounds of glass per hour). This system will be operated in both pouring and idling conditions to study the settling, accumulation and removal of crystals of different sizes and concentrations, which will be dispersed in the silicone oils of different viscosities. The collected data will be incorporated into fluid dynamic model that is being developed at INL and will be also used to validate the results from the research-scale melter (RSM) at the Pacific Northwest National Laboratory (PNNL).

2.1 <u>Materials</u>

Particles of appropriate size, shape, and density will be identified as well as fluids to simulate properties of spinel crystals and molten glass (density and viscosity) as found in the melter. These materials will be consistent with (if not the same) as those used in previous testing at PNNL.[7,8] A more detailed description of the test components is presented in the following sections.

2.1.1 Particles for testing

The particle size, density, and concentration as well as the fluid viscosity are important parameters and will be evaluated. The particles and fluids will be selected to allow reasonable tests durations while still providing realistic conditions as observed in the discharge outlet of the melter during idling and pouring. The difference in the densities and in the ratio of densities for the particles and fluids will also be evaluated. It is recognized that room temperature simulants will not match the densities of molten glass and spinel crystals. However, a density ratio similar to that of molten glass and spinel crystals should provide settling behavior that can simulate well the settling of crystals in molten glass. This correlation may also allow for settling experiments to be performed faster, while still providing data that can simulate the melter conditions. Room temperature testing previously conducted by PNNL[7,8] provides data for the baseline particle/fluid systems to be used in this testing program.

Testing will be conducted with octahedral particles as well as irregular shapes. Octahedral particles that are being considered for testing are Fe_2O_3 crystals and Spinel crystal powder, which have densities of ~5.29 and 3.64 g/cm^3, respectively. Chromite sand will be used to simulate agglomerated or irregular shaped particles. Table 2-1 lists the particles for testing including their shape, size and density. Sieving might be used to provide desired size distributions.

Table 2-1. Properties of Particles

Particulate	Shape	Size (μm)	Density (g/cm^3)
Fe_2O_3 crystals	Octahedral	80	5.29
Spinel crystal powder	Octahedral	80	3.64
Chromite sand	Irregular	75	4.40

2.1.2 Fluids for testing

The primary transparent fluids to be used to support this testing will be silicone based fluids, which offer a range of stable viscosities at room temperature. Initial testing will establish the ability to measure/confirm the viscosities against published data for the selected fluids. The silicon oils identified have specific gravities less than that of molten glass but offer enough difference to help establish trends related to particle/fluid density differences and ratios. The ability to vary the viscosity of the fluid may be applicable to different temperature zones in the actual melter. This is important since the riser is anticipated to drop in temperature relative to the melt pool, especially during idle periods. Tailoring the fluid and test apparatus appropriately could allow for changes in viscosity as a function of temperature to be simulated. The fluids selected for testing and their properties are given in Table 2-2, along with the properties of molten glass for comparison. Again, it is recognized that room temperature simulants will not match the densities of molten glass and spinel crystals. It is therefore hypothesized that simulants with a density ratio similar to that of molten glass and spinel crystals will provide settling behavior that can be correlated to crystal settling in molten glass. Other silicone oils may be used if higher viscosities are needed.

Table 2-2. Properties of Fluids for Phase 1 Experiments

Solution	Density (g/cm^3)	Viscosity (Pa·s)
Molten glass @ 1050 °C[8]	2.62	12.0
Molten glass @ 1083 °C[8]	2.62	8.6
Silicone oil, 50 cSt	0.959	0.048
Silicone oil, 350 cSt	0.970	0.34
Silicone oil, 1000 cSt	0.970	0.97

2.1.3 Particulate Detection Methods

Several methods to monitor the position of the particles in the test fluid will be evaluated in order to select the appropriate method(s) for use in the Phase 2 system. Depending on particle size or color, visual measurement may be adequate. Alternate methods include light transmission and sensitive photography equipment[a] that can monitor particle movement. If necessary, the column may be modified to provide flat faces to eliminate distortion associated with a cylindrical surface that could interfere with the camera image. Potential impacts of this modification to the prototypic shape of the riser design (and therefore, particle settling behavior) in Phase 2 testing are acknowledged and will be evaluated.

2.1.4 Test Conditions

The primary goal of the Phase 1 experiments is to identify the appropriate measurement and detection methods at a smaller scale or on a mock-up of discharge outlet alone. Multiple approaches to developing an accumulated layer of crystals will be evaluated. Depositing known quantities of particulate on the top of a fresh fluid filled cylinder will potentially allow rapid identification of particulate settling behavior. Starting with a homogeneous mixture of the selected fluid and suspended particles in the entire cylinder is more representative of the actual process and will be tested for comparison to the results of depositing particles on the surface of the fluid. Several particulate and fluid combinations will be tested to confirm settling times and guide the design of Phase 2 experiments. Comparison to Stoke's Law and previous testing[12,13] will allow for relating the simulant data to actual melter conditions.

[a] For example, high resolution camera with a long working distance lens equipped with a polarizing filter. The camera could be connected to a computer with image analysis software to evaluate the movement of the settling front and the growth of the accumulation layer in real time.

2.2 Phase 2

The primary goal of Phase 2 testing is to evaluate the effects of spinel accumulation on the operation of the WTP HLW melter riser. The riser is considered to be most vulnerable to the detrimental effects of spinel accumulation. The mockup will provide dynamic measurements of flow conditions, including resistance to pouring, as well as allow visual observation of accumulation behavior. Test conditions and material properties will be chosen to provide results over a variety of parameters, which will permit the extrapolation of mockup operating conditions and results to scale melter testing, and ultimately lead to the development of a process control strategy for the full scale melter.

A full scale mockup of a WTP HLW melter riser and trough will be fabricated for Phase 2 experiments. The mockup will be constructed from clear acrylic material to support observations of crystal settling and re-suspension. A pumping system will provide flow through the mockup to simulate melter pour conditions, including stopping, idling, and restarting a pour. Pressure and flow will be measured to characterize the pour conditions. Of interest will be any resistance to pouring as indicated by the pressure and flow measurements as test conditions such as solids concentration are varied, since this resistance is expected to indicate a reduce ability to pour glass from the melter. The physical behavior of particulates settling in the riser will be characterized. The use of transparent materials of construction will allow visual observation and facilitate the use of the additional detection methods, identified through testing in Phase 1, to detect and quantify settling characteristics.

2.2.1 Equipment Design

A preliminary diagram of the mockup is shown in Figure 2-1. Dimensions of the throat, riser, and pour trough will be identical to those of the full scale melter. Fluid flow will be generated by an air lift lance to provide a consistent and controllable flow rate. Flow and pressure into the air lift lance will be measured and recorded as well as solution temperature in the slurry tank. Test solutions will be premixed and stored in the slurry tank where an agitator will keep the supply homogeneous during a test. Flow rate through the mockup will be matched to expected glass pour rates through the use of a variable frequency drive.

In later stages of the work, a temperature control system may be added to the riser (by means of a water jacket) and the slurry tank (cooling coils) to control the temperature of the fluids whose properties are temperature dependent. Separate temperature control systems will be used for the riser and slurry tank to allow for the simulation of cooler (and therefore, more viscous) glass in the riser during idling conditions, as compared to higher temperature conditions in the melt pool.

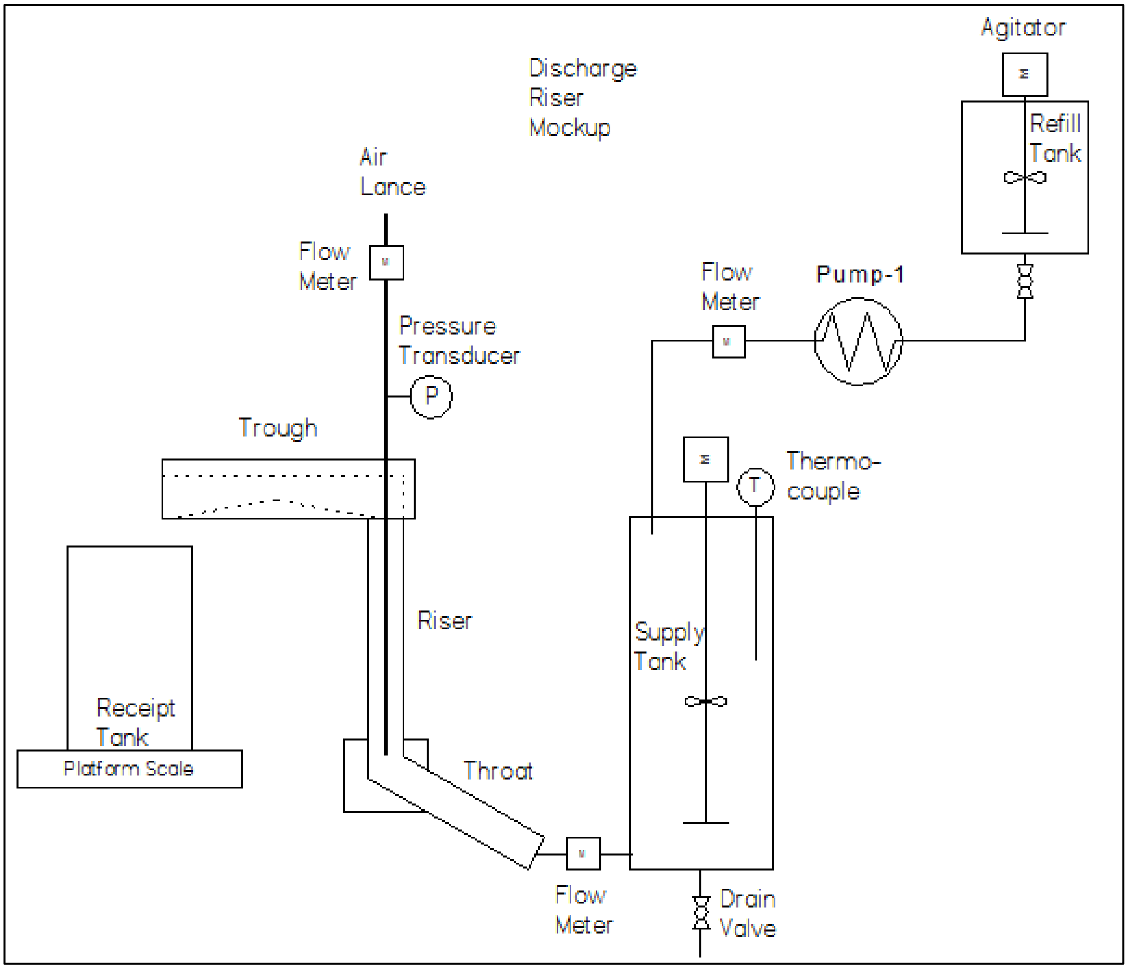

Figure 2-1. Preliminary Design of Room Temperature Riser Test System

2.2.2 Test Conditions

The main variable for riser testing will be solids concentration in the fluid, given that bulk density will increase with concentration (causing an increase in pressure required to pour) as well as the possibility of pluggage in the riser throat area. Concentrations of 1%, 10%, and 20% by volume will be targeted initially to determine bulk effects. Finer increments could be tested as warranted. Settling time will be another variable and will demonstrate the effect of solids accumulation and packing at the bottom of the vertical riser. The settling time will be based on empirical results from Phase 1 testing and will be confirmed with values estimated by Stoke's Law (with allowance for hindered settling based on the particulate concentration). Tests will be conducted with different particulate and fluid combinations. Optimal candidates for the particulates and fluids will be determined in the Phase 1 testing. The candidates will be chosen to provide relatively quick test times (hours or days instead of weeks) while maintaining properties that can be correlated to those in the melter (particle size, shape, viscosity, and density).

The system will provide a testing platform for a variety of experiments. A brief description of planned experiments is presented below, in order of priority. Additional test conditions may be developed as data are collected and accumulation conditions are better understood.

1. Concentration test – The concentration of the particulate material will be varied to determine the effect on resistance to restarting pouring. The mockup will be filled with the slurry by simulating a pour, the flow will be stopped to allow the particulates to settle in the riser, and then the flow will be restarted. Particulate concentration will be varied, with concentrations of 1%, 10%, and 20% by volume. Resistance to flow will be quantified as the pressure required to restart and maintain a pour, and will be correlated to the expected reduction in melter throughput. Different particulate/fluid combinations will be tested based on the Phase 1 results to provide data on the behavior of candidate simulant systems.

2. Settling time test – The settling time for a particulate/fluid combination will be varied to determine the effect on resistance to restarting pouring. The riser will be filled with the slurry by simulating a pour, the flow will be stopped to allow the particulates to settle in the riser, and then the flow will be restarted. The settling time will vary from test to test with initial times chosen for incomplete settling and latter times chosen for complete settling, including particulate packing. Resistance to flow will be quantified as the pressure required to restart and maintain a pour.

3. Plug test – Different size and shape plugs will be placed at the bottom of the vertical riser to simulate agglomerated particulate material. The plugs will effectively reduce the throat flow area and create a resistance to flow in the riser. Tests with and without particulates will be conducted. Another method of simulating a plug will be to attract and pack magnetic particles at the bottom of the vertical riser using a magnet. The magnetically coupled particles may provide a better representation of agglomerated spinels.

4. Longer term tests – The concentration test described above will be repeated with particulate/fluid combinations that produce a very long settling time (30+ days), one that is more representative of spinels settling in the melter riser. The properties of the particulates and fluids will be closer to the values of actual spinels and molten glass (size, shape, density, and viscosity). These tests would provide additional data to correlate the ambient temperature results to scale melter operation.

5. Bubbler test – A bubbler tube will be inserted into the vertical riser from the top to the bottom of the riser. The bubbler will be used during the restart of pouring to study its ability to help re-suspend settled particulates in the riser. Test conditions from concentration tests that produced significant resistance to pouring would be repeated using the bubbler tube to quantify benefits to restarting the pour.

3.0 Summary

This experimental plan defines crystal settling experiments to be in support of the DOE-ORP crystal tolerant glass program. The experiments described in this plan are divided into two phases. Bench scale tests will be used in Phase 1 (using the appropriate solid and fluid simulants to represent molten glass and spinel crystals) to verify the detection methods and analytical measurements prior to their use in a larger scale system. In Phase 2, a full scale, room temperature mockup of the WTP melter riser will be fabricated. The mockup will provide dynamic measurements of flow conditions, including resistance to pouring, as well as allow visual observation of crystal accumulation behavior. Test conditions and material properties will be chosen to provide results over a variety of parameters, which will permit the extrapolation of mockup operating conditions and results to Research Scale Melter testing, and ultimately lead to the development of a process control strategy for the full scale WTP melter.

4.0 References

1. Certa, P. J., R. D. Adams, G. K. Allen, J. D. Belsher, P. A. Empey, J. H. Foster, T. M. Hohl, R. T. Jasper, R. A. Kirkbride, R. L. Lytle, F. L. Meinert, J. S. Ritari, R. M. Russell, K. R. Seniow, E. B. West, M. N. Wells, and L. M. Bergmann, "River Protection Project System Plan," *U.S. Department of Energy Report ORP-11242, Revision 6*, U.S. Department of Energy - Office of River Protection, Richland, WA (2011).

2. Vienna, J. D., D. C. Skorski, D. S. Kim, and J. Matyáš, "Glass Property Models and Constraints for Estimating the Glass to be Produced at Hanford by Implementing Current Advanced Glass Formulation Efforts," *U.S. Department of Energy Report EWG-RPT-003, Revision 0,* Pacific Northwest National Laboratory, Richland, WA (2013).

3. Belsher, J. D. and F. L. Meinert, "High-Level Waste Glass Formulation Model Sensitivity Study 2009 Glass Formulation Model Versus 1996 Glass Formulation Model," *U.S. Department of Energy Report RPP-RPT-42649, Revision 0,* Washington River Protection Solutions, Richland, Washington (2009).

4. Vienna, J. D., D. S. Kim, M. J. Schweiger, J. S. McCloy, J. Matyáš, G. F. Piepel, and S. K. Cooley, "Test Plan: Enhanced Hanford Waste Glass Models," *U.S. Department of Energy Report TP-EWG-00001, Revision 0,* Pacific Northwest National Laboratory, Richland, WA (2013).

5. Matlack, K. S., W. K. Kot, W. Gong, W. Lutze, I. L. Pegg, and I. Joseph, "Effects of High Spinel and Chromium Oxide Crystal Contents on Simulated HLW Vitrification in DM100 Melter Tests," *U.S. Department of Energy Report VSL-09R1520-1*, Vitreous State Laboratory, The Catholic University of America, Washington, DC (2009).

6. Matyáš, J., J. D. Vienna, A. A. Kruger, D. K. Peeler, K. M. Fox, and C. C. Herman, "Road Map for Development of Crystal-Tolerant High Level Waste Glasses," *U.S. Department of Energy Report SRNL-STI-2013-00734, Revision 0 / PNNL-23363,* Savannah River National Laboratory, Aiken, SC (2014).

7. Matyáš, J., J. D. Vienna, A. Kimura, M. Schaible, and R. M. Tate, "Development of Crystal-Tolerant Waste Glasses"; pp. 41-51 in Ceramic Transactions, Vol. 222, *Advances in Materials Science for Environmental and Nuclear Technology*. Edited by K. M. Fox, E. N. Hoffman, N. Manjooran and G. Pickrell. John Wiley & Sons, Inc., Hoboken, NJ, 2010.

8. Matyáš, J., J. D. Vienna, and M. Schaible, "Determination of Stokes Shape Factor for Single Particles and Agglomerates"; pp. 195-203 in Ceramic Transactions, Vol. 227, *Advances in Materials Science for Environmental and Nuclear Technology II*. Edited by S. K. Sundaram, T. Ohji, K. M. Fox and E. N. Hoffman. John Wiley & Sons, Inc., Hoboken, NJ, 2011.

9. Matyáš, J., A. R. Huckleberry, C. P. Rodriguez, J. B. Lang, A. T. Owen, and A. A. Kruger, "Empirical Model for Formulation of Crystal-Tolerant HLW Glasses"; pp. 121-128 in Ceramic Transactions, Vol. 236, *Advances in Materials Science for Environmental and Energy Technologies*. Edited by T. Ohji, M. Singh, E. Hoffman, M. Seabaugh and G. Yang. John Wiley & Sons, Inc., Hoboken, NJ, 2012.

10. Matyáš, J., D. P. Jansik, A. T. Owen, C. A. Rodriguez, J. B. Lang, and A. A. Kruger, "Impact of Particle Agglomeration on Accumulation Rates in the Glass Discharge Riser of HLW Melter"; pp. 59-68 in Ceramic Transactions, Vol. 241, *Advances in Materials Science for Environmental and Energy Technologies II*. Edited by J. Matyáš, T. Ohji, X. Liu, M. P. Paranthaman, R. Devanathan, K. M. Fox, M. Singh and W. Wong-Ng. John Wiley & Sons, Inc., Hoboken, NJ, 2013.

11. Choi, A. S., D. H. Miller, and D. M. Immel, "Determination of HLW Glass Melt Rate Using X-Ray Computed Tomography (CT)," *U.S. Department of Energy Report SRNL-STI-2010-00767, Revision 0*, Savannah River National Laboratory, Aiken, SC (2011).

12. Kloužek, J., J. Alton, T. J. Plaisted, and P. Hrma, "Crucible Study of Spinel Settling in High-Level Waste Glass"; pp. 301-308 in Ceramic Transactions, Vol. 119, *Environmental Issues and Waste Management Technologies in the Ceramic and Nuclear Industries VI*. Edited by D. R. Spearing, G. L. Smith and R. L. Putman. The American Ceramic Society, Westerville, OH, 2001.

13. Hrma, P. R., "Impact of Particle Size and Agglomeration on Settling of Solids in Continuous Melters Processing Radioactive Waste Glass," *U.S. Department of Energy Report ORP-39901, Revision 0,* Pacific Northwest National Laboratory, Richland, WA (2008).

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