**U.S. Department of Energy**
P.O. Box 450, MSIN H6-60
Richland, Washington, 99352

MAR 29 2012

12-WTP-0120

The Honorable Peter S. Winokur
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, DC 20004-2901

TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD (DNFSB) RECOMMENDATION 2010-2 IMPLEMENTATION PLAN (IP) DELIVERABLE 5.5.3.5

Dear Mr. Chairman:

This letter provides you the deliverable responsive to Commitment 5.5.3.5 of the U.S. Department of Energy plan to address Waste Treatment and Immobilization Plant (WTP) Vessels Mixing Issues; IP for DNFSB 2010-2.

The attached report provides overall definition and qualification requirements of simulants for testing to establish Tank Farm performance capability. Test specific simulant qualification details are to be included in corresponding test plans, as qualification of simulant is integral with each individual test objective.

Large-Scale Integrated Mixing System Expert Review Team review comments and resolution are also included with this transmittal.

If you have any questions, please contact me at (509) 376-6727 or your staff may contact Ben Harp, WTP Start-up and Commissioning Integration Manager at (509) 376-1462.

Sincerely,

Dale E. Knutson

Dale E. Knutson, Federal Project Director
Waste Treatment and Immobilization Plant

WTP:WRW

Attachments (2)

cc w/attachs: See Page 2

WRPS CC Recv'd 03/29/2012

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F. M. Russo, BNI
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ATTACHMENT 1
to
12-WTP-0120

# TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD (DNFSB) RECOMMENDATION 2010-2 IMPLEMENTATION PLAN (IP) DELIVERABLE 5.5.3.5

## Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing, RPP-PLAN-51625, Rev. 0, dated 03/20/12

(Total Number of Pages: 78)

# Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing

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Key Words: Tank Farm Mixing and Sampling, Waste Feed Delivery, DNFSB Recommendation 2010-2

Abstract: This plan defines the objectives, basis, and selection of simulants to be used in tank farm performance testing. Specific formulations will be subsequently defined in test plans and finalized after the preparation and sampling of trial batches.

DATE:
Mar 22, 2012
HANFORD RELEASE

**APPROVED**
*By G.E. Bratton at 12:50 pm, Mar 21, 2012*

Release Approval

Date

Release Stamp

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LS 3/22/12 per KPL

RPP-PLAN- 51625
Rev. 0

# Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-08RV14800

washington river
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# EXECUTIVE SUMMARY

The primary purpose of the Tank Operations Contractor (TOC) Waste Feed Delivery (WFD) Mixing and Sampling Program is to mitigate the technical risks associated with the ability of the tank farms WFD systems to adequately mix and sample High Level Waste (HLW) feed to meet the Hanford Waste Treatment and Immobilization Plant (WTP) Waste Acceptance Criteria (WAC). The TOC has identified two critical risks TOC-12-65 and TOC-12-64 per TFC-PLN-39 (Risk Management Plan, Rev. G) which address emerging waste acceptance criteria and sampling method requirements. In addition, in November 2011, U.S. Department of Energy (DOE) issued the Implementation Plan (IP) for the Defense Nuclear Facility Safety Board Recommendation (DNFSB) 2010-2 (DOE Rec. 2010-2, Rev. 0, *Implementation Plan for Defense Nuclear Safety Board Recommendation 2010-2*) which addresses safety concerns associated with the ability of the WTP to mix, sample, and transfer fast settling particles.

This document defines the objectives, criteria, and selection of simulants to be used in tank farm performance testing. This document satisfies DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.5, "Definition and qualification of simulants for testing to establish tank farm performance capability."

ASTM C1750-11, *Standard Guide for Development, Verification, Validation, and Documentation of Simulated High-Level Tank Waste* has been used for guidance on simulant selection. The guidelines provide a simulant selection methodology that ensures simulant selection is relevant to the test objectives.

Coordination with WTP simulant selection is an important part of selecting simulants for tank farm performance testing and is discussed herein.

Three base simulants, representing Low, Typical, and High particle-size density distributions (PSDDs), are described, using gibbsite, zirconium oxide (ZrO), sand, and stainless steel (SS) as undissolved solids particulate materials. These simulants are shown in this document to be representative of the as-characterized Hanford waste for metrics of particle mobilization, suspension, settling, and pipeline transfer. Four spike particles, sand, SS, tungsten carbide grit, and tungsten grit are chosen to represent density ranges for limits of performance testing. Where sand and SS are used as spike particles, their sizes will be distinct from those in the base simulant to permit sieving as a means of analysis of the spike particles. Tungsten carbide and tungsten will be used to simulate high density particles in the waste.

Ranges for the suspending fluid density and viscosity, for Newtonian fluids, that represent the expected range of Hanford waste are specified. Candidate sodium salts, including sodium thiosulphate and sodium nitrate, which can be used individually or in combination, are identified. Other options for higher viscosities in the expected range are described. The base simulant particles and the spike particles will be added to these liquids.

The range of Bingham yield stress that represents the expected range of non-Newtonian yield stress Hanford slurries is identified. Slurries of kaolin clay or mixtures of kaolin and bentonite clays are two candidate materials identified for covering the expected range of Bingham yield stress. The spike particles will be added to these slurries without the base simulants.

This document provides the basic simulant components to be used for tank farm scaled testing. Individual test plans will specify the precise formulations (component combinations) that are appropriate for each specific test.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ASME | American Society of Mechanical Engineers |
| BNI | Bechtel National, Inc. |
| CFD | computational fluid dynamics |
| DBE | Design Basis Event |
| DOE | U.S. Department of Energy |
| DNFSB | Defense Nuclear Facilities Safety Board |
| DST | double-shell tank |
| DQO | data quality objective |
| ECR | effective cleaning radius |
| EFRT | External Flowsheet Review Team |
| FBRM | Focused Beam Reflective Measurement |
| HLW | high-level waste |
| HTWOS | Hanford Tank Waste Operations Simulator |
| ICD | Interface Control Document |
| IP | Implementation Plan |
| LAW | low-activity waste |
| LSIT | Large-Scale Integrated Testing |
| M3 | External Flowsheet Review Team Major Issue 3 |
| MJP | mixer jet pump |
| ORP | Office of River Protection |
| PJM | Pulsed Jet Mixer |
| PNNL | Pacific Northwest National Laboratory |
| PSD | particle size distribution |
| PSDD | particle size density distribution |
| QA | Quality Assurance |
| RPP | River Protection Project |
| RSD | Remote Sampler Demonstration |
| SRNL | Savannah River National Laboratory |
| SSMD | Small-Scale Mixing Demonstration |
| SST | single-shell tank |
| SS | Stainless Steel |
| TOC | Tank Operations Contract |
| TPA | Tri-Party Agreement |
| UDS | undissolved solids |
| V&V | Verifying and Validating |
| WAC | waste acceptance criteria |
| WRPS | Washington River Protection Solutions, LLC |
| WTP | Hanford Waste Treatment and Immobilization Plant |

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# UNITS

| | |
|---|---|
| ft | feet |
| in | inch |
| gpm | gallons per minute |
| µm | micron |
| cP | centipoise |
| m | meters |
| Pa | Pascal |
| rps | Revolutions per Second |
| s | seconds |

# 1.0 INTRODUCTION

The primary purpose of the Tank Operations Contractor (TOC) WFD Mixing and Sampling Program is to mitigate the technical risks associated with the ability of the tank farms feed delivery systems to adequately mix and sample High Level Waste (HLW) feed to meet the Hanford Waste Treatment and Immobilization Plant (WTP) Waste Acceptance Criteria (WAC). The TOC has identified two critical risks TOC-12-65 and TOC-12-64 per the TFC-PLN-39 (Risk Management Plan, Rev. G) which address emerging WAC and sampling method requirements. In addition, in November 2011, U.S. Department of Energy issued the Implementation Plan (IP) for the Defense Nuclear Facility Safety Board Recommendation (DNFSB) 2010-2 (DOE Rec. 2010-2, Rev. 0, *Implementation Plan for Defense Nuclear Safety Board Recommendation 2010-2*) which addresses safety concerns associated with the ability of the Waste Treatment and Immobilization Plant (WTP) to mix, sample, and transfer fast settling particles.

Report RPP-PLAN-41807, *Waste Feed Delivery Mixing and Sampling Program Plan and Test Requirements* defines the three test requirements as follows:

- Limits of performance - Determine the range of waste physical properties that can be mixed, sampled, and transported under varying modes of operation. Also included is the evaluation of the performance of the Isolok™[1] sampler and the PulseEcho critical velocity detection instrument. These tests will use both the remote sampler demonstration (RSD) platform and the small-scale mixing demonstration (SSMD) platform. In addition, a demonstration using a full-scale slurry transfer pump will be performed.
- Solids accumulation - Perform scaled testing to understand the behavior of remaining solids in a double-shell tank (DST) during multiple fill, mix, and transfer operations that are typical of the high-level waste (HLW) feed delivery mission. These tests include activities at the Savannah River National Laboratory (SRNL) mixing demonstration tank and the SSMD platform.
- Scaled performance - Demonstrate mixing, sampling, and transfer performance using a realistic simulant representing a broad spectrum of Hanford waste to meet WTP waste acceptance criteria Data Quality Objectives (DQO) sampling confidence requirements. These tests will use both SSMD and RSD platforms.

This represents a broadening of objectives from earlier SSMD testing. The simulants in this earlier testing were intended to simulate the particle size and density distribution of tank AY-102, the first tank waste to be delivered to WTP. Simulants will now need to be developed to represent the complete range of physical properties for a broader spectrum of Hanford waste, and to address specific testing requirements summarized above. Simulant selection will also need to be coordinated with WTP simulant selection as discussed in Section 4.0.

The selection of simulants described in this document support tank farm performance testing by the TOC to reduce risk associated with the ability of the TOC to deliver waste that meets the WTP waste acceptance criteria.

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[1] Isolok®™ is a registered trademark of Sentry Equipment Corp. of Oconomowoc, Wisconsin

## 2.0 BACKGROUND

The Office of River Protection (ORP) has defined the interface between the two prime River Protection Project (RPP) contractors, Bechtel National, Inc. (BNI) and Washington River Protection Solutions (WRPS), in a series of interface control documents (ICDs). The primary waste interface document is 24590-WTP-ICD-MG-01-019, *ICD-19-Interface Control Document for Waste Feed* (ICD-19). Continued updates to ICD-19 are anticipated as new information is generated. ICD-19 identifies a significant incompatibility between the TOC baseline equipment configuration and capabilities and the WTP baseline design and regulatory assumptions requirements for tank waste feed delivery to WTP. Section 2.3 of ICD-19 states that the TOC baseline sampling plans and capabilities are not currently compatible with WTP sample and analysis requirements as described in *Integrated Sampling and Analysis Requirements Document (ISARD)* (24590-WTP-PL-PR-04-0001), the *Initial Data Quality Objectives for WTP Feed Acceptance Criteria* (24590-WTP-RPT-MGT-11-014), and the *Regulatory Data Quality Optimization Report* (24590-WTP-RPT-MGT-04-001).

The original objective of the WFD Mixing and Sampling Program was to mitigate the technical risks associated with the ability of the tank farms WFD systems to mix and sample HLW feed adequately to meet the WTP waste acceptance criteria. These risks address emerging waste acceptance criteria and sampling method requirements. The focus of the original testing was to model the particle size and density distribution of tank AY-102, which is the first tank waste to be delivered to WTP. Testing also performed by WTP used a basis of simulant that is focused on the WTP design basis and is further discussed in Appendix A.

In November 2011, the U.S. Department of Energy (DOE) issued the Implementation Plan (IP) for the DNFSB 2010-2, DOE Rec. 2010-2, Rev. 0, *Implementation Plan for Defense Nuclear Safety Board Recommendation 2010-2*, which addresses safety concerns associated with the ability of the WTP to mix, sample, and transfer fast settling particles.

To ensure tank farms and WTP mixing and sampling systems are coordinated and compatible and that the uncertainties identified by testing to date are addressed, the TOC WFD Mixing and Sampling Program has been expanded to include the following.

- Define the DST mixing, sampling, and transfer system limits of performance with respect to the ability to transfer waste to the WTP with varying physical properties, solid particulates sizes and densities, and under various modes of operation (i.e., defining the expected range of particle size and density and consideration of data uncertainty).
- Define the propensity of solid particulates to build up, and the potential for concentration of fissile material over time in DSTs during the multiple fill, mix, and transfer operations expected to occur over the life of the mission.
- Define the ability of DST sampling system to collect representative slurry samples and in-line critical velocity measurements from a fully mixed waste feed staging tank.
- Develop sufficient data and methodology to confidently predict full-scale DST mixing, sampling, and transfer system performance; such that a gap analysis against WTP feed receipt system performance can be adequately completed.

# 3.0 PURPOSE AND SCOPE

## 3.1 PURPOSE

This document satisfies Defense Nuclear Facility Safety Board Recommendation (DNFSB) 2010-2 Sub-Recommendation 5, Commitment 5.5.3.5, "Definition and qualification of simulants for testing to establish tank farm performance capability," and will be used to direct simulant selection in all future related test work.

The primary purpose of the TOC WFD Mixing and Sampling Program is to mitigate the technical risks associated with the ability of the tank farms feed delivery systems to adequately mix and sample HLW feed to meet the WTP waste acceptance criteria (24590-WTP-RPT-MGT-11-014, *Initial Data Quality Objectives for WTP Feed Acceptance Criteria).* This document defines the objectives, criteria, and selection of simulants to be used in tank farm performance testing.

## 3.2 SCOPE

The scope of this document includes descriptions of:

- Simulants used for mixing and sampling studies to date,
- The objectives of the current and future selection of simulants to support planned testing,
- The criteria that are being applied to the selection of simulants, and identification of the parameters that the simulant needs to match,
- Available simulant material, and
- Specific components, including supernatant, particulate, and spike components that will be used to develop the needed simulants for the three types of testing described in Section 1.0

Specific formulations, based on the components identified herein, will be subsequently defined in test plans and finalized after the preparation and sampling of trial batches. Coordination with the WTP mixing program will occur as their simulant needs are further identified. Currently WTP simulant requirements stem from the verification and validation testing being performed on the computational fluid dynamics (CFD) program used to model the mixing in the vessels. The WTP and TOC mixing programs are presently addressing different targets (see Section 4.0), which do not require identical simulants. As the programs progress, they will develop a common base simulant, modified as needed, to meet specific testing requirements.

## 3.3 SIMULANT SELECTION AND PREPARATION PROCESS

ASTM C1750-11, *Standard Guide for Development, Verification, Validation, and Documentation of Simulated High-Level Tank Waste* has been used for guidance on the simulant selection described in this document. The guidelines provide a simulant selection methodology that ensures simulant selection is relevant to the test objectives.

Figure 3-1, taken from ASTM C1750-11, illustrates an overview of the simulant selection and preparation process.

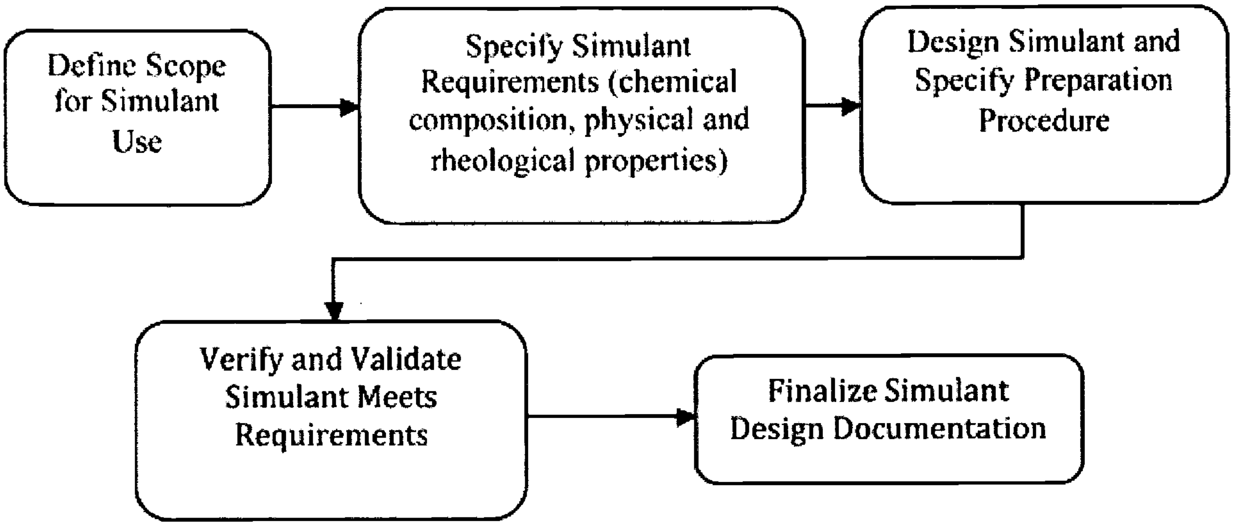

**Figure 3-1, Simulant Development, Verification, Validation, and Documentation Flow**

This document is intended to address the first two steps shown above plus conceptually designing the needed simulants. Preparation procedures and the development of specific formulations will be addressed by specific test plans. The specific test plans may consider other factors, such as color/visual distinction, instrument detection capability, and hardness.

## 3.4 SIMULANT QUALIFICATION

Qualification of simulant is integral with each test plan and can be dependent on the specific test objectives, equipment set-up, and analytical needs of each test. The test plans will identify the appropriate Quality Assurance (QA) requirements and the simulant qualification activities necessary to verify and validate that the specific simulant formulation meets the needs of the test and complies with the requirements of the simulant definition document. Qualification of simulant for enhanced quality testing will include, as a minimum, appropriate QA level documentation that verifies chemical composition, identifies important physical characteristics (e.g. particle size distribution), and documents important rheological properties as necessary to support the specific test objectives. The qualification documentation may come directly from the supplier or a third party analytical laboratory and must have a QA pedigree commensurate with the specific test requirements and objectives.

## 4.0 COORDINATION WITH WTP SIMULANT SELECTION

Coordination with WTP simulant selection is an important part of selecting simulants for tank farm performance testing. In comparing simulants, two factors are important to consider.

- Simulants are selected to meet specific test objectives, which differ in some cases between tank farm performance testing and WTP testing. As the programs progress, they will converge on a common base simulant spiked to address specific test objectives.
- It is recognized that the WTP design basis simulant based on RPP-9805, *Values of Particle Size, Particle Density, and Slurry Viscosity to Use in Waste Feed Delivery Transfer System Analysis* does not meet the definition of "bounding" for Hanford waste. More challenging simulants will be used for tank farm performance testing.

Differences between tank farm performance testing and WTP testing have been identified. For example, the near-term schedules have the TOC developing a simulant to determine the upper end of particle size and density which could transported to WTP in response to the Implementation Plan (IP) for DNFSB recommendation 2010-2. WTP is planning to initiate similar Pulsed Jet Mixer (PJM) mixing and transfer system performance limits tests in 2013 and the TOC simulant is not expected to be appropriate for that testing scope (e.g., it will be possible to transport large particles to WTP with higher liquid phase viscosity, but it is not currently known whether a high or low viscosity case is more limiting for the PJM systems.) Similarly, the current simulant development activities at WTP are in response to the FLUENT computational fluid dynamic model verification and validation effort described in the 2010-2 IP. This simulant will be based on the Newtonian tank design basis particle distribution at the WTP. There is no existing scope where it would be reasonable for the TOC to test with this simulant as they have already demonstrated that they can transport large stainless steel particles. As another example, the WTP will be developing simulants that represent the intermediate or product streams of various WTP treatment processes that occur after the waste has been delivered to from the TOC to the WTP. The TOC will not develop simulants for these waste streams.

For the limits of performance testing, it is important to coordinate simulant selection for the DST and PJM systems to allow for assessment of the performance gaps between the systems. The gaps determined from TOC and WTP testing results will be identified and evaluated in the future (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.9, scheduled 8/31/2014). A key aspect of defining simulant requirements and subsequent testing is recognizing that changing the simulant properties may change the performance of the DST and PJM systems by different amounts. Accordingly, it is important to select simulants that span the full and representative range of Hanford waste properties to allow the gap between DST and PJM performance to be determined.

Examples where the same simulant might be employed by both TOC and WTP are simulants used for mixing scale-up evaluations (depending on the specific scope developed for these tests) and the final waste simulant developed after the mixing and transfer system capabilities have been determined at both sites and the methodology developed to close any gap demonstrated by these test campaigns has been determined. This final simulant could be used to verify that wastes not meeting the WTP waste acceptance criteria can be detected at WRPS and that the WTP systems are capable of mixing and transporting this bounding waste slurry.

Coordination of simulant selection for the TOC and WTP has been initiated and is being managed under the One System concept where the TOC and WTP work scope will be coordinated and managed under one management organization (RPP-54471, Rev. 0 and 24590-WTP-CH-MGT-11-008, *2020 Vision One System IPT Charter*). Simulant basis and planning documents, including this document, are now routinely being reviewed by both teams. However, the testing conducted by the two programs is performed with simulants designed to answer site-specific questions.

## 5.0 SIMULANT SELECTION OBJECTIVES

The shift in testing philosophy away from demonstrating adequate performance in a conservative simulant (e.g. non-cohesive particulates in water) to a testing philosophy that defines limits of performance to support a gap analysis also requires a shift in simulant philosophy.

Successful completion of the TOC WFD Mixing and Sampling Program depends upon the selection of appropriately complex simulants that are reflective of the full range of expected tank conditions, coordinated with WTP simulant selection, and supported by accurate analytical techniques to characterize the material of interest. Testing will use more complex simulants that are more representative of all Hanford tank waste.

The following specific objectives are associated with the three types of testing identified by RPP-PLAN-41807.

Scaled Performance: Scaled Performance testing will demonstrate mixing, sampling, and transfer performance using a realistic simulant representing a broad spectrum of Hanford waste to meet WTP waste acceptance criteria Data Quality Objectives (DQO) sampling confidence requirements. This simulant will be considered a "base simulant" for other testing and will cover the bounding physical properties important for the waste acceptance criteria.

Limits of Performance: Limits of performance testing will test progressively larger particle sizes and densities to identify the largest size and density particles that can be mixed and transferred from the SSMD transfer system. Limits of performance related to sampling, which is expected to be different from the mixing and transfer limits, will also be tested. The Isolok® needle size limits the size of particles that can be sampled. Therefore, the limit of solids that can be sampled may be smaller than the solids that can be transferred. Results from planned early tests will be used to understand the significance of this gap.

As discussed in Section 6.0, the supernatant density and viscosity, along with particulate size and density, are important to determining limits of performance. The base simulant with spikes to challenge the limits of performance will be used to determine the range of waste properties that can be retrieved, sampled, and transferred.

Solids Accumulation: Solids accumulation testing will focus on accumulation of total solids over time and the propensity for simulated, fissile material, localized concentration to change over time. The simulant will be the base simulant spiked to model the presence of fissile material in a broad spectrum of Hanford waste.

The requirements for the simulants are intended to represent the range of Hanford waste properties that are pertinent to the DST mixing, sampling, and batch transfer system behavior. They are also pertinent to the PJM system behavior in the WTP receipt vessel. A number of previous studies have shown that the following simulant parameters are important for the DST system behavior:

- Distribution of particle size,
- Distribution of particle densities,
- Critical shear stress for erosion of a settled layer of non-cohesive particles,
- Suspending fluid density,
- Suspending fluid viscosity (for Newtonian liquids),

- Suspending fluid rheology (such as Bingham yield stress and consistency for non-Newtonian slurries), and
- Slurry concentration.

See for example,

- RPP-49740, *Small Scale Mixing Demonstration Sampling and Batch Transfer Results Report* 2011;
- RPP-47577, *Small Scale Mixing Demonstration Initial Results Report*, 2011;
- SRNL-STI-2011-00278; *Demonstration of Mixing and Transferring Settling Cohesive Slurry Simulants in Tank AY-102*;
- SRNL-STI-2010-00521, *Demonstration of Mixer Jet Pump Rotational Sensitivity on Mixing and Transfers of the AY-102 Tank*;
- SRNL-STI-2009-00717, *Demonstration of Simulated Waste Transfers from Tank AY-102 to the Hanford Waste Treatment Facility;* and
- SRNL-STI-2009-00326, *Demonstration of Internal Structures Impacts on Double Shell Tank Mixing Effectiveness.*

The critical shear stress for erosion of a settled layer of non-cohesive particles is an important parameter. There are no direct measurements of Hanford waste for this parameter and its range of behavior can be estimated from particle size and density information. The parameters listed above, with the exception of slurry concentration, may also be considered important to the PJM system performance in the WTP.[2] The range of Hanford waste properties for these parameters and the target ranges defining the simulant requirements are given in Section 6.0, with the exception of the slurry concentration. The slurry concentration is an important parameter, and an appropriate range will need to be included in defining the simulant requirements, but the range of this parameter is established by waste processing plans. Accordingly, an evaluation of Hanford waste data for slurry concentration is not needed in Section 6.0.

There are additional parameters that could play roles in the three types of testing defined above for the DST mixing, sampling, and batch transfer system, but they are not currently being evaluated as part of the simulant requirements.

Particle shape is not currently considered important to simulant definition, but other testing may show the need to consider it.

The presence of a strong cohesive layer, that is only partially mobilized, in a DST will certainly influence the fraction of the settled layer that can be suspended and transferred. However, the presence of an un-mobilized portion of the layer primarily causes a reduction in the amount of

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[2] In a draft document entitled "Hanford Waste Treatment Plant Pretreatment Mixing Large Scale Integrated Testing: Properties that Matter for Design Basis Testing" by Koopman, Martino, and Poirier of SRNL, these properties are listed as the most important for PJM behavior. This document when issued will meet commitment 5.2.3.1 of the implementation plan (DNFSB Rec. 2010-2). The list of most important properties in this document includes waste adhesiveness because it may play a role in heel management, and perhaps other aspects of PJM performance, in WTP vessels. Waste adhesiveness likely influences the shear strength and critical shear stress for erosion of settled layers in at DST, and this is considered a secondary parameter for DST system performance as discussed below in this section.

suspended solid particles, and thus should not directly influence the behavior of the portion of the waste that was suspended, except indirectly through changes in the concentration of the suspended particles. If an initial strong cohesive layer is sufficiently deep and only partially mobilized, the layer may deflect the jets and thus affect the behavior of the suspended particles. The current simulant requirements are not addressing deep layers that are only partially mobilized, but this can be included in the future if the presence of deep and strong cohesive layers is considered important.

Time dependent rheological properties are known to affect the mixing behavior of turbulent jets (PNWD-3551, 2005, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*). There is no specific requirement that will be defined for the time-dependent rheological behavior, but non-Newtonian simulants should be used that represent waste slurries (simulants with slurries of cohesive particles are appropriate). Mixing tests completed to date (RPP-50557) have shown sufficient mobilization and mixing within the scaled DST systems to allow evaluation of sampling and mixing performance without regard to the amount of solids remaining on the tank bottom. If future testing with non-Newtonian simulants results in noticeably inadequate mobilization or mixing (e.g. the majority of solids remain on the tank bottom or are not distributed throughout the tank volume), then the assumption regarding the need to consider time-dependent rheological behavior will be re-addressed.

While the shear strength, critical shear stress for erosion, and time-dependent behaviors are not being specifically included in the simulant requirements for testing the DST system, these parameters may be more important in the feed receipt vessel at the WTP.

# 6.0 SIMULANT SELECTION BASIS

As described in Section 5.0, the testing philosophy includes determining the limits of performance for DST mixing, transfer, and sampling and to coordinate this testing and simulant selections with the related effort to determine the performance of PJM mixed vessels in the WTP. The focus of this TOC testing is on transport of particulates with an emphasis on fast-settling particulates, as they are mixed in a DST with rotating centrifugal pumps and transferred out of the tank via a submerged centrifugal pump. Successful completion of the TOC WFD Mixing and Sampling Program depends upon selecting appropriately complex simulants that reflect the full range of expected tank conditions, coordinating the selection of these simulants with the simulants needed to evaluate PJM performance, and selecting simulants where accurate analytical techniques can be used to characterize the material of interest.

A key aspect of the simulant selection criteria is recognizing that changing the simulant properties may change the mixing performance of the DST and PJM systems by different amounts. Accordingly, it is important to span a full and representative range of simulant properties to allow the gap between DST and PJM performance to be determined for the full range of expected waste properties to support (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.9.

Prior testing focused on demonstrating adequate DST mixing and sampling system performance in a conservative simulant. The conservative simulants in this testing were non-cohesive particles in water. These simulants gave conservative behavior for these prior tests because it was shown that a smaller amount of these particles were removed in batch transfer testing using water compared to the amount of the same particles removed using more viscous Newtonian liquids or non-Newtonian slurries with a yield stress (SRNL-STI-2011-00278; *Demonstration of Mixing and Transferring Settling Cohesive Slurry Simulants in Tank AY-102*). To address the limits of performance of the DST system and to allow a gap analysis with PJM limits of performance, simulants are needed with higher liquid density and viscosity relative to water. Simulants with non-Newtonian waste rheology representing cohesive solids are also needed.

Previous studies have demonstrated that the DST mixing performance depends, in part, on the distribution of particle sizes and densities. It is expected that the limits of performance for transferring any specific, rapidly settling particle will depend on overall size and density distribution of the particulate in the simulant. In previous testing, the solid particulate used in the simulant was representative of a typical waste (PNNL-20637, *Comparison of Waste Feed Delivery Small Scale Mixing Demonstration Simulant to Hanford Waste*). To fully represent the range of Hanford waste, simulants that are representative of the most challenging and the least challenging wastes, as described in PNNL-20637, will be needed to determine the limits of performance for transferring rapidly settling particles in the full range of Hanford waste.

The subsections below summarize data for Hanford waste liquid density and viscosity, slurry rheology, and solid particulate size and density distributions. These sections discuss the influence of these waste parameters on system performance.

## 6.1 LIQUID DENSITY AND RHEOLOGY

As concluded in PNNL-20637, previous testing has shown that the batch transfer of settling SS particles in a slurry of dense salt solution and fine gibbsite particles was more effective than batch transfers of identical SS particles when the suspending fluid was water or glycerol/water solutions. Analysis, via a simple model including the suspending-fluid density and viscosity, gives the correct qualitative effect of the effective cleaning radius (ECR). The ECR is the radius within which particulate is removed from the tank floor when jets are directed at it. It increases with increasing suspending-fluid density and decreases with increasing viscosity, but the analysis does not give good quantitative predictions based on the limited data.

A summary of available data shows that a change in fluid properties, such as increased viscosity that decreases the ECR, may still increase the amount of settling particles transferred. The batch transfer data clearly show that transferring settling SS particles in water is more challenging than in the gibbsite/salt solution slurry or the glycerol/water solution. In both cases the predicted ECR is higher in water, but the increased density and/or viscosity of the other fluids improves the overall suspension and transfer of particles. Thus, higher liquid density and viscosity is expected to increase the performance of the WFD system for transferring rapidly settling particles to the WTP.

The summary of the liquid density for all 177 of the Hanford tanks provided in PNNL-20646, *Hanford Waste Physical and Rheological Properties: Data and Gaps*, is combined with the liquid volume of the respective tanks from that same report to provide the cumulative volume distribution of Hanford liquid waste density as shown in Figure 6-1. The Hanford liquid waste density ranges from essentially water at 1 g/mL to concentrated salt solutions of 1.57 g/mL. The general waste types of sludge, saltcake, and mix (combination of sludge and saltcake) identified in Figure 6-1 are classified as such based on the relative concentrations of soluble and insoluble undissolved solids (UDS). As specified in RPP-10006, Rev. 8, *Methodology and Calculations for the Assignment of Waste Groups for the Large Underground Waste Storage Tanks at the Hanford Site*, a tank is classified as sludge if at least 75 volume percent (vol%) is sludge solids (insoluble UDS), and similarly, saltcake if it is at least 75 vol% saltcake/salt slurry solids (soluble UDS). A mix tank does not meet either of these criteria.

The results of the entire data set liquid viscosity model accounting for both liquid density and temperature developed in PNNL-20646 are shown in Figure 6-2 over the range of liquid density provided in Figure 6-1. The PNNL-20646 model is based on liquid rheology data for 11 of the 177 large underground storage tanks. The solid lines of Figure 6-2 indicate the predicted liquid viscosity, and the dashed lines indicate the prediction limits.

From Figure 6-1 and Figure 6-2, the liquid density and viscosity of Hanford waste can significantly exceed those of water. If, for example, the median density from Figure 6-1 is considered, 1.4 g/mL, the viscosity at 20°C can be as high as 20 cP. Therefore, development of the liquid phase of a simulant that is conservative for limits of performance of the WFD system to the WTP must consider increased liquid density and viscosity.

The range of liquid densities that are expected for each transfer batch of waste feed is not quite as broad as the range of liquid densities for Hanford waste shown in Figure 6-1 due to blending. This range of expected densities for transfer batches can be determined using available information from the Hanford Tank Waste Operations Simulator (HTWOS) model output. The HTWOS model output files for the latest revision of ORP-11242, *River Protection Program Integrated System Plan*, are listed in Table 3-3 of RPP-RPT-48681, *Hanford Tank Waste Operations Simulator Model Data Package for the River Protection Project System Plan Rev.6 Cases*. The data providing the input for the calculation of the liquid density for the 643 transfer batches from the TOC to the WTP are included in SVF-2116, Rev.1. The input data was filtered to exclude low-activity waste (LAW) output and truncated to exclude batch transfers after 2040 to exclude a series of high predicted density transfers (1.6 g/ml) that occur late in the transfer mission. For all of the predicted transfers, the density varies from 1.1 to 1.37 g/mL. These density values are also shown in Table 6-1, together with the range of liquid viscosities for these densities from Figure 6-2. This range is appropriate as the requirement for the simulant density range and viscosity range.

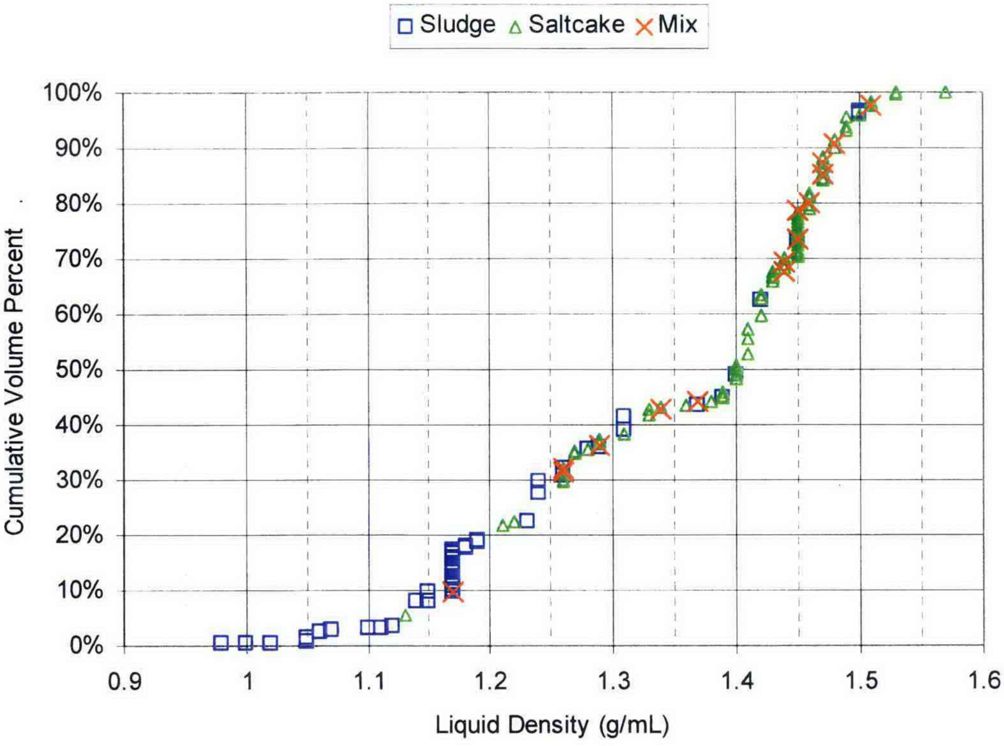

**Figure 6-1. Cumulative Volume Distribution of Hanford Waste Liquid Density**

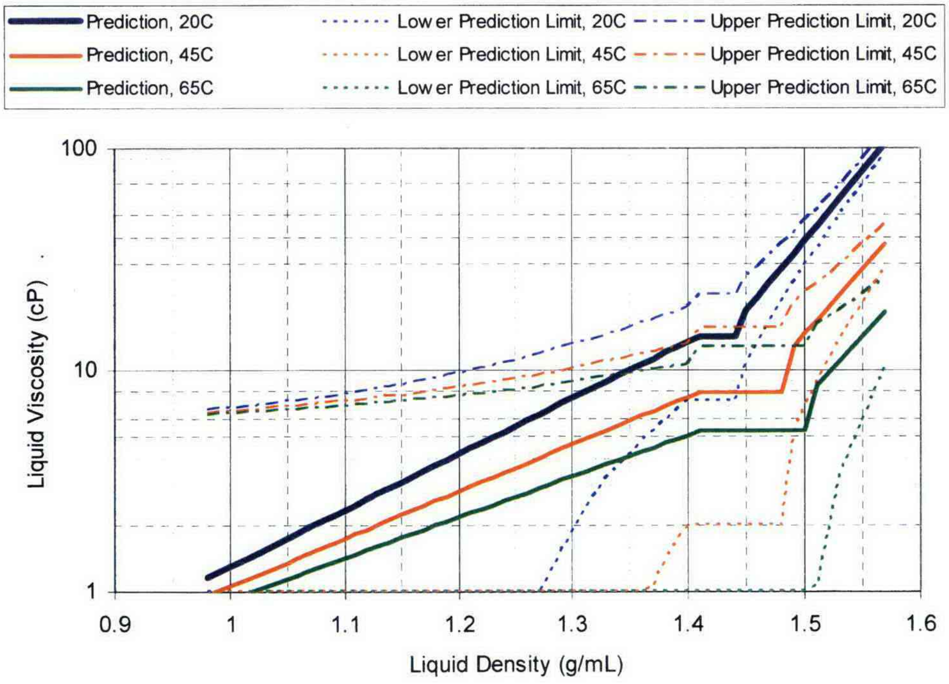

**Figure 6-2. Calculated Hanford Waste Liquid Viscosity as a Function of Liquid Density and Temperature**

**Table 6-1. Range of Batch Transfer Liquid Densities and Viscosities as Predicted from HTWOS**

| | Density (g/mL) | Low Viscosity[1] (cP) | High Viscosity[1] (cP) |
|---|---|---|---|
| Low Density (from HTWOS[3]) | 1.1 | 1 | 8 |
| High Density (from HTWOS[3]) | 1.37 | 1 | 15 |

1- Viscosity values from Figure 6-2 for the specified density

2- Determined from HTWOS model output files in RPP-RPT-48681

## 6.2 SLURRY RHEOLOGY

The evaluation in PNNL-19245, *The Role of Cohesive Particle Interactions on Solids Uniformity and Mobilization During Jet Mixing: Testing Recommendations*, showed that cohesive particle interaction will have multiple effects on solids uniformity and mobilization during jet mixing through a number of different mechanisms. Hence it was concluded that testing with only non-cohesive particles will create technical uncertainty in meeting the objectives of the WFD Mixing and Sampling Program.

Scoping tests to determine the magnitude of the impact caused by cohesive particle interactions, and hence non-Newtonian fluid rheology, on mixing were subsequently performed and are reported in SRNL-STI-2011-00278. These tests demonstrated that the batch transfer of settling particles in water transferred a lower quantity of solids when compared to similar tests in a non-Newtonian yield stress fluid. These tests specifically demonstrated that increasing the yield stress resulted in an increased transfer of rapidly settling particles. Thus, the limits of performance for transferring rapidly settling particles is expected to increase with an increase in the yield stress of the fluid.

Hanford slurries can be characterized rheologically as non-Newtonian, Bingham plastic fluids. The Bingham rheological model parameters consistency (viscosity) and yield stress for waste type samples from PNNL-20646 are shown as functions of UDS concentration and temperature in the following figures. For the current work, only those tanks and waste types that are primarily sludge are considered because retrieval activities can dissolve the soluble waste. The general waste types of sludge, saltcake, and mix are classified as described in Section 6.1.

In Figure 6-3 through Figure 6-8, Bingham yield stress values are shown for sludge waste slurries at temperatures ranging from 20° to 35° C, 40° to 65° C, and 70° to 95° C. Corresponding plots for the Bingham viscosity are provided in Appendix B. For Figure 6-3 through Figure 6-5, the symbol colors represent the percentage of the characterized UDS volume that data point represents at any temperature, concentration, or waste type. UDS volumes are taken from PNNL-20646. For example, in Figure 6-3, for a UDS mass fraction of approximately 0.01 to 0.1, the Bingham yield stress can approximately range from 0.1 to 40 Pascal (Pa). However, the latter result is for wastes that comprise less than 1% of the characterized volume. For samples that comprise 1% to 5% of the characterized UDS volume, the Bingham yield stress at the same UDS mass fraction range reduces to approximately 0.1 to 4 Pa. This case may represent a more likely Bingham yield stress range based on waste volume. The Bingham viscosity results of Appendix B can be interpreted similarly.

In Figure 6-6, the volume-based probability of the sludge waste's Bingham parameters at 20° - 35° C is considered further. For the ranges of UDS mass fractions specified in the figure legends, the data are volume weighted by their respective UDS volume in the particular data set. For repeat tank/waste groups, the volume is weighted by the number of repeats. The data sets start at higher than zero probability due to Bingham yield stress results less than 0.1. Continuing with the prior example for a UDS mass fraction of approximately 0.01 to 0.1, the 100th percentile approximately 40 Pa yield stress is clearly shown as approximately 2% less likely than the 98th percentile result of nominally 6.5 Pa. The median yield stress by UDS volume at this concentration range is shown at approximately 0.2 Pa. Following Figure 6-6, Bingham yield stress results are shown for slurries at temperatures ranging from 40° to 65° C in Figure 6-7 and for 70° to 95° C in Figure 6-8. The volume-based probability of the sludge waste's Bingham viscosity is provided in Appendix B for the three temperature ranges.

As described in PNNL-20646 for individual wastes, the Bingham viscosity in general decreases as expected with increasing temperature while the Bingham yield stress response to temperature varies.

Increasing Bingham yield stress with increased UDS concentration is shown for individual wastes in PNNL-20646. However, only 26 vol% out of the represented 51 vol% Hanford UDS inventory (includes saltcake waste) has sufficient data for this functionality to be evaluated. Within this limited data set, there are anomalies to the expected trend due to waste solubilities and interaction with diluting fluids. Thus the lack of indication through the preceding figures for the expected trend of increasing rheology with increasing UDS concentration can be attributed to the varied waste and sample conditions represented.

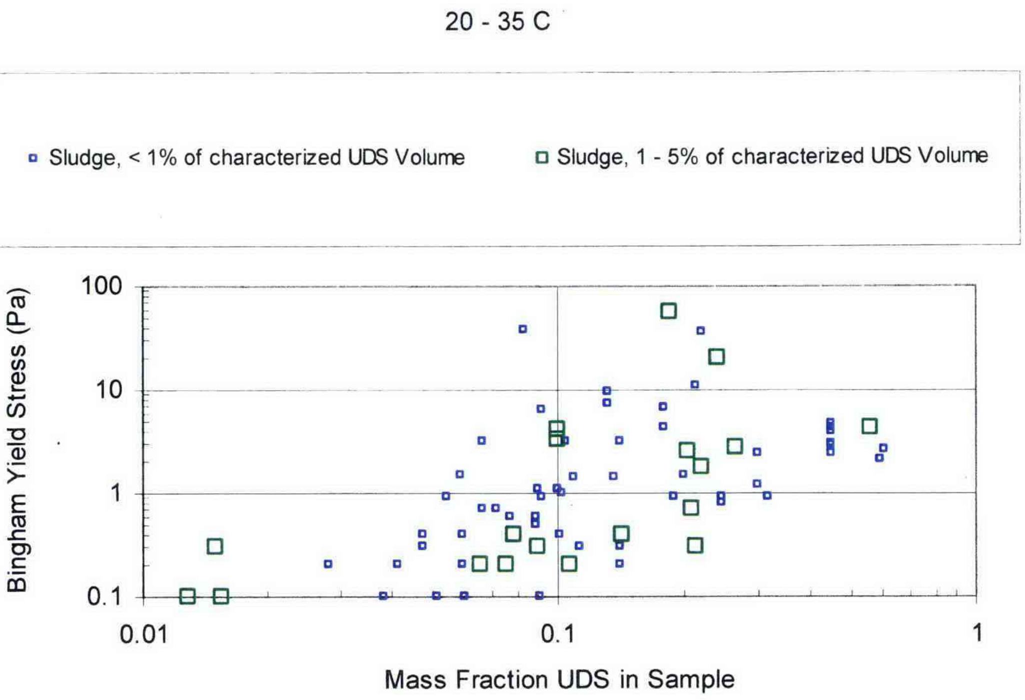

**Figure 6-3. Hanford Waste Slurry Bingham Yield Stress as a Function of Mass Fraction UDS, 20 - 35 C.**

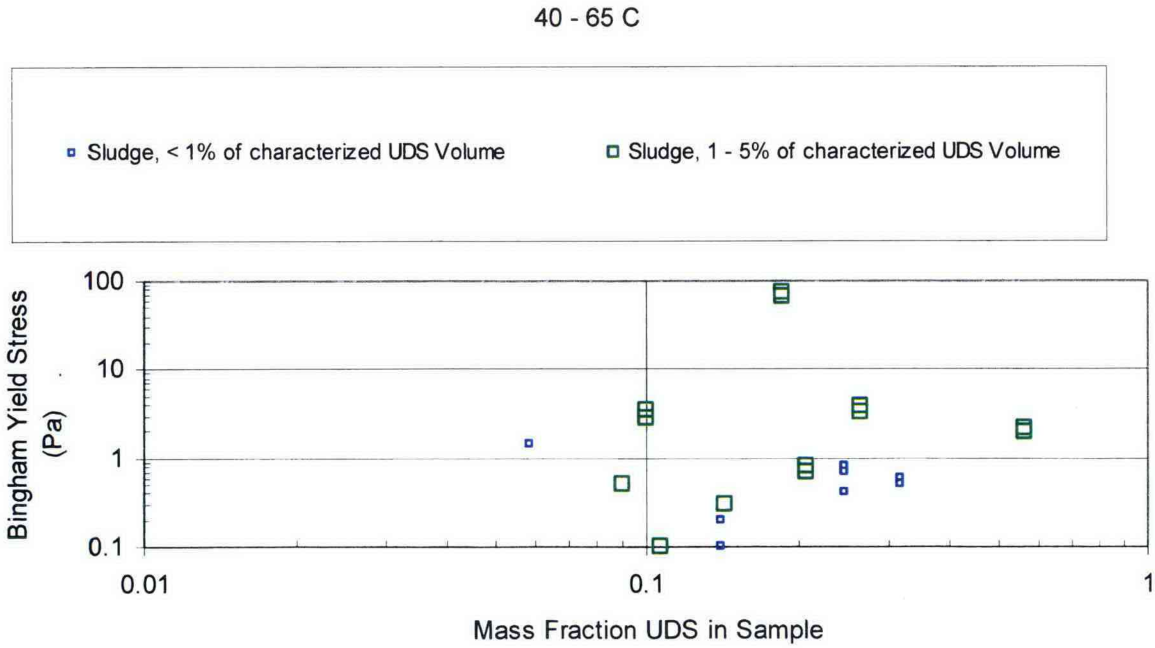

**Figure 6-4. Hanford Waste Slurry Bingham Yield Stress as a Function of Mass Fraction UDS, 40 - 65 C.**

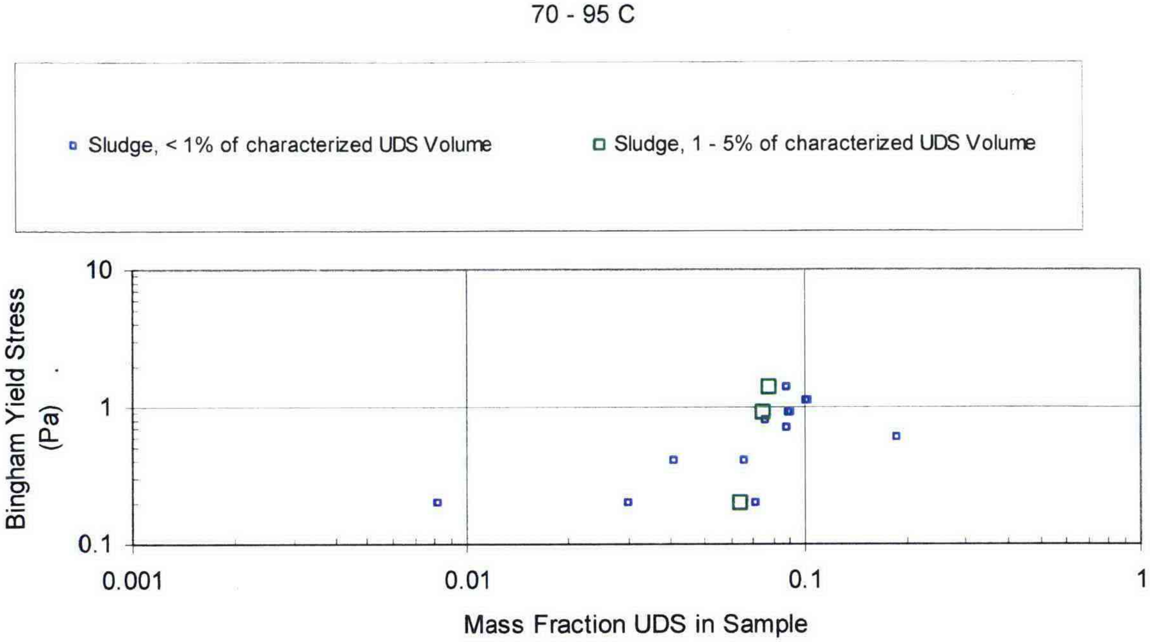

Figure 6-5. Hanford Waste Slurry Bingham Yield Stress as a Function of Mass Fraction UDS, 70 - 95 C.

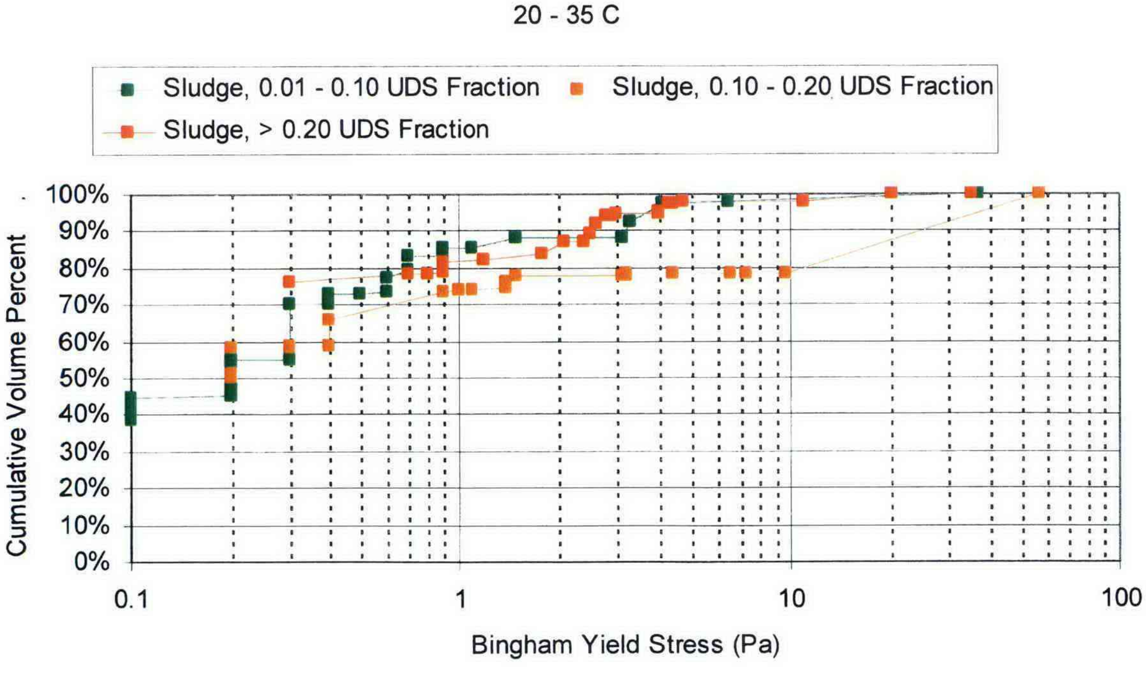

Figure 6-6. Hanford Waste Sludge Slurry Bingham Yield Stress, 20 - 35 C.

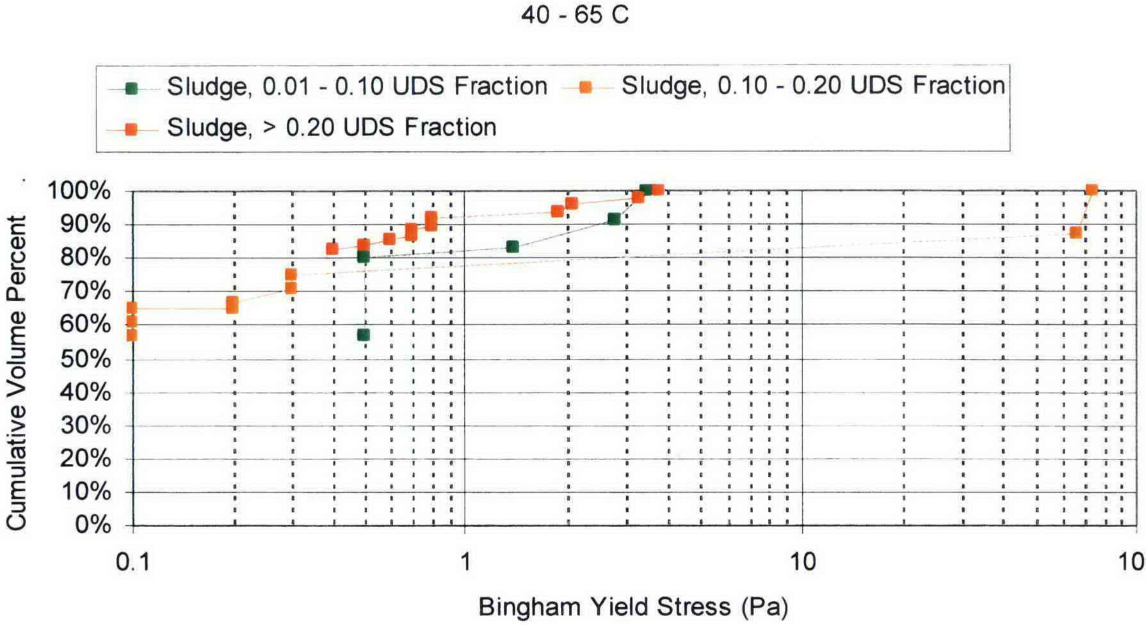

Figure 6-7. Hanford Waste Sludge Slurry Bingham Yield Stress, 40 - 65 C.

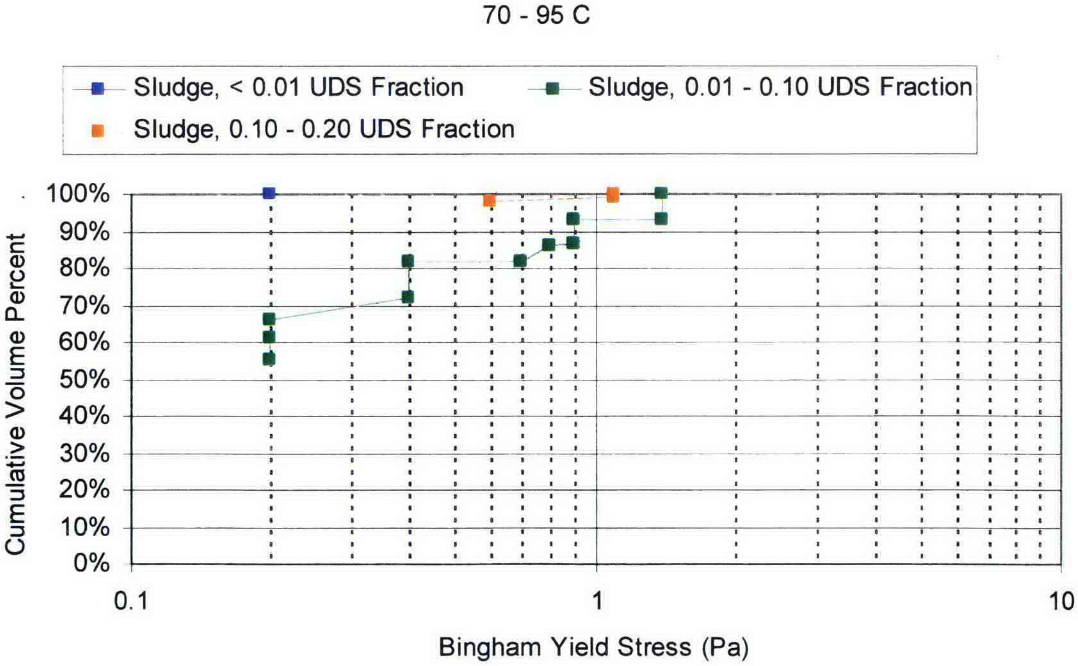

Figure 6-8. Hanford Waste Sludge Slurry Bingham Yield Stress, 70 - 95 C.

The batch transfer results of reference document SRNL-STI-2011-00278, Rev. 0, that show increased transfer of settling solids with increasing rheology and the effect of cohesive particle interaction as evidenced by the likely potential for non-Newtonian yield stress fluids in Hanford waste. Therefore, the development of a simulant that is conservative for limits of performance of the WFD system to the WTP should consider cohesive effects.

Based on the available data, from the preceding figures which represents a limited fraction of the Hanford UDS inventory, the highest Bingham yield stress for the 95th percentile by volume is 70 Pa, and 72 Pa is the overall maximum. Both these values are possible upper targets for simulants. However, ICD-19 (24590-WTP-ICD-MG-01-019, 2011) currently places an upper limit of 1 Pa for the Bingham yield stress for waste delivered to the WTP, though this value is noted as still under investigation and may change. If retrieved slurries exceed the 1 Pa Bingham yield stress limit, in-line dilution could be used as needed to reduce the yield stress of the retrieved waste to meet the specified limit of waste feed to the WTP. Specific plans for waste retrieval, blending, and dilution to meet a specific limit on the yield stress for delivered waste are not yet available, but it is expected that waste will be blended and staged in a manner that avoids the retrieval of waste with very high yield stresses that will require a large amount of transfer line inlet dilution.

With the current level of WFD planning and uncertainty in the current 1 Pa limit in ICD-19, the upper Bingham yield stress target for simulant selection and limits of performance testing needs to be determined, in part, by judgment. It is deemed unlikely that the upper limit for the Bingham yield stress for waste delivered to the WTP will be elevated substantially above the current 1 Pa limit. Hence, upper limit Bingham yield stress values as high as the maximum value of 72 Pa would be unexpected. PNNL-17707 evaluated the ability of PJMs in the WTP receipt vessel to fully mobilize the vessel contents for slurries with a range of Bingham yield stresses based on prior scaled testing results and turbulent jet models. The PNNL-17707 results showed that full-tank mobilization can be achieved for slurries with Bingham yield stress up to 11 Pa.

Previous scoping tests for the impact of increasing Bingham yield stress on the transfer of large dense particles in DSTs, SRNL-STI-2011-00278, targeted a Bingham yield stress range of 0 to 10 Pa. This range was selected from PNNL-119245 because it encompassed the majority of sludge waste for UDS concentrations up to approximately 16 wt%. Higher Bingham yield stress values have been measured for a fraction of the waste as shown in this section from the updated data of PNNL-20646, and may also occur with stratified mixing (i.e. higher UDS loading at the bottom of the tank) or increased tank overall UDS loading. In addition, the DST mixer pump specification (RPP-SPEC-43262, *Procurement Specification for Hanford Double-Shell Tank Submersible Mixer Pumps,*) gives a range for the mobilized waste yield stress (Pa) range of "0 to 16 (90th percentile)". The upper value of 16 Pa is for mobilized waste, so that the pump can likely process higher yield stress slurries.

Although there are wastes with higher Bingham yield stress values, and the DST mixer pumps should be able to process higher yield stress slurries, 10 Pa is suggested as a plausible upper bound for the current simulant selection and testing based on the potential for an increase in the current ICD-19 limit of 1 Pa. It is acknowledged that this suggested 10 Pa limit does not bound actual waste data, and thus there is potential that a higher Bingham yield stress slurry could transfer larger more dense particles to the WTP via the DST feed system. This potential is based on the previous testing (SRNL-STI-2011-00278) that demonstrated a higher fraction of SS (median particle size by volume ~ 100 μm, 8 g/mL) were transferred with increasing Bingham yield stress for values up to 7 Pa (maximum tested value). The trend of the SRNL-STI-2011-00278 data indicates that an even higher yield stress would be more capable of transferring large/dense particulate. Accordingly, 10 Pa may not be the correct upper limit to identify the maximum limiting particle that could be transferred from a DST, but 10 Pa is likely a reasonable upper limit for the Bingham yield stress for waste delivered to the WTP. Should the feed limit to the WTP be set higher than 10 Pa, then the Bingham yield stress limit for simulant selection will require reevaluation. The preceding discussion does not consider transfer line capabilities.

As shown in Table 6-2, there are limited fractions of waste by volume that exceed the suggested 10 Pa Bingham yield stress limit. The values listed in Table 6-2 are approximated via linear interpolation for 10 Pa from Figure 6-6 through Figure 6-8. Specific rheological simulants to span the range of up to 10 Pa will be defined in the test plan (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.6), and should have a Bingham viscosity indicated from the waste data range (Appendix B) as appropriate for the target yield stress.

**Table 6-2. Percentage of Characterized Waste with a Bingham Yield Stress Less than 10 Pa**

| **Waste Temperature (°C)** | **Percentage of Characterized Waste with a Bingham Yield Stress Less than 10 Pa [Mass fraction UDS]** | | |
|---|---|---|---|
| | **[0.01 - 0.10]** | **[0.10 - 0.20]** | **[> 0.20]** |
| 20 - 35 | 98 | 79 | 98 |
| 40 - 65 | 100 | 82 | 100 |
| 70 - 95 | 100 | 100 | 100 |

## 6.3 PARTICLE SIZE AND DENSITY DISTRIBUTION

Previous studies have demonstrated that the DST mixing performance depends on the distribution of particles sizes and densities and it is expected that the limits of performance for transferring any specific, rapidly settling particle will depend on overall size and density distribution of the particulate in the simulant. For slurries that have particle sizes and densities that vary, a useful method to compare different slurries is to calculate a single property that combines the effect of size and density. For the PNNL-20637 comparison of the SSMD Complex Simulant (see Appendix A) used for the scaled testing of RPP-49740 to Hanford sludge waste, a set of metrics addressing the different functionalities of particle size and density for mobilization, suspension, settling, and pipeline transfer was considered. For example, specific property that is pertinent for DST mixing is the settling velocity of the particles, which is directly related to the Archimedes (Ar) number. The Archimedes number and a correlation for the settling velocity used in PNNL-20637 are given below.

$$U_T = \frac{\nu}{d}\left[\sqrt{15+\sqrt{\frac{Ar}{0.3}}}-\sqrt{15}\right]^2 \qquad (6\text{-}1)$$

where $U_T$ is the settling velocity and Ar is the Archimedes number defined by:

$$\mathrm{Ar} = \frac{\left(\frac{\rho_S}{\rho_L} - 1\right) g d^3}{\nu^2} \tag{6-2}$$

and d is the particle diameter, $\rho_S$ is the UDS density, $\rho_L$ is the liquid density $\nu$ is the kinematic viscosity of the liquid, and g is the gravitational constant.

Figure 6-9 shows a cumulative distribution of Archimedes numbers for wastes from a number of tanks. The settling velocities were determined using particle size density distribution (PSDD) data as described in PNNL-20637. Figure 6-15 also shows the cumulative distribution of Archimedes numbers for the previously used SSMD Complex Simulant, which is the gold colored line and symbols roughly in the middle of the other distributions. The Archimedes number, and thus settling velocity, is one useful way to identify target distributions that represent actual waste for polydisperse size and density particles. There are a number of alternate metrics used in PNNL-20637 to represent the waste behavior, and these alternate metrics typically have a different dependence on particle size and density than the Archimedes number.

The identification of the Limits of Performance, i.e. the limiting particle size of a particulate "spike," is dependent on the remainder of the simulant components. For example, consider a two-solid component simulant of kaolin clay and stainless steel (SS) in water. If the mass fraction of total undissolved solids is held constant at 0.30, the particle size limit at which the SS will remain suspended in the kaolin/water slurry under quiescent conditions is dependent on the relative concentrations of the SS and kaolin. This is because the rheology of the kaolin/water slurry will change with the concentration of the kaolin, thereby changing the slurry's capability to retain the SS in suspension.

Similarly, if rheology effects are neglected and the settling velocity of the SS is considered (as in a turbulence-sheared system for example), the density change of the kaolin/water slurry with changing kaolin concentration alters the settling velocity of the SS, so the particle size "limit" for a given settling velocity of the SS changes. The settling velocity is of course also influenced via the concentration of the SS directly. It follows that the determination of the limiting particles that a system is capable of mixing and suspending is dependent on the remainder of the simulant components, and thus three distributions will be used to represent the range of the waste PSDD for a "base" particulate simulant. An example of the effect of the base particulate on a "limit" of spike particle size is provided in Section 8.3.

One of the three target PSDDs, identified as the "High" simulant, is chosen to represent the waste distributions with, for example, the higher Archimedes numbers. A second target distribution, called the "Typical" simulant will represent the PSDD of typical waste[3], and a third target, the "Low" simulant, will represent the wastes with the smallest Archimedes numbers. For the Ar number example of Figure 6-9, the Low target waste is C-103 (light blue line), Typical target waste is the Sludge, No-flow Unsonicated (not subject to ultrasonic agitation) (composite (black line and squares), and the High target waste is C-104 ~up to 55th percentile (dark blue

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[3] The "typical" waste target is the composite waste PSDD developed in PNNL-20646. This composite PSDD is the UDS volume weighted combination of the PSD and composition data of the tanks that comprise the PSDD; i.e. those tanks listed in the legend of Figure 6.9.

line), SY-102 ~55th to 80th percentile (grey line), and AZ-101 ~80th percentile and above (red line).

In Section 7.0 candidate simulant components are listed, and in Section 8.0, specific mixtures of simulant particles will be compared with a number of important metrics to identify candidate mixtures for the High, Typical, and Low simulants.

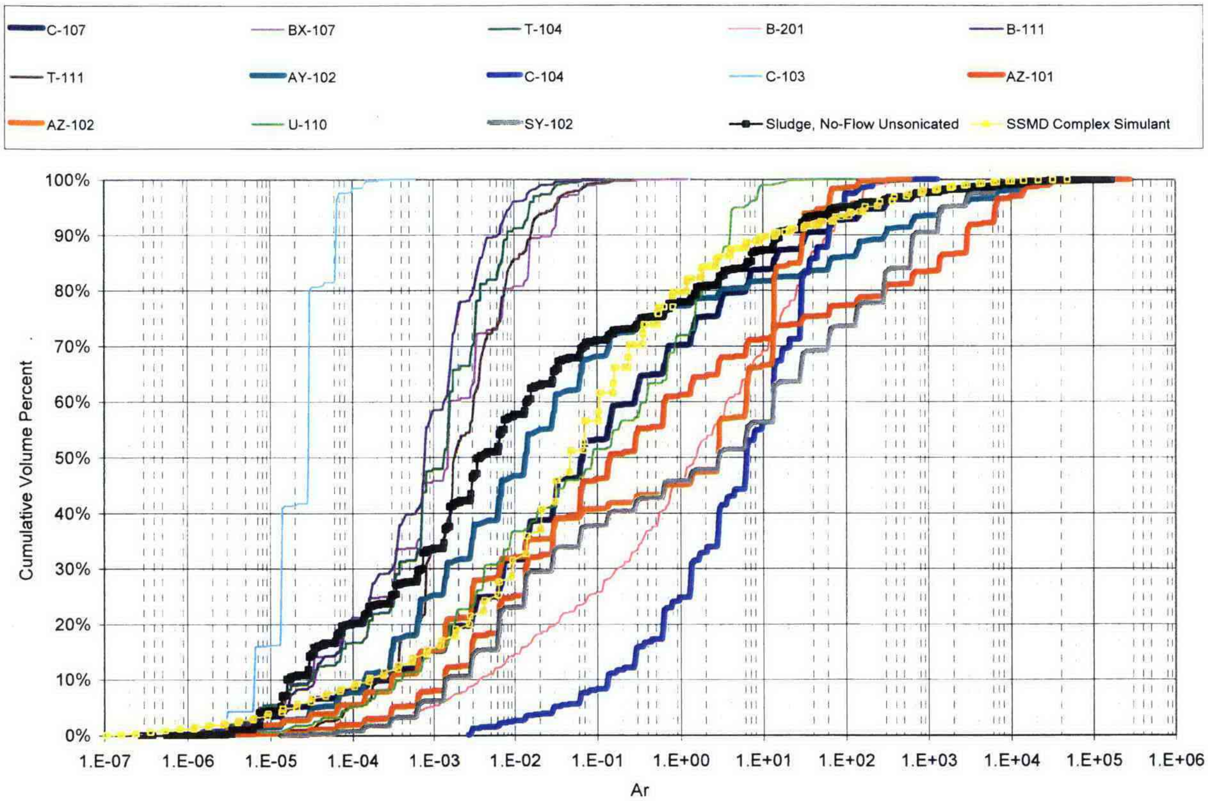


**Figure 6-9. Archimedes Number Distributions for Hanford Waste and a Comparison with SSMD Complex Simulant. No-Flow, Unsonicated PSD Data.**

## 7.0 AVAILABLE SIMULANT COMPONENT CANDIDATES

The availability and functionality of simulants focuses on their density, particle size, potential to damage equipment, and cost. To appropriately model the particles found in Hanford waste feed, density and particle size are two important determinants as described above. During the selection process, however, potential hardness and cost of simulant are also taken into account. Mohs hardness is a numerical value that characterizes the scratch resistance of materials and gives an indication of materials that may cause damage to test equipment. The SSMD platform in place at the Monarch test facility has previously been damaged by simulants with a challenging hardness, resulting in the Mohs hardness number being an additional consideration for selection. The following table lists many of the simulants available for purchase listed with their respective density, particle size, Mohs hardness factor, and cost. A range of additional particle sizes is available for these materials. Other factors taken into account in selection of simulant components including staining of the equipment from materials such as iron oxide which may inhibit visual observations, the ease or difficulty of analysis and the related costs, and the costs of disposal.

**Table 7-1. Available Simulant Components**

| **Name** | **Density (g/cm$^3$)** | **Size** | **Size (µm)** | **Mohs Hardness** | **Cost ($)** | | **Notes** |
|---|---|---|---|---|---|---|---|
| LG-50 Steel grit | >7 | .18-.71 mm | 180-710 | 5-6 | 980 | /1000lbs | "L" hardness |
| LG-10 Steel grit | >7 | 1.7-2.8 mm | 1700-2800 | 5-6 | 950 | /1000lbs | "L" hardness |
| HG-120 Steel grit | >7 | .075-.3 mm | 75-300 | 5-6 | 990 | /1000lbs | "H" hardness |
| S-280 steel shot | >7 | .6-1.18 mm | 600-1180 | 5-6 | 960 | /1000lbs | |
| S-780 steel shot | >7 | 1.7-2.8 mm | 1700-2800 | 5-6 | 955 | /1000lbs | |
| S-70 steel shot | >7 | .125-.425 mm | 125-425 | 5-6 | 987.5 | /1000lbs | |
| Granulated Tungsten Powder | 19.3 | -12+20 Mesh | 841-1680 | 7.5 | 42.84 | /lb | |
| Tungsten Grit | 19.3 | -20+40 mesh | 420-841 | 7.5 | 35.25 | /lb | |
| Tungsten Grit | 19.3 | -60+100 mesh | 149-250 | 7.5 | 35.77 | /lb | |
| Silica Sand | 2.7 | 100 mesh #70 (.09-.4 mm) | 90-400 | 6-7 | 520 | 2800/lb | 50 lbs/bag 56 bags/pallet |
| Silica Sand | 2.7 | 20/40 (.4-.5 mm) | 400-500 | 6-7 | 520 | 2800/lb | 50 lbs/bag 56 bags/pallet |
| Silica Sand | 2.7 | 10/20 (1.1-1.5 mm) | 1100-1500 | 6-7 | 520 | 2800/lb | 50 lbs/bag 56 bags/pallet |
| Silica Sand | 2.7 | 8/12 (1.7-2 mm) | 1700-2000 | 6-7 | 520 | 2800/lb | 50 lbs/bag 56 bags/pallet |
| Tungsten Carbide Grit | 14 | 20/30 | 595-841 | 9 | 25.65 | /lb | Other sizes available |
| Tungsten Carbide Grit | 14 | 30/40 | 420-595 | 9 | 25.65 | /lb | Other sizes available |
| Cast Tungsten | 8.19 | 20/30 | 595-841 | 8 | 55 | /lb | Other sizes available |
| Cast Tungsten | 8.19 | 30/40 | 420-595 | 8 | 55 | /lb | Other sizes available |

**Table 7-1. Available Simulant Components**

| Name | Density (g/cm$^3$) | Size | Size (µm) | Mohs Hardness | Cost ($) | | Notes |
|---|---|---|---|---|---|---|---|
| CW55 | 12.6 | 3/16" | 4762.5 | -- | 242.19 | /lb | 1/8" may be available, 3/16 is the smallest readily available |
| SS wire shot | 8 | 0.35 mm -3.2 mm | 350-3200 | 5.5 | 3-6 | /lb | price was quoted for 2000 lb quantity, smaller orders may change |
| basalt | 2.9 | .35 mm-8mm | 350-8000 | 8-9 | 300 | /ton | |
| granite | 2.65-2.75 | .35 mm-8mm | 350-8000 | <7 | 600 | /ton | |
| XL Sci-Tech, Inc. W alloy powder | 11.2 | | | -- | 875 | /lb | Laboratory made formulation for exactly 11.2 g/cm$^3$, size can be customized |
| Gibbsite | 2.42 | d50 10 µm | | 3.4 | 1.65 | /lb | Previously used at SSMD other sizes available |
| ZrO | 5.7 | d50 12 µm | | 8 | 7.3 | /lb | Previously used at SSMD other sizes available |
| SiC | 3.2 | d50 8-350 µm | | 9.5 | 1 | /lb | Previously used at SSMD other sizes available |
| $Bi_2O_3$ | 8.9 | d50 38 µm | | 4.5-5 | 34 | /lb | Previously used at SSMD other sizes available |
| NaBr | | | | | 4.98 | /lb | Density Modifier Used at RSD |
| Glycerin | | | | | 900 | 55/gal | Viscosity Modifier used in WTP Testing |
| Iron Oxide | | | | | 6.87 | /lb | Rheology Modifier Used at RSD |
| Laponite | | | | | 21.62 | /lb | Rheology Modifier |
| Kaolin | | | | | ~7 | /lb | Rheology Modifier |
| Bentonite | | | | | ~7 | /lb | Rheology Modifier |
| NaCl | | | | | 0.83 | /lb | Rheology Modifier |
| CaCl2 | | | | | 1.1 | /lb | Rheology Modifier |

# 8.0 SIMULANT DETERMINATION

As described in PNNL-20637, development of the UDS particulate PSDD of the simulant can be achieved by mimicking the PSDDs of the high, typical, and low waste (e.g. Section 6.0) for metrics for particle mobilization, suspension, settling, and pipeline transfer where the dependence of these metrics on particle size and density may be different. The metrics considered in PNNL-20637 include:

- Settling velocity, $U_T$, Camenen (2007),
- Archimedes number, Ar, Camenen (2007),
- Critical shear stress for erosion of noncohesive particles, $\tau_c$, Paphitis (2001),
- Just-suspended impeller speed, $N_{js}$, Zwietering correlation, Paul et al. (2004),
- Jet velocity needed to achieve a certain degree of solid suspension, $U_n$, Kale and Patwardhan (2005),
- PJM critical suspension velocity for noncohesive solids, $U_{CS}$, Fort et al. (2010),
- PJM cloud height for noncohesive solids, $H_C$, Fort et al. (2010), and
- Pipeline critical transport velocity, $U_C$, Oroskar and Turian (1980).

In this section, candidate Newtonian and non-Newtonian suspending fluids are discussed and conceptual UDS particulate base simulants are developed using constituents selected from those listed in Section 7.0. Approaches specific to defining the limits of performance using the spike particles are also described.

## 8.1 CANDIDATE SUSPENDING FLUIDS

Candidate Newtonian and non-Newtonian suspending fluids are described.

### 8.1.1 Newtonian

The base simulant particles, together with spike particles for limits of performance testing, will need to be added to the Newtonian suspending fluids with densities and viscosities that span the range given in Table 6-1 (entries for HTWOS). Candidate materials for spanning the needed range of densities and viscosities are given below. Depending on the specific density and viscosity target, one or more of these components may need to be combined and the chemical compatibility of the materials will need to be evaluated to avoid potential problems such as precipitation.

- Sodium salts typical of tank waste (hydroxide, nitrate, chloride, carbonate, acetate)
- Sodium salts non-typical of tank waste but appropriate for testing (bromide, thiosulfate)
- Glycerol
- Water

Specific target viscosities and densities and then simulant mixture concentrations will be defined in the test plan (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.6). Additional salts and more complicated mixtures of salts may be needed to meet viscosity and density targets in the test plans, and simulant cost, disposal, and chemical hazards will play a role in the final selection. In general, the range of viscosities given in Table 6-1 (entries for HTWOS) can be achieved with mixtures of sodium hydroxide and the other salts, but the caustic hydroxide solutions present chemical hazards. Glycerol is an additional material that can achieve the higher viscosity solutions in water and has a low chemical hazard, but may need to be blended with salts to achieve target densities. The chemical compatibility of salts in water/glycerol solutions has not yet been evaluated.

### 8.1.2 Non-Newtonian

The spike particles for limits of performance testing will need to be added to non-Newtonian suspending fluids with Bingham yield stresses that span the range discussed in Section 6.2. Candidate materials for spanning the needed range of Bingham yield stress are discussed below.

Kaolin, bentonite, and kaolin/bentonite mixture clay slurries are readily available and have a relative ease of handling. Numerous experimental studies related to the storage and retrieval of waste from Hanford and SRS storage tanks have employed clay slurries as simulants to represent the waste of interest. These studies have included investigations of gas retention and release (Gauglitz et al. 1994, 1995, 1996, Stewart et al. 1996, etc.), sediment mobilization (Powell et al. 1995, Enderlin et al. 2003, Bontha et al. 2005, Kurath et al. 2007, etc.), and slurry transport (Poloski et al. 2009, Bontha et al. 2010). Gauglitz and Aiken (1997) developed a method to obtain shear strength estimates for Hanford sediment via visual observation of waste core extrusion behavior in comparison to clay simulants.

Kaolin clay and bentonite clay slurries have uniquely different relations between clay concentration and rheology, and essentially bound this relationship for the limited examples of characterized Hanford waste (PNNL-20646). Distinctions in of the erosion behavior of kaolin clay vs. kaolin/bentonite clay slurries at similar rheology were observed in the scaled DST mixing experiments of Powell et al. (1995). It may also be noted that kaolin clay slurries tend to show slight rheopectic properties (hysteresis loop on rheogram with lower stress, for any given strain rate, in the strain rate ramp-up curve vs. the ramp-down curve) whereas actual waste typically does not and may, in some instances, be significantly thixotropic (opposite on a rheogram to rheopectic for the ramp-up vs. the ramp-down curve relation). While there are certainly differences in the rheological behavior of clays and actual waste, the intention in selecting kaolin and bentonite clay slurries is to minimize any rheopectic or thixotropic (time dependent rheological) behavior in the simulants.

The slurry with an 80:20 mixture by mass of kaolin/bentonite developed in Rassat et al. (2003) is representative of the waste with respect to UDS concentration and rheology, and was selected by Poloski et al. (2004) for use in scaled prototypic PJM tests. Kaolin slurries were used by Adamson and Gauglitz (2011) for their investigation of the mixing and transfer of settling cohesive simulants for the SSMD program. Kaolin and 80:20 kaolin/bentonite clay in water slurries are the preferred non-Newtonian fluid simulants to match the slurry rheology ranges presented in Section 6.2. Specific non-Newtonian fluid simulant formulations will be defined in the specific test plans (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.6).

## 8.2 CONCEPTUAL SIMULANT BASE PSDDS

For each conceptual simulant, the concentrations of potential simulant components are adjusted such that the calculated metric results for the simulant and target waste are similar. Selection of specific candidate simulant components for the base components was conducted by a team consisting of WRPS, Pacific Northwest National Laboratory (PNNL), BNI, and Energy Solutions staff with expert knowledge of Hanford waste UDS properties and direct experience with Hanford waste simulant development and operations testing. The short-list of components includes materials that are representative of waste characteristics, non-hazardous, available, reasonable with respect to cost, amenable for simulant preparation and handling, relatively non-eroding of test system components, and acceptable for commonly applied analysis techniques. The base components from Section 7 include:

- Gibbsite,
- Zirconium oxide,
- Sand, and
- Stainless Steel.

Particle size density distributions of the High, Typical, and Low waste are taken from the No-Flow Unsonicated PSDDs of PNNL-20646. The No-Flow Unsonicated PSDD type data show the largest particulate as well as the largest tank-to-tank variability. As noted on PNNL-20637,

- There is no conclusive evidence that characterization of the Hanford waste particle size via any of the three PSD techniques (including the No-Flow Unsonicated type) over-represents the settling characteristics of particles suspended by jet mixer pump operation. In fact, it was observed in HNF-8862, *Particle Size Analysis of HLW Tank Sludges,* that PSDs of settled material from laboratory tests failed to identify very many large particles despite their being visible during the settling tests. It was also noted in HNF-8862 Rev. 0 that, in comparison to sieving analysis of particle size, the light-scattering particle-size analyzer was poor at finding particles above 500 μm in size. Thus, larger particulates may be under-represented by these instruments.
- There is no conclusive evidence that representing the particle density of Hanford waste particles by assuming that all particles have a density equal to the UDS compound crystal density regardless of the measured particle size (including the No-Flow Unsonicated PSD type) over-represents the settling characteristics of particles suspended by jet mixer pump operation.

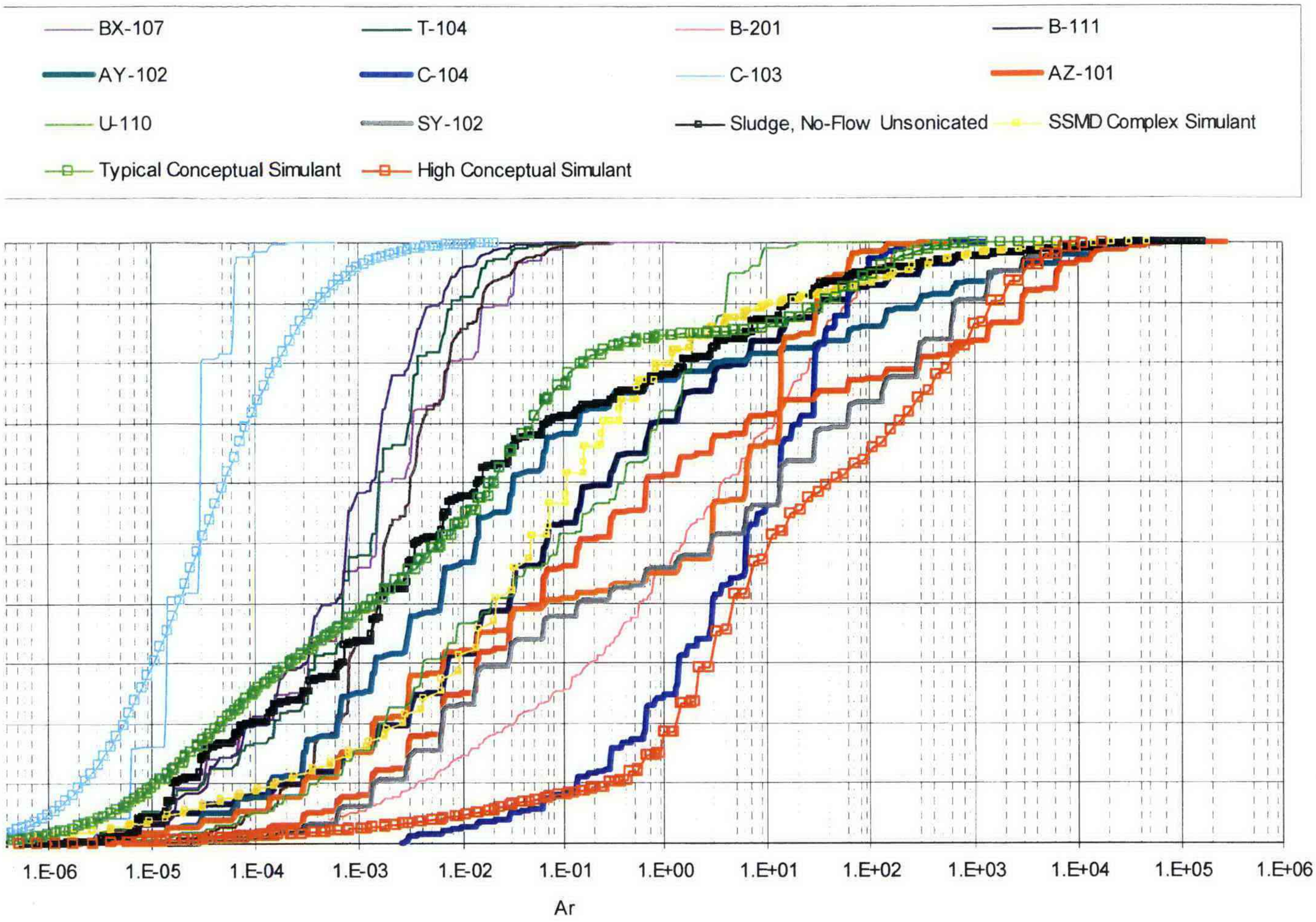
Thus, following the simulant PSDD adjustment examples of PNNL-20637, the No-Flow Unsonicated PSDDs are used here to define the simulant targets. A limited fraction of the waste is characterized by these PSDDs (~18 vol% of the Hanford sludge UDS), and it is possible that the variation in the limited characterization of the waste under-represents the variation of the waste inventory, PNNL-20637. Therefore tanks with the maximum metric results at any given percentile are used as the "target" for the High PSDD. The target Typical PSDD is the composite PSDD result (volume-weighted combination of all waste data with the No-Flow

Unsonicated PSDD type, see PNNL-20646), and the Low PSDD target is the minimum metric results at any given percentile.

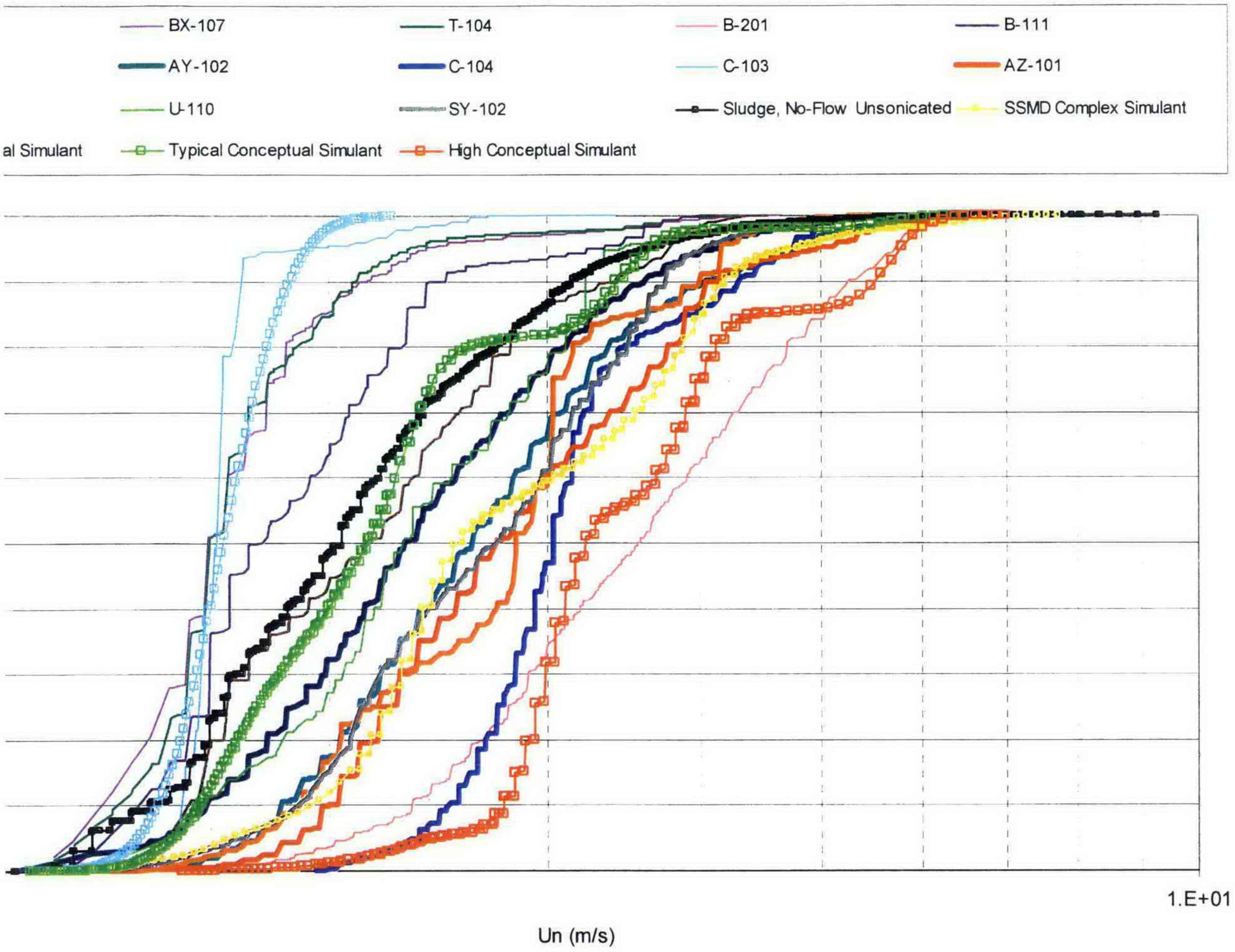
Adjustment of the selected simulant component concentrations is made such that the calculated simulant and the waste targets for the majority of the metrics are similar. In some instances, different particle size distributions of the same component are required to match the range of metric results for the waste target. The weighted average density of the particulate relative to the target waste is also considered.

Following the simulant adjustment example of PNNL-20637, and considering the mobilization and suspension of UDS particulate with a liquid-jet, the Archimedes number, Ar, and the jet velocity needed to achieve a certain degree of solid suspension, $U_n$, are used to represent the simulant comparison as they reflect the difference in functionality of particle size (d) and density (S, ratio of solid to liquid density) as $Ar \rightarrow (S - 1)d^3$ and $U_n \rightarrow (S - 1)^{0.38}d^{0.14}$. Results for all of the previously listed metrics considered in PNNL-20637 are shown in Appendix C. All other metric parameters, e.g. UDS concentration, pipe diameter, etc. are set constant to PNNL-20637 values. This over-all approach provides demonstration that the simulant is representative of the as-characterized Hanford waste for metrics of particle mobilization, suspension, settling, and pipeline transfer.

Figure 8-1 and Figure 8-2 show the comparison of three conceptual simulants, denoted as the “Low” (light blue line and symbols), "Typical" (bright green line and symbols) and "High" (red line and symbols) Conceptual Simulants to actual waste data for Ar and $U_n$ respectively. The Low Conceptual Simulant is shown to agree reasonably well with the least challenging waste tank data (C-103, pale blue line) for both for Ar and $U_n$. Similar results are shown for both the Typical and High simulants in comparison to the waste composite (black line and symbols) and most challenging wastes (e.g. Ar, C-104 ~up to 55th percentile, dark blue line; SY-102 ~55th to 80th percentile, grey line; AZ-101 ~80th percentile and above, red line) respectively. Likewise, relatively close comparison is shown for the other metrics considered in PNNL-20637, Appendix C.



**s Number Comparison. SSMD simulant (PNNL-20637), gold line and symbols, Conceptual Simulants:
d symbols, Typical, bright green line and symbols, High, red line and symbols ; composite waste PSDD,
and symbol; bold lines denote the tanks common to all three PSDD types of PNNL-20646.**



**Needed to Achieve a Certain Degree of Solid Suspension Comparison. SSMD simulant (PNNL-20637), Conceptual Simulants: Low, light blue line and symbols, Typical, bright green line and symbols, High, composite waste PSDD, black line and symbol; bold lines denote the tanks common to all three PSDD types of PNNL-20646.**

A summary of the metric comparisons for the waste target and conceptual simulant is provided in Table 8-1. The Typical and High conceptual simulants are relatively similar for 7 and 6 out of 8 metrics respectively. The Low conceptual simulant is typically relatively more challenging than the target waste, which is likely due to the very small particle size of the target waste (see Table 8-2). The simulant compositions are shown to be representative of a broad spectrum of Hanford waste as indicated by the metrics considered in Table 8-1.

**Table 8-1. Metric Comparison Summary**

| Metric | Figure Reference | Conceptual Simulant | | |
|---|---|---|---|---|
| | | Low | Typical | High |
| Archimedes number<br>Ar | Figure 8-1, C-2 | MC | S | S |
| Just-suspended impeller speed<br>$N_{js}$ (rps) | Figure 8-2, C-4 | S | S | S |
| Settling velocity<br>$U_T$ (m/s) | Figure C-1 | MC | S | S |
| Critical shear stress for erosion of non-cohesive particles<br>$\tau_c$ (Pa) | Figure C-3 | MC | S | S |
| Jet velocity needed to achieve a certain degree of solid suspension<br>$U_n$ (m/s) | Figure C-5 | LC | S | LC |
| PJM critical suspension velocity for non-cohesive solids<br>$U_{CS}$ (m/s) | Figure C-6 | S | S | S |
| PJM cloud height for non-cohesive solids<br>$H_C$ (m) | Figure C-7 | MC | S | S |
| Pipeline critical transport velocity<br>$U_C$ (m/s) | Figure C-8 | MC | MC | LC |

S - Waste target and conceptual simulant are relatively similar.

MC - Conceptual simulant is relatively more challenging than ~ 50% by volume of waste target (~ 10% by volume at a given metric value).

LC - Conceptual simulant is relatively less challenging than ~ 50% by volume of waste target (~ 10% by volume at a given metric value).

The compositions for the Low, Typical, and High Conceptual Simulants, taken from the short list of base components previously listed, are provided in Table 8-2, and the simulant component characteristics are summarized in Table 8-3 and simulant component PSDs are provided in Figure 8-3 through Figure 8-9. These PSDs are typical PSDs. Actual PSDs will depend on available material from the selected vendor(s). Lower density and size components are shown to be used for the Low Conceptual simulant relative to the Typical simulant, and similarly to the High simulant, which follows the trend of the actual waste targets. The volume-weighted average densities and density and size ranges of the conceptual simulants likewise compare somewhat favorably with the waste targets with the exception of the Low conceptual simulant. Specific base simulants will be defined in the test plan (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.6).

**Table 8-2. Conceptual Simulant Compositions by Volume Fraction and Mass Fraction**

| **Component** | **Low** | | **Typical** | | **High** | |
|---|---|---|---|---|---|---|
| | **volume** | **mass** | **volume** | **mass** | **volume** | **mass** |
| Small Gibbsite | 1.00 | 1.00 | 0.30 | 0.27 | - | - |
| Large Gibbsite | - | - | 0.50 | 0.44 | 0.05 | 0.03 |
| Small Sand | - | - | - | - | 0.47 | 0.35 |
| Medium Sand | - | - | 0.13 | 0.13 | - | - |
| Large Sand | - | - | - | - | 0.28 | 0.21 |
| $ZrO_2$ | - | - | 0.05 | 0.10 | 0.05 | 0.08 |
| Stainless Steel | - | - | 0.02 | 0.06 | 0.15 | 0.33 |
| Volume weighted average UDS density (g/mL) | 2.42 | | 2.73 | | 3.59 | |
| Density Range (g/mL) | 2.42 | | 2.42 to 8 | | 2.42 to 8 | |
| Size Range (μm) | 0.10 to 11.5 | | 0.10 to 517 | | 0.17 to 1020 | |
| **Target Waste (Ar number example)** | | | | | | |
| Volume weighted average UDS density (g/mL) | 2.53 | | 2.46 | | 2.45 to 3.02 | |
| Density Range (g/mL) | 2.25 to 8.9 | | 1.62 to 11.43 | | 1.62 to 11.43 | |
| Size Range (μm) | 0.60 to 2.2 | | 0.36 to 1292 | | 0.36 to 1668 | |
| - component not used | | | | | | |

Table 8-3. Conceptual Simulant Component Properties

| Component | Density (g/mL) | Median Particle Size by Volume (μm) | Notes |
|---|---|---|---|
| Small Gibbsite | 2.42 | 1.3 | APYRAL 40CD, Nabaltec AG, approximate PSD based on vendor info |
| Large Gibbsite | 2.42 | 10 | Noah Technologies, PSD from SSMD project characterization |
| Small Sand | 2.65 | 57 | Modified-size un-sieved sand component distribution, PNNL-19085 |
| Medium Sand | 2.65 | 148 | |
| Large Sand | 2.65 | 382 | |
| $ZrO_2$ | 5.7 | 6 | Reade Advanced Materials, PSD from SSMD project characterization |
| Stainless Steel | 8 | 112 | Pellets LLC, PSD from SSMD project characterization |

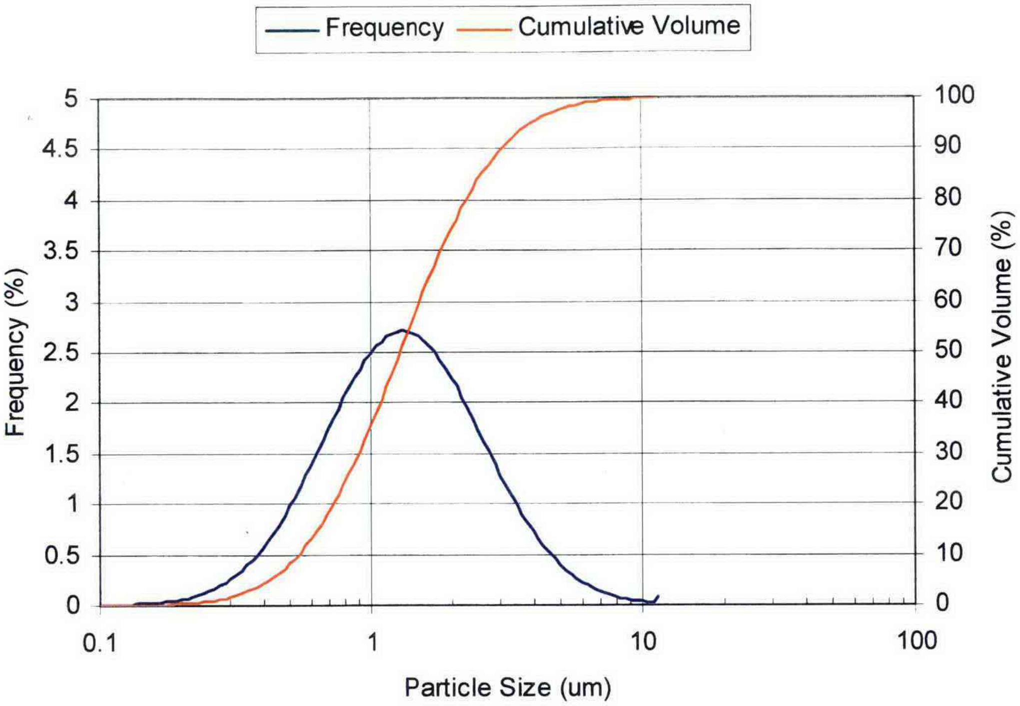


Figure 8-3. Small Gibbsite PSD by Volume

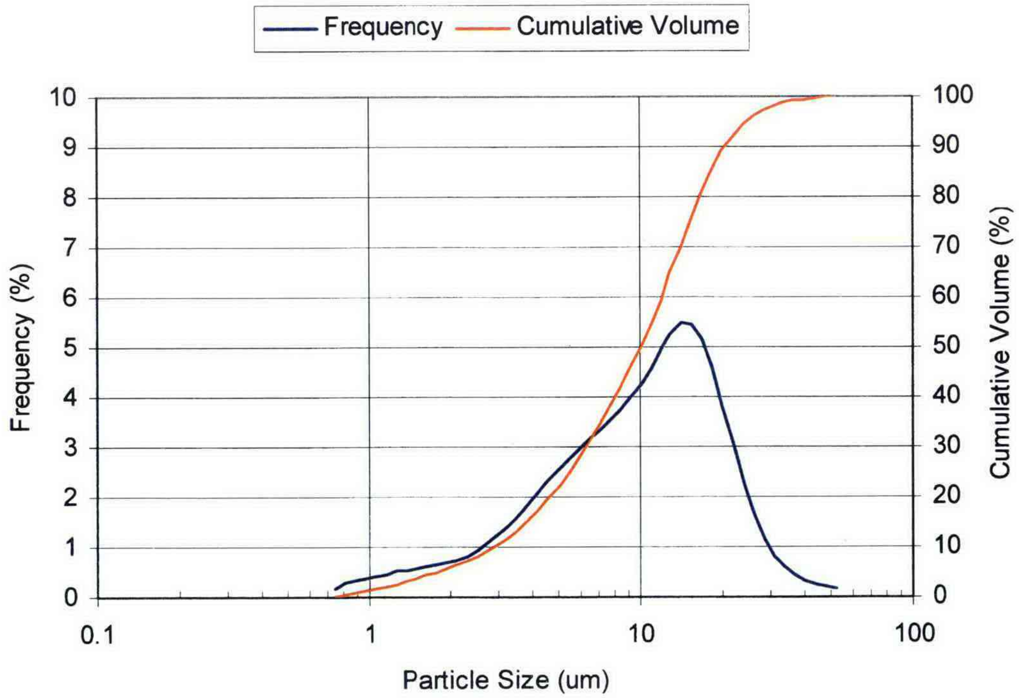


Figure 8-4. Large Gibbsite PSD by Volume

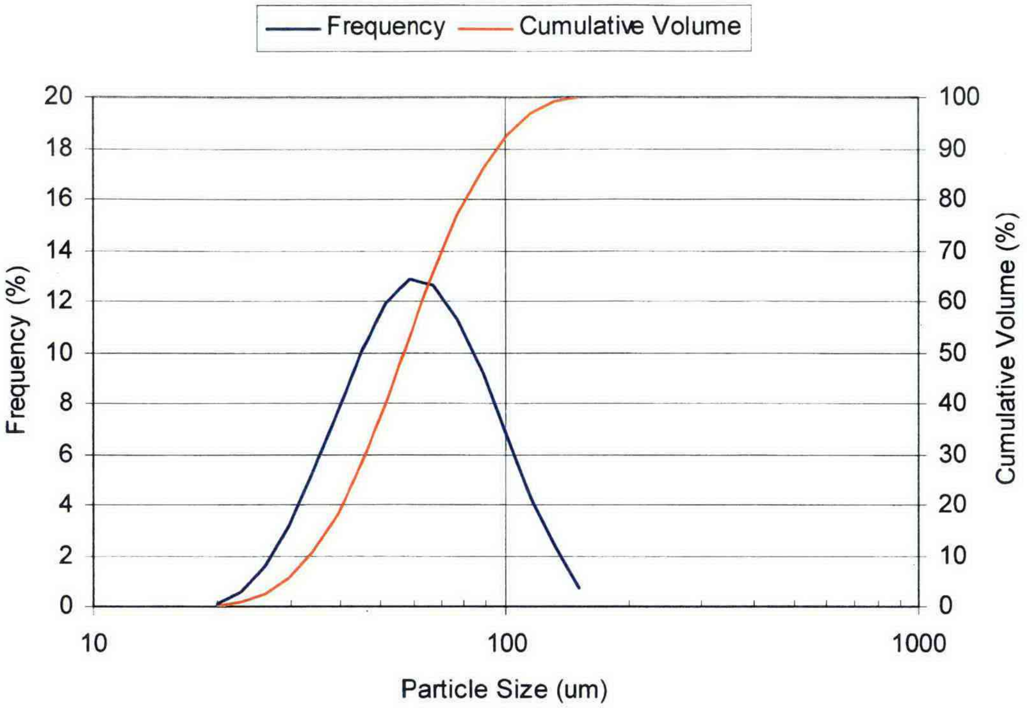


Figure 8-5. Small Sand PSD by Volume

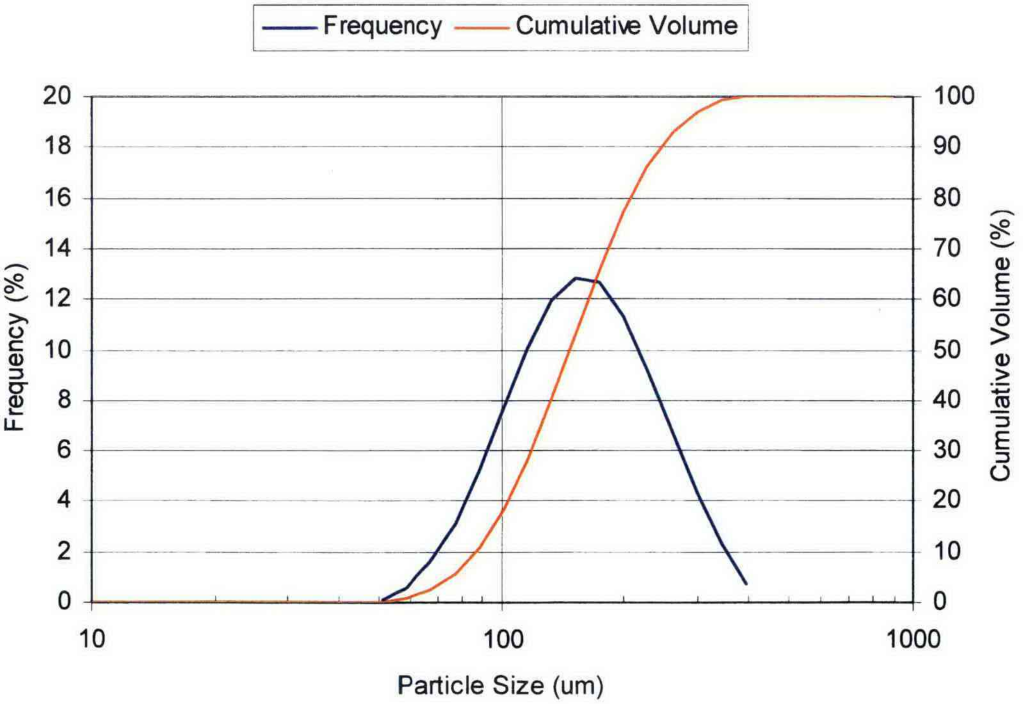


Figure 8-6. Medium Sand PSD by Volume

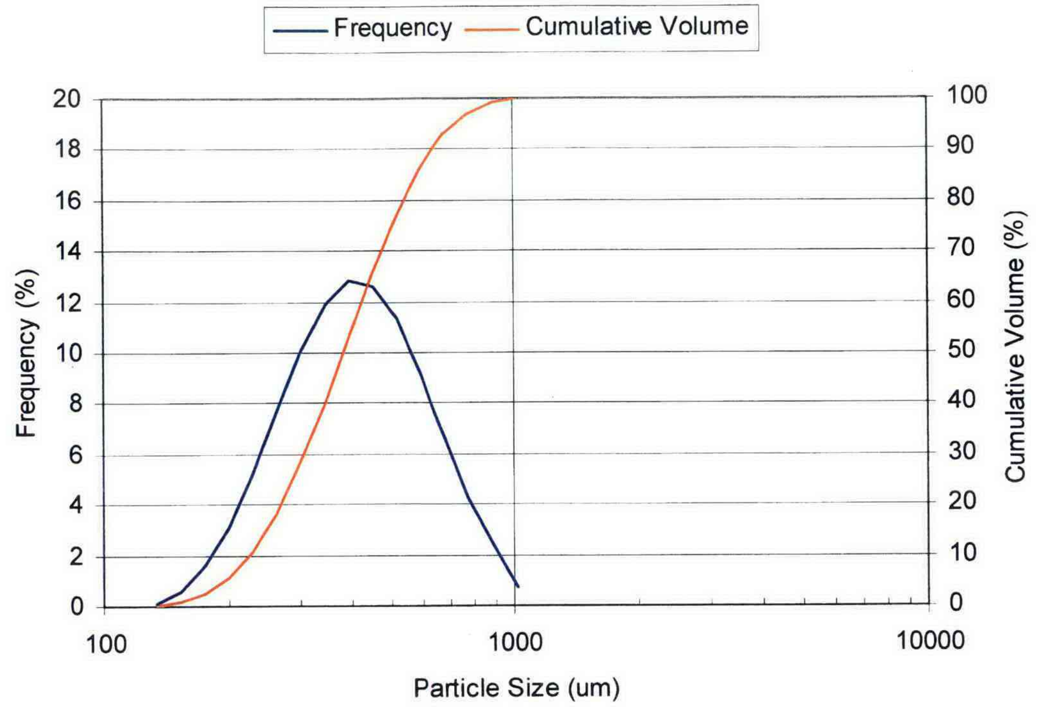


Figure 8-7. Large Sand PSD by Volume

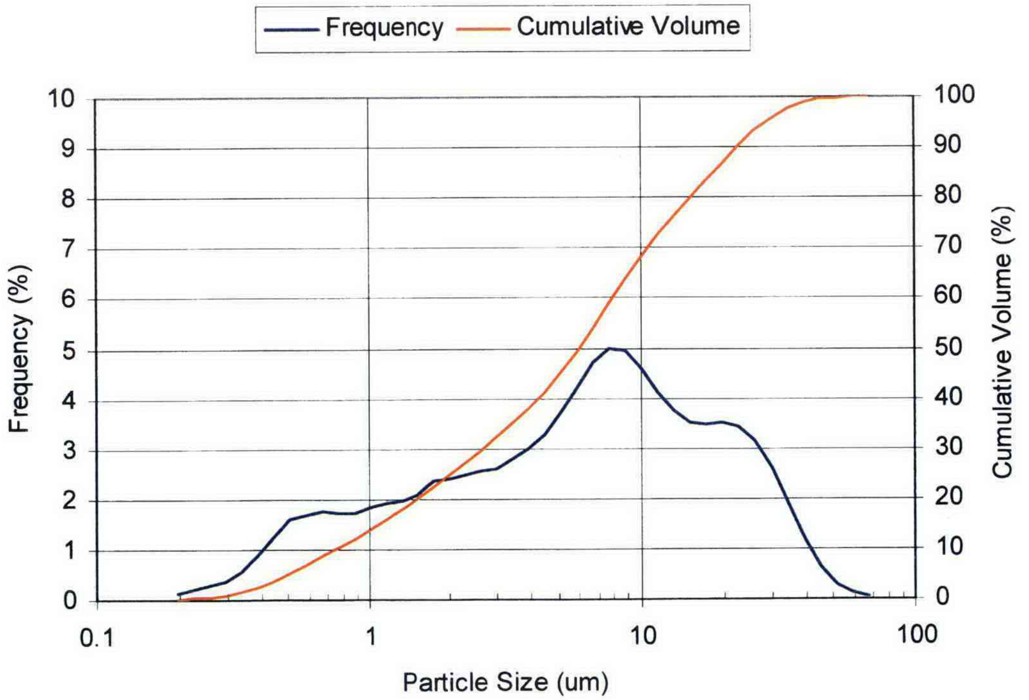


Figure 8-8. $ZrO_2$ PSD by Volume

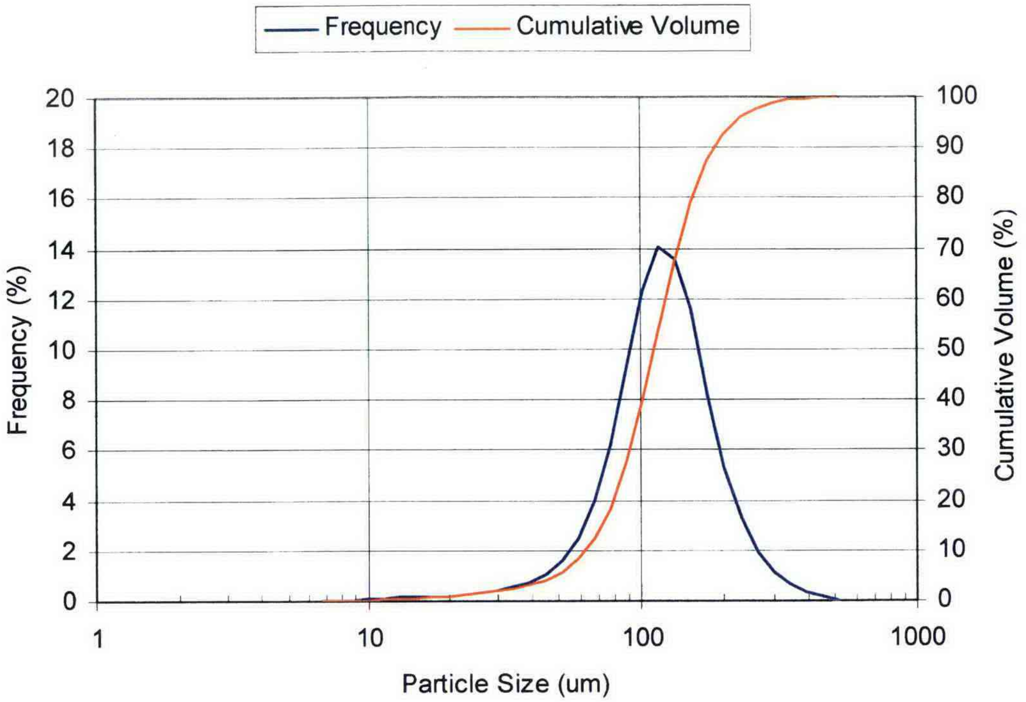


Figure 8-9. Stainless Steel PSD by Volume

## 8.3 APPROACH TO DEFINING LIMITS OF PERFORMANCE

Spike particles can be used with the High, Typical, and Low PSDD conceptual base simulants (Section 8.2) to define the limits of performance. Selection of specific candidate spike simulant components was conducted, as for the base components, by a team consisting of WRPS, PNNL, BNI, and Energy Solutions staff with expert knowledge of Hanford waste UDS properties and direct experience with Hanford waste simulant development and operations testing. Candidate spike components selected from Section 8.0 include:

- Sand (larger than base sand, Section 8.2),
- Stainless steel (larger than base SS, Section 8.2),
- Tungsten carbide grit, and
- Tungsten grit.

These spike particles are selected not only as meeting the previously stated requirements, but also for the range of particle density relative to the characterization of Hanford waste. Sand, at 2.65 g/mL, is used to approximate the lower density solids such as gibbsite and $NaAlSiO_4$, SS, at 8 g/mL, as the high density solids such as $Bi_2O_3$, $BiFeO_3$, and $Pb(OH)_2$, tungsten carbide grit, at 14 g/mL, as the high density solid $PuO_2$ (waste solid composition from PNNL-20646) , and tungsten grit, at 19.3 g/mL, as the very high density solid Pu metal (RPP-RPT-50941). In addition, these components are available as large particulate (e.g. > 500 μm SS of the base).

The spike component(s) can be added to either the base PSDD simulants for a Newtonian liquid suspending fluid or used alone when a non-Newtonian yield stress fluid is used as the suspending fluid. The characteristics and concentration of the spike particles in either case must be sufficient to enable 1) separate identification from base simulant, and 2) identifiable alteration of system performance on the spike without influence on the remainder of the simulant as explained below. For requirement 1, the spike particle must be separable from the base simulant for identification via any of the commonly employed analyses such as sieving or chemical analysis such that system capability relative to the spike can be understood. For a sand or SS spike, an analysis such as sieving will be necessary, so the spike must be uniquely different in size than the base components of the same composition. Chemical analysis would potentially be applicable for the tungsten carbide grit given its uniqueness relative to both the base/Newtonian fluid as well as the non-Newtonian yield stress fluid.

Requirement 2 addresses both the potential effect of the spike on the system performance as well as identification of the spike performance in that system via the test metric(s). Specifically,

- Addition of the spike must not change the system performance relative to the remainder of the simulant (base in Newtonian fluid or non-Newtonian yield stress fluid). This specification provides an upper limit for the spike concentration at a specific composition.
- Enough spike material must be added such that it can be measured and quantified via the analysis techniques for the test metric(s). This specification provides a lower limit for the spike concentration at a specific composition.

- The size of the spike of a specific composition and concentration in a set fluid (base in Newtonian fluid or non-Newtonian yield stress fluid) must be varied such that the test metric(s) of the spike is (are) sufficiently varied such that a "pass/fail" criterion can be identified.

For illustration of the first specific for requirement 2, addition of the spike must not change the system performance relative to the remainder of the simulant; examples are evaluated for the conceptual simulant bases provided in Section 8.1. The potential effect of the spike on the system performance is considered with respect to the Zweitering correlation for the just-suspended impeller speed, $N_{js}$, required to suspend all of the particulate in a vessel. In these examples, the just-suspended impeller speed is used as a surrogate for the mixing and batch transfer metric(s) of the SSMD program. The mixture $N_{js}$ is approximated via a power model combination.[4] As in Section 8.1, the computational methodology for $N_{js}$ is the same as described in PNNL-20637 with water (1 g/mL, 1 cP) as the liquid phase.

The calculated effect of varying the size and concentrations of a SS spike component on $N_{js}$ is shown in Figure 8-10. The base simulant is shown to have a pronounced effect as referenced in Section 6.3. The $N_{js}$ result for the Typical and High bases are approximately 120% to 60% higher than the Low base results depending on the particle size, with the High base results are only slightly elevated (2%). The effect of particle size is significant for the Low base, ~42% increase from 750 to 6000 μm, in comparison to the Typical and High base results, ~6% increase. For the Low base, the addition of the spike over a size range is shown to change the system performance relative to the remainder of the simulant, and thus requirement 2) is not met for this case. Regardless of the base, there is negligible effect of concentration for the 1% to 10% by volume of spike addition considered.

As illustrated, there may be large variation in the limiting particle for a given performance metric depending on the base simulant, and the appropriate testing range for the spike particles varies with the base simulant. Specific spike properties and concentrations will be defined in the test plan (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.6).

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[4] Presentation by Ayranci I, T Ng, AW Etchells, and S Kresta. 2011. *A Design Rule for Prediction of the Just Suspended Speed of Mixed Slurries.* AIChE Meeting, October 17, 2011.

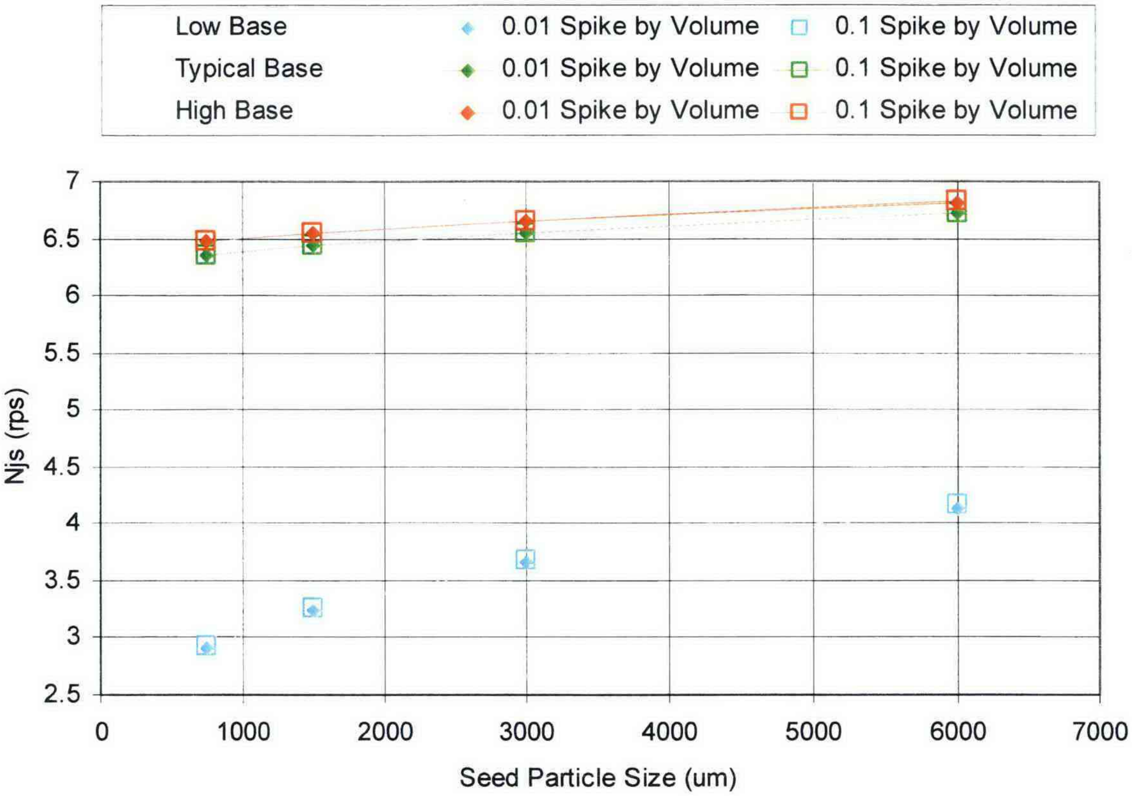

**Figure 8-10. Calculated Effect of Stainless Steel Spike Particle Effect on $N_{js}$ as a Function of Size and Concentration**

# 9.0 CONCLUSION AND PATH FORWARD

This document provides conceptual UDS particulate simulants using available simulant constituents to meet the testing requirements defined by RPP-PLAN-41807. A test plan (DNFSB 2010-2 Sub-Recommendation 5, Commitment 5.5.3.6) will follow that will define more specific testing to address:

- Limits of performance
- Solids accumulation
- Scaled performance

The recommended basic simulant components include:

Liquid density and viscosity: Ranges for the suspending fluid density and viscosity, for Newtonian fluids, that represent the expected range of Hanford waste are specified. Candidate sodium salts including sodium hydroxide and sodium nitrate, which can be used individually or in combination, are identified for covering this range of properties. Glycerol is an additional material that is identified for increasing the suspending fluid viscosity. Glycerol may need to be used together with salts to achieve a desired density and the chemical compatibility of the salts in water/glycerol solutions has not yet been evaluated.

Slurry Rheology: The range of Bingham yield stress that represents the expected range of Hanford waste is identified. Slurries of kaolin clay or mixtures of kaolin and bentonite clays are two candidate materials identified for covering the expected range of Bingham yield stress. The spike particles will be added to these slurries.

Base Particulates: Three base simulants, representing Low, Typical, and High PSDDs, are described, using gibbsite, zirconium oxide, sand, and SS as UDS particulate materials. These simulants are shown to represent the as-characterized Hanford waste for metrics of particle mobilization, suspension, settling, and pipeline transfer.

Spike Particulates: Three spike particles, sand, SS, and tungsten carbide grit, are chosen to represent density ranges for limits of performance testing. Where sand and SS are used as spike particles, their sizes will be distinct from those in the base simulant to permit sieving as a means of analysis of the spike particles.

Specific test plans will be required for discrete phases of testing. The specific test plans will include specific formulations for simulants and provision for preparation and sampling of trial batches.

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# APPENDIX A. SIMULANTS USED TO DATE

Simulants used to date include testing demonstrations at five main platforms; the WTP M3 test program, the small scale mixing platform (SSMD), remote sampler demonstration (RSD), Savannah River National Laboratory (SRNL) and the Pacific Northwest National Laboratory (PNNL).

## WTP M3 TESTING

In October 2005, an External Flowsheet Review Team (EFRT), made up of experts from industry, national laboratories, and universities, assembled by BNI conducted a thorough, in-depth review of the process flowsheet for the design of the WTP. They identified numerous issues associated with the design with the following issue being the genesis of the WTP mixing program:

Issue M3: Issues were identified related to mixing system designs that will result in insufficient mixing and/or extended mixing times. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There was also insufficient testing of the selected designs.

The Issue M3 test program was divided into three test phases. Phase I testing was performed by PNNL and focused on the following objectives defined in WTP-RPT-182, *Pulse Jet Mixing Tests with Non-cohesive Solids:*

1. Determine through experimental results whether there is a high probability that for vessel HLP-22, 0.10 m (4-in.) nozzles operating at 8 m/s discharge velocity will not be adequate for re-suspending settled solids.
2. Provide experimental results from a scaled HLP-22 mixing system for constant volume discharges that provide the relative difference in performance with respect to off-bottom suspension for a variety of conditions.
3. Obtain measurements of the critical suspension velocity over a range of test conditions in scaled vessels to evaluate the dependence of vessel mixing performance on parameters associated with waste properties, equipment design, and process operations.
4. Obtain test results at multiple geometric scales to allow scaled test results to be used to predict vessel mixing performance at full scale.
5. Develop tools/models that will allow WTP Mechanical and Process Engineering staff to rate/evaluate/bin WTP vessels designs at a coarse level and to determine with high confidence any WTP vessels that will not meet minimum required performance levels.
6. Obtain test results, observations, and experience that facilitate development of a focused/reduced test matrix for M3 scaled tests.

To support this work simulants were selected for use based on particle size and particle density. For the density parameter, two materials were selected: soda-lime glass with a density of approximately 2.5g/cm$^3$ and a high-density glass with a density of 4.2 g/cm$^3$. For the particle size distribution (PSD) two types were used, a broad size distribution in 2007 and a narrow size distribution in 2008. Table A-1, details the Potter glass beads and their particle size and density used in the two test campaigns.

**Table A-1. Simulants for WTP M3 Phase I Testing**

| Simulant Designation | Particle Size, $d_{50}$ (μm) | Density ($g/cm^3$) | Test Campaign |
|---|---|---|---|
| p1d8 | 90 | 2.45 | 2007 |
| p1d7 | 178 | 2.45 | 2007 |
| p2d6 | 766 | 2.46 | 2007 |
| s1d5 | 44 | 2.50 | 2008 |
| s1d2 | 69 | 2.48 | 2008 |
| s1d1 | 167 | 2.46 | 2008 |
| s2d2 | 76 | 4.18 | 2008 |
| s2d1 | 164 | 4.17 | 2008 |

Phase I testing completed the listed objectives above. Phase II testing was conducted by Energy Solutions at Mid-Columbia Engineering and tested a functionally prototypic Pulsed Jet Mixer (PJM) drive system installed in a single 44-in diameter test vessel. To support this testing a simulant was selected that consisted of six minerals in water; this selection is documented in 24590-WTP-ES-PET-09-001, *M3 Platform Test Data Analysis Study*. Four of the components were selected to approximate the expected average size, density, and size distribution of high-level waste (HLW) as received from the tank farms. The other two components are included as spikes to represent the large size and the large density particulate expected. The four components were developed based on WTP-RPT-153, *Estimate of Hanford Waste Insoluble Solid Particle Size and Density Distribution* and RPP-9805. WPT-RPT-153 focused on reviewing available Hanford waste PSD and solid-phase compound data to determine the representative particle size and density distributions (PSDDs) of Hanford waste insoluble solids. Report RPP-9805 supplies recommended values for PSD, particle density, and slurry viscosity to provide a succinct source of physical property data.

Three simulants were selected for M3 Phase II closure testing: control simulant, 4-particle HLW simulant and spikes. The simulant particles are found in Table A-2:

**Table A-2. Simulant Particles for WTP M3 Phase II Testing**

| Test Matrix Identifier | Description | Material | Specific Gravity | Nominal Size, µm |
|---|---|---|---|---|
| G(175-24) | Control simulant glass beads | Potters Ballotini, MIL-8 | 2.45 | 178 |
| G(70-24) | Control simulant glass beads | S1D2 from Phase I testing | 2.48 | 69.3 |
| C(1-52) | HLW component Iron Oxide | Prince Minerals 2568 or 5001 | 5.24 | 0.6 |
| C(6-24) | HLW component, medium gibbsite | Almatis C-333 | 2.42 | 7 |
| C(24-26) | HLW component, ground silica | U.S. Silica SIL-CO-SIL 75 | 2.65 | 24 |
| C(85-24) | HLW component, coarse gibbsite | Almatis C-31C | 2.42 | 85 |
| S(10-89) | HLW spike-bismuth oxide | Cerac B-1067 | 8.90 | 10 |
| S(200-26) | HLW spike-unground silica | U.S. Silica L-60 | 2.65 | 200 |

The control simulant was a mono-dispersed particulate comprised of spherical glass beads, G(70-24) and G(175-24).

The HLW simulant was designed to represent the tank waste and used the following particles:

- C(1-52) – 5 weight percent
- C(6-24) – 45 weight percent
- C(24-26) – 40 weight percent
- C(85-24) – 10 weight percent

The spikes used in the simulants were the bismuth oxide [S(10-89)] and the unground silica [S(200-26)]. They were intended to represent the limiting particles discussed in WTP-RPT-153 distribution.

For the final phase of EFRT Issue M3 testing program the requirements for simulants were found in 24590-WTP-RPT-PET-10-008, Revised Simulant Design and Basis for FEP-17, FRP-02, HLP-22 and UFP-01 Vessels for EFRT M3 Mixing Studies.

In order to conservatively bound key waste types, the M3 vessel mixing assessment used the following parameters as bounding:

- The 95% UL particle distribution provided in RPP-9805, modified to limit the maximum particle size to 700 micron (µm).
- A maximum assumed $PuO_2$ particle size of 10 µm.
- An average solids density of 2.7 g/mL.

- The tank mixing particle simulants will be suspended in water to represent the fluid suspending the leached and washed HLW particles in the WTP rather than the higher viscosity and density fluids expected to be received from the tank farm.
- The simulant will have shear strength consistent with the 200 Pa high shear strength properties projected from Hanford HLW.

Three waste simulants were developed in 24590-WTP-RPT-PET-10-008 using the above parameters to satisfy the mixing requirements: HLW Sludge Simulant, FRP-Conditioned HLW Simulant, and Post Design Basis Event (DBE) Settle Waste Simulant. For the purpose of this report only the HLW simulant is relevant and discussed.

The HLW Sludge Simulant was used to assess the PJM configuration mixing performance for the scaled WTP vessels, essentially to determine the ability of the mixing vessel design to meet the mixing requirements. This simulant is a combination of inert particles in water from the objectives above which:

- Conservatively approximate the 95% UL waste particle size distribution, focusing on the largest particle sizes.
- The maximum particle size is 700 um.
- An average solids density is 2.9 g/mL.
- Provide a simulation of a 10 um $PuO_2$.

To achieve these objectives the simulants in Table A-3 were selected:

**Table A-3. Simulants for WTP M3 Final Phase Testing**

| Component | Weight Percent of Solids | Density [g/mL] |
|---|---|---|
| Tungsten Carbide ($PuO_2$ surrogate) | 3% | 11.2 |
| Medium Gibbsite | 35% | 2.42 |
| Ground $SiO_2$ | 25% | 2.65 |
| $Al_2O_3$ | 33% | 3.8 |
| Un-sieved Sand | 4% | 2.65 |
| Mixture | 100% | 2.90 |

The tungsten carbide here is used to represent the 10 um $PuO_2$ particle.

Issue M3 testing has concluded, however WTP is moving into additional testing with the Large Scale Integrated Testing (LSIT) project. The first part of this testing involves verifying and validating (V&V) the computational fluid dynamics (CFD) program that is used to represent WTP vessels. Table A-4 has the simulant formulation for use in the V&V CFD testing.

**Table A-4. V&V CFD Testing Simulant**

| Component | Density | Wt% Solids | Specs, µm | Specs, US Sieve Mesh |
|---|---|---|---|---|
| SiC | 3.2 | 52 | 0.5-16 | <400 |
| PRAXAIR W-121-2 | 9.6 | 4 | 6.0-25.0 | <400 |
| Glass Powder | 2.5 | 38 | 50-100 | 120 >dp>300 |
| Aluminum Oxide | 3.9 | 3.5 | 180-400 | 40>dp>80 |
| Silica Sand | 2.65 | 1 | 500-850 | 20>dp>35 |
| Glass Beads | 2.5 | 1.5 | 1000-1200 | 16>dp>18 |

Simulants used for WTP testing will be coordinated with TOC simulant selection as described in Section 4.0.

## SMALL SCALE MIXING DEMONSTRATION

During the first phase of SSMD simulant testing, the primary objective of the simulant was to accurately bound tank AY-102. Phase I simulant selection focused on the particle size distribution (PSD) of the AY-102 waste and selected nontoxic and nonreactive components to replicate the range of particle sizes. While the nominal range of particle sizes was found to be from 0.6 to 16 µm, the 99th percentile particle was identified as 167 µm. Because of the desire to bound the particle sizes, the simulants were selected to match the larger PSD range. In addition to the PSD of the constituents within the tanks, the density is also an important parameter in simulant selection. Data from RPP-9805 for AY-102 indicates that approximately 97% of the waste is comprised of waste with densities ranging from 2.5 to 5.5 g/ml. Therefore, the simulants are then expected to have a density range of 2.5 to 5.5 g/mL.

During Phase I testing it became apparent that the silicon carbide SiC was prone to causing equipment wear, especially in the jet mixers. The silicon carbide was also difficult to measure using the Focused Beam Reflective Measurement (FBRM) due to its reflectance, multifaceted nature, and low concentration. To correct for this, the size of the silicon carbide was reduced for Phase II. In addition to that adjustment, SS was also added as a constituent for Phase II testing as a spike to represent the bounding denser particles. The remainder of the simulants retained varying particle size from the Phase I testing to provide better bounding conditions. The SSMD simulant, however, is not as challenging compared to the other HLW sludges that may be encountered in other DSTs. As much as 50% by volume of the HLW sludge waste particulate is potentially more challenging than the SSMD simulant relative to properties such as settling velocity, pipeline transport, and Archimedes number (PNNL-20637). Therefore a simulant that is more representative of these more challenging tank wastes must be developed to support the TOC WFD Mixing and Sampling Program objectives.

## REMOTE SAMPLER DEMONSTRATION

To date the Remote Sampler Demonstration (RSD) test system focused on verifying and validating the ability of the Isolok® sampler to accurately and repeatedly sample from the process stream transferring simulated waste. The sampler is bolted to a collection chamber that is directly welded into the process piping allowing the sampler to collect samples directly from the simulant moving through the pipe. To accomplish this objective, a simulant was selected with the intention to the bound the PSDD of the Hanford waste. Initially the RSD used similar simulant to that of the SSMD project, with the exception of a rheological modifier. The table below summarizes the simulants used in the RSD test program. Noticeably absent is the silicon carbide, which was not used during testing due to its abrasive nature and difficulty in analyzing methods. As the RSD testing continues, the ability of the Isolok® to sample more difficult particles will be explored.

**Table A-5. Primary Components of RSD Sampler Demonstration Simulants**

| Simulant Material | Tank Waste Material and Property to be Represented |
|---|---|
| Gibbsite<br>Specific Gravity (SpG) 2.42, d50 10 µm. | Al(OH)3, represents 53% of the waste by volume, and has an SpG of 2.42 (PL-SSMD-PR-0001, Rev. 1, *Waste Feed Delivery Small Scale Mixing Demonstration Simulant Selection Report*). |
| Zirconium Oxide<br>SpG 5.7, d50 12 µm | Fe2O3 and MnO2, which together make up approximately 40% of the simulated waste by volume and have a SpG of approximately 5.7 (PL-SSMD-PR-0001, Rev. 1). |
| Bismuth Oxide<br>SpG 8.9, d50 38 µm | The bismuth oxide shall be used to represent the PuO2 and the bounding material density within the tanks (PL-SSMD-PR-0001, Rev. 1 |
| SS<br>SpG 8.0, d50 128 µm | The SS shall be used to represent the bounding density and particle size within the tanks (PL-SSMD-PR-0001, Rev. 1). |
| Iron Oxide<br>SpG 5.24 | Fe2O3 represents 30% of the simulant by mass, and has a SpG of 5.24 (RPT-RSD-EG-0001). This material is used only as a rheological modifier and is not intended to match Hanford waste. |

Future RSD testing will include measuring critical velocity through incorporation of the Pulse Echo measurement device into the RSD flow loop. Critical Velocity is the flow velocity in the pipe at which solids settle out of solution and are no longer transported through the pipe.

## PULSE ECHO (PNNL)

The PulseEcho system is an essential part to the RSD system, as it allows measurement of critical velocity of the slurryflowing in the pipe. The PulseEcho system was selected using a down-select process where initially three different systems were tested. The PulseEcho had the highest recommendation for development as an individual instrument, PNNL-19441 *Test Loop Demonstration and Evaluation of Slurry Transfer Line Critical Velocity Measurement Instruments.* Final selection of the PulseEcho system pushed development into Phase IV testing, which focused on the following:

- Expand the sensitivity of the PulseEcho system to detect particulates between 20 and 50 um with very high densities (8 to 11 g/cc),
- Evaluate the ability of the PulseEcho to perform reliably using prototypic pipe wall thickness (3-inch Schedule 40),

- Evaluate the effect of carrier fluid density on the performance of the PulseEcho system, and
- Evaluate the detection sensitivity versus PulseEcho scan time.

To support these objectives two different kinds of simulants were used.

Broad PSD Particles: These particles were specifically chosen to evaluate the capability of the 5-MHz transducer to detect critical velocity at or near the full wall thickness of a Schedule 40 SS pipe. This simulant was previously used during Phase III with a goal to establish repeatability of sensor performance, as well as establish the effect of wall thickness on sensor sensitivity. In addition, since these particles have a PSD range from 7 to 500 μm, this simulant was used to simultaneously evaluate the capability of a higher frequency transducer to detect critical velocity. The formulation of the Broad PSD simulant used for two tests is listed in PNNL-20350.

Stainless Steel Particles: These particles were mainly chosen to establish the ability of the high-frequency PulseEcho transducers to detect the critical velocity of small, fast-settling, high-density particles. This simulant is the same as that used during the M1 issue resolution. Stainless steel has a density of ~8 g/cm3 and a broad distribution with a significant portion of the particles falling in the range of 10 to 30 μms. Gibbsite (7.9 μm d(50)) and iron oxide (2.0 μm d(50)) were chosen as carrier fluid particles because these components are representative of materials present in tank waste. The test matrix employed during testing is given in PNNL-20350, Table 5.1.

Using the SS particles was designed to evaluate the detection limitations of the two transducers being evaluated. Two non-Newtonian carrier fluids, kaolin and iron oxide, were selected to evaluate the capability of PulseEcho to detect the SS particles in a high background concentration of non-settling particles. The kaolin was used for consistency with previous Phase III testing, while the iron oxide was chosen as a high-density, fine particle that is known to be present in tank waste. The yield stress and carrier fluid viscosity were not controlled during testing; the carrier fluid particles were used simply as background particles. Gibbsite was also used as a carried fluid particle because it is also a known component found in tank waste. The gibbsite used had a comparable PSD to the kaolin used, but unlike kaolin, gibbsite slurry does not have appreciable rheological properties at the concentrations used and was considered a Newtonian fluid.

The PulseEcho system will continue to be tested using simulants used on the RSD project in order to progress and challenge the instrumentation in a more relevant environment.

### SRNL

Work performed at the Savannah River National Laboratory (SRNL) in support of the WFD Mixing and Sampling Program used simulants designed to represent an average Hanford tank waste. This testing was conducted using a 1/22$^{nd}$ scaled AY-102 tank that was designed and constructed at the test facility. Testing was broken up into three phases to focus on different and evolving objectives of the mixing program. Phase I, documented in SRNL-STI-2009-00717, *Demonstration of Simulated Waste Transfers from Tank AY-102 to the Hanford Waste Treatment Facility,* strove to demonstrate the impact internal tank structures have on the effectiveness of mixing solids within a DST using the baseline case of the AY-102 equipment configuration. Eight demonstrations were performed during this phase; five with obstructions and three without obstructions. The obstructions represented the forced air circulators within the tank. Testing concluded that obstructions did not have an effect on the mixing ability in the tank. Phase II work, documented in SRNL-STI-2010-00521 *Demonstration of Mixer Jet Pump Rotational Sensitivity on Mixing and Transfers of the AY-102 Tank,* focused on determining the affect various mixer pump rotation scenarios have on the batch transfer consistency, in addition to evaluating the effect of reducing the particle size of the more dense particles to the same size range as the less dense particles. Phase III testing determined the impact that cohesive particle interactions in the simulants have on tank mixing using 1/22nd scale mixing system and batch transfer of spike particles. The intent of the testing was to provide support of the assumption that testing with water is conservative.

To support the above laboratory testing, SRNL used a spectrum of simulants as representation of Hanford tank waste. For the Phase I testing, a readily available simulant that had been prepared for a previous test was used. The Fractional Crystallization Pilot-scale Testing simulant had been unused, but was designed to represent an average Hanford tank waste. The simulant in Phase II testing involved using the following components and varying their composition to form three different simulants; simulated Hanford Tank AY-101 supernate, gibbsite particles, and silicon carbide particles/SS particles. The density of the supernate was 1,289 kg/m$^3$ with a viscosity of 2.55 cP. The same amount of gibbsite was used for all three varieties with the amount of silicon carbide and SS changed. As the purpose of Phase III testing was to determine if using water was a conservative approach the simulant was modified to provide a higher yield stress and elevated viscosity. These tests were conducted with non-Newtonian cohesive simulants with Bingham yield stress ranging from 0.3 Pa to 7 Pa. The highest viscosity used was 6.2 cP to match the Bingham consistency of the higher yield stress kaolin slurries. The tests concluded that a higher viscous and higher yield stress fluid transferred particles better than a water-based solution, making the water a conservative solution with which to test transfers.

# APPENDIX B. SLUDGE WASTE SLURRY BINGHAM VISCOSITY

Figure B-1 through Figure B-6 are the mass fraction summary and volume-based probability of the Hanford sludge waste's Bingham viscosity as referenced in Section 6.2 at the specified temperatures.

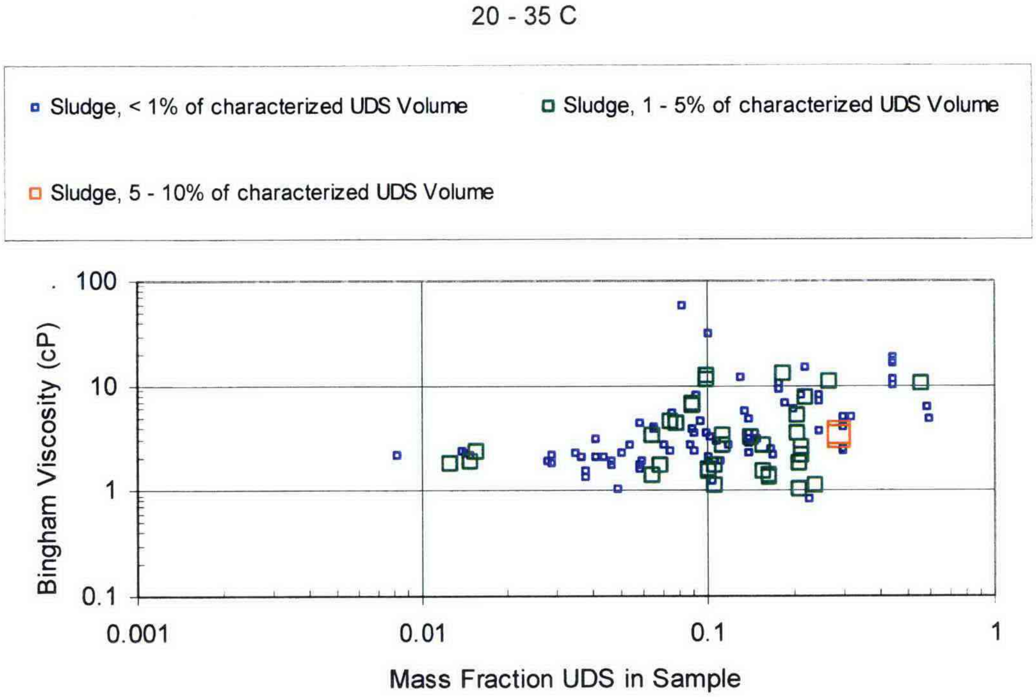


**Figure B-1. Hanford Waste Sludge Slurry Bingham Viscosity as a Function of Mass Fraction UDS, 20 - 35 C.**

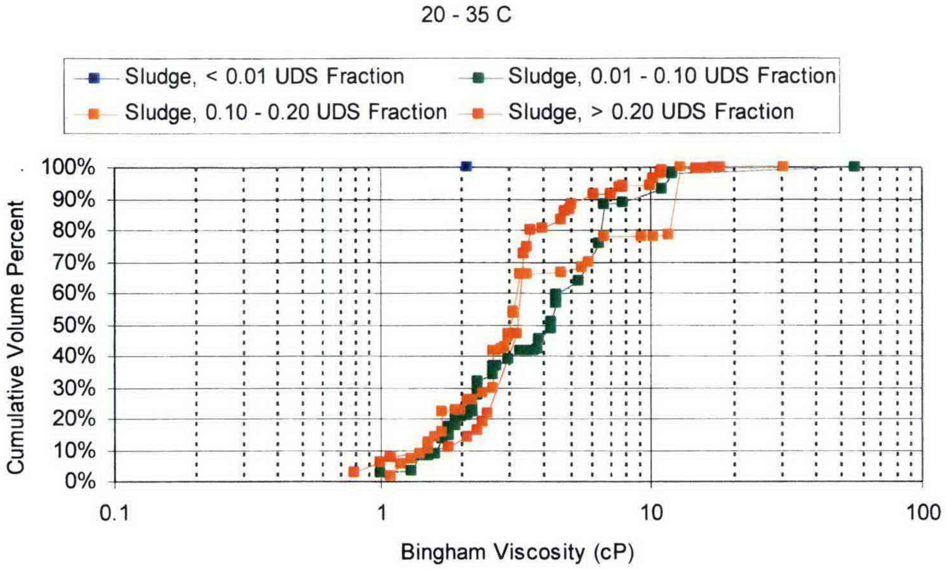


Figure B-2. Hanford Waste Sludge Slurry Bingham Viscosity, 20 - 35 C.

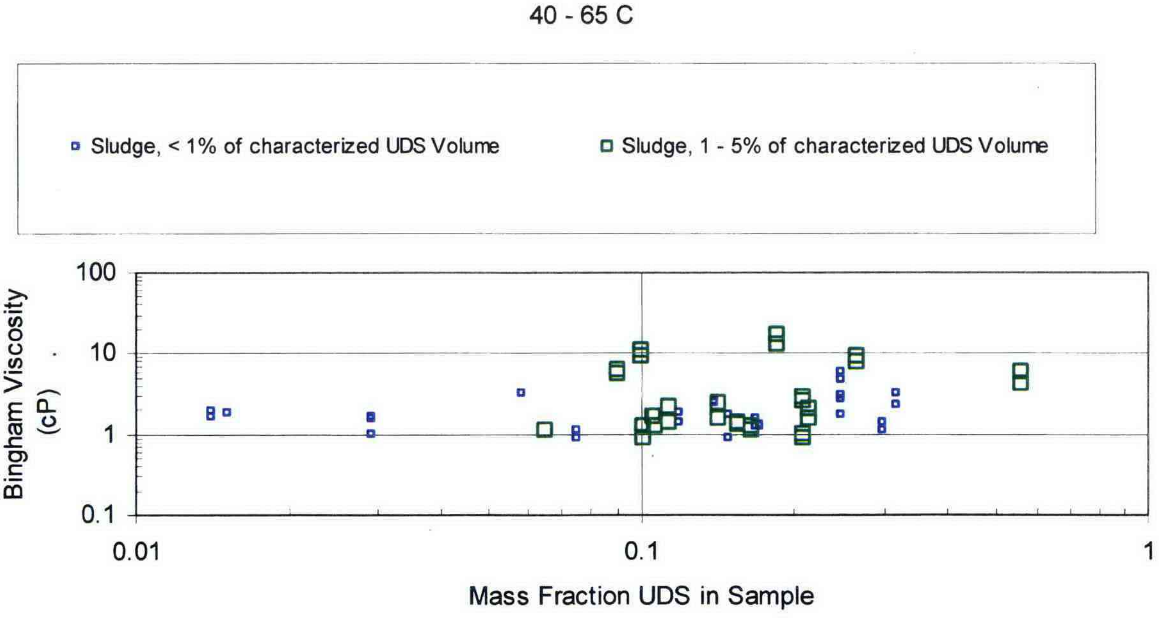


Figure B-3. Hanford Waste Sludge Slurry Bingham Viscosity as a Function of Mass Fraction UDS, 40 - 65 C.

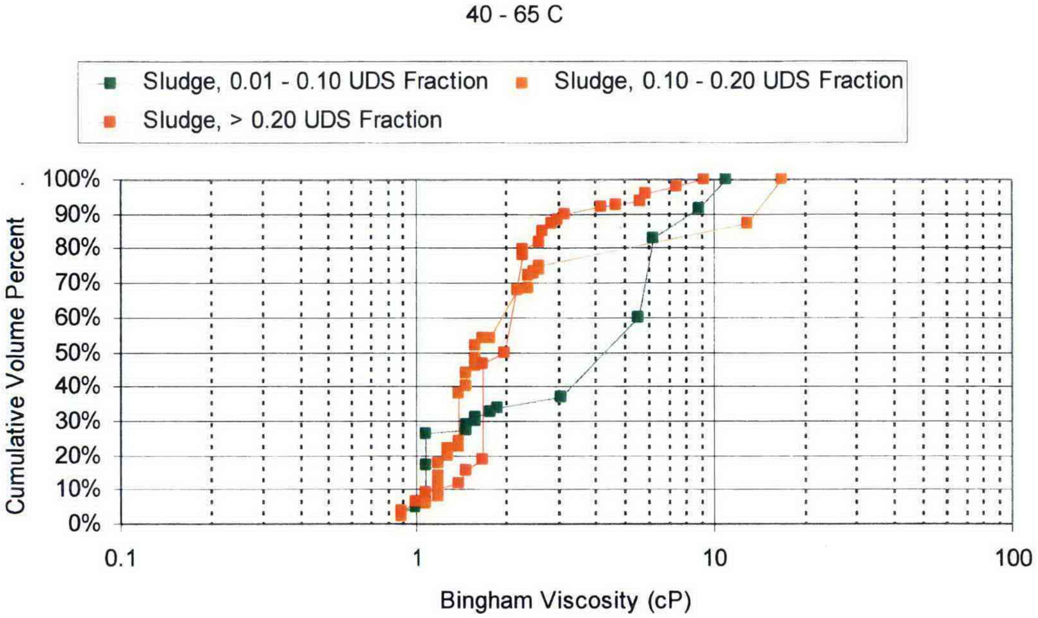


Figure B-4. Hanford Waste Sludge Slurry Bingham Viscosity, 40 - 65 C.

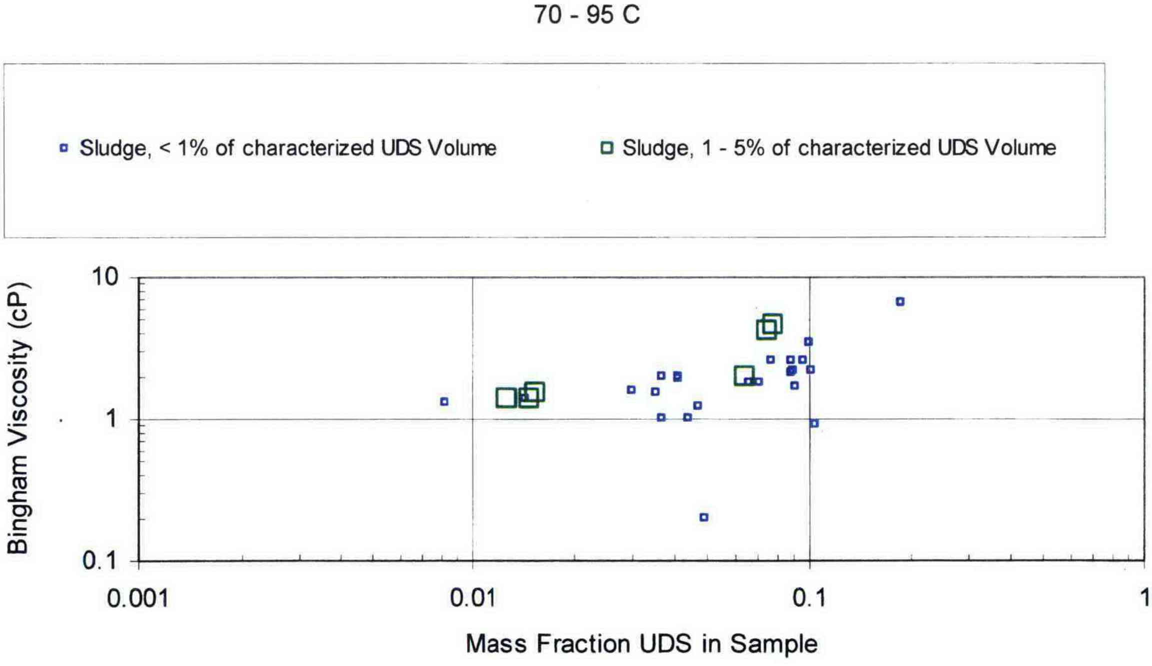


Figure B-5. Hanford Waste Sludge Slurry Bingham Viscosity as a Function of Mass Fraction UDS, 70 - 95 C

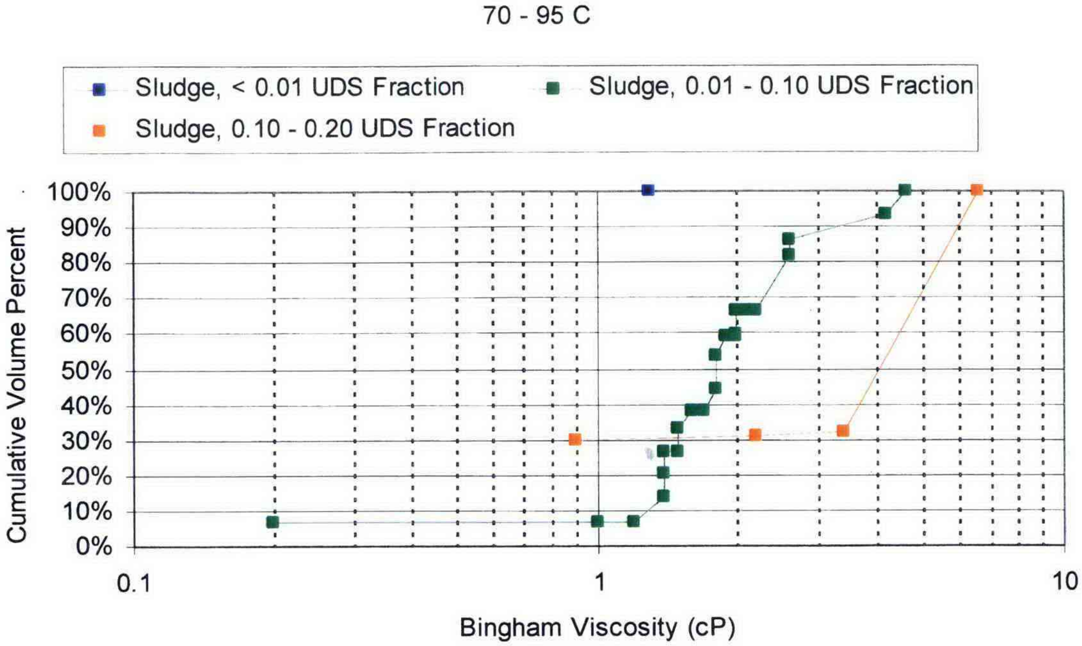


**Figure B-6. Hanford Waste Sludge Slurry Bingham Viscosity, 70 - 95 C.**

# APPENDIX C. PARTICLE SIZE DENSITY DISTRIBUTION COMPARISON PLOTS

As referenced in Section 8, PSDD comparison plots of the Low, Typical, and High conceptual simulants are provided here for the metrics of PNNL-20637 and listed in Section 8.0. The "Low" (light blue line and symbols), "Typical" (bright green line and symbols) and "High" (red line and symbols) are the Conceptual Simulants. Individual waste tank results are shown by the colored lines, and the waste composite is shown by black line and symbols. The SSMD Complex Simulant, RPP-49740, is denoted by the gold colored line and symbols.

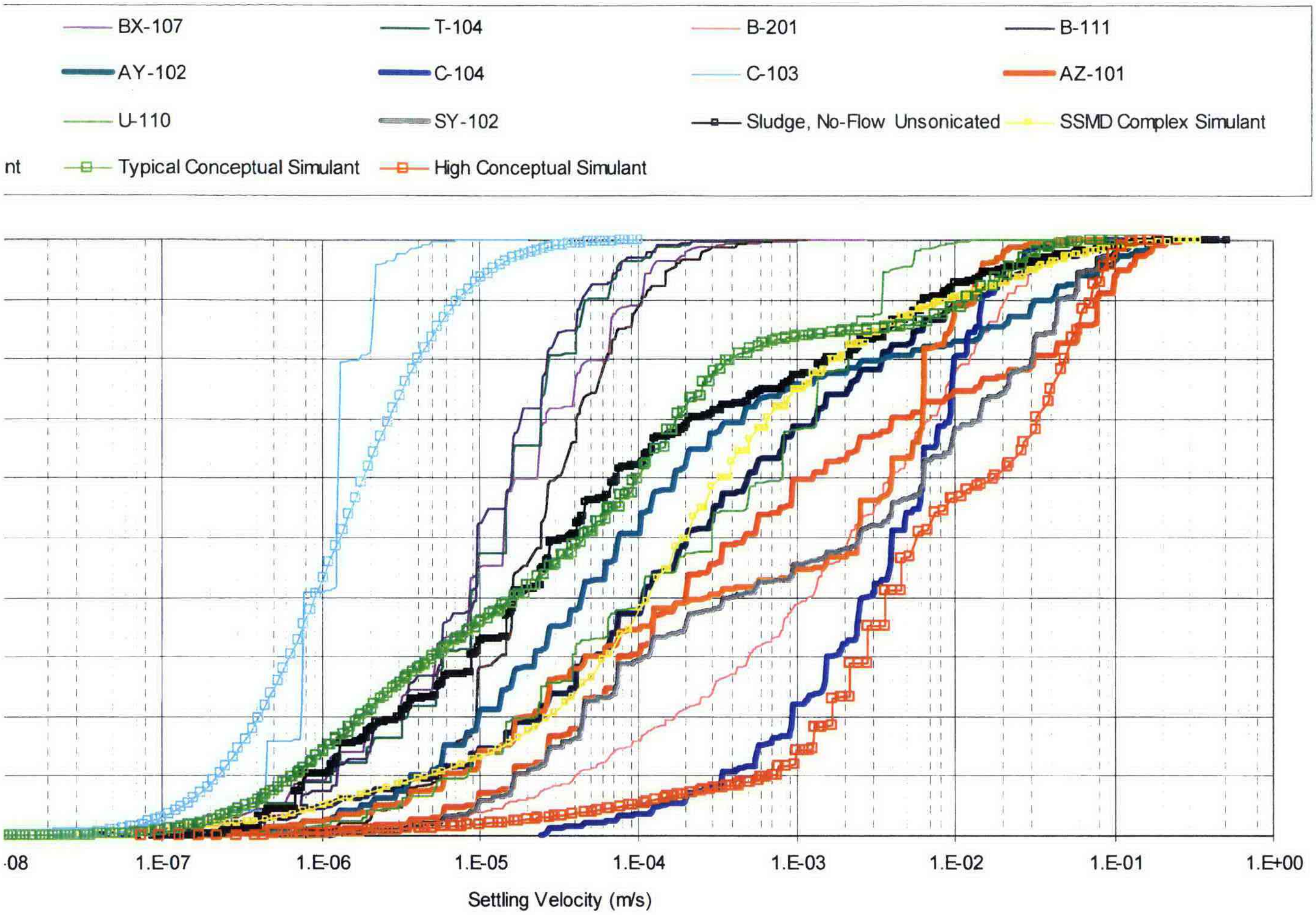


**Figure C-1. Settling Velocity Comparison.**

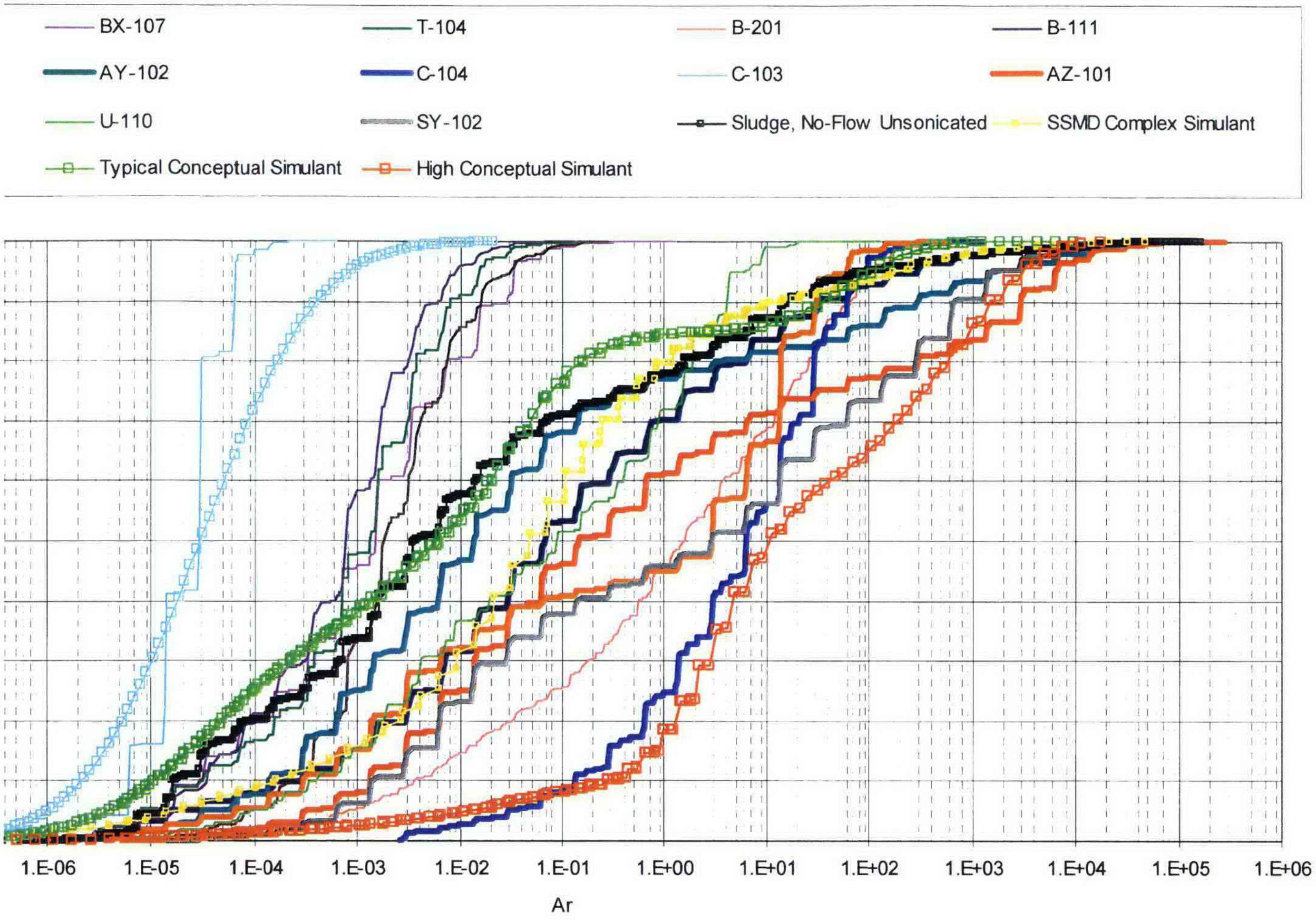
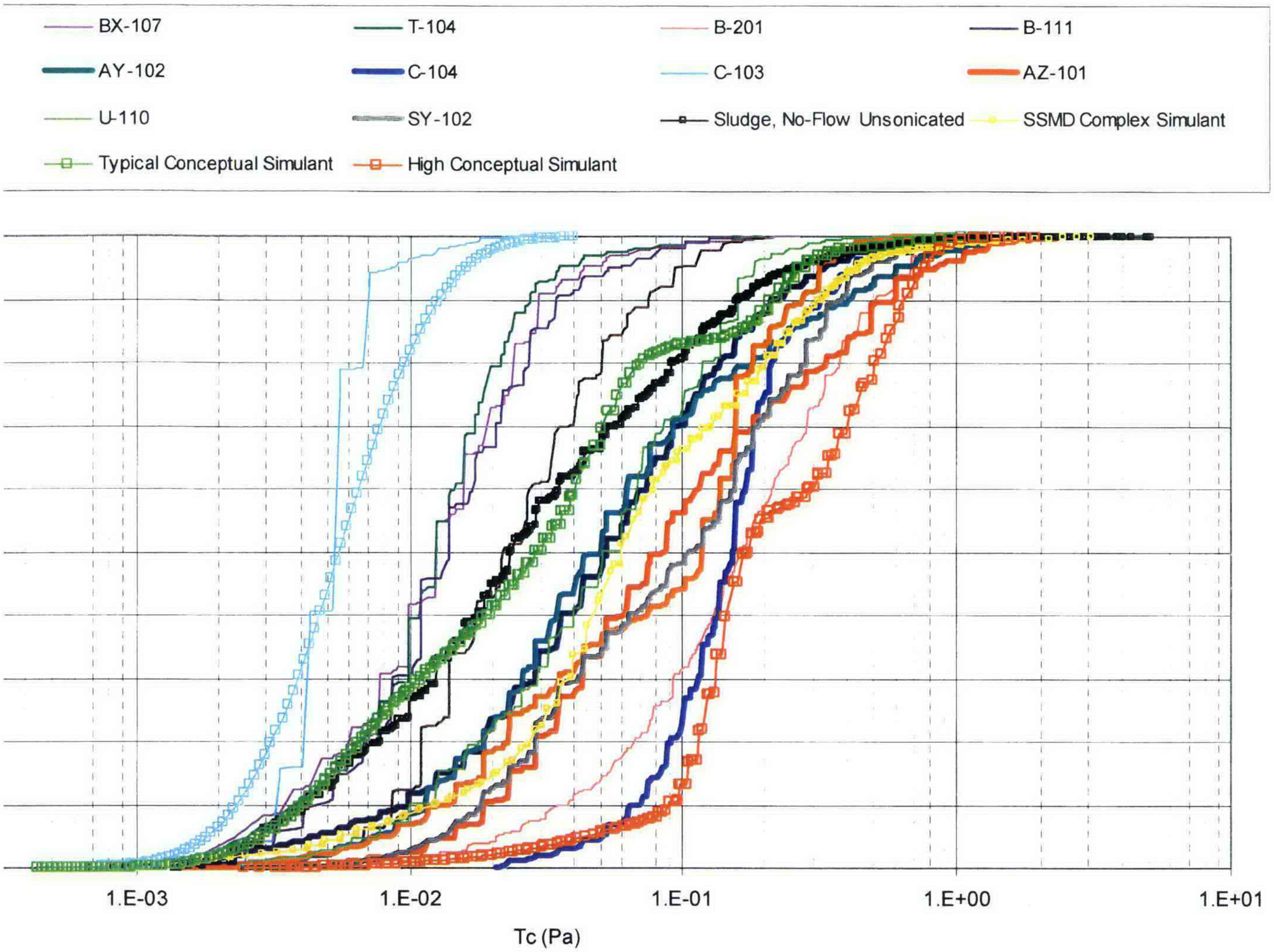


**Figure C-2. Archimedes Number Comparison.**



**gure C-3. Critical Shear Stress for Erosion of Non-Cohesive Particles Comparison.**

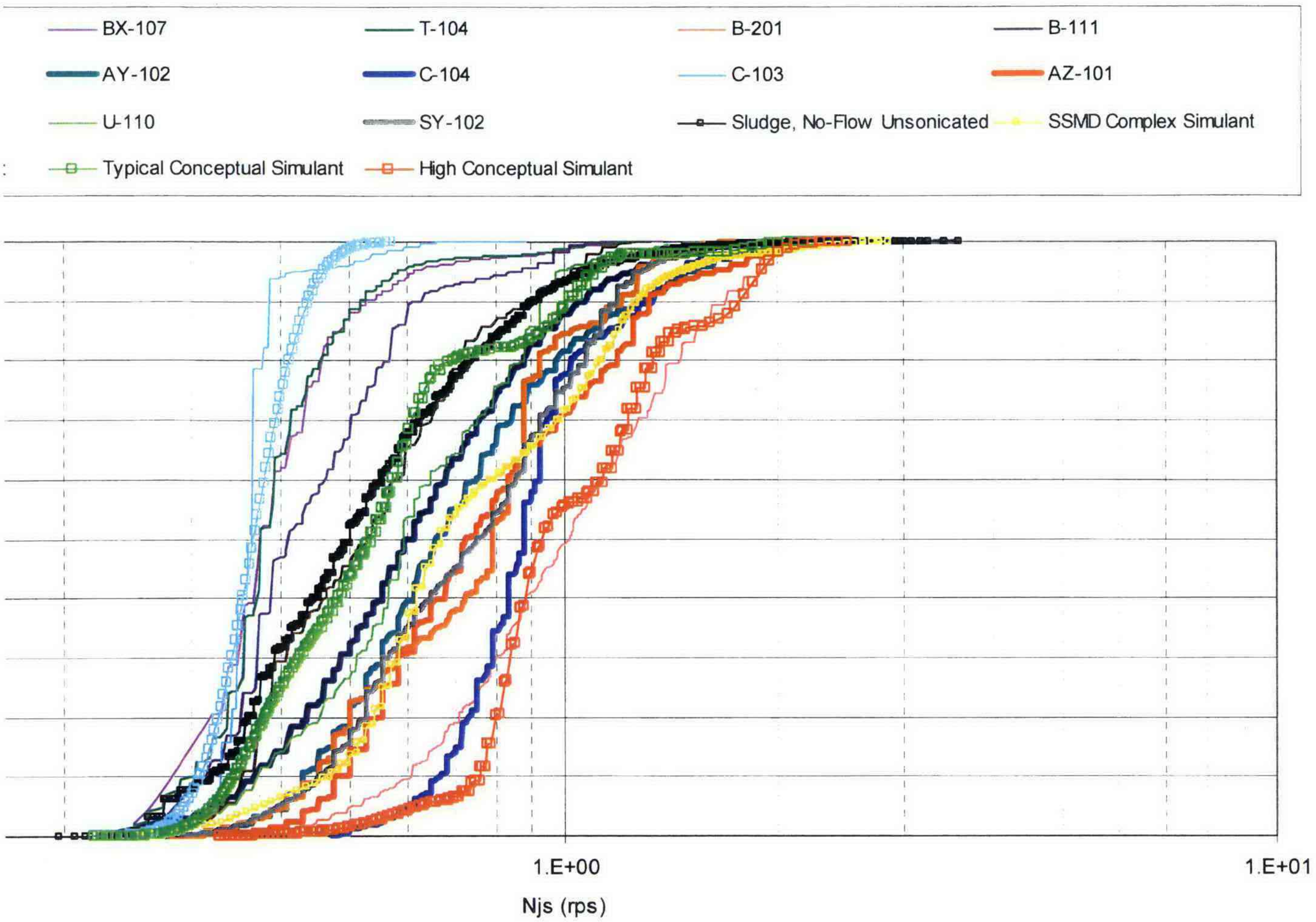
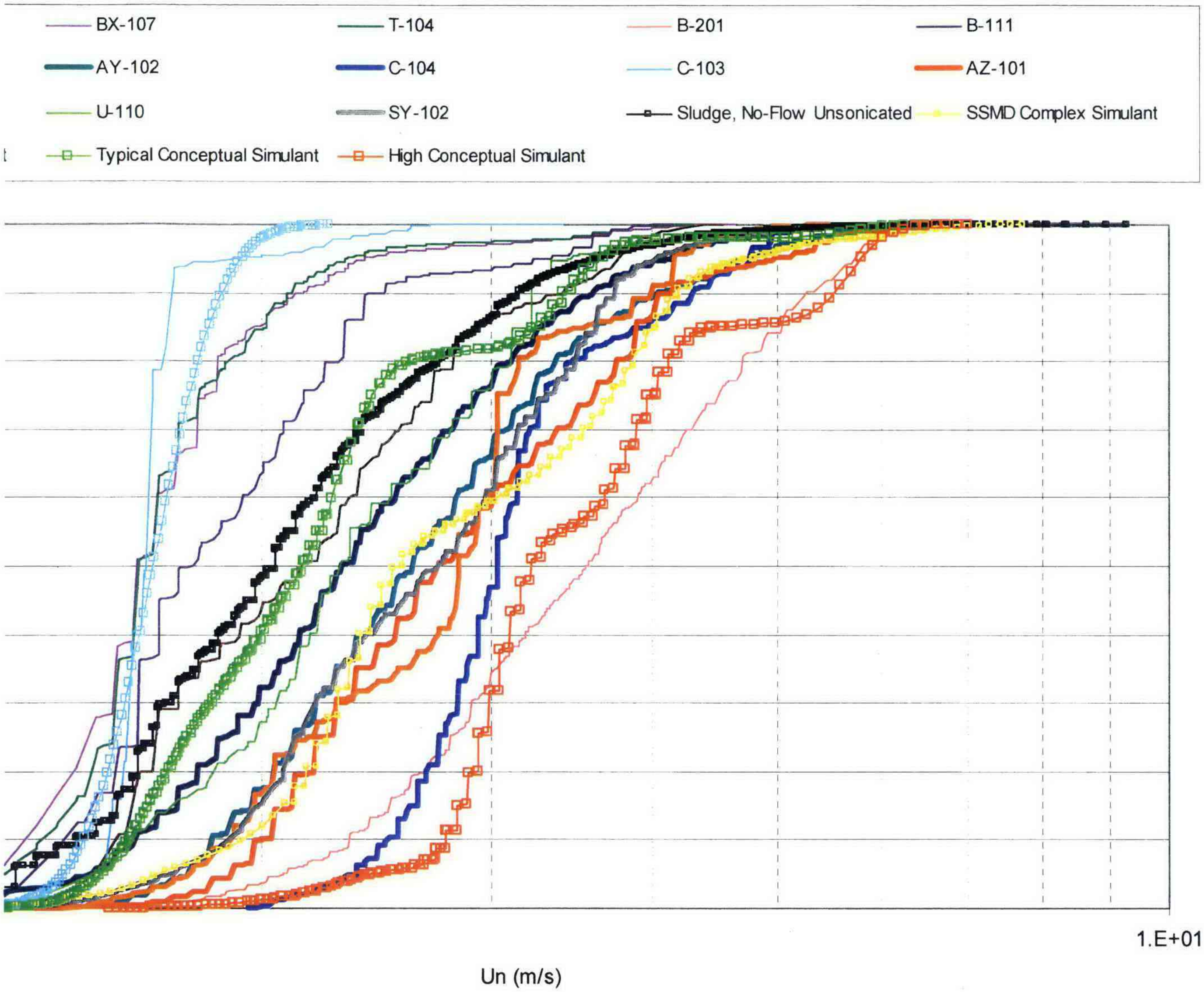
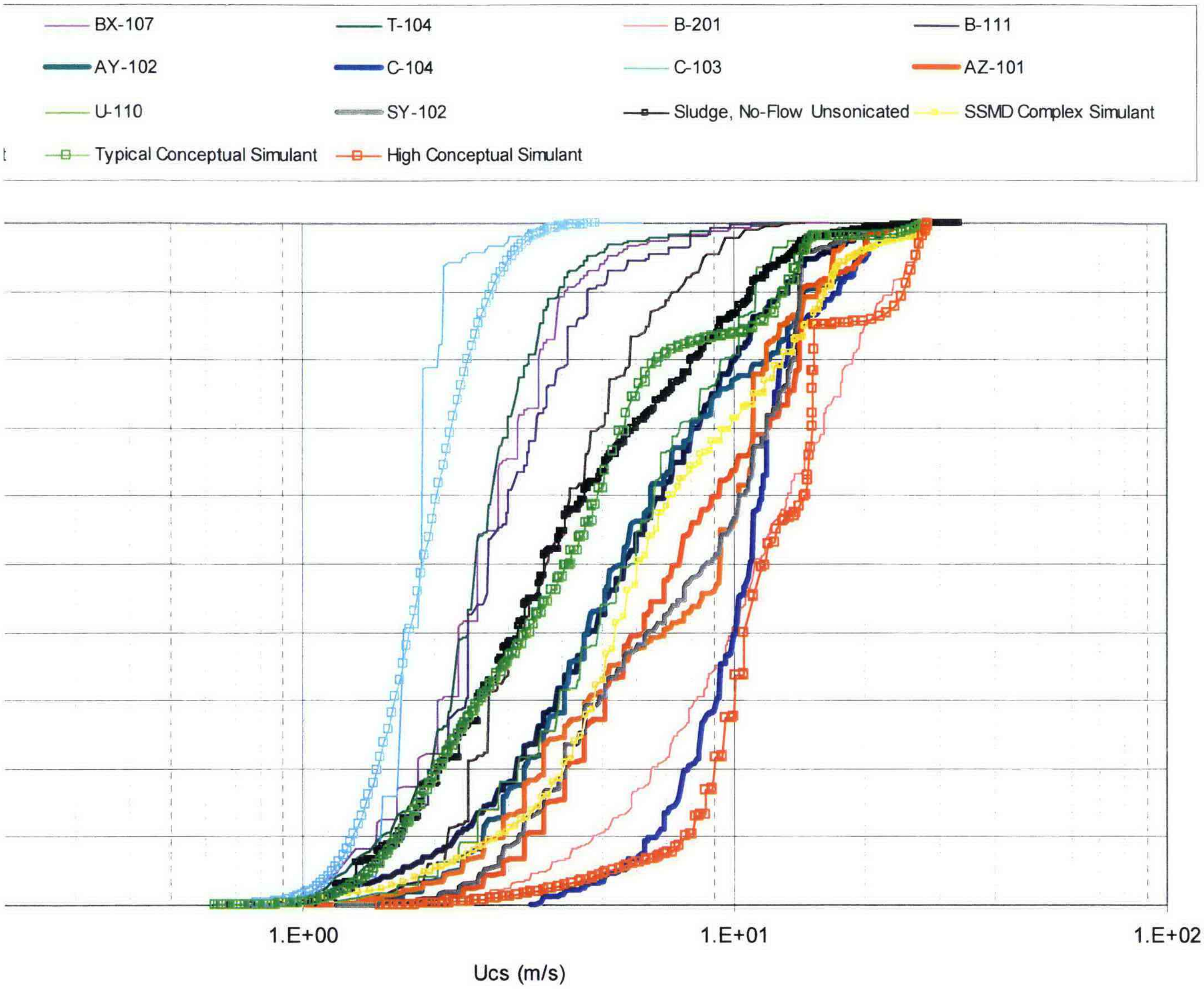


**Figure C-4. Just-Suspended Impeller Speed Comparison.**



**C-5. Jet Velocity Needed to Achieve a Certain Degree of Solid Suspension Comparison.**



**gure C-6. PJM Critical Suspension Velocity for Non-Cohesive Solids Comparison.**

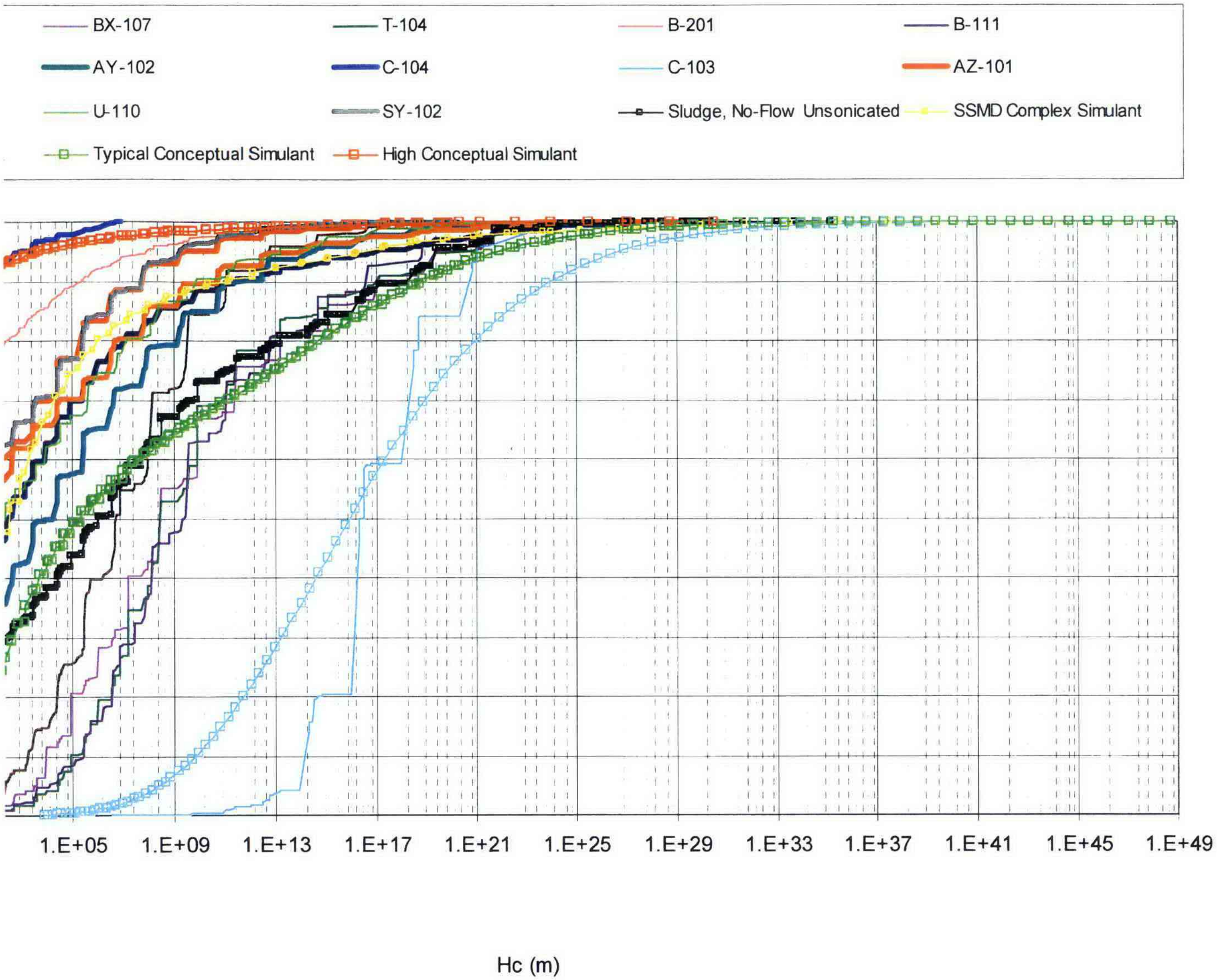


**Figure C-7. PJM Cloud Height for Non-cohesive Solids Comparison.**

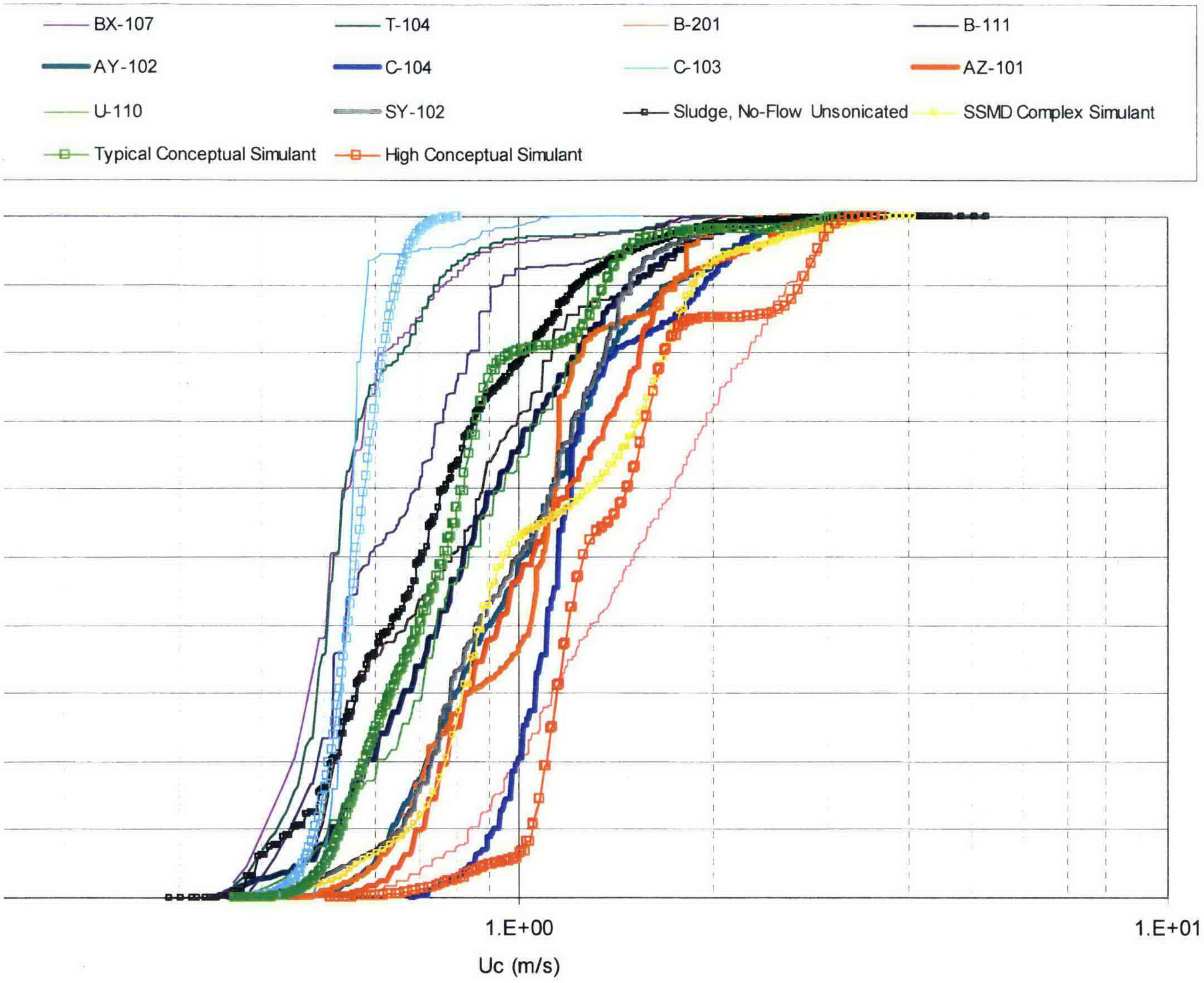


**Figure C-8. Pipeline Critical Transport Velocity Comparison.**

# DISTRIBUTION SHEET

| | | |
|---|---|---|
| To<br>Document Control | From<br>KP Lee | Page 1 of 1 |
| Project Title/Work Order<br>Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing, RPP-PLAN-51625 Rev 0 | | Date 03/19/2012<br>EDT No. N/A; DRF<br>ECN No. N/A |

| Name | MSIN | Text With All Attach. | Text Only | Attach./ Appendix Only | EDT/ECN Only |
|---|---|---|---|---|---|
| Beric Wells (PNNL) | K7-15 | | | | |
| Phil Gauglitz (PNNL) | K7-15 | | | | |
| Loni Peurrung (PNNL) | K9-09 | | | | |
| Rich Sexton | A3-06 | | | | |
| Mike Thien | B1-55 | | | | |
| Ted Wooley | B1-55 | | | | |
| Tamika Pirtle Moore | B1-55 | | | | |
| Kearn Lee | | | | | |

# ATTACHMENT 2
to
12-WTP-0120

# TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD (DNFSB) RECOMMENDATION 2010-2 IMPLEMENTATION PLAN (IP) DELIVERABLE 5.5.3.5

- WRPS Letter, from R. J. Skwarek to to Dr. L. M. Peurrung, PNNL, "One System Technical Team Response to Review of Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing (ERT-12)," WRPS-1201012-OS. (3 pages)

- LSIMS ERT Document Review Record, ERT-12 Feed Simulant Defn., "Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing," RPP-PLAN-51625, Rev 0a. (12 pages)

- ERT-12 Feed Simulant Defn, Large-Scale Integrated Mixing System Expert Review Team (L. Perurrung, R. Calabrese, R. Grenville, E. Hansen, R. Hemrajani) to Tom Fletcher, "Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing (ERT012)," dated March 2, 2012. (3 pages)

- ERT-12 Feed Simulant Defn, Large-Scale Integrated Mixing System Expert Review Team, from Loni Peurrung to Ray Skwarek, "Concurrence on Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing (ERT-12)," dated March 15, 2012. (1 page)

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WRPS-1201012-OS

Dr. L. M. Peurrung, Chair
Large-Scale Integrated Mixing System Expert Review Team
Pacific Northwest National Laboratory
Post Office Box 999
Richland, Washington 99352-0999

Dear Dr. Peurrung:

ONE SYSTEM TECHNICAL TEAM RESPONSE TO REVIEW OF WASTE FEED DELIVERY AND SAMPLING PROGRAM SIMULANT DEFINITION FOR TANK FARM PERFORMANCE TESTING (ERT-12)

The One System Technical Team appreciates the Large-Scale Integrated Mixing System Expert Review Team (ERT) review (Enclosure 1) of the subject document. This response letter addresses the one specific technical concern and the two general comments identified by the ERT. The specific technical concern is identified below followed by the One System response.

1. *The ERT continues to feel that the Zwietering Correlation (which was developed for impeller driven mixing) is not applicable to jet mixing. Zwietering has been used by Hanford and PNNL authors as one means of comparing simulant size- and density-related behavior in mixed slurries. While it is not intended to estimate specific performance parameters, the ERT feels that there are better alternatives for predicting suspension properties.*

We understand and agree with the ERT's position that the Zwietering correlation is not directly applicable to rotating jet mixing in a double-shell tank (DST) and not appropriate as a primary means of simulant performance comparison. Our technical team, in collaboration with the Waste Treatment and Immobilization Plant (WTP) mixing program team, has selected the Kale and Patwardhan (2005) correlation for the suspension of solids with radial wall jets as a more appropriate primary performance comparison metric. This metric is focused on liquid-jet stirred suspension as opposed to impeller-stirred suspension and correlates liquid-jet velocity and suspension of settled particles which is an important phenomenon that occurs in both tank farm and WTP tanks. We believe that selection of a common metric between the WTP and tank farms programs is important to allow a common comparison of simulants even though it may not precisely mimic the somewhat different mixing phenomena that occur in the feed delivery and feed receipt tanks.

The performance metrics presented in the document are not intended to precisely represent all of the physical phenomena that occur during mixing nor are necessarily directly related to mixing, sampling and transfer performance in the DST feed vessels, but rather provide an indicator of how the relationship between physical properties can be used to compare simulant and tank waste behavior. For comparison purposes, the document also presents alternative metrics that address different functionalities of particle size and density for mobilization, suspension, settling, and pipeline transfer.

The below items are the general comments from your review letter followed by the One System response.

1. *In general, the ERT finds this plan to be well written and well thought out. It does not seem to go quite as far might be expected to "define and qualify" specific simulants per the wording in the Implementation Plan. We would interpret qualification of a simulant to be the selection of a specific simulant and an evaluation of that simulant showing that it will meet certain established requirements. At this point, the simulant is still conceptual. That said, the document does seem to meet its own goal to define a simulant approach that will satisfactorily envelope the complete range of physical properties for the waste feed to WTP.*

The simulant definition document defines simulant requirements that cover a spectrum of specific testing activities that will be spaced over the remainder of the calendar year and will be governed by test-specific test plans. Qualification of simulant is integral with each test plan with the details dependent on the specific test objectives, equipment set-up, and analytical needs of each test; therefore, our approach is to define simulant qualification details in the test plans rather than the simulant definition document. In order to clarify this approach, we have added a discussion to the document that addresses the test specific nature of simulant qualification and clarifies those details will be included in the test plans.

2. *In the document, an upper limit of 20 Pa on the Bingham yield stress has been proposed. The selection of that value is (as admitted in the report) a judgment call. A stronger justification for selecting a specific upper limit would improve the plan...*

We agree with the ERT position that a stronger justification for the selected value is needed. The selection of an upper Bingham yield stress value requires judgment which balances projected tank farms retrieval, blending, and operating constraints with yet-to-be-defined WTP receipt tank performance capability. The tank farms mixing program team has reevaluated the upper limit and strengthened the justification with a link to the value used by recent non-Newtonian mixing studies (SRNL-STI-2011-00278), an analysis of potential mixing performance of the WTP receipt vessel (PNNL-17707), an estimate of volume percent of waste covered by the selected value, and an assumption of the ability to operationally adjust (e.g. dilute) outlier wastes prior to being staged in million-gallon feed delivery batches. It is acknowledged that, should WTP receipt tank testing result in a higher Bingham yield stress limit, reevaluation of tank farm testing limits will be required.

In addition to the specific responses highlighted above, the One System Technical Team has reviewed the ERT document suggestions and modified the DNFSB commitment document. The updated draft document (Enclosure 2) incorporating comments received from all reviewers, and the disposition of the ERT individual review comments (Enclosure 3) are attached for your information.

If you have any questions concerning this matter, please contact me at 372-9138, or Mr. M. G. Thien at 372-3665.

Sincerely,

R Skwarek

R. J. Skwarek
One System IPT Manager

MGT:MES

Enclosures:
1. ERT-12 Feed Simulant Defn (3 pages)
2. RPP-PLAN-51625, Rev. 0b, draft, "Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing (78 pages)
3. LSIMS ERT Document Review Record (12 pages)

cc: ORP Correspondence Control
T. W. Fletcher, ORP
R. A. Gilbert, ORP
B. J. Harp, ORP

WRPS Correspondence Control
M. D. Johnson, WRPS
S. A. Saunders, WRPS
M. G. Thien, WRPS

G. Duncan, WTP
P. K. Freeman, WTP
R. F. French, WTP
W. W. Gay, WTP
R. M. Kacich, WTP

|  |  |  |
|---|---|---|
| **LSIMS ERT<br>DOCUMENT REVIEW RECORD** | **REVIEW NUMBER:** | ERT-12 Feed Simulant Defn. |
|  | **DOCUMENT NUMBER:** | RPP-PLAN-51625 Rev. 0a |
|  | **DOCUMENT TITLE:** | Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing |

| Comment |  |  | Comments and Recommendations: | Resolution: |
|---|---|---|---|---|
| Number | Reviewer | Type* |  |  |
| 1 | LMP | O | Per the Implementation Plan for DNFSB Recommendation 2010-2, this document provides “Definition and qualification of simulants for testing to establish tank farm performance capability”. The document does a reasonably good job of “defining the objectives, criteria, and selection of simulants to be used” (per the document’s summary) but doesn’t go as far as one might expect to “qualify” simulants. Is this sufficient? | This is the scope WRPS intended, leaving flexibility in test plans to address test specific objectives. |
| 2 | LMP | O | Figure 4-1 is so conceptual that I’m not sure it’s really helpful. It may be more helpful to provide concrete examples (such as appears in the text on page 14 in reference to liquid phase viscosity). | Accepted - Figure 4-1 has been deleted. |
| 3 | LMP | E | There are many incorrect references to tables and figures in Section 6. | Accepted and Corrected |
| 4 | LMP | O | Page 20, “The range of liquid densities that are expected for each batch of waste feed is not quite as broad.” Why? It’s not clear to me why the HTWOS output is narrower than the other data. Is this a difference between waste in situ in tanks and retrieved waste, something wrong with HWTOS, ? | The HTWOS output is narrower because it reflects some blending. The text has been revised to clarify. |
| 5 | LMP | O | Is WRPS tracking the issue of the high-density transfers after 2040, described on page 20, separately? | Yes |
| 6 | LMP | E | Table 6.1 footers are missing footnote numbers. | Corrected |
| 7 | LMP | E | Figures 6.3 and 6.4 (and 6.7, 8, 11, and 12) are a little hard to understand. Is there another way to convey this information? For example, could you use the size of the symbol rather than its color to denote larger percents of the characterized volume? | Accepted |
| 8 | LMP | E | Figures 6.4 and 6.5 do not address salt cake waste. Is that okay? | Yes the document focuses on sludge waste. The document has been revised to clafify this. |
| 9 | LMP | E | Last two senteces in the first paragraph of page 26: is rheology expected to increase with temperature or decrease? The sentences | Text has been corrected |

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**O** – Optional, comment resolution would provide clarification, but does not impact the integrity of the document
**M** – Mandatory, comment shall be resolved, reviewer identifies impact on the integrity of the document

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| | | | seem contradictory. | |
| 10 | LMP | O | The selection of 20 Pa as an upper target for Bingham yield is, as admitted, somewhat arbitrary. It's hard to defend arbitrary. Is there some somewhat firmer rationale (the text notes an equipment limitation) that could serve as a basis? | This selection has been revised and the rationale strengthened. |
| 11 | LMP | E | Section 8.1.1 Seems like one of the bullets here should be "water". | Accepted |
| 12 | LMP | O | The ERT generally does not support the use of just-suspended impeller speed as predicting by the Zwietering correlation for jet mixing. | Accepted - This discussion has been revised. |
| 13 | LMP | E | Page A-5: the references to tables and figures are again off. | Corrected |
| 14 | RRH | O | Page 17- I fully agree with the statement "The critical shear stress for erosion of a settled layer on non-cohesive particles is an important parameter". I believe this is the most important parameter reflecting on capability of Rotating Pump Jet Mixer to suspend particles | Acknowledged |
| 15 | RRH | O | Page 17- It is okay to exclude for now the parameters for cohesive particles and time dependent rheological parameters. These parameters may become important if solids are allowed to accumulate for an extended period. | Yes - The testing focuses on mixing and transfer. The accumulation of solids is deemed to not directly influence the behavior of the portion of the waste that is suspended. |
| 16 | RRH | **M** | General- There are several mentions of PJMs in the document for comparison with WTP vessels. This comparison may not be helpful and applicable because PJM technology is significantly different from Rotating Pump Jet Mixing technology. Also integrating this testing and simulant selections with PJM vessels may not provide much value. | Acknowledged. Some coordination with WTP is needed and the discussion of coordination with WTP has been clarified. |
| 17 | RRH | O | Page 19-middle of page- Statement "*To fully represent the range of Hanford Waste, simulants that are representative of the most challenging and the least challenging wastes will be needed to determine the limits of performance...*" From mixing and transfer point of view if most challenging wastes are addressed, least challenging one can be assumed to be addressed; unless there are some other issues of the system | The "least challenging" or "Low" simulant will provide specific results when spiked to test limits of performance. |

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| LSIMS ERT<br>DOCUMENT REVIEW RECORD | REVIEW NUMBER: | ERT-12 Feed Simulant Defn. |
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| | | | requirements. | |
| 18 | RRH | O | Page 19 6.1- I agree with the observation that ECR increases with increase in liquid density and decreases with increase in liquid viscosity, while transfer of particles increase with increase in both density and viscosity. This can be explained by effects of density and viscosity on the settling behavior. Decrease in ECR with increase in viscosity can be explained by faster decay of velocity as viscosity increases. While particle transfer increases, the floor coverage may be reduced thereby leaving some solids behind. | Acknowledged |
| 19 | RRH | **M** | The report does not explain well why yield stress of 20 Pa has been chosen as upper limit. Data plotted in Figure 6.3,6.4,6.7 and 6.8 and Table 6-2 show some measurements at 72-100 Pa yield stress. Please explain clearly how limiting yield stress to 20 Pa is justified. | The limit has been changed to 10 Pa and the discussion revised to provide a stronger basis. |
| 20 | RRH | O | Page 32- Equation 6.1 for calculating settling velocity is different from some literature correlations that show variations in functionalities based on ranges of Particle Reynolds number. Attachment A provides one set of correlations available in the literature. | Acknowledged |
| 21 | RRH | O | 8.1.2- It should be clearly pointed out that rheopectic and thixotropic fluids have time-dependent rheology not observed with Tank Farm fluids and will not be included in the simulant. | This discussion has been revised for clarity. “While there are certainly differences in the rheological behavior of clays and actual waste, the intention in selecting kaolin and bentonite clay slurries is to minimize any rheopectic or thixotropic (time dependent rheological) behavior in the simulants.” |
| 22 | RRH | **M** | Page 38. & Section 8.3- Use of Zwietering Njs is not relevant for assessing suspension/mobilization characteristics, because this correlation was developed in agitated tanks and mechanism of flow generation is entirely different from that with horizontal jets. I suggest that Figure 8.2 should n ot be included. | Accepted, text and figure 8.2 have been modified. |
| 23 | RRH | O | 8.2- It is not clearly explained why there are three different stimulant designs. If ‘High’ stimulant is used in testing, ‘Low’ stimulant | The “Low” simulant will provide specific results when spiked to test limits of performance. |

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| LSIMS ERT<br>DOCUMENT REVIEW RECORD | | |
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| | | | may not be needed because performance for suspension and transfer would be better. | |
| 24 | RRH | **M** | 8.3- The concept of spiking is good for defining limits of performance. However the discussion covers only use of Zwietering Njs, which I believe is not relevant for mixing with horizontal jets or pumping slurry in a pipe. | Accepted |
| 25 | RRH | O | Appendix C- Since settling velocity and Ar show very similar comparison, I suggest using only one of the two. I believe Critical Shear Stress for Erosion in Figure C3 is most important for assessing suspension performance. The report does not provide equations for Jet Velocity needed to achieve a certain degree of suspension. Depending on the basis of this correlation, this parameter may or may not be relevant. Pipeline critical transport velocity as a parameter is important for solids transfer. | Acknowledged, the graphs are provided for information and use the metrics of PNNL-20637 |
| 26 | RVC | O | Section 5, p. 17: Given all the restrictions on what is being considered, exactly what type of waste will this simulant represent? If it can only address a subset of issues, how will its specification guide development of next-generation simulants? | The property of highest risk (and the primary subject of DNFSB 2010-2) is the behavior of fast settling solids. The simulant is built around properties important to transporting fast settling solids. If future work identifies other properties that are important to TOC testing, they will be addressed. |
| 27 | RVC | O | Section 5, p. 17: What are the implications of excluding particle shape? Does this mean that what ever simulant is selected for testing, it will only contain spherical particles? If this is a deferred issue, how far down the path before it is addressed? | Spherical shapes are currently thought to be conservative (harder to mobilize and transport). SRNL work is currently investigating particle shape for WTP testing. Not all particles are spherical, but specific shape requirements are not proposed or varied to support testing. |
| 28 | RVC | O | Section 5, p. 17: For partial mobilization, is it assumed that the composition of the mobilized portion is the same as for the unmobilized portion? Given the targeted PSDD, is this a good assumption? | The initial mobilization of waste will result in the composition of the mobilized portion being the same as the unmobilized portion. Where solids resettle in mounds, the composition of the settled solids and those remaining in suspension will vary. |
| 29 | RVC | O | Section 5, p. 18: Is there no design basis event under consideration for the DST's? | Reference to a design basis event for WTP has been deleted. |
| 30 | RVC | O | Section 5, p. 18: What evidence is there that the conceptual simulants defined herein have | The discussion of simulant selection has been expanded. |

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| | | | a preparaple counterpart in application? | |
| 31 | RVC | O | Section 6.0: Like others, I do not fully appreciate the weight given to a "least challenging" waste simulant. If TOC expects to get there by dilution, then you can also dilute the most challenging waste simulant. If you had to throw one out, which would it be – least or middle? How do you bring that recommendationforward to the groups tasked with the next steps? | The "least challenging" or "Low" simulant will provide specific results when spiked to test limits of performance. |
| 32 | RVC | O | p.20: High density transfers after 2040 - echo question by LMP. How would their inclusion affect Table 6.1? | If all the feed batches were included (even those beyond 2040) then the feed batch density range is from 1.11 to 1.6 g/ml and the 1.37 g/ml cited in the table would represent the 96th-percentile of the data. The 95th-percentile is ~1.36 g/ml. |
| 33 | RVC | E | Section 6: Some captions and figures need to be re-alligned. | Corrected |
| 34 | RVC | O | Figures 6.1 & 6.2: In the figures, is there an interdependence between density and viscosity? Or can any combination of wastes yield a particular density? | See the discussion in Section 6.1 |
| 35 | RVC | E | p.23, 3rd paragraph: Numerous incorrect references to Figures. | Corrected |
| 36 | RVC | O | Naïve question: Why is the waste Bingham? Am I wrong to suspect that talk farm wastes may have sufficiently deviant rheology? | The Bingham rheological model is considered imperfect, but appropriate for these purposes. |
| 37 | RVC | O | Section 6.2: Figs.6.3 to 6.14 are too much, especially given the scatter plot like nature of the non-cumulative plots. Dealing with them diffuses the message, so except for a few, examples, they should be put in an appendix. | This section has been modified. |
| 38 | RVC | O | Section 6.2: If expected trends do not always occur, what does that say about the quality, accuracy and representativeness of the data? | This section has been modified for clarity. |
| 39 | RVC | O | Table 6-2: The variation of yield stress with mass fraction jumps off the chart. How do you justify/explain the strong peak at the central mass fraction? The presence of the table raises more questions than the text associated with it can dispel. | The table has been revised and simplified for clarity. |
| 40 | RVC | O | Section 6.3: This section should be expanded a bit. It is imbalanced relative to Section 6.2. Here, most of the figures are in the appendix. | Section 6.3 defers more to section 8 to define the particulate. |

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| | | | Should we imply that Archimedes No. is the most relevant scaling parameter? See next comment. | |
| 41 | RVC | O | Section 6 & Appendix C: Eqns. 6.1 & 6.2 show the relation between settling velocity and Archimedes No. Why are both plotted (Figs.C-1 & C-2)? The broader question is what is the point of having eight different ways to look at things if some are repetitive and others are not physically relevant? You have already heard about Zwietering. No matter how well all 8 are justified, it still looks like smoke to the less informed (not less technically skilled) reader. It would be best to identify a few that are arguably the most relervant and focus on them. | Some of the section has been simplified. Some more thoroughly explained to explain the use of the plots. |
| 42 | RVC | O | Section 7, p.34: It is stated, "*Other factors that may be taken into account in selection of simulant components including staining of the equipment from materials such as iron oxide, the ease or difficulty of analysis and the related costs, and the costs of disposal.*" Analysis accuracy and costs can eventually make or break the simulat, so they should be considered sooner rather than later. | Acknowledged – The wording has been modified slightly to clarify the selection process. |
| 43 | RVC | O | Table 7-1: What diameters are specified? What is an expected mean and standard deviation? In practice, can broad distributions be tolerated? Why are the size of the clay particles not important? | The intent of Table 7-1 is to provide a range of materials that are available. In some cases the acceptable standard deviation will be related to specific analytical techniques that will be called out in the test plans.<br>Clay is used as a rheology modifier, not as a particulate. |
| 44 | RVC | O | Section 8.1: I am not sure about Newtonian vs. non-Newtonian suspending fluids. Clays form a slurry or suspension which is not a pure fluid. Will their presence alone set the yield stress and consistency? Will the presence of other particles affect rheology? | Yes, clay slurries are non-Newtonian yield stress fluids. The addition of particles will be done at a range to avoid significant impact to the rheology. |
| 45 | RVC | O | p.37: Why do you bring up rheopetic and thixotropic behavior here after having dismissed them previously? Are the rheopectic properties of clay a significant, unresolved or controversial issue? | No, the point is to minimize the time dependent behavior in the simulants. |
| 46 | RVC | O | Figure 8.2: Zwietering already discussed. | Accepted |
| 47 | RVC | O | Figures 8.3 to 8.9: These could be put in an | Accepted |

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| | | | appendix. It would be quite useful to include the standard deviations and other meaningful statistics in Table 8.3. | In some cases the acceptable standard deviation will be related to specific analytical techniques that will be called out in the test plans. |
| 48 | EKH | E | Page vi, EXECUTIVE SUMMARY: primary objective addresses the need to mix, sample and transfer fast settling particles. Could additional (more detail on why NN have to be tested) discussions be provided why non-Newtonian fluids should be included? NN fluid can have properties that easily negate the safety issue stated in the first paragraph. | Acknowledged, some additions to the executive summary have been made |
| 49 | EKH | E | Page vi, Page vi, EXECUTIVE SUMMARY: Recommend stating why the low PSD simulant (3rd para) is worthy of testing, since this is contrary to the objective (e.g. fast settling particles). | The "Low" simulant will provide specific results when spiked to test limits of performance. |
| 50 | EKH | E | Page, 12, background 2nd para: Recommend providing a table of physical properties of interest in the present "WAC". This provides the reader a point of reference. | The proposed testing is evaluating limits of performance which are not identified in the current WAC. The risk is related to fast settling solids which are not currently identified as an acceptance criteria. |
| 51 | EKH | E | Page, 12, background 2nd para; This is for my information only, was transfer not an identified as an original risk? This seems to be repeated in section 3.0 as well. | The risks cited are related to transfer and sampling capabilities as they relate to emerging waste acceptance criteria. |
| 52 | EKH | E | Page 17, 2nd to last para: Recommend stating that viscoelastic polymer solutions must be avoided as well as fluids where the continuous phase (liquid) is non-Newtonian. Fluids with such properties affect both the settling behavior of solids and as well as general flow behavior that is not consistent with actual waste behavior. | This statement has been simplified. |

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| **LSIMS ERT DOCUMENT REVIEW RECORD** | **REVIEW NUMBER:** | ERT-12 Feed Simulant Defn. |
|---|---|---|
| | **DOCUMENT NUMBER:** | RPP-PLAN-51625 Rev. 0a |
| | **DOCUMENT TITLE:** | Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing |

| | | | | |
|---|---|---|---|---|
| 53 | EKH | O | Page 17, last paragraph. I highly recommend that if testing is performed using a non-Newtonian (NN) simulant such as kaolin, tests should be performed to determine if the mixing system can adequately mix the settled bed (containing solids) to a homogenized state. In this case, time dependent properties maybe of importance, though for the real wastes they are unknown. Trying to mix a settled bed to a homogenized state is a different problem than trying to mix a homogenized NN fluid that contains solids. **NOTE,** I'm presently doing some vane tests with Kaolin that has been used to support the Hanford Tank farm testing at SRNL. Starting wt% is 33.5% and Bingham Plastic yield stress is around 35 to 40 Pa. The homogenized kaolin was placed into a 1 foot diameter by 5 feet tall vessel and has been allowed to settle for 10 weeks. It has only settled 11.3%. Settled bed height might have to be considered, if such tests are to be performed. | The proposed testing is not focused on cleaning of the tank, but on limits of transfer and sampling. |
| 54 | EKH | E | Page 18, 2nd Para: I didn't know the ASTM was used in any simulant program as of yet (due to it was recently issued). If so, provide references where the ASTM was used for simulant development. WTP has a procedure that was used for simulant development and it was also used to develop this ASTM. NOTE: It is my understanding that WTP will have to use their procedures, not the ASTM. | The statement has been clarified to state that the standard was used in the development of this simulant definition. |
| 55 | EKH | O | Section 6.1. My definition of salt cake is verify specific, it's the crystalized state of the salts. Recommend you use salt solutions rather than salt cake. | As explained on page 20, definitions are based on RPP-10006, Rev. 8, |
| 56 | EKH | O | Table 6-1. The upper limit of 50 cP is unrealistic. Do you really expect to process a salt solution that has such a high viscosity in the tank to WTP? The data that you obtain from such tests would be meaningless. | Table 6-1 has been revised to focus only on the feed batches as modeled by HTWOS. |

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| 57 | EKH | O | Page 20/21, Table 6-1. From this table, which set of data are you recommending for testing, specifically the upper limit for both carrier fluid density and viscosity? Not clear. | Table 6-1 has been revised to focus only on the feed batches as modeled by HTWOS. |
| 58 | EKH | O | Section 6.2, the figures are very confusing and not described in adequate detail in this section. Dr. Wells provided a verbal description, but even that at times got confusing. This data, if used, needs to be presented or described better. | This section has been updated. |
| 59 | EKH | O | Page 31, Table 6-2 is inconsistent. Recommend removing the >0.20 data unless additional reasoning is provided why the Bingham Plastic properties change to a thinner fluid as the solids content increases. This only adds more confusion. Also, exclude data that is above what will be considered the maximum operating or processing temperature. | Table 6-2 has been simplified, but still retains the same temperature and mass fraction UDS ranges. |
| 60 | EKH | O | Page 31, there has to be a better way to describe what the maximum yield stress of the Bingham Plastic fluid should be. Mechanical systems have limitations that are dependent on physical properties and if such systems have been selected, then these limits should be used as a starting basis. For instance, I do not expect that you'll be able to mix a vessel containing a fluid with a BP yield stress of 70 Pa. Even a 20 Pa fluid will be challenging, especially for a full tank. | This section has been updated with a lower limit and more rationale. |
| 61 | EKH | O | Page 31, the upper limit of 20 Pa should have a better basis. If the equipment cannot mix such a fluid, why test it! Note that this document does not provide any relationship on how to scale using NN properties. Is this going to be provided in another document? If so, state it. | This section has been updated with a lower limit and more rationale. |
| 61A | EKH | O | Section 6.2. Recommend how one goes about getting to a steady state NN fluid, starting with a settled bed of cohesive material (containing large particles). Time effects cannot be ignored. The erosive behavior of the settled bed will also determine how much time it may take to homogenize the mixing vessel. | This testing does not focus on cleaning of the tank or the time required to homogenize. |

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| 62 | EKH | E | Page 32, please provide additional detail why the "low" simulant should be tested, since this is contrary to the DFSNB recommendation. | The "Low" simulant will provide specific results when spiked to test limits of performance |
| 63 | EKH | O | Page 34. Where did you guys get this definition of "'Mohs hardness' is a numerical value given to material that communicates the solidity of the simulant"? Please provide this reference (an external reference, not an internal reference) that defines Mohs hardness as stated in this document. Or revise the statement on what Mohs hardness is and how it is used for simulant development. Also clearly state that there has been no "Mohs hardness" measurements obtained on actual waste. | The definition and its use herein has been clarified. |
| 64 | EKH | E | Table 7-1, Size and Micron should be one table. Also recommend have a column for the vendor if known. | The size in microns column has been moved alongside the nominal size column. The intent of the table is to provide a range of materials available for this selection, not to guide or limit procurement. Therefore, vendors have not been listed. |
| 65 | EKH | E | Page 35, table 7-1, Iron oxide, laponite, kaolin, and bentonite have size data and some also have mohs data. Complete the table. | These are listed as rheology modifiers, so the size and hardness are not considered. |
| 66 | EKH | E | Section 8.1.2. Consider the effect of settled beds (time effects to erode and mix), though not quantified for actual wastes, since homogenizing to 20 Pa requires a bed that has a higher yield stress than 20Pa. | This testing does not focus on cleaning of the tank or the time required to homogenize. |
| 67 | EKH | E | Section 8.1.2, pg. 37. The 80:20 mixture may not settle that much if you're targeting a 20 Pa fluid. A different combination maybe required. | The limit has been reduced and provided with more rationale. |
| 68 | EKH | E | Section 8.2, pg 38, 1st burger dot: Recent testing by WTP on their 6 part simulant is contrary to 2nd to last paragraph. Light scattering will typically yield a large PSD than sieving for larger particles. Also see the following reference provide by WTP. http://www.malvern.com/LabEng/technology/laser_diffraction/sieve_results.htm | The statement summarizes the test results cited. |

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## LSIMS ERT
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| 69 | EKH | E | Section 8.2. Do not recommend using Njs as one of the primary means of comparison, since this correlation was developed for a mechanical agitator centrally located in a mixing vessel, typically with baffles, not for a continuous jet pump in a +1M gallon mixing vessel with no symmetry to itself. You can use Njs, but done make it a primary metric. I believe the other ERT members have added comments to such use. | It is included in Table 8.1 along with several other metrics. |
| 70 | EKH | E | Section 8.2. How were the PSD measured? Provide both figure and tabular data (see below for an example). Some people like to have the raw data as well. | We can provide this as requested. This is beyond the scope we intend for this document. |
| 71 | EKH | O | Section 8.3. Recommend using another metric as an example and also show how it would shift the PSD distribution from a baseline condition(s). | This was the only available metric to make this point with a polydispersed system. |
| 72 | EKH | O | Section 9.0. No discussion of NN fluids? Please provide some discussion on NN fluids. | This section has been expanded. |
| 73 | EKH | E | Appendix A. Check Table references, rather than A - #, it has 4 - #. | Corrected |
| 74 | EKH | E | Page A-8, Pulse Echo. Does it measure the critical velocity of the fluid flow in the pipe or the critical velocity of the solids? | The statement is clarified to "as it measures the critical velocity of the particulate carried by fluid flowing in the pipe." |
| 75 | EKH | E | Page A-8, last para: What were the particle size range for the gibbsite and iron oxide? Please provide for completeness. | Particle sizes included in the report have been added. |
| 76 | EKH | O | Appendix B. Is saltcake going to be transferred to the WTP? If not, why do we have this data? Is the salt cake at Hanford not soluble? As before, confusing figures. | Saltcake figures have been removed |
| | RKG | | All comments have been addressed by other ERT members. | Acknowledged |

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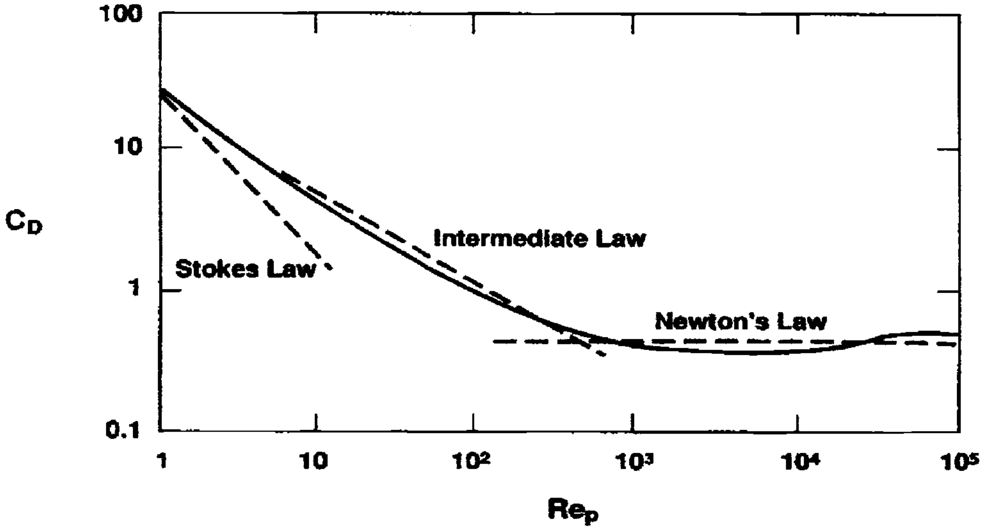
# AppendixA

# PARTICLE SETTLING VELOCITY

**EQUATION OF PARTICLE MOTION UNDER GRAVITATIONAL FIELD AND ZERO ACCELERATION FOR SPHERICAL PARTICLES**

**TERMINAL SETTLING VELOCITY** $u_t = \sqrt{\dfrac{4gD_p\Delta\rho}{3\rho C_D}}$

**THE DRAG COEFFICIENT $C_D$ HAS DIFFERENT FUNCTIONALITIES WITH PARTICLE REYNOLDS NUMBER $R_{ep}$ IN THREE DIFFERENT REGIMES**



| Region | Stokes | Intermediate | Newton's |
|---|---|---|---|
| $Re_p$ | < 0.3 | 0.3 - $10^3$ | $10^3$ - $10^5$ |
| $u_t$ = | $\dfrac{g\,D_p^2\,\Delta\rho}{18\,\mu}$ | $\dfrac{0.15\,g^{0.7}\,D_p^{1.14}\,\Delta\rho^{0.7}}{\rho^{0.3}\,\mu^{0.4}}$ | $1.74\sqrt{\dfrac{gD_p\,\Delta\rho}{\rho}}$ |

## Large-Scale Integrated Mixing System Expert Review Team

(L. Peurrung, Chair; R. Calabrese, R. Grenville, E. Hansen, R. Hemrajani)

**To:** Tom Fletcher, Tank Farms Federal Project Director; Michael D. Johnson, WRPS President and Project Manager, Tank Operations Contract

**Cc:** Ray Skwarek, One System IPT Manager; Rick Kacich, One System IPT Deputy Manager; Mike Thien; ERT Members

**Subject:** *Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing* (ERT-12)

**Date:** March 2, 2012

The Large-Scale Integrated Mixing System Expert Review Team (ERT) was asked to review the draft WRPS document *Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing*, RPP-PLAN-51625 Rev 0a. WRPS will issue this document to meet Commitment 5.5.3.5 of the Implementation Plan for DNFSB Recommendation 2010-2. Per the Implementation Plan, this document provides "Definition and qualification of simulants for testing to establish tank farm performance capability" as part of an effort to "conduct testing to determine the range of waste physical properties that can be retrieved and transferred to WTP and determine the capability of tank farm staging tanks sampling systems to provide samples that will characterize waste and determine compliance with the (Waste Acceptance Criteria)". Per the summary of RPP-PLAN-51625 itself, it more specifically "defines the objectives, criteria, and selection of simulants to be used in tank farm performance testing. Specific recipes will be subsequently defined in test plans and finalized after the preparation and sampling of trial batches." The document previously reviewed by the ERT, "Waste Feed Delivery Mixing and Sampling Program Plan and Test Requirements", included a section describing simulant philosophy. Specifically, that document indicated that:

> "Successful completion of the TOC Mixing and Sampling Program depends upon the selection of appropriately complex simulants that are reflective of expected tank conditions, integrated with WTP simulant selection, and supported by accurate analytical techniques to characterize the material of interest. Testing will use more complex simulants that are more representative of all Hanford tank waste... ASTM C1750-11 (Standard Guide for Development, Verification, Validation, and Documentation of Simulated High-Level Tank Waste) will be used for guidance on simulant selection. The guidelines will be used to help identify realistic simulants that envelope the complete range of physical properties for the high-level waste expected to be staged for WTP WFD."

The lines of inquiry for the ERT's review were:

- Are these simulants appropriate and technically defensible to meet the needs of the testing described? Do they meet the objective of selecting appropriately complex simulants that are reflective of all Hanford waste and expected tank conditions and therefore envelope the complete range of physical properties for the waste feed to WTP?

In general, the ERT finds this plan to be well written and well thought out. It does not seem to go quite as far might be expected to "define and qualify" specific simulants per the wording in the Implementation Plan. We would interpret qualification of a simulant to be the selection of a specific simulant and an evaluation of that simulant showing that it will meet certain established requirements. At this point, the simulant is still conceptual. That said, the document does seem to meet its own goal to define a simulant approach that will satisfactorily envelope the complete range of physical properties for the waste feed to WTP.

The ERT has one specific technical concern that has been previously conveyed to WTP. The ERT continues to feel that the Zwietering correlation (which was developed for impeller driven mixing) is not applicable to jet mixing. Zwietering has been used by Hanford and PNNL authors as one means of comparing simulant size- and density-related behavior in mixed slurries. While it is not intended to estimate specific performance parameters, the ERT feels that there are better alternatives for predicting suspension properties. We would be happy to work with the document authors and with WTP to identify a different performance measure to highlight simulant comparisons. We do agree with the authors that critical shear stress for erosion of a settled layer is an important measure for this system.

In the document, an upper limit of 20 Pa on the Bingham yield stress has been proposed. The selection of that value is (as admitted in the report) a judgment call. A stronger justification for selecting a specific upper limit would improve the plan. Presumably, a higher yield stress could result in more transport of heavy particles to WTP. It is easier to conclude that the simulants "envelope the complete range of physical properties" if a higher value is used. Yet, if waste is expected to be diluted during retrieval or to meet WTP acceptance criteria to a much lower yield stress, then high values are unrealistic and much time and effort in testing could be wasted.

Comments from individual ERT members (attached) are offered to help improve the document. The ERT hopes you find this review helpful, and we look forward to your response per the ERT Charter.

**Review Participants:**

***February 27, 2012***: Rich Calabrese, Ramesh Hemrajani, Richard Grenville, Erich Hansen, Loni Peurrung, Beric Wells, Mike Thien, Rich Sexton, Pat Lee

***March 1, 2012:*** Rich Calabrese, Ramesh Hemrajani, Richard Grenville, Erich Hansen, Loni Peurrung

**Large-Scale Integrated Mixing System Expert Review Team**

(L. Peurrung, Chair; R. Calabrese, R. Grenville, E. Hansen, R. Hemrajani)

**To:** Ray Skwarek, One System IPT Manager

**From:** Loni Peurrung, Chair, Large-Scale Integrated Mixing System Expert Review Team

**Subject:** Concurrence on *Waste Feed Delivery and Sampling Program Simulant Definition for Tank Farm Performance Testing* (ERT-12)

**Date:** March 15, 2012

Dear Mr. Skwarek:

The Large-Scale Integrated Mixing System Expert Review Team (ERT) concurs with the WRPS disposition of ERT comments documented in our review ERT-12 Feed Simulant Defn as described in your response letter WRPS-1201012-OS. We will be taking a deeper look at the correlation by Kale and Patwardhan for jet mixing. While we haven't had time to study this paper in detail, we agree that it is more appropriate than Zwietering for this application, and we understand that it is being used in conjunction with other well established measures such as settling velocity and Archimedes number. The explanation of your approach to simulant qualification is adequate, and we appreciate the addition of that discussion to the document. The justification of your selection of an upper limit value on Bingham yield stress has been improved, and the ERT can support the revised value (10 Pa vs. 20 Pa in the draft document) since you acknowledge that you will reevaluate testing limits in the future if this value proves not to be conservative.

There has been some dialog to resolve two specific detailed comments by an ERT member. We propose amending the comment resolution form as attached with another attachment documenting that email dialog.

This letter closes review ERT-12 Feed Simulant Defn.