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

AUG 16 2012

12-WTP-0255

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

Dear Mr. Chairman:

TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD (DNFSB) RECOMMENDATION 2010-2 IMPLEMENTATION PLAN (IP) DELIVERABLE 5.5.3.6 (SECOND DOCUMENT)

This letter provides the deliverable responsive to Commitment 5.5.3.6 of the U.S. Department of Energy, Waste Treatment and Immobilization Plant (DOE-WTP) plan to address WTP Vessels Mixing Issues, IP for DNFSB 2010-2.

An attachment provides the second of three test plans to establish Tank Farm performance capability. Testing will be conducted to determine the range of waste physical properties that can be retrieved and transferred to WTP and determine the capability of Tank Farm staging tank sampling systems to provide samples that will characterize waste and determine compliance with the waste acceptance criteria.

This test plan identifies and describes testing activities that will be performed to address the technical risks associated with waste feed delivery mixing and sampling. The plan has been prepared separately so that the initial test results can inform this testing. The change to sequential delivery of three test plans will be reflected in the revision to the DNSFB 2010-2 IP currently under development.

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) 376-8830, or your staff may contact Ben Harp, WTP Start-up and Commissioning Integration Manager at (509) 376-1462.

Sincerely,

Scott L. Samuelson, Manager
Office of River Protection

WTP:WRW
Attachment

cc w/attach: (See page 2)

cc w/attach:

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M. R. Johnson, WRPS
S. A. Saunders,WRPS
R. G. Skwarek, WRPS
M. G. Thien, WRPS
BNI Correspondence
WRPS Correspondence

Attachment
to
12-WTP-0255

TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SFAETY BOARD (DNFSB) RECOMMENDATION 2010-2 IMPLEMENTATION PLAN (IP) DELIVERABLE 5.5.3.6 (SECOND DOCUMENT)

Total No. of Pages, excluding coversheet: 241

washington river protection solutions
PO Box 850
Richland, WA 99352

August 9, 2012 WRPS-1203074-OS

Ms. S. E. Bechtol, Contracting Officer
U.S. Department of Energy
Office of River Protection
Post Office Box 450
Richland, Washington 99352-0450

Dear Ms. Bechtol:

CONTRACT NUMBER DE-AC27-08RV14800 – ONE SYSTEM - WASHINGTON RIVER PROTECTION SOLUTIONS LLC TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD RECOMMENDATION 2010-2 IMPLEMENTATION PLAN REQUIREMENTS FOR COMMITMENT 5.5.3.6 (SECOND DOCUMENT)

One System transmits the enclosed documents to support the U.S. Department of Energy, Office of River Protection (ORP) transmittal of the commitment requirements to the Defense Nuclear Facilities Safety Board (DNFSB). In accordance with the Washington River Protection Solutions LLC 2010-2 Commitment Document Review Plan, we have completed the second document associated with DNFSB Recommendation Commitment 5.5.3.6 and are providing the appropriate documents to ORP. Support documents include the following:

- RPP-PLAN-52623, Rev. 0, "One System Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan" (Enclosure 1)

- WRPS-1202839-OS, WRPS Large-Scale Integrated Mixing System Expert Review Team (ERT) Comment Response Letter to L. M. Peurrung, ERT Chair. Letter also includes ERT comment dispositions and draft document with ERT review comment incorporations (Enclosure 2)

- ERT Comment Response Concurrence Letter (Enclosure 3)

As previously discussed with ORP and DNFSB staff, this test plan is the second of three test plans associated with DNFSB 2010-2 Commitment 5.5.3.6. This change to a sequential delivery of multiple test plans will be reflected in the proposed revision to the DNFSB 2010-2 Implementation Plan currently being developed.

If you have any questions concerning this matter, please contact Mr. M. G. Thien at 372-3665 or Mr. S. A. Saunders at 372-9939.

Sincerely,

(Signature Attached)

R. J. Skwarek, Project Manager
One System Integrated Project Team

(Signature Attached)

C. A. Simpson
Contracts Manager

MGT:MES

Enclosures:
1. RPP-PLAN-52623, Rev. 0, "One System Waste Feed Delivery Mixing and Sampling System Performance Test Plan" (71 pages)
2. Letter, R. J. Skwarek, WRPS, to L. M. Peurrung, PNL, "One System Technical Team Response to Review of Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan (ERT-18)," WRPS-1202839-OS, dated July 19, 2012 (95 pages)
3. ERT Comment Response Concurrence Letter, dated August 7, 2012 (71 pages)

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DOCUMENT RELEASE FORM

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(b) Reviewer (Optional, Print/Sign):

_____ **Date:** _____ _____ **Date:** _____

_____ **Date:** _____ _____ **Date:** _____

_____ **Date:** _____ _____ **Date:** _____

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ONE SYSTEM WASTE FEED DELIVERY MIXING AND SAMPLING PROGRAM SYSTEM PERFORMANCE TEST PLAN

Kearn Patrick Lee
Washington River Protection Solutions, LLC

Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-08RV14800

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Key Words: One System, Tank Farm Mixing and Sampling, Waste Feed Delivery, DNFSB Recommendation 2010-2, Scaled Performance, System Performance, Small Scale Mixing Demonstration, Remote Sampler Demonstration

Abstract: This plan addresses the technical approach and test requirements for the Small-Scale Mixing Demonstration Scaled Performance, and Remote Sampler Demonstration System Performance test activities being performed under the Mixing and Sampling Program to support waste feed delivery to the Hanford Waste Treatment and Immobilization Plant. The program will include activities to support determination of the range of waste physical properties that can be retrieved and transferred. It will also determine, based on testing and analysis, the capability of the tank farm mixing, sampling, and transfer systems to obtain samples that can be characterized to assess the bounding physical properties important for the Waste Acceptance Criteria comparison

EXECUTIVE SUMMARY

The primary purpose of the Tank Operations Contractor Mixing and Sampling Program is to mitigate the technical risks associated with the ability of the tank farms waste feed delivery systems to mix and sample High-Level Waste feed adequately to meet the Hanford Waste Treatment and Immobilization Plant Waste Acceptance Criteria. The Tank Operations Contractor will conduct tests to determine the range of waste physical properties that can be retrieved and transferred. Using two geometrically scaled tanks, testing and analysis will determine the scale-up relationship for a full-scale, feed staging tank based on batch transfer consistency with pre-transfer samples (i.e., replicating the waste acceptance process). The capability of the tank farm mixing, sampling, and transfer systems to obtain representative samples to assess properties important for the waste acceptance criteria comparison will also be determined. This test plan is the second of three test plan documents that are being prepared to address Defense Nuclear Facilities Safety Board DNFSB 2010-2, Sub-Recommendation 5, Commitment 5.5.3.6, "Test Plan to establish Tank Farm performance capability" and addresses the technical approach and test requirements for the scaled/system performance test activities being performed to support waste feed delivery.

The tests being conducted to define the capabilities of the mixing, sampling, and transfer system are focused on three areas: limits of performance, solids accumulation, and scaled/system performance. Limits of performance testing and developmental work supporting solids accumulation are currently being conducted under the first of the three test plans, RPP-PLAN-52005, *One System Waste Feed Delivery Mixing and Sampling Program Limits of Performance and Solids Accumulation Scouting Studies Test Plan*. Additional solids accumulation testing will be conducted under a future test plan. Scaled/system performance is performed in accordance with this test plan. Scaled/system performance testing will be conducted to demonstrate mixing, sampling, and transfer performance using simulants representing a broad spectrum of Hanford waste. Testing will be performed with simulants that are characteristic of Hanford waste and approach or exceed waste acceptance criteria action levels in terms of bulk density, solids loading, yield stress, and slurry viscosity. Testing with simulants that approach the Hanford Waste Treatment and Immobilization Plant design basis ensures that the system is capable of identifying waste that may be outside the envelope of acceptance. Testing will also be performed with slurries containing dense particles (8 g/ml) having particle sizes exceeding 100-microns for assessing the capability of sampling fissile material for comparisons to requirements with action limits for uranium (U) and plutonium (Pu); (e.g., Pu to metals loading ratio and $U_{Fissile}$ to U_{Total} ratio). These tests will use both the Small-Scale Mixing Demonstration and Remote Sampler Demonstration test platforms used in previous Waste Feed Delivery Mixing and Sampling Program test activities; however, the operating conditions and simulants tested will be expanded to collect additional performance data.

For each test activity covered in this test plan, the test objectives along with success criteria are identified. The necessary equipment to conduct the tests and collect the necessary data is identified and described. The simulants that are appropriate for testing are identified and qualified in accordance with the recommendations in RPP-PLAN-51625, *Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing*. Testing with different simulants is included to explore the capabilities of the individual systems.

Because the test objectives for the Small-Scale Mixing Demonstration scaled performance and Remote Sampler Demonstration system performance activities are similar, the test matrices evaluate similar test conditions (e.g., base simulant components, supernatant properties, and mass loadings). The most important properties identified for scaled/system performance work include variations to: mixer jet nozzle velocity (Small-Scale Mixing Demonstration only), transfer pump capture velocity (Small-Scale Mixing Demonstration only), Newtonian slurry solids simulant composition, supernatant density and viscosity, Newtonian solid simulant mass loading, and the Bingham plastic yield stress of a non-Newtonian slurry simulant.

Small-Scale Mixing Demonstration scaled performance testing will be conducted to:

- Use Newtonian simulants in the 1:8- and 1:21-scale Small-Scale Mixing Demonstration platform to build confidence in the pre-transfer sampling representativeness and the predictions of full-scale performance.

- Evaluate the suitability of using the scaled relationship determined for Newtonian slurries to mobilized non-Newtonian slurries.

Mixing and transfer data at two scales will be collected and analyzed to increase the confidence in the scale up relationship for mixing, sampling, and transfer. Specifically, thirty tests, including replicates and verification runs, will be conducted in the 1:21 and 1:8 scale mixing tanks in the Small-Scale Mixing Demonstration test platform. Scaled testing will be conducted with five different nozzle velocities, three different transfer pump capture velocities, two different Newtonian simulant compositions, and three different supernatant compositions. Scaled testing will also be conducted using a non-Newtonian simulant at four different nozzle velocities.

Remote Sampler Demonstration system performance testing will be conducted to:

- Demonstrate, with different simulant compositions (Newtonian and non-Newtonian), the capability of the Isolok® Sampler to collect representative samples in the vertical configuration.

- Demonstrate the Ultrasonic PulseEcho system for monitoring bulk solids settling in the flow loop.

- Define operational steps for the Isolok® Sampler and describe functional requirements for supporting systems necessary for field deployment.

Remote Sampler Demonstration test data will be collected and analyzed to provide additional confidence in the systems capabilities to sample a wider range of Hanford waste characteristics. System testing includes 15 tests that include different combinations of two Newtonian simulant compositions, two solids loadings, and three supernatant compositions. System testing will also include non-Newtonian simulants with two different Bingham plastic yield stresses. Testing will also include the Ultrasonic PulseEcho system that detects bulk particle settling in the flow loop and can be used to determine critical settling velocities of the transferable slurry.

CONTENTS

FIGURES

TABLES

TERMS

Abbreviations and Acronyms

ASME	American Society of Mechanical Engineers
BNI	Bechtel National, Inc.
DOE	U.S. Department of Energy
DNFSB	Defense Nuclear Facilities Safety Board
DST	double-shell tank
DQO	data quality objective
HLW	high-level waste
ICD	Interface Control Document
MDT	SRNL mixing demonstration tank
ORP	Office of River Protection
Pu	plutonium
PNNL	Pacific Northwest National Laboratory
RPP	River Protection Project
RSD	Remote Sampler Demonstration
SF	scale factor
SRNL	Savannah River National Laboratory
SSMD	Small-Scale Mixing Demonstration
TOC	Tank Operations Contract
UPE	Ultrasonic Pulse Echo system
U	uranium
WC	Tungsten carbide grit
WAC	waste acceptance criteria
WFD	Waste Feed Delivery
WRPS	Washington River Protection Solutions, LLC
WTP	Hanford Waste Treatment and Immobilization Plant

Units

°C	degrees Celsius
cP	centipoise
ft	feet
in	inch
g	gram
gpm	gallons per minute
l	liter
Hz	hertz
MHz	megahertz
ml	milliliter
Pa	Pascal
s	second

1.0 INTRODUCTION

1.1 INTRODUCTION

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 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-12-64 and TOC-12-65 per the TFC-PLN-39, Rev. G, *Risk Management Plan*, which address sampling methods and emerging changes to WAC requirements. The root of the mixing and sampling risk is the ability to collect samples that are characteristic of the tank waste, including the rapidly settling solids in the HLW for the purpose of demonstrating compliance with the WTP waste acceptance requirements. In addition, in November 2011, the U.S. Department of Energy (DOE) issued the implementation plan for the Defense Nuclear Facility Safety Board (DNFSB) Recommendation 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.

Report RPP-PLAN-41807, *Waste Feed Delivery Mixing and Sampling Program Plan and Test Requirements* defines the three test requirements for continued the WFD Mixing and Sampling Program testing to address DNFSB concerns as follows:

- Limits of performance - determine the range of waste physical properties that can be mixed, sampled, and transported under varying modes of operation. These tests will use both the Remote Sampler Demonstration (RSD) platform and the Small-Scale Mixing Demonstration (SSMD) platform. In addition, a test using a full-scale slurry transfer pump will be performed.
- Solids accumulation - perform scaled testing to understand the accumulation and distribution of the remaining solids in a double-shell tank (DST) during multiple fill, mix, and transfer operations that are typical of the HLW feed delivery mission. These tests include activities at the Savannah River National Laboratory (SRNL) Mixing Demonstration Tank (MDT) and the SSMD platform.
- Scaled/system performance - demonstrate mixing, sampling, and transfer performance using a realistic simulant representing a broad spectrum of Hanford waste to meet WTP WAC Data Quality Objectives (DQO) sampling confidence requirements. These tests will use both the SSMD and the RSD platforms. The RSD platform is full scale; therefore, RSD system performance testing activities will collect additional system performance data at full scale.

This represents a broadening of objectives from earlier SSMD and RSD testing. The simulants and operating conditions in this earlier testing were intended to simulate the particle size, density distribution, and operating configuration of Hanford DST 241-AY-102, the first tank waste to be delivered to WTP. The particle size distribution for the SSMD simulant for DST 241-AY-102 (1% is 0.39 microns, 50% is 13.2 microns, 95% is 200 microns, and 99% is 394 microns) is

documented in PNNL-20637, *Comparison of Waste Feed Delivery Small-Scale Mixing Demonstration Simulant to Hanford Waste.* The range of particle sizes in the simulant was smaller than the particle size distribution for the 95% confidence limit for 95% of the population (1% is 2 microns, 50% is 22 microns, 95% is 460 microns, and 99% is 700 microns) used in the waste feed transfer system analysis used in the WTP design basis, RPP-9805, *Values of Particle Size, Particle Density, and Slurry Viscosity to Use in Waste Feed Delivery Transfer System Analysis*. Simulants and operating conditions will need to be developed to represent the complete range of physical properties for the broader spectrum of Hanford waste tanks, and to address specific testing requirements summarized above.

The TOC will conduct tests to determine the range of waste physical properties that can be retrieved and transferred to WTP, and determine the capability of tank farm staging tank sampling systems to provide samples that will characterize the tank waste to determine compliance with the WAC. These tests will reduce the technical risk associated with the overall mixing, sampling, and transferring of HLW feed to WTP so that all WAC requirements are met.

This test plan is the second of three test plan documents that will be prepared to address DNFSB 2010-2 Sub-Recommendation Commitment 5.5.3.6, "Test Plan to establish Tank Farm performance capability". The first, RPP-PLAN-52005, *One System Waste Feed Delivery Mixing and Sampling Program Limits of Performance and Solids Accumulation Scouting Studies Test Plan* addresses the technical approach and test requirements for the SSMD Limits of Performance, RSD Limits of Performance, Full-Scale Transfer Pump Limits of Performance, and SSMD Solids Accumulation Scouting Studies being performed to support feed delivery to the WTP. This test plan identifies and describes the test objectives, test requirements, and test methods for the SSMD Scaled Performance and RSD System Performance test activities. The testing approach is guided by input from internal subject matter experts and external consultants familiar with the objectives of the test program (WRPS-1105293, *Small-Scale Mixing Demonstration Optimization Workshop Meeting Minutes* and WRPS-1201374-OS, *One System DNFSB 2010-2 Sub-Recommendation 5 Test Plan Summit Meeting Minutes*). The third test plan will cover additional testing related to the accumulation of solids in a waste feed tank. Additional information is being generated as part of parallel work that may result in further refinements to the test program. This parallel work includes Commitment 5.5.3.2, which estimates, based on current information, the range of waste physical properties that can be transferred to WTP and Commitments 5.7.3.1 and 5.7.3.4, which identify potential new WAC requirements based on known technical issues, preliminary documented safety analyses, and process capabilities and compatibilities.

1.2 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* (also known as ICD-19). 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.

The objective of the WFD Mixing and Sampling Program continues to be the mitigation of the technical risks associated with the ability of the tank farms WFD systems to mix and sample HLW feed adequately to meet the WTP WAC. Initial work for the SSMD and RSD projects has demonstrated the concept functionality for the first feed tank to deliver consistent feed delivery batches. However, uncertainties related to scale-up, simulant representativeness, data uncertainty, optimizing system performance, applicability to all feed tanks, feed conditioning, and understanding emerging WTP solids handling risks still need to be addressed.

DNFSB Recommendation 2010-2 has raised WTP safety issues related to tank farms ability to mix, sample, and transfer solids. In response, DOE developed an implementation plan to resolve these issues (DOE Rev. 0 2010-2). As discussed in Section 1.0, this test plan is one of multiple test plan documents that will be prepared to address Commitment 5.5.3.6 of the Implementation Plan. This test plan is being prepared to address any outstanding key uncertainties pertaining to the bounds of the SSMD and RSD equipment performance identified during the TOC Mixing and Sampling workshop held in Richland, Washington October 10–12, 2011 (WRPS-1105293).

To ensure that tank farms and WTP mixing and sampling systems are integrated and compatible (i.e., execution of the One System approach) and that the uncertainties identified to date are addressed, the WFD Mixing and Sampling Program has been expanded to include the following:

- Define DST mixing, sampling, and transfer system limits of performance with respect to the ability to transfer waste to the WTP that exceeds any limitations of the WTP mixing and transfer systems. The capability of the Tank Farm's WFD system, including a consideration of data uncertainty, will be characterized using simulants with varying physical properties that are important to mixing, sampling and transfer (solid particulates sizes and densities, yield stress, and viscosity), and may not be properties that will be directly measured and compared to WAC requirements.
- Define 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 (see Section 3.3.4 for definition) slurry samples and in-line critical velocity measurements from a fully mixed waste feed staging tank.
- Develop sufficient data and methodology to predict full-scale DST mixing, sampling, and transfer system performance confidently; such that a gap analysis against WTP feed receipt system performance can be completed adequately.

The first task listed above is the subject of the test plan RPP-PLAN-52005. Initial work supporting the second task is also included in RPP-PLAN-52005 and follow-on work will be documented in a subsequent test plan. The latter two tasks are the subject of this test plan.

2.0 SCOPE

The original objective of the 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 WAC. Testing focuses on the ability to achieve adequate mixing and representative sampling and on minimizing variability between batches transferred to WTP. Testing to date (RPP-49740, *Small-Scale Mixing Demonstration Sampling and Batch Transfers Results Report*) has demonstrated the potential ability to adequately mix, deliver, and sample DST 241-AY-102 simulated waste using prototypic DST mixing and transfer systems. However, waste in DST 241-AY-102 did not represent the most challenging waste expected over the feed delivery mission and testing using simulants representing more challenging wastes will be conducted.

While test data collected to date has provided some insight to mixing, sampling, and transfer performance (e.g., RPP-50557, *Tank Waste Mixing and Sampling Update*), more data is needed to predict full-scale performance that covers the range of physical properties of Hanford waste confidently. The objective of SSMD scaled performance activities is to test mixing and transfer performance at two scales using simulants representing a broad spectrum of Hanford waste to meet WTP WAC DQO sampling confidence requirements. Testing will continue to be performed at two scales in accordance the recommendations developed at the initial planning workshop, which provided guidance that a decision regarding a third scale should be held until after performance at the smaller scales is demonstrated (Section 4.2 of RPT-1741-0001, *Tank Farm Mixing Demonstration Planning Workshop*). The objective of RSD system performance activities is to evaluate the performance of the RSD, including the Isolok[1]® Sampler system and Ultrasonic PulseEcho system Ultrasonic Pulse Echo system (UPE) in a configuration that addresses field deployment constraints.

The current WFD Mixing and Sampling Program being executed to address the issues is being performed in a phased approach that will:

- Demonstrate the tank farms capability to mix, sample, and transfer HLW
- Demonstrate the viability of systems to meet waste acceptance requirements in small-scale or full-scale environments, and upon successful demonstration
- Exhibit system capability in a full-scale DST (i.e., a DST that will be providing hot commissioning feed to WTP).

Three major areas of testing that will be executed by the WFD Mixing and Sampling Program to demonstrate capability and viability include limits of performance, solids accumulation, and scaled/system performance. The test requirements for all limits of performance scope and the initial solids accumulation development work are described in RPP-PLAN-52005. This test plan documents the test requirements for the SSMD scaled performance and RSD system performance activities. A subsequent test plan will provide the test requirements for SSMD solids accumulation performance evaluation scope.

Isolok® is a registered trademark of the Sentry Equipment Corp. of Oconomowoc, Wisconsin.

Figure 2-1 shows test sequence and portrays how information learned from early testing activities is used to develop the test plans for subsequent scope.

This plan defines test requirements to address Tank Farm mixing, sampling, characterization, and transfer system capability, to predict full-scale performance and demonstrate the capability of the RSD to collect representative waste samples to meet the expanded requirements associated with DNFSB Recommendation 2010-2. Testing will be performed with Hanford waste simulants that approach or exceed ICD-19 WAC action levels in terms of bulk density, solids loading, yield stress, and slurry viscosity. Testing with simulants that approach the WTP design basis ensures that the system is capable of identifying waste that may be outside the envelope of acceptance. Testing will also be performed with slurries containing dense particles (8 mg/l) having particles sizes exceeding 100 microns for assessing the capability of sampling fissile material for comparisons to ICD-19 requirements with action limits for U and Pu (e.g., Pu to metals loading ratio and $U_{Fissile}$ to U_{Total} ratio). As described in RPP-PLAN-41807, the objectives of the test activities are to develop a scaling relationship to predict full-scale performance and determine the range of waste physical properties that can be retrieved and transferred to the WTP. They will also determine the capability of the tank farm staging, tank sampling systems to obtain samples that can be characterized to assess the bounding physical properties important for the WAC.

The Waste Feed Delivery (WFD) Mixing and Sampling Program testing is evaluating the feasibility of a baseline design for waste feed delivery. Testing is developmental and is not evaluating a field deployable design against specific functional characteristics and performance requirements. Testing is performed in accordance with Phase I testing described in TFC-PLAN-90, *Technology Development Management Plan*. Phase I development testing addresses a TOC technology need when existing processes are inadequate, inefficient, or not proven for the intended application. During Phase I testing functional criteria and performance requirements for the promising technology are defined, a prototype working model is constructed, and the prototype is evaluated against the performance criteria. Phase I development implements a graded application of the quality assurance program requirements. Upon successful completion of Phase I testing, which may be an iterative process, additional development (Phase II) may be pursued. Phase II development and testing is performed to a higher quality assurance standard and invokes TOC approved procedures and quality assurance requirements for design control, including design verification, and qualification testing. The WFD Mixing and Sampling Program test planning, test review, test control, and test results reporting requirements are communicated through this test plan and are guided by testing principles described in TFC-ENG-DESIGN-C-18, *Testing Practices*. The WFD Mixing and Sampling Program testing falls outside the scope of TFC-PLAN-26, *Test Program Plan*, which defines additional requirements for oversight, development, and the conduct of factory acceptance, construction acceptance, and operational acceptance tests for demonstrating the operability and integrity of new or modified tank farm facilities and systems.

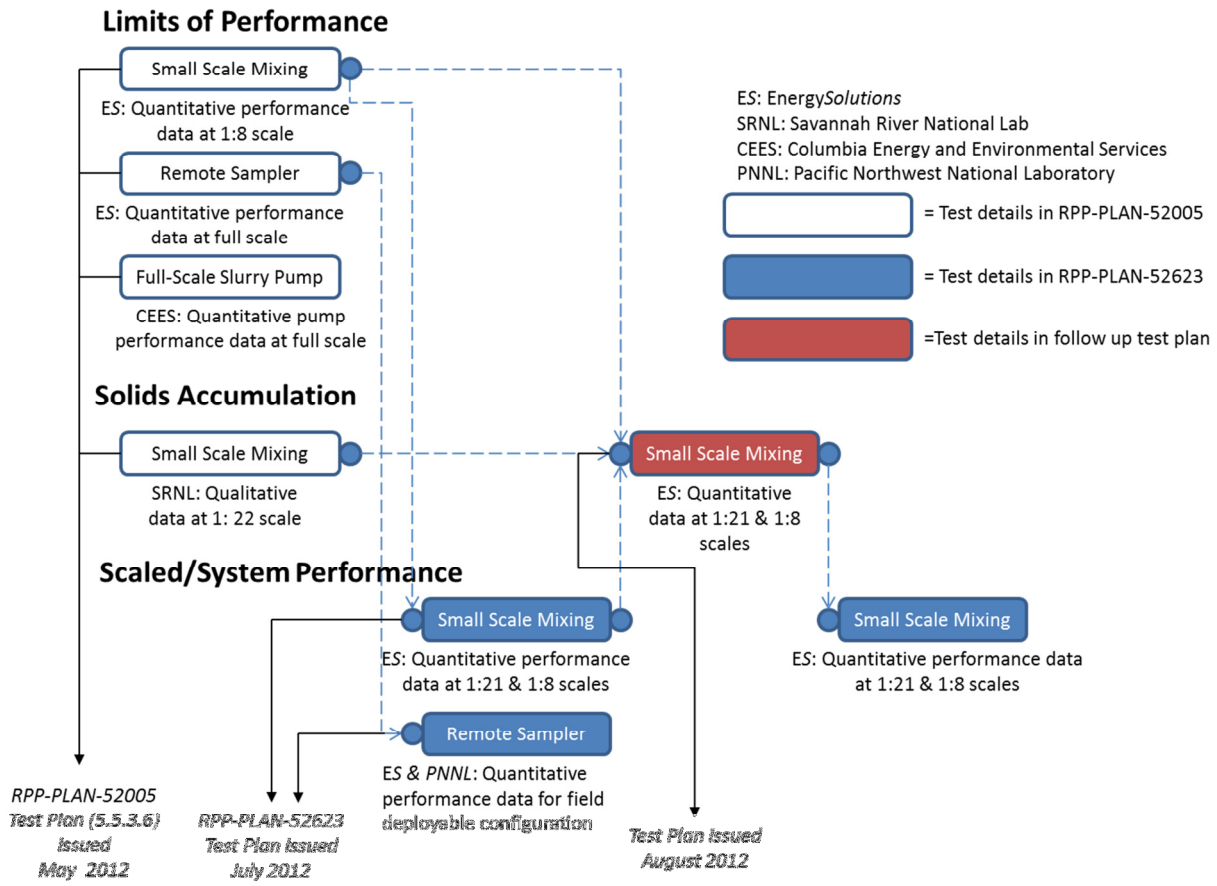


Figure 2-1. WFD Mixing and Sampling Program Test Sequence

2.1 SMALL-SCALE MIXING DEMONSTRATION SCALED PERFORMANCE TEST OBJECTIVES

The overall objective of the WFD Mixing and Sampling Program is to build confidence in the capability of the full-scale mixing and transfer system to deliver feed batches that are consistent with pre-transfer samples collected to characterize the feed. The SSMD scaled performance testing will extend previous work using simulants that are more representative of a broader distribution of Hanford tank wastes. In order to achieve this objective, small scale mixing and transfer testing will be conducted to collect the data necessary to build confidence in the mixing and transfer scaling relationship (Equation 3-8 in Section 3.2.1). Specifically, chemical composition data for each of five transfer batches will be collected at two different scales. Multiple tests, varying the mixer jet pump nozzle velocity, the simulant composition and/or the transfer pump capture velocity (also known as suction velocity or the average velocity across the pump suction inlet opening) will be performed at each scale. The batch composition data will then be converted into a metric for evaluating batch consistency with the pre-transfer sample. This metric will then be fit to an empirical model that includes a functional dependency on the varied parameters and will incorporate the theoretical scaling model shown in Equation 3-8 in Section 3.2.1. The scaling relationship is determined when the models predict equivalent performance, as related to batch consistency with the pre-transfer sample or other performance metric.

Using the SSMD test platform, which includes both a 1:21 and 1:8-scale mixing and transfer system (see Figure 2-2), a series of tests will be conducted at two scales and batch transfer data, including the chemical composition of each transfer batch, will be collected and analyzed to improve the knowledge and understanding of the scaled mixing systems. The primary performance metric that will be evaluated is transfer batch chemical composition consistency with the pre-transfer samples that are collected to characterize the transferrable slurry. Additionally, system performance information related to limits of performance and solids accumulation (e.g., effective cleaning radius, dimensions of the mounding solids in the "dead-zone(s)", and cloud height) will also be collected for each test condition to support DNFSB 2010-2 Deliverable 5.5.3.1, *Initial gap analysis between WTP WAC and tank farm sampling and transfer capability*. The test objectives are summarized in Table 2-1.

Additionally, tests using a non-Newtonian simulant that includes solids represented in the Newtonian slurry (e.g., stainless steel and zirconium oxide) will be conducted and batch transfer data for the added solids will be collected. The data will be analyzed to determine if the scaled relationship developed for the Newtonian slurry is suitable for predicting full-scale performance of non-Newtonian slurry that is mobilized during mixing and transfer.

Test plan details, including a discussion of the requirements for test equipment, simulants, operating parameters, test matrix, sample collection, and data analysis are provided in Section 3.2.

Table 2-1. Small-Scale Mixing Demonstration Scaled Performance Test Objectives

Objective	Success Criteria
Use Newtonian simulants in the 1:8- and 1:21-scale SSMD platform to build confidence in the pre-transfer sampling representativeness and the predictions of full-scale performance.	Mixing and transfer tests are performed with Newtonian slurries at multiple jet nozzle velocities. The slurry contains moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste. These particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Mixing and transfer tests are performed with Newtonian slurries at multiple jet nozzle velocities with variations in the base (solids) simulant, supernatant compositions, and transfer pump capture velocities. Performance data (i.e., sample composition of each transfer batch) is collected at two scales and is used to refine the scaling relationship for the integrated mixer jet pump and slurry transfer system. The sensitivity of the scaling relationship to the varied parameters is evaluated. The scaling relationship is refined and used to predict waste transfer performance at full-scale.
Use non-Newtonian simulants in the 1:8- and 1:21-scale SSMD platform to evaluate the suitability of using the scaled relationship determined for Newtonian slurries to mobilized non-Newtonian slurries.	Mixing and transfer tests are performed with non-Newtonian slurries at multiple jet nozzle velocities. Additional solids, including moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste are added to the slurry. These particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Performance data (i.e., sample composition of each transfer batch) is collected at two scales and is used to evaluate the suitability of the scaling relationship developed for Newtonian slurries to mobilized non-Newtonian slurries.

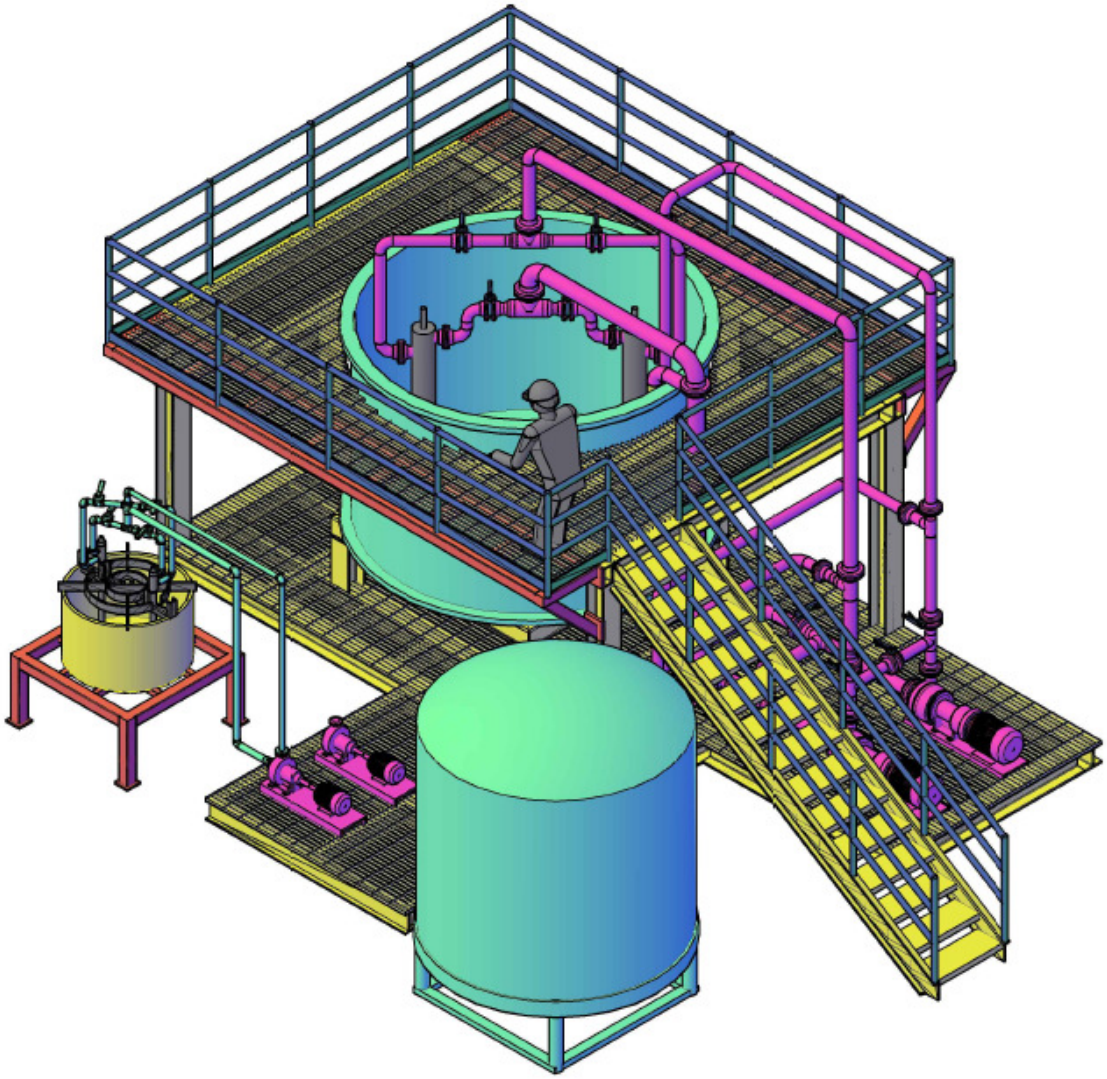


Figure 2-2. Schematic of Small-Scale Mixing Demonstration Test Platform

2.2 REMOTE SAMPLER DEMONSTRATION SYSTEM PERFORMANCE TEST OBJECTIVES

While the SSMD test activities support the overall objective of the WFD Mixing and Sampling Program to build confidence in the capability of the full-scale mixing and transfer system to deliver feed batches, the RSD test activities are performed to build confidence that the collected pre-transfer samples are *representative* (see Section 3.3.4 for explanation of *representative*) of the feed. The objective of RSD system performance activities is to evaluate the performance of the RSD, including the UPE, with simulants that represent a broader distribution of Hanford tank wastes.

The objective of RSD system performance test activities is to continue to optimize the RSD configuration of the Isolok® Sampler system (see Figure 2-3) to demonstrate the ability of the sampler to obtain samples that have the same content as the slurry within the waste characterization flow loop. Operating parameters that will be investigated include variations in simulant composition (base solids and supernatant) and simulant mass loading. Additionally, RSD system performance testing will use the UPE with the 10 MHz transducer for monitoring bulk solids settling (i.e., the onset of critical velocity) in the flow loop. Using transparent sections located both upstream and downstream of the UPE (transparent sections are not shown in Figure 2-3), bulk particle settling will also be visually observed to evaluate the performance accuracy of the UPE. Critical velocity evaluations will expand upon testing performed during RSD limits of performance testing (RPP-PLAN-52005). In addition, the system design will be evaluated against field deployable constraints and limitations.

The test objectives are summarized in Table 2-2.

Table 2-2: Remote Sampler Demonstration System Performance Test Objectives

Objective	Success Criteria
Demonstrate, with different simulant compositions (Newtonian and non-Newtonian), the capability of the Isolok® Sampler to collect representative samples in the vertical configuration.	Isolok® sampling tests in the vertical configuration are performed in the RSD flow loop with a base simulant that contains moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste, a supernatant simulant and some challenging spike particles. Base and spike particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Collected samples are analyzed for chemical composition and quantified relative to a full diversion sample. Sampler performance is evaluated by comparing the mean square of the sampling error to a standard of representativeness of 10% relative to the full diversion samples. Correlations relating the relative difference between the Isolok® samples and full diversion samples are evaluated with respect to the changes in the test conditions (i.e., variations in the liquid and solid simulant composition and loading).
Demonstrate the Ultrasonic PulseEcho system for monitoring bulk solids settling in the flow loop.	Identify critical velocity of simulants based on bulk particle settling as detected by the Pacific Northwest National Laboratory (PNNL) Ultrasonic PulseEcho system and visual monitoring of the settled slurry in the adjacent transparent sections. The critical settling velocity determined visually and using the Ultrasonic PulseEcho system are within 0.3 ft/s for critical settling velocities exceeding 2 ft/s.
Define operational steps for the Isolok® Sampler and describe functional requirements for supporting systems necessary for field deployment.	Develop operational protocols for the Isolok® Sampler system that allow consistent and integrated sample collection of HLW slurries coming from a mixed DST, and document results in a report. Identify field deployment considerations for the remote sampling system, based on the experience gained during the RSD activities.

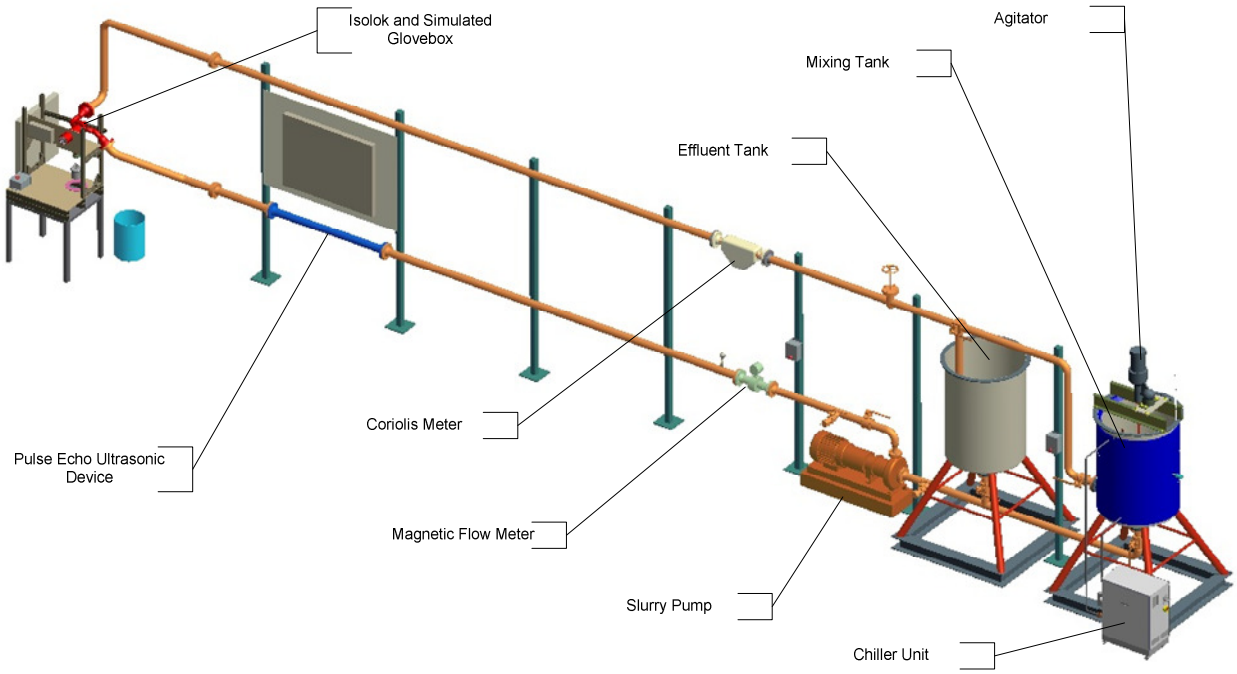


Figure 2-3. Schematic of Remote Sampler Demonstration Test Platform

3.0 TEST REQUIREMENTS

Test requirements and test guidance have been developed to meet the SSMD scaled performance and RSD system performance test objectives identified in Section 2.0.

In addition to this test plan, each testing contractor will develop operational procedures that include or reference the test configuration, test objectives, test requirements, and provisions for assuring that prerequisites and suitable environmental conditions are met, adequate instrumentation is available and operational, and that necessary monitoring is performed.

3.1 TEST SIMULANTS

The capability gap between the TOC and the WTP is defined by the TOC's capability to mix, sample, and transfer large and dense particles, and the WTP's capability to process these particles. Therefore, integral with defining the gap in capabilities is the selection of appropriately complex simulants, integrated with WTP simulant selection, and supported by accurate analytical techniques to characterize the material of interest. The Hanford waste simulants for DNFSB 2010-2 testing are developed and described in RPP-PLAN-51625. As detailed in RPP-PLAN-51625, particle size and density are expected to be the most important solids properties for predicting system performance. Liquid density and viscosity are expected to be important liquid phase properties. Unlike previous limits of performance test activities described in RPP-PLAN-52005, which included irregularly shaped base simulant particles and very large and dense spherical spike particles, the particles used in the scaled and system performance test activities are generally irregularly shaped base simulant particles.

The simulants used for SSMD scaled performance and RSD system performance test activities are consistent with DNFSB 2010-2 testing performed in accordance with RPP-PLAN-52005. Simulant selection considers parameters (e.g., particle size, density, viscosity, and yield stress) important to mixing, sampling, and transfer performance. Simulant properties such as hardness and abrasiveness, which are important to evaluating erosion and wear of the tank and pipe walls and the mixing and transfer equipment, are not primary considerations for understanding the capability of the system to mix, sample, and transfer slurries characteristic of Hanford tank waste. However, simulant selection does favor materials that result in less wear on the test equipment when alternatives that match the critical characteristics are available.

Although SSMD and RSD testing is Phase I technology development and generally performed to the subcontractors own quality assurance procedures, simulant procurement, preparation, and simulant property data collection are performed to enhanced quality assurance standards as defined in TFC-ESHQ-Q_ADM-C-01, *Graded Quality Assurance*. As such, additional level of controls beyond the providers published or stated attributes of the item, service, or process are needed to verify critical attributes of the simulants. Simulant materials procured as commercial grade items shall be prepared and qualified to match the critical characteristics of the simulants. The critical characteristics for the Newtonian base simulant materials are the particle size distribution and density of the materials. The particle size distributions and densities of the components in the composite slurry are used to calculate performance metrics (e.g., distribution of Archimedes numbers) for the composite to qualify the simulant for use. For the supernatant, the critical characteristics are the liquid density and liquid viscosity. For non-Newtonian

simulants the critical characteristics are the Bingham plastic yield stress and density. Bingham plastic consistency (i.e., plastic viscosity) is a secondary characteristic that is measured and reported. To qualify the supernatant and non-Newtonian slurry for use, the critical characteristics will be measured when the simulant batches are prepared.

Newtonian simulant batches of base material and supernatant are prepared according to prepared recipes. By specifying the mass fraction of each solids component, the density of each solids component, the density of the supernatant, the solids loading, and the batch volume, the required amounts of each solids component are fully defined. Supernatant and non-Newtonian slurry recipes are determined from test batches prepared to match the critical characteristics. The base simulant and supernatant simulant for Newtonian simulants and the non-Newtonian simulant described in this test plan are described below. Selection and justification of the simulants to be used in each test activity are provided in the test requirements for each test activity.

3.1.1 Base Simulant

As discussed in RPP-PLAN-51625, during simulant development for DNFSB 2010-2 test activities metrics were selected that are relevant to mixing and sampling and are similar to the metrics for the Hanford tank waste. The calculated values for the metrics are not used to set operating conditions for testing; metric comparisons are only used to demonstrate that the developed simulants are similar to the Hanford tank waste.

3.1.1.1 Base Simulant Description

The base simulant is the mixture of solid particles in the Newtonian slurry representing the Hanford tank waste. Report RPP-PLAN-51625 recommends three base simulants for WFD Mixing and Sampling Program test activities, low conceptual, typical conceptual, and high conceptual. The low conceptual base simulant is a single component base composed of gibbsite particles. As described in RPP-PLAN-51625, the low conceptual simulant is similar to the least challenging waste with respect to the distribution of Archimedes numbers and jet velocity needed to achieve complete solids suspension. Considering these same two metrics, the high conceptual simulant is more challenging than most of the measured waste and the typical conceptual simulant is in between these two and is similar to much more of the waste. The typical conceptual and high conceptual base simulants are complex (i.e., multicomponent mixtures) simulants composed of gibbsite particles, sand particles, zirconium oxide particles, and stainless steel particles. Differences in recommended particle sizes of gibbsite and sand, as well as differences in the mass fractions of each component mixture distinguish the typical and high conceptual simulants. Table 3-1 provides the composition of the base simulants recommended in RPP-PLAN-51625. The selected base simulant used in each test is specific to the objective of the test and justified in the Test Simulants sections (Sections 3.2.3 and 3.3.2) of the test plan.

In addition, following the recommendations in RPP-PLAN-51625, tests will also be performed using non-Newtonian slurry with a Bingham plastic yield stress between 3 and 10 Pa. Tests requiringnon-Newtonian, cohesive slurry will be made from kaolin clay. Based on initial laboratory work performed to develop simulant recipes at lab scale quantities and test batches prepared in the 43.2-inch diameter SSMD test vessel, a non-Newtonian slurry with a yield stress of 3 Pa and a density of about 1.16 g/ml is obtained by adding 22 wt%) kaolin clay to tap water.

A non-Newtonian slurry with a Bingham plastic yield stress of 10 Pa and a density of about 1.22 g/ml is obtained by adding 28 wt % kaolin clay to tap water. The method of mixing the kaolin into the simulant liquid has a big effect on the resulting simulant properties. Therefore, test samples shall be prepared to confirm the simulant preparation technique, simulant makeup, and the critical properties (i.e., the yield stress and density) of the test batch prior to testing. In addition, the Bingham plastic consistency shall also be measured and reported. Table 3-1 includes the properties for the non-Newtonian simulant. For a non-Newtonian slurry with a yield stress of 3 Pa and a higher density, sodium thiosulfate at 24-wt % can be added to 16-wt % kaolin clay in tap water. For a non-Newtonian slurry with a yield stress of 10 Pa and a higher density, sodium thiosulfate at 17-wt % can be added to 23.4 wt % kaolin clay in tap water.

Kaolin clay slurries with a targeted Bingham plastic yield stress of 3 Pa are determined to be acceptable in the range of 2 to 4.5 Pa. Slurries with a targeted Bingham plastic yield stress of 10 Pa are determined to be acceptable in the range of 7 to 13 Pa. This is based on the time-varying nature of a non-Newtonian simulant, and the necessary accuracy needed to resolve the effect of the yield stress on the capability of the system. Preparing consistent simulant batches from test to test will facilitate the analysis of the data between tests and is expected to be more important for the data analysis than performing tests at specific conditions (i.e., 3 and 10 Pa).

Table 3-1: Base Particulate Simulant Characteristics

Newtonian Base					
Compound	**Solid Density (g/ml)**	**Median Particle Size (micron)**	**Mass Fraction**		
			Low	**Typical**	**High**
Small Gibbsite	2.42	1.3	1.00	0.27	0
Large Gibbsite	2.42	10	0	0.44	0.03
Small Sand	2.65	57	0	0	0.35
Medium Sand	2.65	148	0	0.13	0
Large Sand	2.65	382	0	0	0.21
Zirconium Oxide	5.7	6	0	0.10	0.08
Stainless Steel	8.0	112	0	0.06	0.33
Non-Newtonian Base					
			Yield Stress		
			Slurry Density (g/ml)	**3 Pa**	**10 Pa**
Kaolin clay	NA	NA	~1.2	22 wt%	28 wt%
Kaolin clay w/ sodium thiosulfate	NA	NA	1.37	16 wt% Kaolin 24 wt% sodium thiosulfate	23.4 wt% Kaolin 17 wt% sodium thiosulfate

3.1.1.2 Base Simulant Qualification

As described in RPP-PLAN-51625, particle size distributions, particle density, and mass fractions of the components in the composite simulant can be used to determine the distributions of Archimedes numbers and jet velocities needed to achieve complete solids suspension for the composite simulant. As discussed in PNNL-20637 the Archimedes number is closely related to the settling velocity and is also a parameter in other mixing and transfer metrics such as pump intake, jet suspension velocity, critical shear stress for erosion, critical suspension velocity, suspended particle cloud height, and pipeline critical velocity. The calculation of the jet velocity needed to achieve complete solids suspension correlates the particle size and density to the jet velocity of a radial wall jet needed to suspend solids in a tank. Base simulant qualification is performed by comparing the distribution of Archimedes numbers and jet velocities needed to achieve complete solids suspension calculated for the procured simulants to the distributions for the recommended simulants documented in Figures 8-1 and 8-2 in RPP-PLAN-51625. To provide comparable results, performance metrics are calculated using the same assumptions used to calculate the metrics for the three conceptual simulants. Metrics are calculated using particle densities and particle size distributions obtained on samples from each procured lot. Because there is no expectation that procured material lots will not be mixed when testing is performed, particle size distributions from multiple lots of similar material may be averaged for the qualification comparisons. For commercial grade material, the particle size distribution provided by the vendor is not adequate for simulant qualification and a particle size analysis of each procured lot shall be performed. Appendix C of RPP-PLAN-51625 includes additional performance metrics, such as the critical shear stress for erosion of non-cohesive particles, just suspended impeller speed, pulse jet mixer critical suspension velocity for non-cohesive solids, pulse jet mixer cloud height for non-cohesive solids, and pipeline critical transport velocity. The procured material will also be compared to the conceptual simulants using these metrics.

The metrics calculated for the conceptual simulants in RPP-PLAN-51625 include typical distributions for some of the components. Therefore, the calculated values represent target values and deviations from the conceptual simulants are anticipated. The appropriateness of candidate material will be evaluated before simulant procurement. For procurement purposes, in absence of samples from actual lots, vendor supplied information (e.g., particle size distributions and particle density) and targeted mass fractions can be used to calculate the performance metrics for comparison to the conceptual simulants. For simulant qualification, calculations will be based on laboratory analysis of samples taken from the procured material and actual weight measurements recorded during testing.

Tests using a non-Newtonian slurry with a Bingham plastic yield stress between 3 and 10 Pa will be made from kaolin clay. The yield stress will be measured to be within the tolerances specified in Section 3.1.1.1 prior to testing. The yield stress measurements will be performed on-site with a rheometer calibrated, controlled, and maintained in accordance with American Society of Mechanical Engineers (ASME) NQA-1-2004, Requirement 12, “Control of Measuring and Test Equipment”including addenda, or a later version. Bingham parameters will be determined using a set program that controls the shear rate to generate the rheogram. The program will include a pre-shear period and two evolutions over the shear rate range. Due to the slight rheopetic nature of the Kaolin clay slurries, Bingham parameters shall be calculated using the second down curve used to generate the rheogram. Functional checks with reference standards covering the

expected range of solutions used during testing shall be performed daily to ensure that the rheometer is being properly maintained. Corrective actions, commensurate with the significance of an out-of-calibration condition, shall be performed. Appropriate instrumentation for measuring the Bingham plastic parameters of the non-Newtonian fluid is a programmable rheometer capable of taking controlled shear rate and controlled shear stress measurements. The rheometer shall also have the capability to control sample temperatures. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, "Test Control" including addenda, or a later version. Bingham parameters will be determined prior to the start of testing to ensure that the time varying qualities of the non-Newtonian slurry do not change significantly before testing is initiated. In addition, Bingham parameters will also be determined at the completion of testing and during testing if necessary, to assess rheological changes that may occur during the course of testing.

3.1.2 Supernatant Simulant

Developing the supernatant composition for DNFSB 2010-2 test activities is informed from modeling Hanford waste processes. Hanford waste process modeling includes tank inventory, accounts for retrieval technologies, waste volume reduction (i.e., evaporation), and includes inventory blending during multiple tank-to-tank transfers. Therefore, an estimate for the chemical composition of each feed batch is calculated and the results are used to select a suitable supernatant density and viscosity for DNFSB 2010-2 test activities.

3.1.2.1 Supernatant Simulant Description

The supernatant simulant is the liquid phase of the simulant slurry. For WFD Mixing and Sampling Program test activities, RPP-PLAN-51625 recommends four supernatant simulants (low density/low viscosity, low density/high viscosity, high density/low viscosity, and high density/high viscosity). These simulants are characterized by liquid density and liquid viscosity. The four supernatant characteristics are taken from Table 6-1 in RPP-PLAN-51625, which is summarized as the target simulant properties in Table 3-2. Table 3-2 also provides tested properties for simulants that have been prepared at 20°C (Centigrade) for each target simulant using non-hazardous, non-reactive components that are readily available at a reasonable cost, and in most instances have been used previously in related testing activities. These compositions are informed from chemical handbooks and previous testing, and were confirmed by preparing test batches at a laboratory scale. Due to strong temperature sensitivity, solutions that use glycerol to increase the liquid viscosity may require adjustments when the testing temperature differs from 20°C. When developing compositions for the liquid simulant, simpler combinations that matched the target density were preferred to facilitate batch production. In some instances, the preference for simpler compositions resulted in viscosity values that exceeded the target values but were considered acceptable for testing.

The targeted supernatant simulants are limiting supernatants and were developed for testing activities that attempt to mobilize large and dense particles during limits of performance testing. A supernatant that is more representative of typical Hanford supernatant is also included in Table 3-2. The liquid density for this supernatant is the median density from the same dataset used to derive the low and high density values in RPP-PLAN-51625. The dataset is the liquid density of the feed batches to the WTP calculated using the Hanford Tank Waste Operations Simulator

model (RPP-RPT-48681, *Hanford Tank Waste Operations Simulator Model Data Package for the River Protection Project System Plan Rev. 6 Cases*). The typical supernatant is characterized as having a liquid density of about 1.29 g/ml and an estimated liquid viscosity of 3.3 cP. The viscosity of the supernatant is determined by the salt(s) used to attain the desired density, and is comparable to the value determined using the relationship in Figure 6-2 of RPP-PLAN-51625. An aqueous solution of 31.5 wt % sodium thiosulfate will produce a supernatant with properties similar to the targeted simulant.

The typical supernatant listed in Table 3-2 is a preferred simulant for SSMD scaled performance and RSD system performance testing. Using a limiting supernatant, which was developed to maximize the capability of each system to mix, transfer, and sample large and dense particles, as was the objective for limits of performance testing, is not necessary for SSMD scaled performance and RSD system performance testing. However, the selected supernatant simulant used in each test is specific to the objective of the test and justified in Section 3.1,Test Simulants section of this test plan.

Table 3-2 also includes a supernatant composition that was not discussed in RPP-PLAN-51625. This supernatant is used in lieu of the high density / high viscosity supernatant when the predicted flow regime (Section 3.1.4) at the inlet of the transfer pump becomes laminar. The density and viscosity preparation tolerances for this modified high supernatant are the same those for the high density / high viscosity supernatant. The simulant can be prepared using sodium thiosulfate to adjust the density to the targeted value and then adding glycerol until the targeted viscosity is attained.

Table 3-2: Newtonian Liquid Supernatant Simulant Characteristics

Supernatant (density/viscosity)	**Target Simulant Properties @ 20°C**		**Simulant Properties @ 20°C**		**Simulant Composition**
	Density (g/ml)	**Viscosity (cP)**	**Density (g/ml)**	**Viscosity (cP)**	
Low/Low	1.1	1	1.098	1.62	12 wt% sodium thiosulfate
Low/High	1.1	8	1.135	8.03	53wt% glycerol
High/Low	1.37	1	1.370	2.00	37 wt% sodium bromide
High/High	1.37	15	1.368	14.6	33.4 wt% sodium thiosulfate and 19.5 wt% glycerol
Typical/Typical	1.29	3.3	1.284	3.60	31.5 wt% sodium thiosulfate
High / Modified High[a]	1.318	8	TBD	TBD	TBD wt% sodium thiosulfate and TBD wt% glycerol

[a] The high density supernatant with reduced viscosity is discussed in Section 3.1.4.

3.1.2.2 Supernatant Simulant Qualification

The simulant recipe for the supernatant simulant was developed in the laboratory, but will need to be scaled to the volume needed for each test. Small test batches prepared at testing temperatures should be prepared to confirm the relative amounts of each constituent needed to

match the simulant properties using the procured materials at testing conditions. Upon confirmation of the recipe, adjusted as necessary, scale up to testing volumes will be performed and the liquid density and liquid viscosity will be measured at testing temperatures to confirm that the prepared batch is within the required range for simulant density and viscosity. Preparing consistent simulant batches from test to test will facilitate the analysis of the data between tests and is expected to be more important for the data analysis than performing tests at specific conditions.

Therefore, for low density/low viscosity fluids, 1.098 g/ml and 1.62 cP, respectively, and typical density and typical viscosity fluids, 1.284 g/ml and 3.60 cP, respectively, the acceptable range of liquid densities and viscosities is ±5% and ±0.5 cP, respectively. These two liquids will be attained using a sodium salt (e.g., sodium thiosulfate). The two properties cannot be adjusted independently using the single component and a broad tolerance is allowed for liquid viscosity. For higher density and viscosity fluids, the acceptable range for the density is also ±5%. The tolerance on the liquid viscosity at levels above 5 cP is ±20% when the measurement is determined at testing temperatures. High viscosities will be attained by adding glycerol. The viscosity of glycerol is dependent on concentration and temperature, increasing as concentration increases and temperature decreases. For a specified concentration, a temperature correlation will be developed so that the viscosity at the measured temperature can be used to evaluate the viscosity at the testing temperature to determine if the prepared simulant meets the 20% tolerance on viscosity.

The liquid property measurements will be measured on-site with the appropriate instrumentation (e.g., hydrometer, viscometer, and rheometer) calibrated, controlled, and maintained in accordance with ASME NQA-1-2004, Requirement 12 including addenda, or a later version. Supernatant viscosity will be determined using a set program that controls the shear rate to generate the rheogram. The program will include a pre-shear period and two evolutions over the shear rate range. The viscosity shall be determined on the second down curve used to generate the rheogram. Functional checks with reference standards covering the expected range of solutions used during testing shall be performed daily to ensure that the instrument is being properly maintained. Corrective actions, commensurate with the significance of an out-of-calibration condition, shall be performed. Appropriate instrumentation for measuring liquid viscosity of the Newtonian fluid is a programmable rheometer capable of taking controlled shear rate and controlled shear stress measurements. The rheometer shall also have the capability to control sample temperatures. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, including addenda, or a later version. To ensure that the prepared simulant is appropriate for use, liquid properties will be measured prior to adding base simulant solids and therefore will be performed at the start of testing. In addition, viscosity will also be measured at the completion of testing, and during testing if necessary, to assess changes that may occur during the course of testing. The base solids in the samples collected during and after testing should be removed by filtering prior to collecting viscosity and density measurements.

3.1.3 Spike Particulates

Unlike limits of performance testing described in RPP-PLAN-52005, SSMD testing will not include large and dense spike particles. However, spiking the base simulant for RSD testing may

be performed based on the limits of performance test work. It is possible that large particles of average density may interfere with the Isolok® Samplers ability to collect representative samples of the base material. Testing using spike materials that can be sampled reliably by the Isolok® sampler, as determined during limits of performance testing, will be considered for RSD system performance testing.

Report RPP-PLAN-51625 recommends four materials for the spike particulates, sand, stainless steel, tungsten carbide grit (WC), and tungsten grit. Sand is a simulant for large particles that have a density comparable to the average density of Hanford waste particles. Stainless steel, tungsten carbide, and tungsten, which have densities of approximately 8 g/ml, 14 g/ml, and 19 g/ml, respectively, are simulants for high-density Pu-containing compounds [e.g., plutonium oxide (~11 g/ml)] in the Hanford tank waste. The sand and stainless steel spike particulates are chemically similar to the components in the base simulant, and therefore must be distinguishable from the base materials to be quantified. The spike materials will be distinguishable by particle size; size exclusion (e.g., sieving) will be used to separate the spike particles from the chemically similar base materials. Soda-lime glass spheres will be used as a surrogate for very large sand particles. The glass spheres are chemically inert, have a density similar to sand, but have consistent sizes in 1,000 micron increments because they are manufactured products. Having a consistent shape will facilitate separation of the spike particles from the base by sieving.

Table 3-3 identifies the spike materials for consideration during RSD system performance testing. The spike materials are a subset of the spikes considered for limits of performance testing. Preliminary limits of performance testing that is underway (conducted in accordance with RPP-PLAN-52005) indicates that the performance of the Isolok® Sampler is unacceptable when particles with diameters of approximately 3000 microns, which approaches the diameter of the internal passages of the sample needle, are present in the slurry. The tabulated particles are only for consideration; limits of performance testing may determine that other particles included in the list cannot be repeatedly sampled by the system.

The sizes of the glass, stainless steel, and tungsten carbide spike particulates in Table 3-3 are for spheres, which are readily available in the sizes listed. Consistent with recommendations in SRNL-STI-2012-00062, *Properties Important to Mixing for WTP Large Scale Integrated Testing*, spherical particles are considered because, compared to irregularly shaped particles with more surface area per volume, spherical particles would settle faster from suspensions, creating a greater challenge to sample these particles. The spike particles listed are commercially available items that have an industrial purpose and are manufactured to size tolerances that exceed the tolerances necessary to distinguish the different sized spike particles from the base solids by sieving. Commercial sources for the listed particles manufacture the particles in either 1000-micron, 1/32-inch or 1/16-inch increments with size variations that typically do not exceed several microns. Qualification of the metal spike particles is limited to demonstrating that 99% of a one pound sample taken from each delivered lot is retained on the sieves used to separate that size from the other particles. Qualification of the glass spike particles, which are manufactured to a lower tolerance for shape, is limited to demonstrating that 98% of a one pound sample taken from each delivered lot is retained on the sieves used to separate that size from the other particles.

The spike materials listed in Table 3-3 have densities characteristic of Hanford tank waste and are provided for test planning purposes; the densities of procured spike materials may be different due to differences in manufacturing processes. Table 3-3 also includes three properties that are relevant to mixing, the Archimedes number, the free settling velocity, and the particle Reynolds number. The tabulated Archimedes numbers (Ar) are calculated according to Equation 3-1. The Archimedes number indicates general settling characteristic particles with higher Archimedes values tend to settle faster than particles with lower Archimedes values. The reported values are calculated for the typical density (1.29 g/ml) and typical viscosity (3.3 cP) supernatant. The tabulated free settling velocity, V_t is calculated in the same supernatant liquid according to Equation 3-2. The free settling velocities result in particle Reynolds numbers, Re_p, (Equation 3-3) in the Intermediate Law regime (between 0.3 and 1000).

$$Ar = \frac{\left(\frac{\rho_s}{\rho_l} - 1\right) g d^3}{v^2} \tag{3-1}$$

$$V_t = \left(\frac{4gd(\rho_s - \rho_l)}{3\rho_l \left(\frac{18.5}{Re^{0.6}}\right)} \right)^{0.5} \tag{3-2}$$

$$Re_p = \frac{\rho_l V_t d}{\mu} \tag{3-3}$$

Where ρ_s is the particle density, ρ_l is the liquid density, g is the gravitational constant, d is the particle diameter, v is the kinematic viscosity of the liquid, and μ is the dynamic viscosity of the liquid. The selected spike particulates, including particle size and spike concentration, used in each test are specific to the objective of the test and justified in Section 3.1, Test Simulants section of this test plan. Alternatives to the spike materials require the concurrence with the TOC technical representative(s) before the material is procured.

Table 3-3: Remote Sampler Demonstration System Performance Simulant Spike Candidates

Compound	Solid Density (g/ml)	Characteristic Particle Size (micron)	Archimedes Number[a]	Free Settling Velocity[a] (ft/s)	Particle Reynolds Number[a]
Borosilicate Glass	2.23	1000 2000	1090 8740	0.19 0.42	23 100
Soda-Lime Glass	2.52	1000 2000	1430 11,400	0.23 0.51	27 120
Stainless Steel (SS)	8.0	1587.5 (1/16") 2380 (3/32")	31,200 105,000	1.3 2.1	250 590
Tungsten Carbide (WC)	14.2	1587.5 (1/16") 2380 (3/32")	60,000 202,000	2.1 3.3	400 940

[a] Calculated for a fluid having a liquid density of 1.29 g/ml and a viscosity of 3.3 cP.

3.1.4 Flow Regime

The flow regime within the transfer line and at the pump suction inlet is determined by the Reynolds number (*Re*) (Equation 3-4).

$$Re = \frac{\rho V D}{\mu} \tag{3-4}$$

Where: ρ and μ are the density and viscosity of the fluid, respectively, *V* is the velocity of the flow and *D* is the pipe or inlet diameter. For Newtonian fluids, the transition regime between laminar and turbulent flow is between *Re* values of 2300 and 4000. For non-Newtonian fluids, the Reynolds number for the transition regime must be calculated. The critical Reynolds number (Re_c) of transition from laminar to turbulent flow for Bingham plastic flow in pipes is determined by Equations 3-5 to 3-7 (Hanks 1963).

$$Re_c = \frac{He}{8\xi_{oc}}\left(1 - \frac{4}{3}\xi_{oc} + \frac{1}{3}\xi_{oc}^4\right) \tag{3-5}$$

$$He = \frac{D^2 \rho \tau_y}{K^2} \tag{3-6}$$

$$\frac{\xi_{oc}}{(1-\xi_{oc})^3} = \frac{He}{16{,}800} \tag{3-7}$$

Where: *He* is the Hedstrom number, $\boldsymbol{\xi_{oc}}$ is the ratio of the yield stress (τ_y) and the wall shear stress at the point of transition from laminar to turbulent flow, and *K* is the Bingham plastic viscosity, which replaces μ in Equation 3-5 when the Reynolds number is determined for Bingham Plastic fluids.

Table 3-4 shows the calculated flow regime for the proposed test conditions for SSMD Scaled Performance testing using a 13 wt% mass loading for Newtonian slurries.

For the standard operating conditions, the flow at the inlet is either transitioning from laminar to turbulent flow or fully turbulent at all scales. However, for the reduced capture velocity testing with the high density / high viscosity supernatant, the flow at the inlet for the Newtonian fluids becomes laminar in the scaled environment with Reynolds number values that drop below the transition value. In order to maintain the same pump out rate for the lower capture velocity (3.8 ft/s), the diameter of the inlet must be increased. In order to maintain flow conditions above the laminar regime, the supernatant viscosity must be reduced to 8.0 cP to keep all tests above laminar conditions. Using a linear relationship between the viscosity and density (see Figure 6-2 in RPP-PLAN-51625), the resulting density for the 8 cP supernatant is 1.318 g/ml. This additional simulant will be included in the test matrix for SSMD scaled performance when the design must be constrained to avoid laminar flow conditions. Both the cyclical jet motion and the squared corners of the pump suction inlet will increase the turbulence at the inlet. However, keeping turbulent conditions at the inlet is not attainable for the lowest capture velocity tests

when the high density/high viscosity supernatant is used. The test matrix either avoids this condition or minimizes the number of runs that are performed under these conditions.

Table 3-4: Flow Regime For Full and Scaled Systems

Scale	Inlet Size (in)	Pump Rate (gpm)	Inlet Velocity (ft/s)	Re	Re_c	Flow Regime
Typical Supernatant (Fluid Density = 1.284 g/ml, Viscosity = 3.6 cP)						
Full	2.25	140	11.3	70,200	2300	Turbulent
1:8	0.32	2.83	11.3	9,980	2300	Turbulent
1:21	0.28	2.17	11.3	8,740	2300	Turbulent
High Supernatant (Density = 1.37 g/ml, Viscosity = 14.6 cP)						
Full	2.25	140	11.3	18,500	2300	Turbulent
1:8	0.32	2.83	11.3	2,620	2300	Transition
1:21	0.28	2.17	11.3	2,300	2300	Transition
Typical Supernatant (Density = 1.284 g/ml, Viscosity = 3.6 cP)						
Full	2.25	90	7.3	45,100	2300	Turbulent
1:8	0.40	2.83	7.2	7,980	2300	Turbulent
1:21	0.35	2.17	7.2	6,990	2300	Turbulent
High Supernatant (Density = 1.37 g/ml, Viscosity = 14.6 cP)						
Full	2.25	90	7.3	11,900	2300	Turbulent
1:8	0.40	2.83	7.2	2,100	2300	Laminar
1:21	0.35	2.17	7.2	1,840	2300	Laminar
High Base/Modified High Supernatant (Density = 1.318 g/ml, Viscosity = 8.0 cP)						
Full	3.9	140	3.8	18,700	2300	Turbulent
1:8	0.55	2.83	3.8	2,680	2300	Transition
1:21	0.48	2.17	3.8	2,350	2300	Transition
Non-Newtonian with Base Solids (Density = 1.18 g/ml, Bingham Plastic Yield Stress = 3 Pa, Bingham Plastic Consistency = 5 cP)						
Full	2.25	140	11.3	46,400	11,700	Turbulent
1:8	0.32	2.83	11.3	6,600	3,270	Turbulent
1:21	0.28	2.17	11.3	5,780	3,070	Turbulent

3.2 SMALL-SCALE MIXING DEMONSTRATION SCALED PERFORMANCE

The SSMD scaled performance test activities documented in Section 3.2 are performed by Energy*Solutions* for WRPS.

The SSMD scaled performance activities described in this test plan will use the 1:21-and 1:8-scale tanks of the SSMD test platform (Figure 2-2) located at Monarch Machine & Tool Company, Inc. in Pasco, WA to evaluate the system performance when test conditions for mixing and transfer are varied. The operating parameters that will be varied during testing are

the mixer jet nozzle velocity and transfer pump capture velocity. The mixer jet rotational rate will be adjusted for each change in nozzle velocity according to Equation -3-9 in Section 3.2.1. In addition to varying the nozzle velocity, transfer pump capture velocity and mixer jet rotational rate, the simulant properties, both solids composition and supernatant composition, will also be varied and include both Newtonian and non-Newtonian slurries. Tests conducted at both scales will use the same simulant compositions so that the results from the two scales can be compared to determine velocities that result in equal performance. Velocities that result in equal performance will be used to determine the scaling relationship that will be used to predict full-scale performance.

3.2.1 Scaling Approach

The SSMD scaling approach was described in detail in test plan RPP-PLAN-52005. The scaling approach for the nozzle velocity and mixer jet pump rotational rate is unchanged and for completeness it is reproduced in Appendix A. The SSMD scaling relationship for nozzle velocity (Equation3-8) is a function of the mixer jet pump nozzle velocities for the two scaled systems, U_{jet}, the tank diameters, d_{tank}, and the scale factor exponent a. The SSMD scaled performance test activities will collect performance data at two scales to determine an appropriate value for the scale factor exponent.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{a} \tag{3-8}$$

As discussed in Section 3.2.6, a performance metric (e.g., the difference between the pre-transfer sample concentration of a component *i* and the average concentration of component *i* in each batch transfer) will be calculated for each test at each scale. Equation 3-8 will be used to determine the scale factor exponent that results in equivalent metric results between scales.

The SSMD scaling relationship for mixer jet pump rotational rates, ω_{tank}, (Equation 3-9) sets an equivalent number of mixer jet rotations in one turnover of the waste volume through the mixer jet pump. The resulting relationship is a function of the full-scale rotation rate, the geometric scaling factor (i.e., the ratio of the tank diameters), and the nozzle velocities for the two systems.

$$\omega_{tank2} = \frac{\omega_{tank1} U_{jet2}}{\left(\frac{d_{tank2}}{d_{tank1}}\right) U_{jet1}} \tag{3-9}$$

For SSMD scaled performance testing, a nozzle velocity will be selected and Equation 3-9 will be used to determine the rotational rate for the test.

3.2.2 Test Equipment and Instrumentation

Scaled performance testing will be performed using the established SSMD test platform at the Monarch Machine & Tool Company, Inc. facility in Pasco, Washington. A schematic of the

SSMD test platform is shown in Figure 2-2. The SSMD test platform has been used for previous test activities and will continue to be used to address uncertainties in the WFD Mixing and Sampling Program. The SSMD test platform was constructed to perform mixer jet pump testing at two different scales, approximately 1:21 (43.2-inch diameter tank) and 1:8 (120-inch diameter tank). Both tanks will be used for scaled performance testing so that the scaling relationship can be evaluated to predict full-scale performance. The properties of the DSTs used to geometrically scale the test tanks and the scaled properties of the two-scaled tanks are provided in Table 3-5. The plan view of DST 241-AY-102 is shown in Figure 3-1 (from H-14-010506, Sheet 4, Rev 1).

The SSMD test platform will continue to be used to assess the capability of the system to mix tank waste simulants and deliver the solids to a receipt tank. The main components of the test platform include: a 3,000-gallon flush tank, a 120-gallon (43.2-inch diameter) clear acrylic test tank (TK-201), a 2,358-gallon (120-inch diameter) clear acrylic test tank (TK-301), dual rotating mixer jet pump assemblies, and the slurry transfer pumps for both TK-201 and TK-301. Flow from the tanks enters the two mixer jet pump suction inlets on the bottom of the mixer jet pump, and is combined into one flow stream as it is routed through the pump driving the system. The pump discharge is split with half of the flow returning to each mixer jet pump. As each mixer jet pump is rotating, the flow is discharged back into the tank through two opposing jet nozzles located on the side of the mixer jet pump just above the pump suction inlet. Between scales, the mixer jet pump assemblies and transfer pumps for each tank are independent. The slurry transfer pumps are not submersible pumps located inside acrylic tanks. The slurry transfer pumps are progressive cavity pumps located outside of the test tanks; the inlets of the pump are connected to suction lines that are placed within the tanks. The end of the suction lines inside each tank is fitted with a nozzle with the desired opening, maintains this length for 1-2 inches, and then quickly transitions to the internal diameter of the transfer line, which is 3/8-inch. The suction nozzle is not fully prototypic. The non-prototypic configuration was selected as an economical alternative to developing a scaled version of the multistage submersible transfer pump and strainer, which is still being designed. The nozzle fitting is sized to achieve the desired suction and approximate, at scale, the zone of influence around the inlet of the transfer pump. The nozzle length is not intended to result in fully developed flow at the capture velocity because this is not the expected condition for flow into the full-scale submersible transfer pump, which enters through the inlet opening and is then subjected to different sized passage ways through the centrifugal pump. The exact configuration of the passage ways through the transfer pump for waste feed delivery is still under development. The desired opening is machined to match the requirements in Table 3-4 and Table 3-5. The transfer pump suction inlet shall be placed consistent with the location of Riser 30. The scaled height of the pump suction inlet shall be equivalent to the height of the transfer pump inlet in the full-scale DST transfer system, which is 0.8 inches from the tank bottom in TK-301 and 0.28 inches from the tank bottom in TK-201 (see Table 3-5). Ancillary equipment, such as the support structure, the control system, video monitoring, and simulated piping to transfer and sample the material from the tank are also part of the test platform.

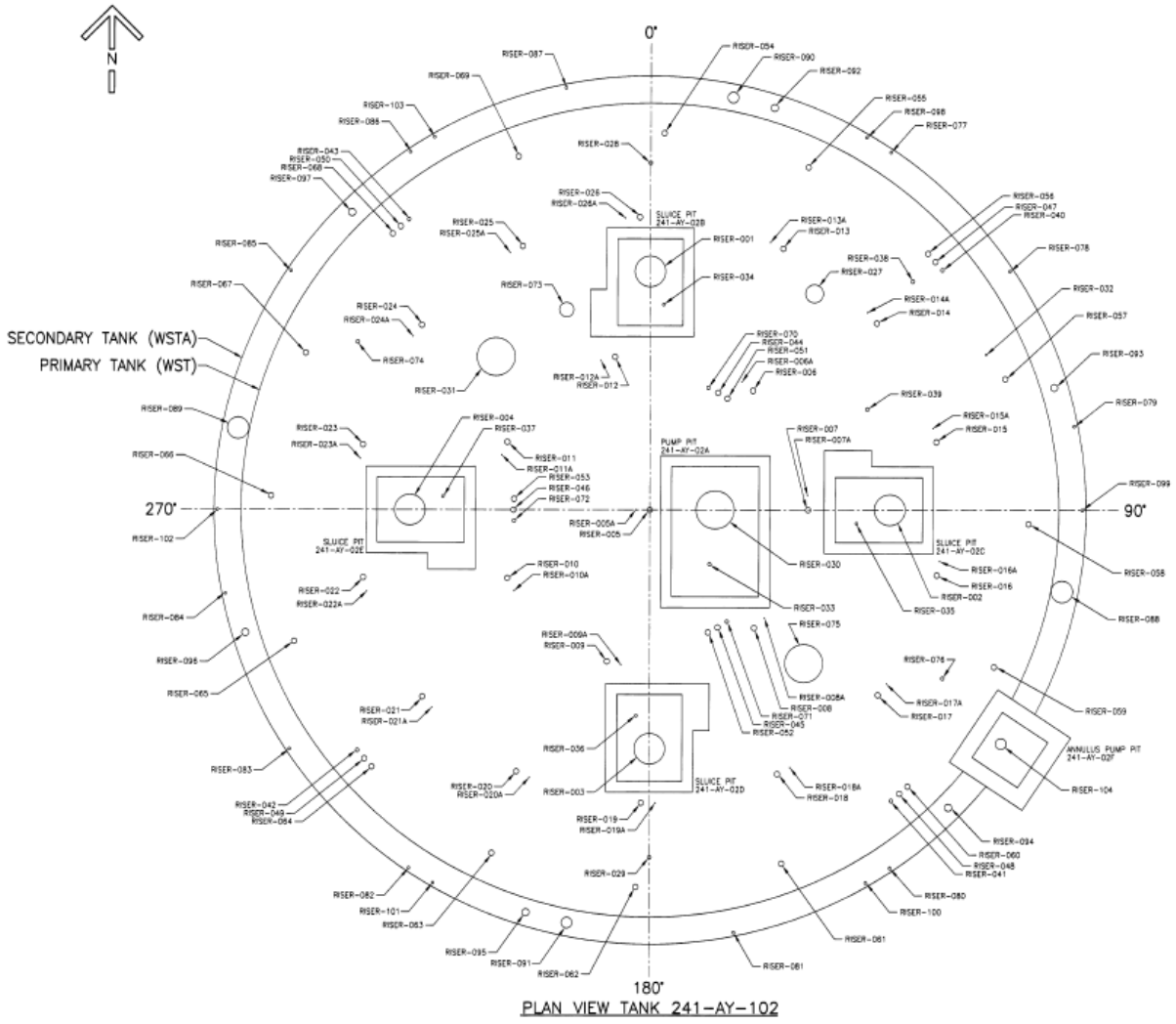
The transfer system piping, valving, and instrumentation (e.g., in-line Coriolis meters, and magnetic flow meters) will replicate the transfer system from previous SSMD testing reported in RPP-49740. The test configuration includes a closed recirculation loop from the tank. The recirculation loop accommodates sample collection. Flow control is automated using programmable logic controllers connected to a human–machine interface. System data,

including date and time, slurry temperature, mixer jet pump rates and position, slurry flow rates, tank level, and specific gravity measurements in the transfer pump discharge, will be monitored and recorded using a data acquisition system.

The internal passageways of the mixer jet pumps driving pump and the slurry transfer pump are larger than the transfer lines; therefore, particles with a high settling velocity (e.g. stainless steel powder in the base simulant) may settle in the pump because the velocity through the pump is reduced below the critical velocity of the particles. Modifications to the pump orientation to minimize the collection of particles will be evaluated. The extent that particles can collect in the transfer pump shall be evaluated in developmental testing so that this condition can be captured as a source of error. In addition, the slurry lines shall be purged in between tests to reduce the potential that settled solids from one test contaminate the results of a subsequent test.

When operating in a recycle mode to stabilize the mixing tank prior to performing batch transfers, the transfer line shall be discharged back into the tank. During batch transfer operations the transfer line shall be discharged for sample collection or waste collection.

All measuring and test equipment, including gauges and instrumentation, used for testing activities shall be controlled, calibrated under conditions typical of the test environment, adjusted, and maintained to required accuracy limits. The condition and the reported accuracy of each instrument shall be documented in a test log.



Note: Mixer jet pumps will be in Riser-001 (0°) and Riser-003 (180°). Transfer pump will be in Riser-030 (90°)

Figure 3-1. Plan View Tank 241-AY-102

Table 3-5: Small-Scale Mixing Demonstration Tank Geometrically Scaled Properties

Property	Full-Scale DST (AY-102)	1:8 Scale	1:21 Scale
Diameter (in)	900	120	43.2
Scale Factor	1	0.1333	0.048
Fill Height (in)	343	45.7	16.5
Bottom Geometry	Flat w/12-inch corner radius	Flat w/1.6-inch corner radius	Flat w/0.6-inch corner radius
Fill Volume1 (gallons)	944,620	~2,200	~100
Mixer Jet Pump 1 Location[2]	Riser-001 0°, 22 feet	90°, 2.9 feet	90°, 0.96 feet (12.7 in as-built)
Mixer Jet Pump 2 Location[2]	Riser-003 180°, 22 feet	270°, 2.9 feet	270°, 0.96 feet (12.7 in as-built)
Mixer Jet Pump Suction Elevation[3] (in)	5±1	0.67±0.13	0.24±0.05
Mixer Jet Pump Suction Diameter (in)	11	1.47	0.53
Mixer Jet Pump Nozzle Diameter (in)	6	0.80	0.28
Mixer Jet Pump Nozzle Elevation[3] (in)	18	2.4	0.86
Mixer Jet Rotation Rate (rpm)	0.2	See Eq. 3-5	See Eq. 3-5
Transfer Pump Location[2]	Riser-030 90°, 6 feet	0°, 0.8 feet	0°, 0.29 feet
Transfer Pump Suction Inlet Diameter (in)[4]	2.25-3.9	0.32-0.55	0.25-0.48
Transfer Pump Suction Inlet Height (in)[4]	6	0.8	0.28
Transfer Line Diameter (in)	3.07 (3-inch Schedule 40)	½"-poly tubing (0.375-inch inner diameter)	½"-poly tubing (0.375-inch inner diameter)
Tank Obstructions	Air Lift Circulators (ALCs)	Simulated ALCs (removable)	Simulated ALCs (removable)

[1] Fill volume is determined by linear scaling of the tank diameter and sludge volume height.

[2] The reference point for DST locations presented in this table defines 0° as the top of 241-AY-102 in a plan view drawing of the tank. Provided distances are design distances from the center of the riser to the center of the tank.

[3] Elevation is relative to the tank bottom.

[4] The pump suction inlet diameter of the Full-Scale Transfer Pump is underdevelopment and the tabulated range of values is based on similar transfer pumps used on the Hanford site to convey waste and preliminary design information. The inlet size on the 1:21 scale tank is not geometrically scaled. The resulting inlet size was too small to accommodate the particle sizes targeted.

3.2.3 Test Simulants

The simulants used in the SSMD scaled performance testing are selected in accordance with the recommendations in RPP-PLAN-51625. Simulant properties and qualifications are described in Section 3.1. Selecting particular simulants for SSMD scaled performance test activities is discussed below. The test matrix showing the combinations of base simulant and liquid supernatant is discussed in Section 3.2.4.

The SSMD scaled performance simulants shall include Newtonian and non-Newtonian simulants. For SSMD limits of performance testing, non-Newtonian testing was conducted with slurries of kaolin clay spiked with large and dense particles. For SSMD scaled performance testing the non-Newtonian solids will also be principally kaolin clay, but stainless steel and zirconium oxide will be added so that batch transfer performance can be quantified. Sodium thiosulfate will be added to increase the density of the non-Newtonian slurries when required in the test matrix.

The Newtonian simulant shall be a complex (i.e., multicomponent) simulant containing base particulates. The liquid phase shall be a supernatant simulant. Sodium thiosulfate will be added to increase the density of the Newtonian slurries when required in the test matrix. Glycerol will be added to increase the viscosity of the Newtonian slurries when required in the test matrix. Recipes for the simulants discussed below are tabulated in Table 3-1 and Table 3-2.

Although RPP-PLAN-51625 recommends three conceptual simulants for WFD Mixing and Sampling Program DNFSB 2010-2 testing, only two simulants are selected for SSMD scaled performance testing, the typical and the high conceptual simulants. The low conceptual simulant is composed entirely of small gibbsite particles, which are readily suspended at even the lowest operational velocities, and are therefore not interesting for determining equivalent performance between scales. Based on the distribution of Archimedes numbers and jet suspension velocities reported in Figures 8-1 and 8-2 in RPP-PLAN-51625, the typical and high conceptual simulants are representative of the typical conceptual simulant to suspend, and most challenging to suspend tank waste. Although the typical conceptual simulant recommends that two different sized gibbsite particles be used, batch consistency performance will be based on chemical analyses of the transferred material, which will not distinguish between the different sized materials and so the scaling analysis will not consider the effect of gibbsite size. A similar limitation is applied to sand in tests with the high conceptual simulant, which includes two different sized sands.

To investigate the effects of the supernatant density and viscosity, three supernatant compositions will be investigated, typical, high, and modified high. For the typical supernatant, the liquid density is 1.284 g/ml and the liquid viscosity is 3.60 cP. The typical supernatant is consistent with the typical density/typical viscosity recommendation in Table 3-2. For the high supernatant, the liquid density is 1.368 g/ml and the liquid viscosity is 14.6 cP. The high supernatant is consistent with the high density/high viscosity recommendation in Table 3-2. For the modified high supernatant, the liquid density is 1.318 g/ml and the liquid viscosity is 8 cP. The modified high supernatant is necessary to prevent laminar flow at the transfer pump inlet when a higher density, Newtonian simulant is evaluated at lower capture velocities. The recipe for the modified high supernatant will be developed as a variant of the high density/high viscosity supernatant by adding less glycerol and sodium thiosulfate. The acceptable preparation

tolerances are discussed in Section 3.1.2. Liquid viscosity shall be evaluated at the operating temperature of the test tank, if the temperature of the sampled material differs from the bulk volume. The high values for liquid density and liquid viscosity are selected because higher densities and higher viscosities are expected to increase the buoyancy effecting solid particles in the mixing tank and reduce critical suspension and settling velocities. Increasing buoyancy and subsequently reducing the critical suspension velocity and settling velocities are expected to promote particle suspension, which will improve mixing within the tank. Although higher viscosities fluids may reduce the capability of the system to clear the solids from the bottom of the tank, SSMD scaled performance testing is evaluating transfer batch consistency with the pre-transfer samples and is not evaluating the capability of the system to mobilize all material from the tanks. Improved mixing within the tank is expected to yield a more representative pre-transfer sample and also result in better batch-to-batch consistency. To confirm this expected correlation, the three supernatant simulants will be used during testing.

The effect of solids loading on batch-to-batch consistency and batch consistency with the pre-transfer sample between scales is difficult to predict. Previous SSMD test results (RPP-49470) indicate that in three of four tests, the fraction of the initial amount of stainless steel transferred from the tank was within 10% of a comparable case with twice as much stainless steel initially present in the tank. In the fourth test, the fraction of stainless steel recovered was less than 50% of a comparable case with twice as much stainless steel initially present in the tank. In these same tests, the amount of zirconium oxide and gibbsite were held constant. The difference in the fraction of the initial amount of zirconium oxide transferred from the tank in each comparable test was within 10%. The differences in the fraction of initial gibbsite transferred out of the tank ranged from 15-to-30%. Therefore, the differences in the stainless steel recoveries are comparable to other solids with initial amounts that did not vary. With these results in mind, the effect of solids loading will not be investigated and will be held constant at 13wt% based on the ICD-19 allowable limit of 200 g/l. The mass loading is equivalent to 180 to 194 g/l depending on the composition of solids and supernatant selected. The effect of solids loading will be revisited during supplemental testing that includes scaled relationship confirmation runs with different mass loadings. These confirmation runs will be performed with lower mass loading values because the mass loading tested is at the upper range of the ICD-19 action level for solids loading.

In addition to the Newtonian tests discussed previously, tests will also be performed using a non-Newtonian slurry with a Bingham plastic yield stress. In order to produce quantitative data stainless steel and zirconium oxide will be added to the kaolin slurry. The amount of stainless steel and zirconium oxide added to the slurry will be equal to the amount added for a Newtonian test using the typical supernatant and typical base simulant with a solids loading of 13 wt%. The non-Newtonian tests will be conducted to test SSMD transfer performance with a non-Newtonian simulant and evaluate whether or not the transfer batch consistency with the pre-transfer sample for a mobilized non-Newtonian simulant scales according to the Newtonian scaling relationship. A fundamental difference between the Newtonian slurry and the Bingham plastic non-Newtonian slurry is the yield stress necessary to get the slurry to behave like a fluid. In a fully mixed tank (i.e., no caverns are formed) the Bingham plastic fluid that is available to be transferred from the tank has overcome the yield stress necessary to mobilize the fluid and is expected to behave like a Newtonian fluid. Therefore, transfer batch consistency with pre-transfer samples may be characterized by Newtonian scaling relationship. If caverns are

observed at the lowest nozzle velocities, then the batch transfer results may not be useful in the evaluation of the non-Newtonian data. If the second lowest nozzle velocity results in the formation of caverns, the velocity will be increased until cavern formation is eliminated. It is recognized that moderate to high yield stress fluids (greater than 5 Pa) may form stagnant areas within the tank that effect transfer performance so that using the same scaling relationship may not be applicable. However, current ICD-19 limits have a yield stress action level of 1 Pa, so that slurries that are expected to be challenging to mix, sample, and transfer (i.e., slurries with a yield stress exceeding 5 Pa) may not be suitable for delivery to the WTP. The SSMD scaled performance testing will begin to evaluate the scaling of non-Newtonian simulants using slurries with a Bingham plastic yield stress of 3 Pa and a density of approximately 1.16 g/ml. The 3 Pa limit was selected because it is similar to values that have been used in mixing tests in the past, and is expected to be manageable in the 120-inch diameter tank. Due to the anticipated formation of stagnant zone in the mixing tank when higher yield stress fluids are evaluated, it is unlikely that non-Newtonian slurry with a Bingham plastic yield stress of 10 Pa will scale equally as Newtonian slurry. The non-Newtonian slurry shall be prepared and measured in accordance with the recipes, methods, and tolerances discussed in Section 3.1.1.

3.2.4 Operating Parameters and Test Methods

The operating conditions for the SSMD scaled performance testing should be consistent with previous SSMD performance testing. The mixer jets shall rotate continuously clockwise with no rotational offset between mixer jet pumps; the streams will be synchronized to meet in the center of the tank. The rotational speed of the jets (ω) shall be set in accordance with Equation 3-9, but mixing performance using five different nozzle velocities will be evaluated. Five nozzle velocities have been selected to evaluate two bounding mixing conditions and three points in between these bounding conditions to characterize the behavior in between the bounds. The two bounding conditions evaluate velocities that result in bottom cleaning and very poor performance. A velocity with poor mixing performance is being evaluated because the determination for equal performance between scales does not require optimal performance.

Testing conditions that are bounding for both acceptable performance and poor performance will ensure that performance differences are observed during testing so that equal performance among scales is observed. Because equal performance is expected to be at velocities between these bounding conditions, three additional velocities approximately equally spaced from the end points will also be evaluated. Selecting two or more velocities in between the bounding conditions will provide additional data points for the functional model applied during analysis, and increase the confidence that the behavior between the bounding conditions is characterized by the fitted model. The five nozzle velocities that will be used during SSMD scaled performance testing are not determined in advance (as discussed below); however, the nozzle velocities used will be consistent with previous testing, which included nozzle velocities in the range of 22.3 ft/s (70 gpm) to 35.4 ft/s (111 gpm) in the larger test vessel (TK-301) and 16.9 ft/s (6.5 gpm) to 27.6 ft/s (10.6 gpm) in the smaller test vessel (TK-201).

Prior to performing batch transfers that remove material from the tank, the system shall be operated in a recirculation mode until a stable state is established. The stable state is indicated by a consistent mass flow rate reading from the Coriolis meter, after adjusting for cyclical variations caused by the rotating jets. Additionally at the stabilized state a steady cloud height

and mixer jet zone of influence should be observed. Previous operator experience indicates that approximately 10-20 rotations of the mixer jets pumps are sufficient to result in a stabilized state once the solids have been added and dispersed throughout the tank. Once the tank reaches the stable condition, pre-transfer samples will be collected as described in Section 3.2.5. Once the pre-transfer samples are collected, batch transfers will be initiated.

After the first batch transfer is completed, the system shall be reconfigured to recirculate the waste until a stable state condition is re-established. Once the stable state condition is re-established, the next batch transfer and sampling operation will be initiated and will proceed like the first batch transfer and sampling operation. The process will be repeated until five batch transfers have occurred. After the last batch transfer is completed, a description of the solids remaining in the tank, including a photographic or video record, will be prepared and the tank will be emptied.

The upper velocity for each tank will be determined in during testing. Prior to performing a batch transfer the nozzle velocity in each tank will be varied to determine the nozzle velocity required to prevent the formation of piles on the sides of the tank when the typical base simulant is mixed with the typical supernatant. If the nozzle velocity required to clear the bottom exceeds the capability of the system or results in unsafe operating conditions (e.g., splashing or tank shaking) then the velocity will be limited to a maximum that can be operated safely. The resulting velocity will be set as the maximum nozzle velocity used during SSMD scaled performance testing. The combination of the typical base simulant in the typical supernatant was selected because it is expected to be the easiest of the tested configurations to be suspended. This expectation is based on observation that the typical base simulant was developed to be easier to mix than the high base simulant. In addition, this expectation is also based on the radial wall jet velocity needed to achieve complete solids suspension discussed in PNNL-20637 (Equation 2.9).

Compared to the high base simulant in both the typical and high supernatants and the typical base simulant in the high supernatant, the predicted nozzle velocity needed to achieve complete solids suspension, keeping everything else equal, is the least for the typical base simulant in the typical supernatant. This expectation is also consistent with effective cleaning radius calculations that use Equation 5.8 in PNNL-20637, to estimate the effective cleaning radius for slurry containing five wt% 100-micron stainless steel particles using the Shields diagram to determine the critical shear stress for erosion. The formula can be used to show that the combination of the higher density and higher viscosity fluid, despite the increase in buoyancy by the higher density fluid, reduces the effective cleaning radius for the particles; the reduction in the effective cleaning radius due to the change in the viscosity over the planned range exceeds the benefit by the increased density. With the expectation that a velocity that effectively cleans the bottom of the tank is higher than that required for acceptable batch-to-batch consistency with the pre-transfer samples, selecting the velocity that achieves complete bottom cleaning for the easiest to suspend solids ensures that the system is not operated above necessary velocities for any scaled performance test.

The lower velocities for each tank are also determined during developmental testing and are based on a minimum effective cleaning radius criterion. Following the discussion for determining the upper nozzle velocity, it is expected that the high base simulant in the high

density and high viscosity supernatant would result in the lowest effective cleaning radius of the simulant combinations planned in the SSMD scaled performance testing. This simulant combination will be used to determine the minimum nozzle velocity to be used during testing. Previous experimental work shows that in the 1:8-scale system batch- to-batch consistency with the pre-transfer samples was poor when the nozzle velocity was 22.3 ft/s (data from RPP-49740). At this nozzle velocity, the effective cleaning radius was measured to be approximately 75% (approximately 55 inches from the mixer jet pump nozzle) of the distance need to achieve complete bottom clearing (i.e. the distance between the mixer jet pump nozzle and the edge of the tank along a diameter that is orthogonal to the diameter containing the mixer jet pumps). Therefore, developmental testing with the high base simulant in the high density and high viscosity supernatant will be used to determine the nozzle velocity at each scale that results in an effective cleaning radius that is 75% the length to achieve complete bottom clearing. Using the most difficult simulant combination will ensure that the nozzle velocity will be high enough to result in acceptable batch transfer performance during the other tests at this nozzle velocity. The resulting velocity for the 1:8-scale system may not be 22.3 ft/s due to differences from the previous tests for both the base solids being suspended and the composition of the supernatant.

Three velocities that are approximately equally spaced between the upper and lower set points will also be used during testing. Selecting specific intervals rather than specific scale factor exponents was preferred for the regression analysis that will correlate nozzle velocity to the performance metric considered.

Scaled performance testing will evaluate three capture velocities. The capture velocity is also referred to as the suction velocity and is defined as the average velocity across the pump suction inlet opening area. The capture velocity is adjusted by changing cross-sectional area of the nozzle for the pump suction inlet (see Section 3.2.2). The maximum capture velocity being evaluated (11.3 ft/s) is equated to the full-scale capture velocity that occurs at the maximum transfer rate (140 gpm). Operating at the maximum flow rate minimizes the waste transfer time. Operating at the maximum capture velocity at the pump suction inlet offers a greater opportunity to capture tank solids. At the maximum capture velocity, the fluid velocities at the transfer pump inlets at the scaled systems are equal. A lower capture velocity is also being evaluated to determine the sensitivity the capture velocity has on the test results. Selection of the lower capture velocity is based on past test experience and uncertainties in the WFD transfer pump design.

Previous reports indicate that the effects of varying the capture velocity are mixed. A recent study evaluating lower capture velocities at both scales (RPT-SSMD-EG-00006, *SSMD Platform Small Scale Mixing Demonstration Low Capture Velocity Follow On Results Report*) indicated that when the capture velocity in the small test vessel (TK-201) was lowered from 11.3 ft/s to 6.3 ft/s with a mixer jet pump flow rate of 27.6 ft/s (10.6 gpm), the cumulative amount of gibbsite transferred in five batches only differed from the predicted amount using the pre-transfer sample by 1% at the maximum capture velocity but was 12% over predicted by the pre-transfer sample at the reduced capture velocity. The cumulative amount of gibbsite transferred at the two capture velocities varied by less than 2%. In the large test vessel (TK-301) the results for gibbsite with a mixer jet pump velocity of 35.4 ft/s (111 gpm) were comparable for the higher capture velocity (11.7 ft/s) but were still over-predicted by 6% at the lower capture velocity (5.9 ft/s). The higher transfer velocity transferred 12% more gibbsite. The results for zirconium oxide were similar.

Comparisons of stainless steel results in the small test vessel show that an equivalent amount of material was transferred at the two capture velocities but the amount transferred was over-predicted by the pre-transfer sample by 18-37%. In the large test vessel, the cumulative amount of stainless steel transferred was within 1% of the predicted amount from the pre-transfer sample at the higher capture velocity, but was over-predicted by 37% at the lower capture velocity. With these results taken into consideration, the effects of the changes in the capture velocity remain uncertain and two different velocities at each scale will be evaluated.

An intermediate capture velocity is equal to the full-scale capture velocity at the lowest planned full-scale operating flow rate (90 gallons per minute) and is 7.3 ft/s when the transfer pump inlet is 2.25 inches in diameter. The alternative capture velocity will be maintained by increasing the cross-sectional area of the pump suction inlet (see Section 3.2.2) while maintaining the same flow rate through the transfer tubing. This method for adjusting the capture velocity was selected to avoid reducing the flow through the transfer tubing downstream of the pump inlet, which may result in particle settling that could interrupt test operations. Inlet sizes for the modified conditions are listed in Table 3-4 and Table 3-5.

A low capture velocity will also be evaluated. The WFD transfer pump is currently being designed and recent communications with the supplier indicate that the pump suction inlet may need to be increased to 3.9 inches to accommodate the requirements specified for the pump. At 140 gpm, the capture velocity for a 3.9-inch inlet drops to 3.8 ft/s. As discussed in Section 3.1.4, this flow velocity results in laminar flow at the inlet of the scaled system when the high density/high viscosity supernatant is used. In lieu of using the high density / high viscosity supernatant under these conditions, tests will be conducted using a reduced viscosity fluid. Testing with the reduced viscosity fluid avoids scaled testing in the laminar flow regime when the flow in the full scale system would be turbulent.

Non-Newtonian tests will be performed using the same nozzle velocities but will only use the higher capture velocity.

Data collection for each test is described in Section 3.2.5.

The test matrix for SSMD scaled performance testing is provided in Table 3-6. In order to reduce the occurrence of systematic errors, such as instrument calibration drift and elevated temperatures as testing progresses to warmer days, the tests should be performed in a random order. In order to minimize contamination of subsequent tests when a random order is followed, the test platform (test tank, transfer lines, transfer equipment, and sample collection containers) shall be thoroughly flushed and cleaned prior to each test. The test matrix is not a full factorial design for the varied parameters, which include the five nozzle velocities, the two base simulant compositions, the three supernatant compositions, and the three capture velocities. Performing a full factorial design for the variables most important to determining the scaling relationship would allow for an inclusion of any interaction effects between the varied parameters. Performing a partial or fractional factorial design for the variables allows quantification of more important variables at the expense of quantifying interaction effects. The specific variations in the test conditions were selected using a computer algorithm. This method, known as a Bayesian I-optimal design algorithm, essentially selects the “best” test runs from the set of all possible combinations of the settings of the specified design factors, where “best” translates to small

variability of predictions. An additional constraint was applied that excluded test conditions that result in laminar flow conditions at the transfer pump inlet suction (Section3.1.4).

In addition to these 18 tests at each scale, four replicate tests will be performed at each scale. The replicates are performed at nozzle velocities that help to reduce the average predicted variance to give greater confidence in the collected data. There are four additional tests for a non-Newtonian slurry. These tests are conducted with the same slurry composition at different nozzle velocities.

In addition to the 22 Newtonian and 4 non-Newtonian tests, four additional confirmation runs are planned. These runs will be performed once the SSMD scaled performance data is collected and analyzed. The confirmations runs that will be performed will be selected once the initial data analysis is completed to determine what additional runs may be necessary. Examples of confirmation runs that will be considered include a nozzle velocity variation. Analysis of the collected data will be used to determine the scale factor exponent for equivalent performance between scales (based on a pre-transfer sample and batch consistency metric). A set of runs using the scale factor exponent to determine the nozzle velocities for each scale will be performed to confirm the analysis. The nozzle velocity verification runs could be performed with different simulant variations. In addition, supplemental confirmation runs may be performed to evaluate parameters that were initially considered less important to assessing the scaling relationship and may include a mass loading variation, another capture velocity variation, and another supernatant variation. The configuration of the confirmation runs may change as the data analysis of the first 26 runs is conducted.

Table 3-6: Small-Scale Mixing Demonstration Scaled Performance Test Matrix

Test Number	Nozzle Velocity 1:21-Scale ft/s (gpm)[d]	Nozzle Velocity 1:8-Scale ft/s (gpm)[d]	Base Simulant Constituent	Supernatant/Non-Newtonian Simulant Properties[a]	Capture Velocity
1	V21-1	V8-1	High	Typical	7.3 ft/s
2	V21-3	V8-3	High	Typical	7.3 ft/s
3	V21-2	V8-2	Typical	Typical	7.3 ft/s
4	V21-5	V8-5	Typical	Typical	7.3 ft/s
5[c]	V21-5	V8-5	Typical	Typical	7.3 ft/s
6	V21-2	V8-2	High	Modified High	3.8 ft/s
7[c]	V21-2	V8-2	High	Modified High	3.8 ft/s
8	V21-4	V8-4	High	Modified High	3.8 ft/s
9	V21-1	V8-1	High	Modified High	7.3 ft/s
10	V21-5	V8-5	High	Modified High	7.3 ft/s
11	V21-3	V8-3	High	Modified High	11.3 ft/s
12[c]	V21-3	V8-3	High	Modified High	11.3 ft/s
13	V21-3	V8-3	Typical	Modified High	3.8 ft/s
14	V21-1	V8-1	Typical	Modified High	7.3 ft/s
15	V21-5	V8-5	Typical	Modified High	7.3 ft/s
16	V21-3	V8-3	Typical	Modified High	11.3 ft/s
17[c]	V21-3	V8-3	Typical	Modified High	11.3 ft/s
18	V21-1	V8-1	High	High	11.3 ft/s
19	V21-3	V8-3	High	High	11.3 ft/s
20	V21-5	V8-5	High	High	11.3 ft/s
21	V21-2	V8-2	High	High	11.3 ft/s
22	V21-4	V8-2	Typical	High	11.3 ft/s
23	V21-1	V8-4	Non-Newtonian (kaolin clay)	Bingham Plastic Yield Stress = 3 Pa, Slurry Density ~ 1.16 g/ml	See Note b
24	V21-2	V8-2			
25	V21-4	V8-4			
26	V21-5	V8-5			

[a] High supernatant properties: density = 1.368 g/ml, viscosity = 14.6 cP; Modified high supernatant properties: density = 1.318 g/ml, viscosity = 8.0 cP; Typical supernatant properties: density = 1.29 g/ml, viscosity = 3.6 cP; non-Newtonian slurry properties, Bingham plastic yield stress = 3 Pa and density ~ 1.16 g/ml.

[b] For non-Newtonian tests, stainless steel and zirconium oxide will be added to the slurry at a mass equivalent to the typical base simulant and typical supernatant (Test #6-11). The capture velocity will be specified to be 11.3 ft/s.

[c] Test is a replicate.

[d] Within a scaled system, test velocities increase from Vx-1 to Vx-5.

3.2.5 Sample Collection and Chemical Analysis

Prior to performing each test, the simulants are prepared and qualified. The solid particulates are qualified for use prior to testing in accordance with Section 3.1.1.2. Base simulant qualification uses a laboratory determined particle size distribution and density for the procured materials to compare computed metrics for the simulants (e.g., distribution of Archimedes number, jet velocities necessary to achieve complete solids suspension, etc.) to the recommended composites from RPP-PLAN-51625. The liquid density and liquid viscosity of the supernatant of the Newtonian simulants and the Bingham plastic yield stress of the non-Newtonian simulant are qualified for use prior to adding base solids. Measurements of the supernatant density and viscosity will be performed on-site with a hydrometer and a rheometer as discussed in Section 3.1.2. Measurements of the Bingham plastic yield stress and Bingham plastic consistency of the non-Newtonian fluid will be performed on-site with a rheometer as discussed in Section 3.1.1. Data collection shall be performed in accordance with NQA-1-2004, Requirement 11including addenda, or a later version.

Prior to conducting the first batch transfer the tank contents are mixed at the operating conditions until mixing in the tank has stabilized. During tank stabilization, the transfer pump is engaged so that the specific gravity of the transferrable slurry can be monitored. The location of the Coriolis meter is downstream from the transfer pump. During tank stabilization the transfer pump discharge is re-circulated back into the tank. Monitoring the mass flow rate and slurry specific gravity will allow an assessment of the systems capability to mix and convey the complex simulant. Once the system has stabilized, two pre-transfer samples are collected. Similar to previous work, pre-transfer and batch transfer samples will be diversion samples through sample ports whose valves are programmatically controlled and correlated to the position of the mixer jet nozzles using encoders. Samples shall be collected downstream of the transfer pump but within the recirculation flow loop. Pre-transfer samples shall be collected in a manner that avoids bias and does not withdraw an excessive amount of material from the tank such that the conditions of the tank would be significantly altered. To avoid bias caused by the cyclical nature of the mixing system that directs the jet directly at the transfer pump twice per revolution, the pre-transfer samples shall be collected for an integer value of full rotations of the mixer jets. The mass and volume of the collected material for the pre-transfer samples shall be measured and recorded. If necessary, the collected sample will be subsampled prior to sending the sample off-site for analysis. Subsampling of collected samples shall be performed according to established procedures (summarized below) for batch samples during SSMD test activities. The collected samples will be analyzed for chemical composition to identify the concentration of the base simulant solids in the collected samples.

Once the pre-samples are collected and the tank contents are re-stabilized, batch transfers are initiated and slurry samples for each transfer batch are collected for chemical analysis. Samples for the 1:21-scale tank shall collect the entire volume of the transfer batch and this volume shall be sub-sampled for chemical analysis. For the 1:8-scale system, only part of the transfer batch will be collected for sampling. For the 1:8-scale system, four slurry samples will be collected during each transfer and the four slurry samples will be combined to form a representative sample for the entire transfer batch. Each of the four samples should be collected at regular intervals during the transfer. The duration for collecting each of the four samples will be equivalent and will be equal to an integer value of mixer jet full rotations. Because the mixer jet

pumps rotate at different speeds for different nozzle velocities, the subsample duration and hence volume of material collected during sampling varies between tests. The total volume of the slurry sample collected during a transfer for the 1:8-scale system should be similar to the full transfer batch volume for the 1:21-scale system. The mass and volume of the collected material for the batch transfer samples shall be measured and recorded. The collected volume is then sub-sampled for chemical analysis.

The collected volume from each pre-transfer sample (as necessary) and batch transfer may exceed the amount necessary for laboratory analysis and may be sub-sampled. The collected volume representing each transfer batch is settled in a large volume container. Settling in the non-Newtonian slurry may be hampered by the kaolin clay particles in the slurry. In previous testing, the collected material is clarified for 24 hours in a mixer barrel prior to decanting the liquid. This method will be refined during developmental testing to ensure that the subsamples can be collected in a reasonable amount of time and be representative of the content of the composited material. The mass and volume of the slurry is recorded. The liquid is decanted and the wetted solids are mixed prior to sub-sampling. Four representative and two archive samples are collected randomly from the solids. The four collected samples are shipped off-site for laboratory analysis; the two archive samples are retained on-site in a managed area to prevent a loss of sample integrity. Off-site analytical services are performed by a laboratory that operates under a Quality Assurance program that has been evaluated against quality requirements in ASME NQA-1-2004 including addenda, or a later version. The four samples that were shipped for off-site analysis are analyzed for the mass of dry solids (Newtonian tests only) and the mass of each primary constituent in base simulant. Analytical data is required to be enhanced quality so that all sample collection, sample analysis, sample handling, and data reporting shall be traceable to the test performed. The sample results shall be reported in a Microsoft Excel[2] compatible format. Prior to the start of testing, analytical method development shall be performed to determine the sample preparation error associated with measuring the base material content in the presence of kaolin clay and the supernatant rheology modifiers. The analytical method is considered acceptable if it produces an unbiased result with a relative standard deviation of less than 10%.

In addition to collecting slurry samples for chemical analysis, other performance data will be collected. Each system in the SSMD test platform has the capability to record operational parameters such as test time, slurry temperature, mixer jet pump flow rate, mixer jet angular position, mixer jet pump rotational rate, tank level, slurry transfer rate and slurry specific gravity. This data is recorded by a data acquisition system and shall record data for the entire test duration. In addition, performance data shall also be recorded in the test log during testing. Performance data describing the dimensions of any accumulated material in the tank shall be collected throughout the test, noting specifically when changes in tank stability occur due to a change or process interruption. In addition, cloud height and effective cleaning radius measurements shall also be recorded in the test log. The effective cleaning radius can be determined while the mixer jets are running by measuring the distance from the edge of the mixer jet pump nozzle to the edge of the pile of solids that has stabilized on the sides of the tank. Multiple measurements shall be collected in each test to determine an average effective cleaning

[2] MS Excel® is a registered trademark of the Microsoft Corporation, Redmond, WA.

radius. Measurements shall be collected for each batch transfer to support an evaluation of changes in the system as the tank level is lowered.

3.2.6 Performance Analysis

Particle movement in stirred tanks is described by multiple physical phenomena related to particle fluid interactions. Some examples of these physical principles include: particle settling, settled particle mobilization, fluid jet decay and propagation, and turbulence affects on particle movement. Because the primary performance metric for this testing, representative pre-sampling of the transferred batches, involves a complex interaction of these fundamental physical phenomena, estimating performance at different scales will be related to the observed behavior of the primary metric at the two test tank scales. Assessing the scaling relationship for the 1:21 and 1:8 scale systems will be performed using the analytical data collected during testing.

The objective is to identify the operating conditions where the two scaled tanks perform equivalently. This will allow definition of a mathematical scaling relationship between the two tanks that can then be applied of other geometrically scaled tanks. Once the scaling relationship is established, the full-scale mixer pump jet velocity can be scaled down to identify the equivalent small-scale tank conditions and therefore allow full-scale performance to be estimated based on the small scale results. Conceptually, to define tank performance equivalence, a test run could be performed at a specified jet nozzle velocity in one scaled tank. Then a test run could be performed in the second scaled tank, where only the jet nozzle velocity and rotational rate were adjusted to provide performance equivalent to that in the first tank. Based on the theoretical scaling model shown in Equation 3-8, the scaling exponent could then be calculated for the two scaled tanks and velocities used. Multiple test runs could be performed in similar fashion on both scales, and the resulting calculated scale exponents could be combined to provide a scale exponent based on the set of tests. However, for batch transfer testing, performance is not quantified until after the batches have been transferred from the mixing tank and the samples have been analyzed at an off-site laboratory, which makes it impractical to perform the testing in this conceptual fashion. As a conceptual alternative, a set of test runs could be made at one scale, over a range of jet nozzle velocities, followed by a set of test runs made over a range of jet nozzle velocities in the second tank. Then these test runs would be "paired-up" to identify the test runs at the two scales which produced the most similar performance. The scale exponent could then be calculated, using Equation 3-8, for each similar pair. If a suitably large number of velocities are chosen for each scaled tank, then it would be likely that multiple estimates of the scale exponent could be obtained. This could also be performed graphically, where the transfer performance values could be plotted against the jet nozzle velocity for each tank scale, and a curve drawn. By using the scaled jet nozzle velocity for one of the scaled tanks for specified values of the scale exponent, the value of the scale exponent which visually makes the curves "closest" could be determined. The scale exponent can essentially be used as a fitting parameter, which would be constrained to values that are typical for mixing (e.g., 0.2 to 0.4), to change the shape of one of the performance curves to most closely match the other curve.

While conceptually this approach makes sense, it requires a sufficient number of tests at each scale to either make direct pairing of equivalent performance likely, or to draw a performance curve for each scale. Additionally, the determination of when the curves are "closest" is

subjective. Both of these concerns can be addressed through a more rigorous statistical approach of fitting a regression model, which incorporates the theoretical scaling model, to the test data. In the simplest form for a specified tank, the regression model is assumed to be a simple polynomial, e.g., cubic, function of the jet nozzle velocity, shown in Equation 3-10.

$$PM_k = b_0 + b_1 U + b_2 U^2 + b_3 U^3 \quad (3\text{-}10)$$

Where PM_k indicates the transfer performance measure of individual simulant component k, U indicates jet nozzle velocity, and $b_0$through b_3 represent the coefficients to be estimated in the model.

Fitting this polynomial to the data collected for each tank scale is essentially drawing the curve for each tank scale. As explained previously, the desire is to identify a scale exponent, based on the theoretical scaling model, which makes the two curves "closest". In the context of the regression model, this is accomplished by incorporating the Equation 3-8 into the Equation 3-10, resulting in Equation 3-11.

$$PM_k = b_0 + b_1 \left(U \left(\frac{T_2}{T_i} \right)^a \right) + b_2 \left(U \left(\frac{T_2}{T_i} \right)^a \right)^2 + b_3 \left(U \left(\frac{T_2}{T_i} \right)^a \right)^3 \quad (3\text{-}11)$$

Where PM_k indicates the transfer performance measure of individual simulant component k, U indicates jet nozzle velocity, T_i represents the diameter of tank i, and a, b_0, b_3 represent the coefficients to be estimated in the model.

There are two important points to note in Equation 3-11. First, the coefficients for the nozzle jet velocity terms are the same, regardless of the tank. This implies that the transfer performance relationship to velocity is the same in both scales, other than the scale effect which depends on velocity. Second, the scale effect is determined by the scale exponent. When the tank is T_2, the scaling model term is equal to one, and the model becomes independent of the scaling exponent for this tank; when the tank is T_1, the nozzle jet velocity for that tank is adjusted according to the scaling exponent. Mathematically, the scaling exponent is determined to make the performance curves "closest", using a non-linear regression procedure.

In the scaled performance testing, other factors are being investigated that may impact the transfer performance. However, they are not expected to impact the scaling of performance; the theoretical scaling model only depends on nozzle jet velocity. Conceptually, incorporating these other factors results in drawing the performance versus velocity curves for each of the different conditions, and then determining the scale exponent that makes the sets of curves for the two different tanks "closest". Clearly, as the number of additional conditions increases, it becomes more difficult to visually compare the multiple sets of curves to identify the scale exponent. Once again, this difficulty can be addressed through a more rigorous statistical approach of fitting a regression model, which incorporates the theoretical scaling model, to the test data.

For the scaled performance testing, the other factors that are being investigated include the supernatant liquid (defined by the density and viscosity), the base simulant material (defined by the amount and type of the constituents), and the transfer line capture velocity. These additional

factors then need to be included in the regression model to account for their anticipated effects on transfer performance. This is shown in Equation 3-12.

$$\begin{aligned} PM_k = {} & b_0 + b_1\left(U\left(\frac{T_2}{T_i}\right)^a\right) + b_2\left(U\left(\frac{T_2}{T_i}\right)^a\right)^2 + b_3\left(U\left(\frac{T_2}{T_i}\right)^a\right)^3 + b_4 BS \\ & + b_5 SN + b_6 SN^2 + b_7 CV + b_8\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\ & + b_9\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] + b_{10}[BS \times SN] + b_{11}[BS \times SN^2] \\ & + b_{12}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] + b_{13}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\ & + b_{14}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] + b_{15}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] \end{aligned} \quad (3\text{-}12)$$

Where PM_k indicates the transfer performance measure of individual simulant component *k*, *U* indicates jet nozzle velocity, *BS* indicates Base Simulant, *SN* indicates Supernatant, *CV* indicates Capture Velocity, T_i represents the diameter of tank *i*, and *a,* and $b_0$through b_{15} represent the coefficients to be estimated in the model.

Equation 3-12 is the result of reviewing the possible effects which might be considered, and selecting those that are deemed most likely to be significant, considering the number of test runs that can be performed. The starting point for this evaluation is a full factorial design, i.e., all combinations of the desired settings of each of the factors. For the nozzle jet velocity, fitting a cubic polynomial requires at least four settings of velocity; the supernatant liquid has three different formulations; there are two different base simulant combinations; two different capture velocities were selected. A full factorial design for these factors and levels would require 48 tests; the associated model contains 48 terms. Within that model are main (linear) effects of each factor, as well as higher-order effects of multiple factors. In particular, for jet nozzle velocity, there will be squared and cubed terms, as well as these terms in combination with other higher-order effects of other factors. In many cases, these higher-order effects are smaller relative to the lower-order effects. Assuming they are negligible allows for a smaller fraction of the factorial design to be used, resulting in fewer test runs, at the corresponding risk of confounding if the higher-order effects really are large. Confounding occurs when the two different effects cannot be estimated separately; the calculated effect is actually the sum of the two confounded terms.

With a maximum of 22 tests available at each scale, which means that 44 data points are collected for the analysis, and the desire to have four replicates to better estimate variability, this suggests that the maximum number of effects that can be estimated is 18. However, it is also desirable to have at least two less model terms than discrete test runs, to allow for an estimate of variability based on the model fit. This then leads to a model which has no more than 16 terms. Looking at each of the factors, the model needs to include terms for the cubic in nozzle jet velocity, and the main effects for each of the other factors. This results in an initial model containing eight terms, which then allows for eight additional higher-order terms. Considering the factors and their expected effects, interaction effects involving the base simulant, the supernatant, and the nozzle jet velocity are expected to be larger; the effect of capture velocity is

expected to be small, based on limited earlier testing. Within the limitations identified previously, this results in Equation 3-12.

When considering the design of the test matrix for the scaled performance testing, a simplified version of Equation 3-12 was used as the design model. Since it was decided that each scale tank would run the same set of tests, at suitably chosen jet nozzle velocities, the model is simplified by ignoring the scaling model component. As mentioned previously, it was desired to run 18 unique test cases and four replicates, for a total of 22 test cases, for each scale tank. Additionally, imposing the restriction that the capture velocity used must not result in being in the laminar flow regime (see Section 3.1.4) results in excluding a portion of the possible test conditions, precluding the use of the original considerations in the factorial design. Excluding those possible test conditions also leads to using more than two levels of the supernatant and capture velocity in the testing, in order to adequately fit the model over the constrained region. To satisfy the various constraints, both budget and physical, on the testing, a Bayesian I-optimal design was chosen, as discussed in Section 3.2.4. This design, generated by a computer algorithm, essentially selects the "best" test runs from the set of all possible combinations of the settings of the specified design factors, where "best" translates to small variability of predictions. The Bayesian I-optimal algorithm generates a design specific to the design model, a simplified form of Equation 3-12, with the additional property of providing some general protection against the possibility of other identified effects. These other identified effects, known as potential terms, were specified as the remaining terms associated with the full factorial design discussed previously.

The basic experimental unit used in Equations 3-10 through 3-12 is the tank. In actual testing, each tank will have pre-transfer samples taken from the recirculation loop, followed by five batch transfers out of the tank, with samples drawn from each batch transfer. Each of these samples will be analyzed for the concentration, expressed as a wt% of the solids of each simulant component. These weight percent measurements can then be used to construct the desired measure of transfer performance. For the purposes of analysis, Equation 3-12 is then expanded to include a batch effect, and an interaction between batch and jet nozzle velocity, as shown in Equation 3-13.

$$
\begin{aligned}
PM_k = {} & b_0 + b_1\left(U\left(\frac{T_2}{T_i}\right)^a\right) + b_2\left(U\left(\frac{T_2}{T_i}\right)^a\right)^2 + b_3\left(U\left(\frac{T_2}{T_i}\right)^a\right)^3 + b_4 BS \\
& + b_5 SN + b_6 SN^2 + b_7 CV + b_8\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\
& + b_9\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] + b_{10}[BS \times SN] + b_{11}[BS \times SN^2] \\
& + b_{12}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] + b_{13}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\
& + b_{14}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] + b_{15}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] \\
& + b_{16} Batch + b_{17}\left[Batch \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right]
\end{aligned}
\tag{3-13}
$$

Where PM_k indicates the transfer performance measure of individual simulant component *k*, *Batch* represents the batch transfer number, *U* indicates jet nozzle velocity, *BS* indicates Base Simulant, *SN* indicates Supernatant, *CV* indicates Capture Velocity, T_i represents the diameter of tank *i*, and *a,* and $b_0$though b_{17} represent the coefficients to be estimated in the model.

For the purposes of the analysis of the mixing and transfer test data, an empirical model of performance will be used, which incorporates the theoretical scaling model shown in Equation 3-8. The purpose of the empirical model is to describe the relevant performance in each tank as a function of the factors that have been manipulated in the testing. Key to determining the scale factor exponent is determining the actual measure of performance that will be used. There are numerous performance measures that are typically used to quantify mixing performance (e.g., effective cleaning radius, cloud height). While these are measures of the actual mixing phenomena in the tank, they may not adequately capture the behavior for a complex simulant. that is being transferred from the mixing tanks in multiple batches. For this reason, different measures of mixing and transfer performance will be investigated for possible relevance. For example, using the measurements of constituent concentrations in each of the batch transfers, equivalent performance could be defined as occurring when the concentrations are most similar. An additional performance measure can be defined based on the amount of the constituent material transferred relative to the amount of the constituent in the tank when the transfer is started. A third measure of performance could be obtained as the difference between the constituent concentration in the batch transfer and in a pre-transfer sample, or as the ratio of the batch transfer amount to the pre-transfer sample. While each of these could be useful measures of performance, it's likely that they would each describe performance differently, providing perhaps different results. Note that these performance measures, based on measurements of each individual constituent, would result in an estimated scaling relationship for each simulant constituent. The data can be evaluated using all these metrics, but the latter two, which are very similar, represent the metric most useful for the WFD waste acceptance process.

3.3 REMOTE SAMPLER DEMONSTRATION SYSTEM PERFORMANCE

The RSD system performance test activities documented in Section 3.3 are performed by Energy*Solutions* for WRPS. Pacific Northwest National Laboratory (PNNL) directs the operation of the UPE and interprets data collected by the device.

Previous work using the RSD flow loop indicated that, compared to a horizontal orientation, samples collected when the Isolok® Sampler was installed in a vertical section of piping more closely matched slurry samples collected from the discharge of the transfer line (RPP-RPT-51796, *Remote Sampler Demonstration (RSD) Phase I Sampling Results Report*). However, most of the initial testing was conducted in the horizontal orientation and supplemental testing in the vertical orientation was recommended. The RSD system performance will evaluate the Isolok® Sampler further in the vertical orientation. The RSD system performance testing will be performed with simulants that span a broader range of Hanford waste than has been previously tested. In addition, RSD system performance testing will continue to evaluate the mechanical handling system for automated sample collection and demonstrate the capability of the UPE. UPE demonstrations are supplemental to the testing activities performed by PNNL at their PDL-East facility in Richland, WA. Results of this previous testing can be found in PNNL-20350 *Hanford Tank Farms Waste Certification Flow Loop Phase IV: PulseEcho Sensor Evaluation*

and PNNL-19441, *Test Loop Demonstration and Evaluation of Slurry Transfer Line Critical Velocity Measurement Instruments*.

3.3.1 Test Equipment and Instrumentation

Integrated flow loop testing for the Isolok® Sampler evaluations shall be performed using the RSD test platform constructed at the Monarch Machine & Tool Company, Inc. facility in Pasco, Washington. The flow loop was constructed at full scale, with the exception of the mixing and transfer system, to demonstrate the capabilities of the Isolok® Sampler, the mechanical handling system, and the UPE. The RSD test platform includes a mixing tank and mechanical (paddle-style) agitator, an effluent tank, a slurry pump, a Coriolis meter, the Isolok® Sampler, the integrated mechanical handling system, the UPE, a simulated glove box, and all associated piping/valving to connect these components. The mechanical handling system is a prototype automated handling system that accepts sample containers, places the containers into position for collecting Isolok® samples, and drops the sample container with the collected sample in a location suitable for retrieval by an operator. The purpose of the mechanical handling system is to minimize operator exposure to the radiation environment at the sample location. A schematic of the flow loop is shown in Figure 2-3.

The mixing tank has an operating capacity of 180 gallons and will be mixed using an agitator (mixing blade) rotating in a down-flow configuration. The vessel will be cooled to maintain operating temperatures. Simulant will be drawn out of the mixing tank around a dispersion plate that creates a ½" circular gap over a three inch line located directly in the middle of the bottom of the tank. The dispersion plate minimizes channeling of simulant solids through the mixing tank. After leaving the tank, the simulant will be pumped through a centrifugal pump capable of operating between 2 and 8 ft/s. Then the waste will enter a straight section of horizontal 3" pipe, configured for operation of the PulseEcho critical velocity measurement equipment. The UPE will be located approximately 60-70 horizontal pipe diameters (15-18 feet) downstream of the last flow disturbance and has 15 pipe diameters (4 feet) of horizontal piping after the device. To ensure that the starting flow rate is sufficient to establish full suspension of the slurry solids and allow visual verification of the critical velocity the sections just prior to and just post UPE equipment are transparent. After leaving the UPE test section the simulant enters the Isolok® sampling section of the system; piping is reduced from 3"inner diameter. to 2" inner diameter and flow is upward in a vertical orientation; about 7 degrees from vertical. The sampler is a Sentry Isolok® MSE sampler, designed for viscous and thixotropic fluids. The Isolok® sampler takes many 5.3ml subsamples to obtain one sample, which can vary based on the size of the sample bottle employed. RSD sampling will employ 250ml sample bottles (requiring 47 subsamples). After leaving the sampler section, the pipe diameter is returned to 3" inner diameter and drains back to the mixing tank with a slope to aid in cleaning.

As the simulant returns to the mixing tank, it first passes through a Coriolis meter, where mass flow rate and specific gravity measurements are obtained, then through an automated full diversion valve. The diversion valve is located in the line a few feet before the mixing tank on the return line, is only operated for a few seconds at a time, allowing operators to take full diversion samples to obtain an accurate representation of the simulant as it flows through the pipe. The volume of a full diversion sample is approximately four gallons. The standard path of the simulant has the material returning to the mixing tank at the top.

The UPE and flow loop shall include data acquisition systems to collect data real time. The data acquisition system for the Coriolis meter may be separate from the system for the UPE, and shall monitor and record the mass flow rate and the specific gravity of the slurry.

Testing shall have three phases for data acquisition. The critical velocity of the simulant being tested will be determined. This may be performed either before samples are taken or after samples are taken, but due to the requirement to adjust the flow rate it cannot be performed during sampling. PNNL will have the lead for the PulseEcho portion of testing. Second, the Isolok® sampler shall be used to obtain characterization samples. Operation of the Isolok® sampler shall include the use of the mechanical handling system to the maximum extent possible, however if mechanical or software issues adversely interrupt testing, the test director may allow use of an Arbor press for Isolok® bottle loading and unloading. After completion of the Isolok® samples full diversion samples shall be taken.

The UPE and adjacent transparent sections will be used during RSD system performance testing to detect bulk particle settling, which will be correlated with an independently measured flow velocity to determine critical velocity of the simulant. Slurry flow velocities between 2 ft/s and 6 ft/s will be used to determine the critical flow velocities of the simulants. Measurements performed by the UPE are representative only of the fraction of the slurry that is present and circulating in the flow loop test section. The UPE transducer is externally attached to the bottom of the 2-ft long UPE spool piece (3-inch inner diameter schedule 40 stainless steel pipe) at a discrete location on the flow loop and is monitoring the conditions only at those locations. The assumption is that the conditions at this location are representative of those along the entire horizontal section of the flow loop. Data reported by the Coriolis meter will be correlated with the UPE data and the visual observations to determine critical velocity.

For testing purposes, evaluating the capability of the Isolok® system is independent of evaluating critical flow velocities. Actual in-field sampling of waste will require confirmation of critical velocity before slurry samples are collected so that re-sampling is minimized. Evaluating the capability of the Isolok® system to collect representative samples of the slurry is also independent of evaluating the mechanical handling of the collected samples. However for completeness testing should be performed with the fully integrated system including the Isolok® Sampler and the mechanical handling system to retrieve the prototypic sample containers.

All measuring and test equipment, including gauges and instrumentation, used for testing activities, shall be controlled, calibrated under conditions typical of the test environment, adjusted, and maintained to required accuracy limits. The condition and the reported accuracy of each instrument shall be documented in a test log.

3.3.2 Test Simulants

The simulants used in the RSD system performance testing are selected in accordance with the recommendations in RPP-PLAN-51625. Simulant properties and qualifications are described in Section 3.1. Selecting particular simulants for RSD system performance test activities is discussed below. The test matrix showing the combinations of base simulant and liquid supernatant is discussed in Section 3.3.3.

The RSD system performance simulants shall include Newtonian and non-Newtonian simulants. For SSMD and RSD limits of performance testing, non-Newtonian testing was conducted with slurries of kaolin clay spiked with large and dense particles. For RSD system performance testing the non-Newtonian solids will be principally kaolin clay, but additional solids will be added so that sampling performance can be quantified.

The Newtonian simulant shall be a complex simulant containing base particulates. The liquid phase shall be a supernatant simulant. The non-Newtonian simulant will be kaolin clay with supplemental solids. Sodium thiosulfate will be added to increase the density of the Newtonian and non-Newtonian slurries when required in the test matrix. Glycerol will be added to increase the viscosity of the Newtonian slurries when required in the test matrix. Recipes for the simulants discussed below are tabulated in Table 3-1 and Table 3-2.

Although RPP-PLAN-51625 recommends three conceptual simulants for WFD Mixing and Sampling Program DNFSB 2010-2 testing, only two simulants are selected for RSD system performance testing, the typical and the high conceptual simulants. The low conceptual simulant is composed entirely of small gibbsite particles, and is therefore not interesting for determining the capability of a multi-component sampler. Based on the distribution of Archimedes numbers and jet suspension velocities reported in Figures 8-1 and 8-2 in RPP-PLAN-51625, the typical and high conceptual simulants are representative of the typical and more challenging Hanford tank waste. Although the typical conceptual simulant recommends that two different sized gibbsite particles be used, sampler performance will be based on chemical analyses of the collected material, which will not distinguish between the different sized materials and so the performance analysis will not consider the effect of gibbsite size. A similar limitation is applied to sand in tests with the high conceptual simulant, which includes two different sized sands. Evaluating different solids compositions will also be used in the demonstration of the UPE. The high conceptual simulant is expected to have a higher critical settling velocity and this will be confirmed during the demonstrations of the UPE.

To investigate the performance of the sampler for a range of tank waste properties three supernatant compositions will also be investigated, low, typical, and high. For the low supernatant the liquid density is 1.098 g/ml and the liquid viscosity is 1.62 cP. For the typical supernatant, the supernatant density is 1.284 g/ml and the liquid viscosity is 3.60 cP. For the high supernatant, the liquid density is 1.368 g/ml and the liquid viscosity is 14.6 cP. Recipes for matching these supernatant properties with water, sodium thiosulfate, and glycerol are provided in Table 3-2. For the low density/low viscosity and typical density/typical viscosity supernatants, the tolerance on the liquid density is ±5% and the tolerance on the liquid viscosity is 0.5 cP. For the high supernatant the tolerance, the liquid density is ±5% and the tolerance on the liquid viscosity is ±20%. For the low and typical supernatant, the tolerance on the viscosity is different than the high supernatant, because the rheology change is expected to be achieved using a single sodium salt. The density and viscosity for a single sodium salt cannot be specified independently. If the temperature of the sampled material differs from the bulk volume, the liquid viscosity tolerance is evaluated at the operating temperature.. In addition to measuring viscosity at the beginning of each test, viscosity measurements are also collected at the completion of testing to identify any changes that occurred during testing.

The range of liquid density and liquid viscosity values are selected because higher densities and higher viscosity fluids are expected to increase the buoyancy, effecting solid particles in the slurry, reducing critical suspension, and settling velocities. Increasing buoyancy and subsequently reducing the critical suspension velocity and settling velocities is expected to promote particle suspension, which will improve mixing and transfer within the RSD flow loop. Improving the distribution of the solids in the flow loop is expected to yield more consistent results. Previous RSD testing in water and a non-Newtonian slurry indicated that the relative standard deviation (i.e., the standard deviation divided by the mean) of samples collected by both the Isolok® Sampler and through the full-diversion method was typically higher for stainless steel and bismuth oxide compared to the relatively easy to suspend solids, gibbsite and zirconium oxide.

In the prepared samples, stainless steel and bismuth oxide represented the more challenging (higher Archimedes numbers) components in the tank waste. During RSD system performance test activities, different supernatant compositions will be tested and the sample results will be compared for each supernatant type to determine if the relative standard deviation of the more challenging particles is reduced in higher density/higher viscosity fluids. Evaluating different supernatant compositions will also be used in the demonstration of the UPE. The slurry is expected to have a lower critical settling velocity at higher densities. This will be confirmed during the demonstrations of the UPE.

To investigate the effects of solids loading, the weight percent of the base simulant will also be varied. Two solids loading levels will be evaluated, 9 wt% and 13 wt %. The 13 wt % is based on the ICD-19 allowable limit of 200 g/l. The mass loading is equivalent to 155 to 194 g/l depending on the composition of solids and supernatant selected. The 9 wt% is based on a lower 125 g/l loading and is equivalent to 105 to 131 g/l depending on the composition of solids and supernatant selected. The resulting slurry density ranges between 1.16 g/l and 1.49 g/ml; the latter being very near the action level identified in ICD-19. Previous RSD testing performed tests with very low (0.1 wt %) amounts of the densest materials (stainless steel and bismuth oxide). The results indicated that these tests were among the worst for sample variability and bias (RPP-RPT-51796). Comparable tests during RSD system performance will include stainless steel at 0.5 wt% (stainless steel is 6% of the typical conceptual simulant solids, which will be included at 9 wt% of the slurry (i.e., 6%×9%=0.5%). Successful testing with simulants that vary over the anticipated range of solids loadings will add confidence that the sampler can collect representative samples of the transferred material regardless of the slurry content.

In addition to the Newtonian tests discussed previously, tests shall also be performed using non-Newtonian slurry with a Bingham plastic yield stress. Kaolin clay slurries will be used as the non-Newtonian simulant. Base particulate solids of stainless steel and zirconium oxide will be added to the slurry to provide a component that can be quantified in the collected samples. The mass of the base solids added will match the equivalent mass of these components when the high conceptual simulant is prepared at 13 wt% solids in the typical density/typical viscosity supernatant. The resulting base particulate solids loading considered the amount of solids necessary to evaluate the UPE. Phase IV testing with the 10-MHz transducer, as described in PNNL-20350, was capable of detecting settling of 14-micron stainless steel particles without false indications at lower mass loadings (2 wt% or higher). The minimum detectable concentrations are expected to change as a function of particle size.

The non-Newtonian tests will be conducted to evaluate the performance of the integrated flow loop with a non-Newtonian simulant and evaluate whether or not a sampler performance is either degraded or improved for non-Newtonian simulant compared to a Newtonian simulant. Previous work indicates that the relative standard deviation for the Isolok® Sampler was comparable for Newtonian and non-Newtonian simulants, but that the bias was less for the non-Newtonian simulant (RPP-RPT-51796). However, the previous work was performed with the Isolok® Sampler in the horizontal configuration. Non-Newtonian work was not performed in the vertical configuration. RSD system performance testing will begin to evaluate the non-Newtonian simulants with the Isolok® Sampler oriented vertically using a slurry with a Bingham plastic yield stress between 3 Pa and 10 Pa. A tolerance of -1 Pa to +1.5 Pa is added to the yield stress measurement for the 3 Pa slurry and a 30% tolerance is added to the 10 Pa slurry because of dynamic changes in the slurry viscosity as it is prepared and mixed. Kaolin clay slurries are slightly rheopectic and may thicken when mixed and transferred.

For tests requiring non-Newtonian, cohesive slurry, kaolin clay shall be used to increase the Bingham plastic yield stress of the simulant to values up to 10 Pa, as measured at the beginning of testing. Bingham parameter measurements shall also be collected at the end of each test to quantify any changes in the test conditions that occur during testing. If necessary, as indicated by measurements that exceed the specified tolerance at the end of testing, supplemental measurements should be taken to monitor changes in the slurry as mixing progresses. The 10 Pa limit was selected in accordance with recommendations in RPP-PLAN-51625. A 3 Pa kaolin clay mixture has a density around 1.16 g/ml and the 10 Pa slurry will have a density of about 1.22 g/ml. Bingham parameter measurements shall be performed prior to testing and at subsequent startups if the slurry is idle for more than 8 hours in between testing.

Testing using a spike particle from the RSD limits of performance test activities is also performed to determine if the large particles that can be sampled by the sampler affect the performance of the sampler to collect a representative sample. For RSD system performance testing a spike particle, for example 1000-micron diameter soda lime glass spheres (see Table 3-3), will be added to a base simulant. The quantity of the spike particle added to the test tank shall be 5 wt % of the total solids added during a test sequence. The 5 wt % value was selected so that an adequate number of particles are present in each test and does not reflect any expected condition in the uncharacterized waste. The size and quantity of the spike material added is subject to change as RSD limits of performance test results are collected and analyzed.

3.3.3 Operating Parameters and Test Methods

When the performance of the Isolok® Sampler is evaluated, the RSD platform shall be configured to adequately suspend the simulant in the mixing tank and transfer the contents to the inlet of the transfer pump. The speed of the mechanical agitators necessary to produce a consistent slurry shall be evaluated during developmental testing. The slurry specific gravity will be monitored by a Coriolis meter as the agitator speed in increased. The agitator speed that yields a stabilized slurry (values that fluctuate by no more than 5% during 10 tank turnovers) for the most challenging simulant should be maintained for all tests. To maintain turbulent flow in the transfer line for Isolok® sample collection in the vertical configuration, the transfer pump flow rate shall be maintained at the maximum transfer flow rate considered for waste feed delivery, 140 ± 5 gallons per minute.

Once the RSD flow loop has stabilized, as evidenced by stable mass flow rates and specific gravity readings from the Coriolis meter, the Isolok® Sampler shall be used to collect ten 250 ml samples. Five of the collected samples will be analyzed for chemical content and the remaining five samples will be retained as archives. After the last Isolok® sample is collected, two full diversion samples shall be collected. The full diversion sample opens a valve in the transfer line downstream of the Isolok® Sampler and captures the discharge to characterize the slurry in the transfer line. Sample collection and analysis is described in Section 3.3.4.

As discussed previously, the testing conditions that are varied for Newtonian slurries include the composition of the base simulant, the composition of the supernatant, and the base simulant solids loading. Two variations of base simulant are used, the typical and high conceptual simulants. Three variations of supernatant are used, the low density/low viscosity, typical density/typical viscosity and high density/high viscosity supernatants. The third testing condition that is varied is the mass loading of the base simulant. Two variations, 9 wt% and 13 wt%, are used during testing. For RSD system performance tests with a non-Newtonian slurry, two tests will be performed. The Bingham plastic yield stress values for the first test will be 3 Pa and 10 Pa for the second test. Recipes for producing the correct slurry are provided in Table 3-1. Preparation tolerances for the kaolin slurry are discussed in Section 3.1.1. In order to quantify the performance of the Isolok® Sampler, base solids will be added to the slurry. The mass of the base solids, stainless steel, and zirconium oxide, will match the equivalent mass of these components when the high conceptual simulant is prepared in the typical density/typical viscosity supernatant.

A verification test will be conducted with large spike particles to determine if the presence of large particles affects the performance of the sampler. In RSD limits of performance testing, spike particles that could be captured by the Isolok® Sampler are evaluated. For a spike particle that could be captured by the Isolok® Sampler, the presence of the spike particle may affect the performance of the system to collect the base particulates. This verification test will use a spike particle that could be repeatedly captured during RSD limits of performance testing to evaluate whether or not the base solids are still representatively sampled in the presence of the larger particles. The spike particle will be added at 5 wt% of the solids for a 9 wt% solids loading of the typical conceptual simulant in the typical density and typical viscosity supernatant.

The test matrix for RSD system performance testing is provided in Table 3-7. In order to reduce the occurrence of systematic errors, such as instrument calibration drift and elevated temperatures as testing progresses to warmer days, the tests should be performed in a random order. In order to minimize contamination of subsequent tests when a random order is followed, the test platform (mixing tank, transfer lines, and sampling equipment) shall be thoroughly flushed and cleaned prior to each test. A full factorial analysis is planned with additional tests for non-Newtonian slurries and a verification run. Replicate analyses are not included in the test matrix. During Isolok® testing, five samples are collected in series and submitted for compositional analysis. The collection of multiple samples over the duration of the test reduces the need for replicate analyses. Furthermore, process operations that contribute to test variability (e.g., simulant preparation, mixing, and variable flow conditions) are mitigated by comparing Isolok® samples to full-diversion tests that are subjected to the same sources of error.

Table 3-7: Remote Sampler Demonstration System Performance Test Matrix

Test Sequence	Base Simulant Constituents	Supernatant Simulant Composition[a]	Base Simulant Mass Loading/non-Newtonian Bingham Plastic Yield Stress
1	Typical	Low	9 wt%
2	Typical	Typical	9 wt%
3	Typical	High	9 wt%
4	Typical	Low	13 wt%
5	Typical	Typical	13wt%
6	Typical	High	13 wt%
7	High	Low	9 wt%
8	High	Typical	9 wt%
9	High	High	9 wt%
10	High	Low	13 wt%
11	High	Typical	13wt%
12	High	High	13 wt%
13	Non-Newtonian	N/A	3 Pa[b]
14	Non-Newtonian	N/A	10 Pa[b]
15	Typical	Typical	13 wt% with 5 wt% of the solids included as spike particles

[a] Low supernatant properties: density = 1.098 g/ml, viscosity = 1.62 cP; Typical supernatant properties: density = 1.284 g/ml, viscosity = 3.6 cP; High supernatant properties: density = 1.368 g/ml, viscosity = 14.6 cP

[b] Non-Newtonian tests include quantification of added stainless steel and zirconium oxide solids. The amount of these solids added to the slurry is equivalent to the amount of these solids in Test #11.

The slurry used to evaluate the capability of the Isolok® Sampler to collect representative samples of broader types of Hanford tank waste will also be used to demonstrate the UPE. At an appropriate time during testing, as determine by the test director, the UPE will be demonstrated using the same simulant compositions. The slurry will be re-circulated through the flow loop at 140 gpm ±5 gpm (6 ft/s) until the specific gravity of the slurry stabilizes. Visual observations through the transparent test sections will be made to ensure that the solids in the transparent sections of the flow loop are not stratified at the starting velocity; if solids are stratified or focused and axial flow is evident, then the flow velocity would be increased as necessary to fully suspend the solid particles. The UPE will be used to constantly monitor particle motion in the UPE test section; however, reportable data will only be recorded once the flow has stabilized at each flow velocity increment. The velocity will be incrementally reduced by up to 1 ft/s increments until solids suspension begins to become challenged and stratification or focused axial motion becomes evident. If a stationary bed forms prior to visual determination of solids suspension becoming challenged and stratification or focused axial motion occurring, deposited solids will be re-suspended and the previous slurry velocity set will be revisited. Then the velocity reduction increments will be dropped to 0.1 ft/s until particle settling results in a stationary bed or until the flow reaches 2 ft/s, the performance limit of the RSD slurry pump. The velocity resulting in a stationary bed is identified as the critical velocity. ICD-19 establishes an action level for the critical velocity at 4 ft/s. Previous testing (PNNL-20350) indicates that the critical velocity determined by the UPE is generally within 0.3 ft/s of the visually determined critical velocity and tends to be conservative (predicts a stationary bed before it is visually observed). The previous testing also indicates that the difference between the two measurement techniques increases with increasing complexity of the simulant. For the UPE demonstrations using the multicomponent simulants discussed in Section 3.3.2, the difference in the critical velocity determined using the UPE and visual observations shall be within ±0.3 ft/s. It is not necessary to determine critical velocities that are below 2 ft/s, the minimum flow velocity from the RSD flow loop transfer pump.

Prior to each velocity reduction, the flow loop is allowed to stabilize and the flow behavior at the stabilized condition is recorded on video and documented in a video log along with the video file name and system operating conditions. Upon identification of the critical velocity, the slurry in the transfer line is re-suspended by increasing the flow velocity. The system is allowed to stabilize and a full-diversion sample is collected to represent the slurry in the transfer line during the demonstration of the UPE.

3.3.4 Sample Collection and Chemical Analysis

The RSD system performance testing shall establish the capability of the vertically oriented Isolok® Sampler to collect representative samples of the slurry in the flow loop. Samples are considered *representative* when the mean square of the sampling error, which is determined for each component of the simulant and includes an estimate of bias and variability, is less than the standard of representativeness. For RSD testing, the standard of representativeness is 10% relative to the average full diversion sample concentrations. The standard of representativeness is determined from sample size graphs presented in 2450-WTP-RPT-MGT-11-014, *Initial Data Quality Objectives for WTP Feed Acceptance Criteria*. According to sample size graphs and the empirical cumulative distribution functions for the waste feed determined by Hanford waste modeling activities, the waste feed is most likely to exceed the WAC for the 95% confidence

level for the ratio of fissile U to total U (see Figures 7-12 and 7-13 in 2450-WTP-RPT-MGT-11-014). When 10% sampling uncertainty is assumed, the required number of samples needed to ensure that the feed batch does not exceed the waste acceptance criterion is less than the maximum currently planned to be collected (10) for approximately 70% of the waste feed. Improving sampling performance or collecting additional samples would be necessary to ensure that the waste acceptance criterion is not exceeded for the balance of the waste.

Prior to performing each test, the simulants are prepared and qualified. The solid particulates are qualified for use prior to testing in accordance with Section 3.1.1.2. The liquid density and liquid viscosity of the supernatant of the Newtonian simulants are qualified for use prior to adding base solids. Measurements of the supernatant density and viscosity of the supernatants and the Bingham parameters for the non-Newtonian simulants will be performed on-site with a hydrometer and a rheometer as discussed in Sections 3.1.1and 3.1.2. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, Test Control in including addenda, or a later version.

Once the simulants are qualified and added to the flow loop, the flow in the flow loop is stabilized, as indicated by the mass flow readings on the Coriolis meter and the Isolok® Sampler is exercised. The Isolok® Sampler is used to collect ten 250 ml samples of slurry in clean sample containers. The mechanical handling system should be used during sample collection to repeatedly exercise the equipment to establish reliability and help identify maintenance requirements. After the Isolok® samples are collected; two full diversion samples are collected. Five of the collected Isolok® samples and one of the two full diversion samples are sent off-site for compositional analysis. Analytical services are performed by a laboratory that operates under a Quality Assurance program that has been evaluated against quality requirements in ASME NQA-1-2004 including addenda, or a later version. These samples shall be analyzed for total slurry volume, total slurry mass, and the mass of each solid constituent (excluding kaolin for non-Newtonian tests). The remaining samples are retained on-site in a managed area of the facility as archive samples to be analyzed as necessary. Analytical data is required to be enhanced quality so that all sample collection, sample analysis, sample handling, and data reporting shall be traceable to the test performed. The sample results shall be reported in a Microsoft Excel compatible format.

The method for collecting the full-diversion sample will be consistent with previous RSD testing activities. The full diversion sample will be performed at the end of each test. The full diversion sample will be approximately 3-5 gallons, and will be taken by placing a 5 gallon bucket into the process stream that is being diverted into the effluent tank (TK-102). Holding the bucket there for 1-2 seconds will yield sufficient volume (approximately 4 gallons). Once the sample has been completed, the bucket will be removed and the process stream will be diverted back to the mixing tank (TK-101). A proper human machine interface has been field mounted to provide adequate protection to personnel and provide a level consistency needed for sample collection. The mass and volume of the collected sample are measured and recorded. The sample is then clarified for a minimum of 24 hours. After the solids have settled, the liquid is decanted and the mass and volume of the decanted liquid is measured and recorded. The wet solids are then loaded into multiple one liter containers for shipping. For each test, the full diversion solids are re-combined, homogenized, and sub-sampled by the analytical laboratory. The purpose of this

sample is to have direct representation of the material in the certification loop during testing activities.

The full diversion sample provides the basis for evaluating the performance of the Isolok® Sampler. Rather than compare sample results to initial simulant makeup content, which may be skewed by mixing in the tank, the comparison sample will be collected from the stream used to collect the Isolok® samples. Differences between the concentration of each component in the full diversion sample and the initial concentration will be attributed to settling in the transfer line and/or inadequate mixing in the mixing tank. Whether or not solids settle in the transfer line at the full-scale flow rate used to collect Isolok® samples will be evaluated when the UPE is demonstrated. Differences between the concentration of each component in the Isolok® samples and the full diversion samples are attributed to the capability of the Isolok® system to collect representative slurry samples from the flow loop assuming that the full-diversion sample is representative of the stream during Isolok® sample collection. To evaluate this assumption, variability in five full diversion samples will be quantified using the high conceptual base simulant in the typical density and typical viscosity supernatant. The difference between the Isolok® sample concentrations and the full diversion sample concentration will be expressed as a percent error (bias). In addition, correlations between the percent errors and the test properties that were changed will be analyzed for correlations. The relative standard deviation between the five collected Isolok® samples will also be calculated to evaluate correlations between sample consistency and the changed test conditions.

The performance of the UPE will be monitored by PNNL. Depending on the capability of the system and test schedule to accommodate collecting samples, full-diversion samples should also be collected before and after each demonstration of the UPE. Collected samples should be analyzed using the same analytical techniques developed for the Isolok® test samples. However, because the same simulants are used during Isolok® testing, full-diversion samples of the material are being collected to characterize the material in the transfer line. Video of the flow behavior at each velocity increment will be recorded. The flow data monitored by the Coriolis meter in the flow loop will be recorded on a data acquisition system for the duration of the test. A separate data acquisition system will be used to capture the signals reported by the ultrasonic transducers during demonstrations of the UPE. The results of the UPE demonstration will be analyzed by PNNL subject matter experts and will be summarized in a test report prepared by PNNL.

4.0 TEST COORDINATION

All testing equipment operations are performed by trained and qualified subcontracted personnel under the supervision of a Test Director. An operations plan, including test run sheets, will be prepared that describes the precautions and limitations, the testing sequences, testing prerequisites, startup conditions, and test procedures in stepwise detail. The TOC technical representative(s) must concur with the operations plan. The Test Director coordinates testing activities including ensuring that all test conditions required for the startup of testing have been performed and all test records (e.g., Test Log, Test Deficiency Reports, Test Change Requests, etc.) are maintained. The Test Director is also responsible for coordinating test activities with the Quality Assurance representative to ensure testing is performed in accordance with the approved quality assurance plan. While tests are conducted, the Test Director will also determine which changes do not adversely affect the acceptance criteria and/or methods by which the acceptance criteria are to be accomplished and are considered "inconsequential" or "minor" and approve these test changes. All other changes require concurrence with the TOC technical representative(s) before the change(s) is/are implemented.

4.1 PRECAUTIONS AND LIMITATIONS

The Job Hazards Analysis is the process for identifying, evaluating, controlling, and communicating potential hazards associated with the work being performed, including modifications to test facilities and test equipment. Testing for the SSMD scaled performance and RSD system performance are being performed in test facilities constructed to perform the testing. Each test facility is governed by a facility specific Job Hazards Analysis documented in a Job Hazards Analysis checklist or equivalent document. Changing conditions that modify the test facility or equipment to accommodate testing will be evaluated in a revision to the Job Hazards Analysis before the modifications to the facility or equipment are performed. Workers performing work in the test facility governed by the Job Hazards Analysis shall review the document hazards and acknowledge that they understand the hazards associated with the work being performed and will abide by controls (e.g., don required personal protective equipment, obey posted signs and placards) put in place to mitigate or eliminate the hazards.

Any special precautions that must be taken or test limitations will be documented in the operations plan specifically prepared for each activity and will be communicated to workers before the start of work during a Pre-Job briefing.

4.2 SEQUENCE OF TESTING

Any special requirements for the testing sequence that are not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

4.3 PLANT CONDITIONS AND SPECIAL EQUIPMENT

Any special requirements for the plant conditions, including connecting to site utilities and site restoration, or special equipment that are not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

5.0 DATA COLLECTION AND TEST RESULTS REPORTING

Testing shall be conducted in accordance with an approved operations plan and an approved data collection and accuracy plan that are prepared in accordance with this test plan. All test activities shall be performed according to test run sheets. All major testing activities shall be documented in a test log. Test deficiencies shall be reported in a Test Deficiency record.

Test data identified in Section 3.0 , including test durations and test conditions, shall be recorded in the test log. Applicable data not recorded by a data acquisition system shall be recorded on the run sheet or recorded in the test log. All electronic data collected by a data acquisition system shall be content reviewed for error and anomalies. Electronic records shall be submitted to the TOC for evaluation.

All laboratory analysis results shall be accompanied by a chain of custody report that was prepared when the samples were collected. The chain of custody shall identify the samples by a unique name, describe the sample type and list the analyses to be performed. The chain of custody shall also document the preparers name and shall acknowledge receipt at the analytical laboratory. All laboratory analysis results shall be submitted to the TOC technical representative in an MS Excel compatible format.

Test result reports shall be prepared for each test activity. Test activities shall be documented in a test data package that is submitted to the TOC by Energy*Solutions*. The TOC shall perform the required analysis and document the findings in a test report that is reviewed by Energy*Solutions*. PNNL will review the data collected by the UPE and document the evaluation in a separate test report.

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APPENDIX A. SMALL-SCALE MIXING SCALING PHILOSOPHY

The WFD Mixing and Sampling Program is performing both full-scale and small scale tests to evaluate mixing, sampling, and transfer performance between the Hanford HLW feed staging tanks and the receipt tanks at the WTP. Full-scale tests using prototypic equipment and operating conditions are being used to demonstrate the performance capabilities of the HLW sampling and transfer system that will be used to characterize the waste prior to transferring it to the WTP. Full-scale testing of components provides experimental data that can be used to evaluate the performance of the integrated system without the need to consider scale. Sampling and transfer testing at full-scale is manageable both fiscally and operationally. However, after considering economics, schedules, and operating complexities, performing full-scale tests of the mixing system was not practical. Therefore, it has been determined that mixing tests would be performed at small scales and full-scale performance will be evaluated using scale-up relationships. Operating at smaller scales is desirable because it reduces the cost of materials (i.e. simulants), labor, and time necessary to perform tests. For example, a full-scale transfer of 950,000 gallons of HLW at the maximum transfer flow rate (140 gpm) would take nearly five days of continuous operation. Using smaller scales, the transfer could be completed in a single work shift. However, operating at smaller scales requires that scaling relationships be understood to predict full-scale performance adequately.

The SSMD test platform contains two scaled systems that are geometrically similar to the DST and transfer system that will be used for first delivery to the WTP (DST 241-AY-102). The scaled properties are provided in Table 3-5. Full-scale DST properties are provided for 241-AY-102. The SSMD test platform was constructed according to scale from 241-AY-102.

The dimensions of the scaled test tanks and placement of the mixing and transfer equipment (e.g., tank diameter, bottom configuration, waste volume, mixer jet and transfer pump spatial locations, mixer jet nozzle diameter, mixer jet pump suction diameter and general tank obstructions) are directly scaled (i.e., proportional) to a full-scale DST filled with actual or anticipated volumes of waste. However, scaling is not full similitude. Consistent with general industry practice for mixing studies and previous testing with the SSMD platform, simulant properties, including particle sizes are not scaled. In addition, to mitigating line plugging with the unscaled simulant, the scaled dimensions for the transfer pump suction inlet diameter and transfer line conduit diameter are also not in direct proportion to a full-scale system. To avoid plugging, the diameter of the pipe should be 3 to 10 times the size of the particles being transferred. Hanford waste simulants are 10s to 100s of microns in size; therefore, the smallest diameter piping that was considered for the scaled systems was ¼-inch (6350 microns), which is much larger than would be used if the pipe diameter was proportionally scaled.

Similarly, scaling the flow rate through a proportionally scaled transfer pump inlet was also not practical for flow hydraulic concerns. For the 1:8 scale system, a proportionally scaled system would pump 12–19 gallons of slurry per minute through an approximate 0.3-inch diameter inlet yielding a transfer velocity of at least 54 feet per second (ft/s), well above the expected capture velocities in the full-scale system. The range for the transfer pump flow rates at each scale is specified to equate the fluid velocity through the inlet. The size and shape of the inlet and the fluid velocity through the inlet establish the velocity gradient into the pump inlet. Particles that enter the area of influence of the pump suction will only be captured by the pump if the pump suction, together with any upward motion induced by mixing, is sufficient to overcome any opposing motion due to particle settling and mixing. For the anticipated range of 90—140

gallons per minute, the fluid velocity through the 2.25 to 2.4 inch diameter inlet ranges between 6.4 and 11.3 feet per second. Because the particles are not scaled, the velocities through the inlet of the scaled systems are equated to full-scale velocities to get equivalent particle capture performance. The transfer pump flow rate is calculated as the product of the fluid velocity, 6.4 and 11.3 feet per second, and the pump suction inlet area in the scaled system.

If the scaling relationship is known, data collection from small-scale experiments performed at two or more different scales can be used to predict full-scale performance. Scaled performance experiments can be conducted at multiple scales to establish or refine scaling relationships. In order to develop scaling relationships, equivalent performance within the scaled systems must be established for known operating conditions. Developing the scaling relationship is performed by using generally accepted scaling relationships, which can be theoretically based or empirically determined from similar experiments, to establish a test matrix for the scales of interest. For SSMD scaled performance testing, the generally accepted scaling relationship used for equivalent mixing among scales, as relates to the distribution of solids throughout the mixed volume, is the equal power-per-unit-volume relationship. The power required to mix a tank with a jet, P_{mix}, can be determined from the kinetic energy supplied by the jet, as shown in Equation A-1.

$$P_{mix} = \left(\frac{\pi}{4} d_{jet}^2 U_{jet}\right)\left(\frac{1}{2}\rho U_{jet}^2\right) = \frac{\pi}{8}\rho d_{jet}^2 U_{jet}^3 \quad \text{(A-1)}$$

Where: ρ is the fluid density, U_{jet} is the nozzle velocity of the jet and d_{jet} is the jet nozzle diameter.

For the equal power-per-volume scaling relationship, the power computed by Equation A-1 is divided by the mixing volume, V, as shown in Equation A-2. Note: the mixing volume is the waste simulant slurry volume, not the capacity of the tank. The mixing volume is characterized by the tank diameter, d_{tank}, and the height, h_{slurry} of the slurry in the tank as it is mixed.

$$\frac{P_{mix}}{V} = \frac{\frac{\pi}{8}\rho d_{jet}^2 U_{jet}^3}{\frac{\pi}{4} d_{tank}^2 h_{slurry}} \quad \text{(A-2)}$$

For two scaled mixing systems with similar geometric properties mixing the same simulant, the nozzle diameter, tank diameter and slurry height from one tank are scaled from the other tank using the scaling factor, SF. The scaling factor is the ratio of the scaled tank diameter and the full-scale tank diameter. Setting the power-per-volume equation equal for the two scales, denoted with subscripts 1 and 2, and substituting in the scaling relationship ($SF=d_{tank2}/d_{tank1}$) is shown in Equation A-3. The simplification of Equation A-3 is shown in Equation A-4.

$$\frac{P_{mix1}}{V_{tank1}} = \frac{\frac{\pi}{8}\rho d_{jet1}^2 U_{jet1}^3}{\frac{\pi}{4} d_{tank1}^2 h_{slurry1}} = \frac{P_{mix2}}{V_{tank2}} = \frac{\frac{\pi}{8}\rho d_{jet2}^2 U_{jet2}^3}{\frac{\pi}{4} d_{tank2}^2 h_{slurry2}} = \frac{\frac{\pi}{8}\rho SF^2 d_{jet1}^2 U_{jet2}^3}{\frac{\pi}{4} SF^2 d_{tank1}^2 SF h_{slurry1}} \quad \text{(A-3)}$$

$$U_{jet1}^3 = \frac{U_{jet2}^3}{SF} \quad \text{(A-4)}$$

The scaling factor exponent for equal power per volume conditions in the SSMD test platform is 1/3, as shown in Equation A-5.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{\frac{1}{3}} \quad \text{(A-5)}$$

Equation A-5 assumes that equal performance is attained when the applied power to mix is directly proportional to the volume to be mixed. The mixer jet pumps are being designed to sustain a flow rate of 5,200 gallons per minute from each of two 6-inch diameter nozzles on each mixer jet. The nozzle velocity exiting the full-scale pump is about 59 ft/s. Using a 1/3 scale factor exponent, nozzle velocities of approximately 30 ft/s and 21 ft/s are determined for the 1:8 and 1:21 scale systems, respectively.

Initially scaling between the two scales in the SSMD test platform was performed to demonstrate that the scaled tanks could be scaled from the full-scale system using the equal power-per-volume scale factor exponent. While this relationship is suitable for mixing, it may not be suitable for other performance metrics, such as the effective cleaning radius, off-bottom suspension, or particle transfer. Equal performance between scales is not just limited to mixing, it could also consider the transfer pumps ability to capture and convey the slurry solids. Therefore, the equal power per unit volume relationship with a scale factor exponent of 1/3 may not be the best relationship to use to scale the integrated system. Equation A-6 replaces the 1/3 scale factor exponent with an unknown value, a, that can be determined for different performance metrics.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{a} \quad \text{(A-6)}$$

The scale factor exponent can be determined through scaled testing. For example, as reported in RPP-RPT-48233, *Independent Analysis of Small-Scale Mixing Demonstration Test*, the mixing data from nine mixer jet pump flow rates at 1:8-scale and 1:21-scale illustrated that equal mixing performance of zirconium oxide in water, as defined by equivalent slurry densities at equal scaled heights, was attained with flow rates of 102.0 gallons per minute (32.6 ft/s) and 9.0

gallons per minute (21.9 ft/s), respectively. The scale factor exponent for the point where mixing performance at the two scales became equal was determined to be 0.39. It is noted that the metric evaluated equal mixing, not adequate mixing as defined by a consistent density at all heights within the tank. The latter was achieved at higher nozzle velocities and equivalent mixing between the scales was maintained at the higher velocities. At the identified flow rates the specific gravity of the zirconium oxide slurry used in the tests was higher at lower heights in both tanks, indicating that the solids (presumably the larger particles) were not being dispersed throughout the entire tank volume. The results also indicate that with increasing nozzle velocities (decreasing scale factor exponent values), mixing performance becomes adequate and plateaus.

Because there is uncertainty in the appropriate scale factor for the performance of the integrated system with simulants that are characteristic of other Hanford tanks, future tests will be performed using two scales and a range of different mixer jet pump nozzle velocities. In addition, the program will begin to evaluate the appropriateness of applying the same scaling relationships to Newtonian and non-Newtonian slurries. Equal performance, as measured by a specific performance metric (e.g., distribution of solids, effective cleaning radius, off-bottom suspension, or particle transfer), will be used to refine previous scaling work.

The rotation rate for the mixer jet pump, ω, is also a scaled property of the integrated system. Similar to work described in Section 2.1.2 of PNNL-14443, *Recommendations for Advanced Design Mixer Pump Operation in Savannah River Site Tank 18F,* the scaling parameter for the mixer jet pump rotational rate equates the number of revolutions that occur in the time required to circulate an entire tank volume through the mixer jet pump inlet (PNNL-14443 Section 2.1.2).

Because the tank diameter and tank height are geometrically scaled from the full-scale, the volume of the scaled tanks, *V*, are related as shown in Equation A-7.

$$V_{tank2} = \frac{\pi}{4} d_{tank2}^2 h_{slurry2} = \frac{\pi}{4} (SF\ d_{tank1})^2 SF\ h_{slurry1} = SF^3 V_{tank1} \quad \text{(A-7)}$$

The time required to circulate an entire tank volume through the mixer jet pump inlet, the turnover time (Θ), is the ratio of the tank volume and the mixer jet pump volumetric flow rate, which is itself a function of the nozzle velocity and the nozzle area. Equation A-8 shows this relationship.

$$\Theta_{tank1} = \frac{V_{tank1}}{Q_{tank1}} = \frac{V_{tank1}}{A_{nozzle1} U_{jet1}} \quad \text{(A-8)}$$

The turnover time for Tank 2 can be related to the turnover time for Tank 1 using the geometric scaling factor when the tank diameter, waste height, and mixer jet nozzle diameter are geometrically scaled as shown in Equation A-9.

$$\Theta_{tank2} = \frac{V_{tank2}}{Q_{tank2}} = \frac{SF^3 V_{tank1}}{A_{nozzle,2} U_{jet2}} = \frac{SF^3 V_{tank1}}{SF^2 A_{nozzle1} U_{jet2}} = \frac{SF U_{jet1} \Theta_{tank1}}{U_{jet2}} \quad \text{(A-9)}$$

Setting the scaling condition (ωΘ) equal between the two tanks yields the angular velocity scaling relationship (Equations A-10 and A-11).

$$\omega_{tank1}\theta_{tank1} = \omega_{tank2}\theta_{tank2} = \omega_{tank2}\frac{SF U_{jet1}\Theta_{tank1}}{U_{jet2}} \quad \text{(A-10)}$$

Therefore,

$$\omega_{tank2} = \frac{\omega_{tank1} U_{jet2}}{SF \quad U_{jet1}} \quad \text{(A-11)}$$

Where: *SF* is the ratio of the tank diameters at the two scales.

Compared to full-scale conditions, as the scale factor exponent decreases, the nozzle velocity and rotational rate for a smaller scale system increase. However, the nozzle velocity for a smaller scale system is generally less than the full-scale nozzle velocity and the rotational rate is usually faster than the full scale rotational rate. Therefore, the nozzle velocity in the smaller scale system equals the full scale nozzle velocity when the scale factor exponent value equals 0 and the rotational rate for a smaller scale system equals the full scale rotational rate when the scale factor exponent value equals unity.

In SRNL-STI-2010-00521, *Demonstration of Mixer Jet Pump Rotational Sensitivity on Mixing and Transfers of the AY-102 Tank*, the effect of the rotational velocity of the mixer jets was evaluated at 1:22-scale and shown to have little effect on the amount of solids transferred in each transfer batch. However, it is noted that the nozzle velocity of the mixer jet was selected so that no "dead zones" were observed in the tank during testing. The testing did not assess whether or not the rotational rate would influence the amount of solids transferred if solids were allowed to accumulate in "dead zones". PNNL-14443 showed that the effective cleaning radius of a mixer jet decreased with increasing mixer jet rotational velocity and decreasing mixer jet nozzle velocity. It can be reasoned that performance metrics aimed at bottom cleaning or metrics that are strongly influenced by the solids on the bottom of the tank would need to evaluate the impact of both mixer jet rotational rate and nozzle velocity.

DISTRIBUTION SHEET

To	From	Page 1 of 1
^Rim DC	Kearn Patrick Lee	Date August 2, 2012
Project Title/Work Order		EDT No. NA
RPP-PLAN-52623, One System Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan		ECN No. NA

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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John Cook (WTP)		x			

FROM THE DESK OF

Raymond J. Skwarek
Manager, One System IPT

Date: July 19, 2012 WRPS-1202839-OS

To: L. M. Peurrung, Chair
Large-Scale Integrated Mixing System Expert Review Team

Subject: ONE SYSTEM TECHNICAL TEAM RESPONSE TO REVIEW OF WASTE FEED DELIVERY MIXING AND SAMPLING PROGRAM SYSTEM PERFORMANCE TEST PLAN (ERT-18)

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 four specific technical subjects identified by the ERT, followed by the One System response.

1. *"The ERT's ability to judge the technical defensibility of the planned SSMD scaled performance testing is hindered by the lack of a clear description of how the data will be analyzed to determine the scaling relationship. Section 3.2.6 of the document lacks some needed detail on the approach. For example, the equations do not reflect that the analysis will need to be done on each component in the simulant. There is no indication of how other variables (such as capture velocity) factor into the analysis. What is the resulting number of regression coefficients returned? Why an empirical rather than a physics-based model? We have a number of questions about the approach, and while the conceptual explanation provided to us by the authors during our discussions June 27th made general sense, we recommend a stronger description of the methodology and the expected results."*

The One System project agrees that section 3.2.6 requires additional detail to more clearly explain the intended analysis approach. This section has been rewritten to provide the necessary clarity. In particular, discussion has been added to reflect that the regression model is being used for each simulant component and to describe how other variables will be incorporated in the analysis through additional terms in the regression model. An empirical model was selected because it is not known how the multiple physics-based models needed to describe the complex mixing behavior interact with one another.

2. *"The ERT observes that the SSMD scaled performance tests metric on batch-to-batch consistency neglects the potentially useful information of whether the samples are more or less concentrated than the (known) bulk concentration in the test vessel. Why relate all batch concentration measurements to a pre-transfer sample concentration, which may be biased by the sampling procedure and essentially normalizes the first data point to one for every test?*

If it is because jet velocities will sometimes be insufficient to completely mobilize solids on the bottom, will that make interpretation of the results more difficult?"

The primary information for WTP feed acceptance will come from an initial (pre-transfer) sample of the staged double-shell tank; therefore, the primary test metric is related to the relationship of the pre-transfer sample to the makeup of the subsequent transfers. Earlier testing (RPP-47557) demonstrated that mixed tank concentration is not homogeneous and that some solids settle in "dead zones" without an opportunity to be mobilized and sampled. We agree that comparing performance to additional reference points, such as initial tank contents, provides an additional useful metric for determining tank performance equivalence. Section 3.2.6 of the document has been modified to include a discussion of additional analysis strategies.

3. *"The scaling factor "a" appears to be treated as a lumped scaling factor for both mixing and transfer. The ERT observes that the use of a separate term for capture velocity in the scaling relationship may aid in the interpretation of the results."*

The ERT's observation is correct that the scale factor "a" is treated as a lumped scaling factor when the measure of performance is related to both mixing and transfer phenomena. The re-write of section 3.2.6 (addressed in item 1 above) describes how the capture velocity is included in the regression model.

4. *"While not clearly documented, it is our understanding, based on our June 27th discussion with the authors, that the scaling factor "a" in Equation 1-2 is not the same as in Equation 1-1; that is, the rotational speed of the pump mixer jets is not scaled with the same exponent as for pump mixer nozzle velocity. The ERT recommends treating the pump rotational velocity as a separate operational parameter and determining its effect on mixing performance as a function of jet velocity and scale*.

Your understanding is correct that the scaling factor "a" in Equation 1-2 is not intended to be the same as Equation 1-1. The mixer pump rotational speed scaling factor is a physics-based calculated value related to nozzle velocities. The document has been updated to express the scaling relationship in terms of the nozzle velocities at each scale to avoid this confusion. Because previous testing (SRNL-STI-2009-00717 and RPP-49845) has shown batch transfer performance to be relatively insensitive to pump rotational velocity changes, the One System Technical team believes estimating the scaling factor will be more successful when there is a broader spectrum of tank performance that is achieved by varying the mixer pump flow velocity. Therefore, mixer pump rotation rate variation impacts are not explored during scaled performance testing but are included in future operational optimization testing currently planned for fiscal year 2013.

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

Please feel free to contact me at 372-9117, or Mike Thien at 372-3665, if you have any further questions regarding our response to the ERT review.

Sincerely,

FOR

R. J. Skwarek, Project Manager
One System Integrated Project Team

MGT:MEH

Enclosure(s):
1. Memorandum, L. Peurrung, to Tom Fletcher, ORP, "ERT-18 Feed Test Plan 2," dated June 29, 2012 (3 pages)
2. RPP-PLAN-52623, Rev. C, Draft, "One System Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan" (68 pages)
3. LSIMS ERT Document Review Record (18 pages)

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WRPS-1202839 OS

Enclosure 1

WRPS-1202839-OS
ENCLOSURE 1

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, WRPS; ERT Members

Subject: *Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan* (ERT-18)

Date: June 29, 2012

The Large-Scale Integrated Mixing System Expert Review Team (ERT) was asked to review "Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan" (RPP-PLAN-52623, Rev A). This document is a second document of three meant to satisfy Commitment 5.5.3.6 in the Implementation Plan for DNFSB Recommendation 2010-2, "Test Plan to establish Tank Farm performance capability." Per the commitment, WRPS will "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 tank sampling systems to provide samples that will characterize waste and determine compliance with the [Waste Acceptance Criteria]. This work will include development of a test plan." This second test plan focuses specifically on scaled/system performance testing to demonstrate mixing, sampling, and transfer performance using, separately, the Small Scale Mixing Demonstration (SSMD) test platforms (at two scales) and the Remote Sampler Demonstration(RSD) test platform (at full scale). The goal of the scaled testing with the SSMD platform, per the document, is "to increase the confidence in the scale up relationship for mixing, sampling, and transfer." The goal of the RSD testing is "to provide additional confidence in the system's capabilities to sample a wider range of Hanford waste characteristics."

As in the review of the first test plan document, the lines of inquiry for the ERT's review were:

- Are the major points of the document communicated well to the intended audience?
- Does the document provide a clear set of test objectives and requirements?
- Are the proposed approaches to testing sufficiently defined and technically defensible?
- Is simulant selection appropriate? Does the document meet its intent of "qualifying" the simulants proposed?

The ERT's ability to judge the technical defensibility of the planned SSMD scaled performance testing is hindered by the lack of a clear description of how the data will be analyzed to

determine the scaling relationship. Section 3.2.6 of the document lacks some needed detail on the approach. For example, the equations do not reflect that the analysis will need to be done on each component in the simulant. There is no indication of how other variables (such as capture velocity) factor into the analysis. What is the resulting number of regression coefficients returned? Why an empirical rather than a physics-based model? We have a number of questions about the approach, and while the conceptual explanation provided to us by the authors during our discussions June 27th made general sense, we recommend a stronger description of the methodology and the expected results.

The ERT observes that the SSMD scaled performance tests metric on batch-to-batch consistency neglects the potentially useful information of whether the samples are more or less concentrated than the (known) bulk concentration in the test vessel. Why relate all batch concentration measurements to a pre-transfer sample concentration, which may be biased by the sampling procedure and essentially normalizes the first data point to one for every test? If it is because jet velocities will sometimes be insufficient to completely mobilize solids on the bottom, will that make interpretation of the results more difficult?

The scaling factor “a” appears to be treated as a lumped scaling factor for both mixing and transfer. The ERT observes that the use of a separate term for capture velocity, which is related to suspension Froude number rather than tank mixing parameters, in the scaling relationship may aid in the interpretation of the results.

While not clearly documented, it is our understanding, based on our June 27th discussion with the authors, that the scaling factor “a” in Equation 1-2 is not the same as in Equation 1-1; that is, the rotational speed of the pump mixer jets is not scaled with the same exponent as for pump mixer nozzle velocity. The ERT recommends treating the pump rotational velocity as a separate operational parameter and determining its effect on mixing performance as a function of jet velocity and scale.

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

Review Participants:

June 26, 2012: Rich Calabrese, Ramesh Hemrajani, Erich Hansen, Loni Peurrung

June 27, 2012: Rich Calabrese, Richard Grenville, Ramesh Hemrajani, Erich Hansen, Loni Peurrung, Mike Thien, Pat Lee, Dan Greer

June 28, 2012: Rich Calabrese, Richard Grenville, Ramesh Hemrajani, Erich Hansen, Loni Peurrung

WRPS-1202839 OS

Enclosure 2

EXECUTIVE SUMMARY

The primary purpose of the Tank Operations Contractor Mixing and Sampling Program is to mitigate the technical risks associated with the ability of the tank farms waste feed delivery systems to mix and sample High-Level Waste feed adequately to meet the Hanford Waste Treatment and Immobilization Plant Waste Acceptance Criteria. The Tank Operations Contractor will conduct tests to determine the range of waste physical properties that can be retrieved and transferred. Using two geometrically scaled tanks, testing and analysis will determine the scale-up relationship for a full-scale, feed staging tank based on batch transfer consistency with pre-transfer samples (i.e., replicating the waste acceptance process). The capability of the tank farm mixing, sampling, and transfer systems to obtain representative samples to assess properties important for the waste acceptance criteria comparison will also be determined. This test plan is the second of three test plan documents that are being prepared to address Defense Nuclear Facilities Safety Board DNFSB 2010-2, Sub-Recommendation 5, Commitment 5.5.3.6, "Test Plan to establish Tank Farm performance capability" and addresses the technical approach and test requirements for the scaled/system performance test activities being performed to support waste feed delivery.

The tests being conducted to define the capabilities of the mixing, sampling, and transfer system are focused on three areas: limits of performance, solids accumulation, and scaled/system performance. Limits of performance testing and developmental work supporting solids accumulation are currently being conducted under the first of the three test plans, RPP-PLAN-52005, *One System Waste Feed Delivery Mixing and Sampling Program Limits of Performance and Solids Accumulation Scouting Studies Test Plan*. Additional solids accumulation testing will be conducted under a future test plan. Scaled/system performance is performed in accordance with this test plan. Scaled/system performance testing will be conducted to demonstrate mixing, sampling, and transfer performance using simulants representing a broad spectrum of Hanford waste. Testing will be performed with simulants that are characteristic of Hanford waste and approach or exceed waste acceptance criteria action levels in terms of bulk density, solids loading, yield stress, and slurry viscosity. Testing with simulants that approach the Hanford Waste Treatment and Immobilization Plant design basis ensures that the system is capable of identifying waste that may be outside the envelope of acceptance. Testing will also be performed with slurries containing dense particles (8 g/ml) having particle sizes exceeding 100-microns for assessing the capability of sampling fissile material for comparisons to requirements with action limits for uranium (U) and plutonium (Pu); (e.g., Pu to metals loading ratio and $U_{Fissile}$ to U_{Total} ratio). These tests will use both the Small-Scale Mixing Demonstration and Remote Sampler Demonstration test platforms used in previous Waste Feed Delivery Mixing and Sampling Program test activities; however, the operating conditions and simulants tested will be expanded to collect additional performance data.

For each test activity covered in this test plan, the test objectives along with success criteria are identified. The necessary equipment to conduct the tests and collect the necessary data is identified and described. The simulants that are appropriate for testing are identified and qualified in accordance with the recommendations in RPP-PLAN-51625, *Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing*. Testing with different simulants is included to explore the capabilities of the individual systems.

Because the test objectives for the Small-Scale Mixing Demonstration scaled performance and Remote Sampler Demonstration system performance activities are similar, the test matrices evaluate similar test conditions (e.g., base simulant components, supernatant properties, and mass loadings). The most important properties identified for scaled/system performance work include variations to: mixer jet nozzle velocity (Small-Scale Mixing Demonstration only), transfer pump capture velocity (Small-Scale Mixing Demonstration only), Newtonian slurry solids simulant composition, supernatant density and viscosity, Newtonian solid simulant mass loading, and the Bingham plastic yield stress of a non-Newtonian slurry simulant.

Small-Scale Mixing Demonstration scaled performance testing will be conducted to:

- Use Newtonian simulants in the 1:8- and 1:21-scale Small-Scale Mixing Demonstration platform to build confidence in the pre-transfer sampling representativeness and the predictions of full-scale performance.

- Evaluate the suitability of using the scaled relationship determined for Newtonian slurries to mobilize non-Newtonian slurries.

Mixing and transfer data at two scales will be collected and analyzed to increase the confidence in the scale up relationship for mixing, sampling, and transfer. Specifically, thirty tests, including replicates and verification runs, will be conducted in the 1:21 and 1:8 scale mixing tanks in the Small-Scale Mixing Demonstration test platform. Scaled testing will be conducted with five different nozzle velocities, three different transfer pump capture velocities, two different Newtonian simulant compositions, and three different supernatant compositions. Scaled testing will also be conducted using a non-Newtonian simulant at four different nozzle velocities.

Remote Sampler Demonstration system performance testing will be conducted to:

- Demonstrate, with different simulant compositions (Newtonian and non-Newtonian), the capability of the Isolok® Sampler to collect representative samples in the vertical configuration.

- Demonstrate the Ultrasonic PulseEcho system for monitoring bulk solids settling in the flow loop.

- Define operational steps for the Isolok® Sampler and describe functional requirements for supporting systems necessary for field deployment.

Remote Sampler Demonstration test data will be collected and analyzed to provide additional confidence in the systems capabilities to sample a wider range of Hanford waste characteristics. System testing includes 15 tests that include different combinations of two Newtonian simulant compositions, two solids loadings, and three supernatant compositions. System testing will also include non-Newtonian simulants with two different Bingham plastic yield stresses. Testing will also include the Ultrasonic PulseEcho system that detects bulk particle settling in the flow loop and can be used to determine critical settling velocities of the transferable slurry.

CONTENTS

FIGURES

TABLES

TERMS

Abbreviations and Acronyms

ASME	American Society of Mechanical Engineers
BNI	Bechtel National, Inc.
DOE	U.S. Department of Energy
DNFSB	Defense Nuclear Facilities Safety Board
DST	double-shell tank
DQO	data quality objective
HLW	high-level waste
ICD	Interface Control Document
MDT	SRNL mixing demonstration tank
ORP	Office of River Protection
Pu	plutonium
PNNL	Pacific Northwest National Laboratory
RPP	River Protection Project
RSD	Remote Sampler Demonstration
SF	scale factor
SRNL	Savannah River National Laboratory
SSMD	Small-Scale Mixing Demonstration
TOC	Tank Operations Contract
UPE	Ultrasonic Pulse Echo system
U	uranium
WC	Tungsten carbide grit
WAC	waste acceptance criteria
WFD	Waste Feed Delivery
WRPS	Washington River Protection Solutions, LLC
WTP	Hanford Waste Treatment and Immobilization Plant

Units

°C	degrees Celsius
cP	centipoise
ft	feet
in	inch
g	gram
gpm	gallons per minute
l	liter
Hz	hertz
MHz	megahertz
ml	milliliter
Pa	Pascal
s	second

1.0 INTRODUCTION

1.1 INTRODUCTION

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 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-12-64 and TOC-12-65 per the TFC-PLN-39, Rev. G, *Risk Management Plan*, which address sampling methods and emerging changes to WAC requirements. The root of the mixing and sampling risk is the ability to collect samples that are characteristic of the tank waste, including the rapidly settling solids in the HLW for the purpose of demonstrating compliance with the WTP waste acceptance requirements. In addition, in November 2011, the U.S. Department of Energy (DOE) issued the implementation plan for the Defense Nuclear Facility Safety Board (DNFSB) Recommendation 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.

Report RPP-PLAN-41807, *Waste Feed Delivery Mixing and Sampling Program Plan and Test Requirements* defines the three test requirements for continued the WFD Mixing and Sampling Program testing to address DNFSB concerns as follows:

- Limits of performance - determine the range of waste physical properties that can be mixed, sampled, and transported under varying modes of operation. These tests will use both the Remote Sampler Demonstration (RSD) platform and the Small-Scale Mixing Demonstration (SSMD) platform. In addition, a test using a full-scale slurry transfer pump will be performed.
- Solids accumulation - perform scaled testing to understand the accumulation and distribution of the remaining solids in a double-shell tank (DST) during multiple fill, mix, and transfer operations that are typical of the HLW feed delivery mission. These tests include activities at the Savannah River National Laboratory (SRNL) Mixing Demonstration Tank (MDT) and the SSMD platform.
- Scaled/system performance - demonstrate mixing, sampling, and transfer performance using a realistic simulant representing a broad spectrum of Hanford waste to meet WTP WAC Data Quality Objectives (DQO) sampling confidence requirements. These tests will use both the SSMD and the RSD platforms. The RSD platform is full scale; therefore, RSD system performance testing activities will collect additional system performance data at full scale.

This represents a broadening of objectives from earlier SSMD and RSD testing. The simulants and operating conditions in this earlier testing were intended to simulate the particle size, density distribution, and operating configuration of Hanford DST 241-AY-102, the first tank waste to be delivered to WTP. The particle size distribution for the SSMD simulant for DST 241-AY-102 (1% is 0.39 microns, 50% is 13.2 microns, 95% is 200 microns, and 99% is 394 microns) is

documented in PNNL-20637, *Comparison of Waste Feed Delivery Small-Scale Mixing Demonstration Simulant to Hanford Waste.* The range of particle sizes in the simulant was smaller than the particle size distribution for the 95% confidence limit for 95% of the population (1% is 2 microns, 50% is 22 microns, 95% is 460 microns, and 99% is 700 microns) used in the waste feed transfer system analysis used in the WTP design basis, RPP-9805, *Values of Particle Size, Particle Density, and Slurry Viscosity to Use in Waste Feed Delivery Transfer System Analysis*. Simulants and operating conditions will need to be developed to represent the complete range of physical properties for the broader spectrum of Hanford waste tanks, and to address specific testing requirements summarized above.

The TOC will conduct tests to determine the range of waste physical properties that can be retrieved and transferred to WTP, and determine the capability of tank farm staging tank sampling systems to provide samples that will characterize the tank waste to determine compliance with the WAC. These tests will reduce the technical risk associated with the overall mixing, sampling, and transferring of HLW feed to WTP so that all WAC requirements are met.

This test plan is the second of three test plan documents that will be prepared to address DNFSB 2010-2 Sub-Recommendation Commitment 5.5.3.6, "Test Plan to establish Tank Farm performance capability". The first, RPP-PLAN-52005, *One System Waste Feed Delivery Mixing and Sampling Program Limits of Performance and Solids Accumulation Scouting Studies Test Plan* addresses the technical approach and test requirements for the SSMD Limits of Performance, RSD Limits of Performance, Full-Scale Transfer Pump Limits of Performance, and SSMD Solids Accumulation Scouting Studies being performed to support feed delivery to the WTP. This test plan identifies and describes the test objectives, test requirements, and test methods for the SSMD Scaled Performance and RSD System Performance test activities. The testing approach is guided by input from internal subject matter experts and external consultants familiar with the objectives of the test program (WRPS-1105293, *Small-Scale Mixing Demonstration Optimization Workshop Meeting Minutes* and WRPS-1201374-OS, *One System DNFSB 2010-2 Sub-Recommendation 5 Test Plan Summit Meeting Minutes*). The third test plan will cover additional testing related to the accumulation of solids in a waste feed tank. Additional information is being generated as part of parallel work that may result in further refinements to the test program. This parallel work includes Commitment 5.5.3.2, which estimates, based on current information, the range of waste physical properties that can be transferred to WTP and Commitments 5.7.3.1 and 5.7.3.4, which identify potential new WAC requirements based on known technical issues, preliminary documented safety analyses, and process capabilities and compatibilities.

1.2 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* (also known as ICD-19). 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.

The objective of the WFD Mixing and Sampling Program continues to be the mitigation of the technical risks associated with the ability of the tank farms WFD systems to mix and sample HLW feed adequately to meet the WTP WAC. Initial work for the SSMD and RSD projects has demonstrated the concept functionality for the first feed tank to deliver consistent feed delivery batches. However, uncertainties related to scale-up, simulant representativeness, data uncertainty, optimizing system performance, applicability to all feed tanks, feed conditioning, and understanding emerging WTP solids handling risks still need to be addressed.

DNFSB Recommendation 2010-2 has raised WTP safety issues related to tank farms ability to mix, sample, and transfer solids. In response, DOE developed an implementation plan to resolve these issues (DOE Rev. 0 2010-2). As discussed in Section 1.0, this test plan is one of multiple test plan documents that will be prepared to address Commitment 5.5.3.6 of the Implementation Plan. This test plan is being prepared to address any outstanding key uncertainties pertaining to the bounds of the SSMD and RSD equipment performance identified during the TOC Mixing and Sampling workshop held in Richland, Washington October 10–12, 2011 (WRPS-1105293*)*.

To ensure that tank farms and WTP mixing and sampling systems are integrated and compatible (i.e., execution of the One System approach) and that the uncertainties identified to date are addressed, the WFD Mixing and Sampling Program has been expanded to include the following:

- Define DST mixing, sampling, and transfer system limits of performance with respect to the ability to transfer waste to the WTP that exceeds any limitations of the WTP mixing and transfer systems. The capability of the Tank Farm's WFD system, including a consideration of data uncertainty, will be characterized using simulants with varying physical properties that are important to mixing, sampling and transfer (solid particulates sizes and densities, yield stress, and viscosity), and may not be properties that will be directly measured and compared to WAC requirements.
- Define 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 (see Section 3.3.4 for definition) slurry samples and in-line critical velocity measurements from a fully mixed waste feed staging tank.
- Develop sufficient data and methodology to predict full-scale DST mixing, sampling, and transfer system performance confidently; such that a gap analysis against WTP feed receipt system performance can be completed adequately.

The first task listed above is the subject of the test plan RPP-PLAN-52005. Initial work supporting the second task is also included in RPP-PLAN-52005 and follow-on work will be documented in a subsequent test plan. The latter two tasks are the subject of this test plan.

2.0 SCOPE

The original objective of the 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 WAC. Testing focuses on the ability to achieve adequate mixing and representative sampling and on minimizing variability between batches transferred to WTP. Testing to date (RPP-49740, *Small-Scale Mixing Demonstration Sampling and Batch Transfers Results Report*) has demonstrated the potential ability to adequately mix, deliver, and sample DST 241-AY-102 simulated waste using prototypic DST mixing and transfer systems. However, waste in DST 241-AY-102 did not represent the most challenging waste expected over the feed delivery mission and testing using simulants representing more challenging wastes will be conducted.

While test data collected to date has provided some insight to mixing, sampling, and transfer performance (e.g., RPP-50557, *Tank Waste Mixing and Sampling Update*), more data is needed to predict full-scale performance that covers the range of physical properties of Hanford waste confidently. The objective of SSMD scaled performance activities is to test mixing and transfer performance at two scales using simulants representing a broad spectrum of Hanford waste to meet WTP WAC DQO sampling confidence requirements. The objective of RSD system performance activities is to evaluate the performance of the RSD, including the Isolok[1]® Sampler system and Ultrasonic PulseEcho system Ultrasonic Pulse Echo system (UPE) in a configuration that addresses field deployment constraints.

The current WFD Mixing and Sampling Program being executed to address the issues is being performed in a phased approach that will:

- Demonstrate the tank farms capability to mix, sample, and transfer HLW
- Demonstrate the viability of systems to meet waste acceptance requirements in small-scale or full-scale environments, and upon successful demonstration
- Exhibit system capability in a full-scale DST (i.e., a DST that will be providing hot commissioning feed to WTP).

Three major areas of testing that will be executed by the WFD Mixing and Sampling Program to demonstrate capability and viability include limits of performance, solids accumulation, and scaled/system performance. The test requirements for all limits of performance scope and the initial solids accumulation development work are described in RPP-PLAN-52005. This test plan documents the test requirements for the SSMD scaled performance and RSD system performance activities. A subsequent test plan will provide the test requirements for SSMD solids accumulation performance evaluation scope.

Figure 2-1 shows test sequence and portrays how information learned from early testing activities is used to develop the test plans for subsequent scope.

Isolok® is a registered trademark of the Sentry Equipment Corp. of Oconomowoc, Wisconsin.

This plan defines test requirements to address Tank Farm mixing, sampling, characterization, and transfer system capability, to predict full-scale performance and demonstrate the capability of the RSD to collect representative waste samples to meet the expanded requirements associated with DNFSB Recommendation 2010-2. Testing will be performed with Hanford waste simulants that approach or exceed ICD-19 WAC action levels in terms of bulk density, solids loading, yield stress, and slurry viscosity. Testing with simulants that approach the WTP design basis ensures that the system is capable of identifying waste that may be outside the envelope of acceptance. Testing will also be performed with slurries containing dense particles (8 mg/l) having particles sizes exceeding 100 microns for assessing the capability of sampling fissile material for comparisons to ICD-19 requirements with action limits for U and Pu (e.g., Pu to metals loading ratio and $U_{Fissile}$ to U_{Total} ratio). As described in RPP-PLAN-41807, the objectives of the test activities are to develop a scaling relationship to predict full-scale performance and determine the range of waste physical properties that can be retrieved and transferred to the WTP. They will also determine the capability of the tank farm staging, tank sampling systems to obtain samples that can be characterized to assess the bounding physical properties important for the WAC.

The Waste Feed Delivery (WFD) Mixing and Sampling Program testing is evaluating the feasibility of a baseline design for waste feed delivery. Testing is developmental and is not evaluating a field deployable design against specific functional characteristics and performance requirements. Testing is performed in accordance with Phase I testing described in TFC-PLAN-90, *Technology Development Management Plan*. Phase I development testing addresses a TOC technology need when existing processes are inadequate, inefficient, or not proven for the intended application. During Phase I testing functional criteria and performance requirements for the promising technology are defined, a prototype working model is constructed, and the prototype is evaluated against the performance criteria. Phase I development implements a graded application of the quality assurance program requirements. Upon successful completion of Phase I testing, which may be an iterative process, additional development (Phase II) may be pursued. Phase II development and testing is performed to a higher quality assurance standard and invokes TOC approved procedures and quality assurance requirements for design control, including design verification, and qualification testing. The WFD Mixing and Sampling Program test planning, test review, test control, and test results reporting requirements are communicated through this test plan and are guided by testing principles described in TFC-ENG-DESIGN-C-18*, Testing Practices*. The WFD Mixing and Sampling Program testing falls outside the scope of TFC-PLAN-26, *Test Program Plan*, which defines additional requirements for oversight, development, and the conduct of factory acceptance, construction acceptance, and operational acceptance tests for demonstrating the operability and integrity of new or modified tank farm facilities and systems.

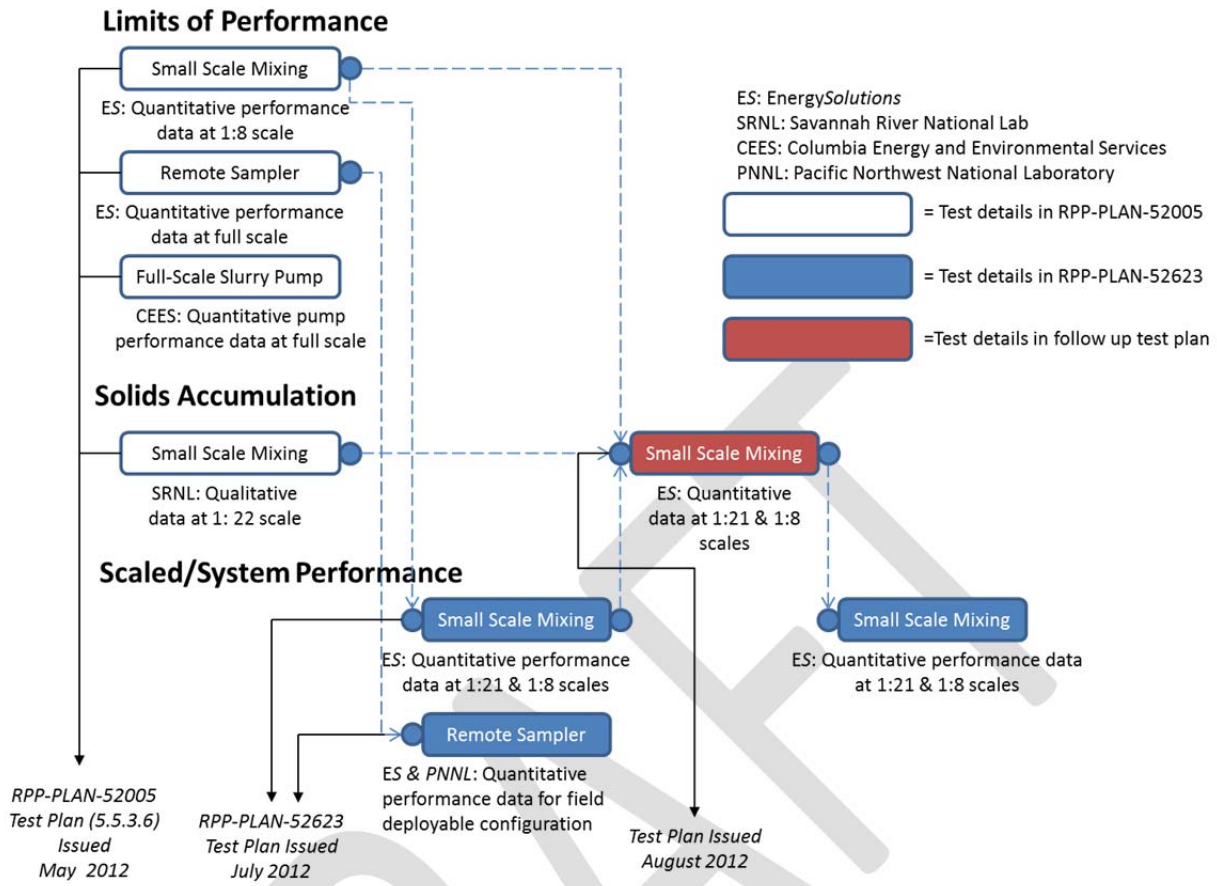


Figure 2-1. WFD Mixing and Sampling Program Test Sequence

2.1 SMALL-SCALE MIXING DEMONSTRATION SCALED PERFORMANCE TEST OBJECTIVES

The overall objective of the WFD Mixing and Sampling Program is to build confidence in the capability of the full-scale mixing and transfer system to deliver feed batches that are consistent with pre-transfer samples collected to characterize the feed. The SSMD scaled performance testing will extend previous work using simulants that are more representative of a broader distribution of Hanford tank wastes. In order to achieve this objective, small scale mixing and transfer testing will be conducted to collect the data necessary to build confidence in the mixing and transfer scaling relationship (Equation 3-8 in Section 3.2.1). Specifically, chemical composition data for each of five transfer batches will be collected at two different scales. Multiple tests, varying the mixer jet pump nozzle velocity, the simulant composition and/or the transfer pump capture velocity will be performed at each scale. The batch composition data will then be converted into a metric for evaluating batch consistency with the pre-transfer sample. This metric will then be fit to an empirical model that includes a functional dependency on the varied parameters and will incorporate the theoretical scaling model shown in Equation 3-8 in Section 3.2.1. The scaling relationship is determined when the models predict equivalent performance, as related to batch consistency with the pre-transfer sample or other performance metric.

Using the SSMD test platform, which includes both a 1:21 and 1:8-scale mixing and transfer system (see Figure 2-2), a series of tests will be conducted at two scales and batch transfer data, including the chemical composition of each transfer batch, will be collected and analyzed to improve the knowledge and understanding of the scaled mixing systems. The primary performance metric that will be evaluated is transfer batch chemical composition consistency with the pre-transfer samples that are collected to characterize the transferrable slurry. Additionally, system performance information related to limits of performance and solids accumulation (e.g., effective cleaning radius, dimensions of the mounding solids in the "dead-zone(s)", and cloud height) will also be collected for each test condition to support DNFSB 2010-2 Deliverable 5.5.3.1, *Initial gap analysis between WTP WAC and tank farm sampling and transfer capability*. The test objectives are summarized in Table 2-1.

Additionally, tests using a non-Newtonian simulant that includes solids represented in the Newtonian slurry (e.g., stainless steel and zirconium oxide) will be conducted and batch transfer data for the added solids will be collected. The data will be analyzed to determine if the scaled relationship developed for the Newtonian slurry is suitable for predicting full-scale performance of non-Newtonian slurry that is mobilized during mixing and transfer.

Test plan details, including a discussion of the requirements for test equipment, simulants, operating parameters, test matrix, sample collection, and data analysis are provided in Section 3.2.

Table 2-1. Small-Scale Mixing Demonstration Scaled Performance Test Objectives

Objective	Success Criteria
Use Newtonian simulants in the 1:8- and 1:21-scale SSMD platform to build confidence in the pre-transfer sampling representativeness and the predictions of full-scale performance.	Mixing and transfer tests are performed with Newtonian slurries at multiple jet nozzle velocities. The slurry contains moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste. These particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Mixing and transfer tests are performed with Newtonian slurries at multiple jet nozzle velocities with variations in the base (solids) simulant, supernatant compositions, and transfer pump capture velocities. Performance data (i.e., sample composition of each transfer batch) is collected at two scales and is used to refine the scaling relationship for the integrated mixer jet pump and slurry transfer system. The sensitivity of the scaling relationship to the varied parameters is evaluated. The scaling relationship is refined and used to predict waste transfer performance at full-scale.
Use non-Newtonian simulants in the 1:8- and 1:21-scale SSMD platform to evaluate the suitability of using the scaled relationship determined for Newtonian slurries to mobilized non-Newtonian slurries.	Mixing and transfer tests are performed with non-Newtonian slurries at multiple jet nozzle velocities. Additional solids, including moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste are added to the slurry. These particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Performance data (i.e., sample composition of each transfer batch) is collected at two scales and is used to evaluate the suitability of the scaling relationship developed for Newtonian slurries to mobilized non-Newtonian slurries.

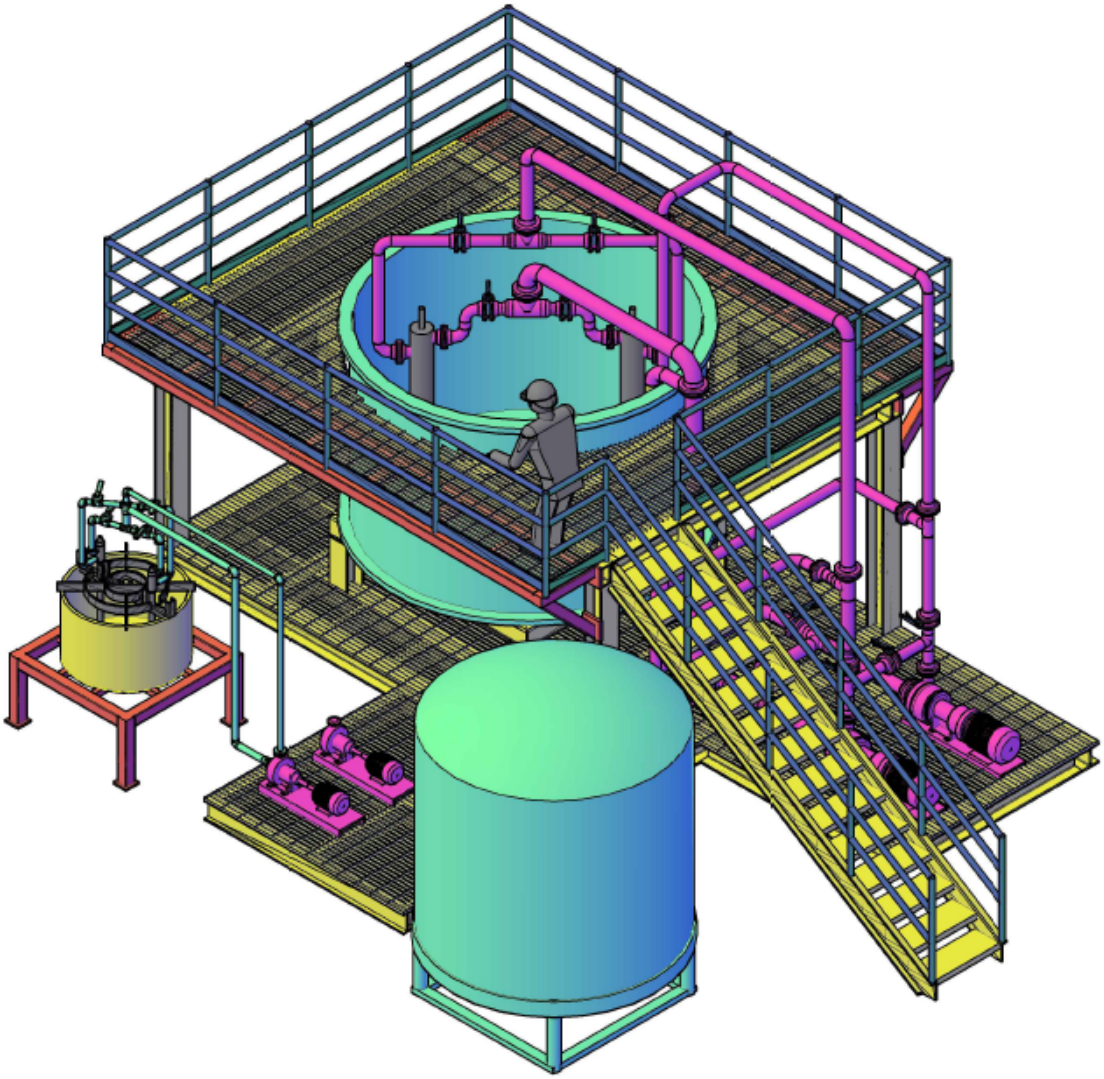


Figure 2-2. Schematic of Small-Scale Mixing Demonstration Test Platform

2.2 REMOTE SAMPLER DEMONSTRATION SYSTEM PERFORMANCE TEST OBJECTIVES

While the SSMD test activities support the overall objective of the WFD Mixing and Sampling Program to build confidence in the capability of the full-scale mixing and transfer system to deliver feed batches, the RSD test activities are performed to build confidence that the collected pre-transfer samples are *representative* (see Section 3.3.4 for explanation of *representative*) of the feed. The objective of RSD system performance activities is to evaluate the performance of the RSD, including the UPE, with simulants that represent a broader distribution of Hanford tank wastes.

The objective of RSD system performance test activities is to continue to optimize the RSD configuration of the Isolok® Sampler system (see Figure 2-3) to demonstrate the ability of the sampler to obtain samples that have the same content as the slurry within the waste characterization flow loop. Operating parameters that will be investigated include variations in simulant composition (base solids and supernatant) and simulant mass loading. Additionally, RSD system performance testing will use the UPE with the 10 MHz transducer for monitoring bulk solids settling (i.e., the onset of critical velocity) in the flow loop. Using transparent sections located both upstream and downstream of the UPE (transparent sections are not shown in Figure 2-3), bulk particle settling will also be visually observed to evaluate the performance accuracy of the UPE. Critical velocity evaluations will expand upon testing performed during RSD limits of performance testing (RPP-PLAN-52005). In addition, the system design will be evaluated against field deployable constraints and limitations.

The test objectives are summarized in

Table 2-2.

Table 2-2: Remote Sampler Demonstration System Performance Test Objectives

Objective	Success Criteria
Demonstrate, with different simulant compositions (Newtonian and non-Newtonian), the capability of the Isolok® Sampler to collect representative samples in the vertical configuration.	Isolok® sampling tests in the vertical configuration are performed in the RSD flow loop with a base simulant that contains moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste, a supernatant simulant and some challenging spike particles. Base and spike particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Collected samples are analyzed for chemical composition and quantified relative to a full diversion sample. Sampler performance is evaluated by comparing the mean square of the sampling error to a standard of representativeness of 10% relative to the full diversion samples. Correlations relating the relative difference between the Isolok® samples and full diversion samples are evaluated with respect to the changes in the test conditions (i.e., variations in the liquid and solid simulant composition and loading).
Demonstrate the Ultrasonic PulseEcho system for monitoring bulk solids settling in the flow loop.	Identify critical velocity of simulants based on bulk particle settling as detected by the Pacific Northwest National Laboratory (PNNL) Ultrasonic PulseEcho system and visual monitoring of the settled slurry in the adjacent transparent sections. The critical settling velocity determined visually and using the Ultrasonic PulseEcho system are within 0.3 ft/s for critical settling velocities exceeding 2 ft/s.
Define operational steps for the Isolok® Sampler and describe functional requirements for supporting systems necessary for field deployment.	Develop operational protocols for the Isolok® Sampler system that allow consistent and integrated sample collection of HLW slurries coming from a mixed DST, and document results in a report. Identify field deployment considerations for the remote sampling system, based on the experience gained during the RSD activities.

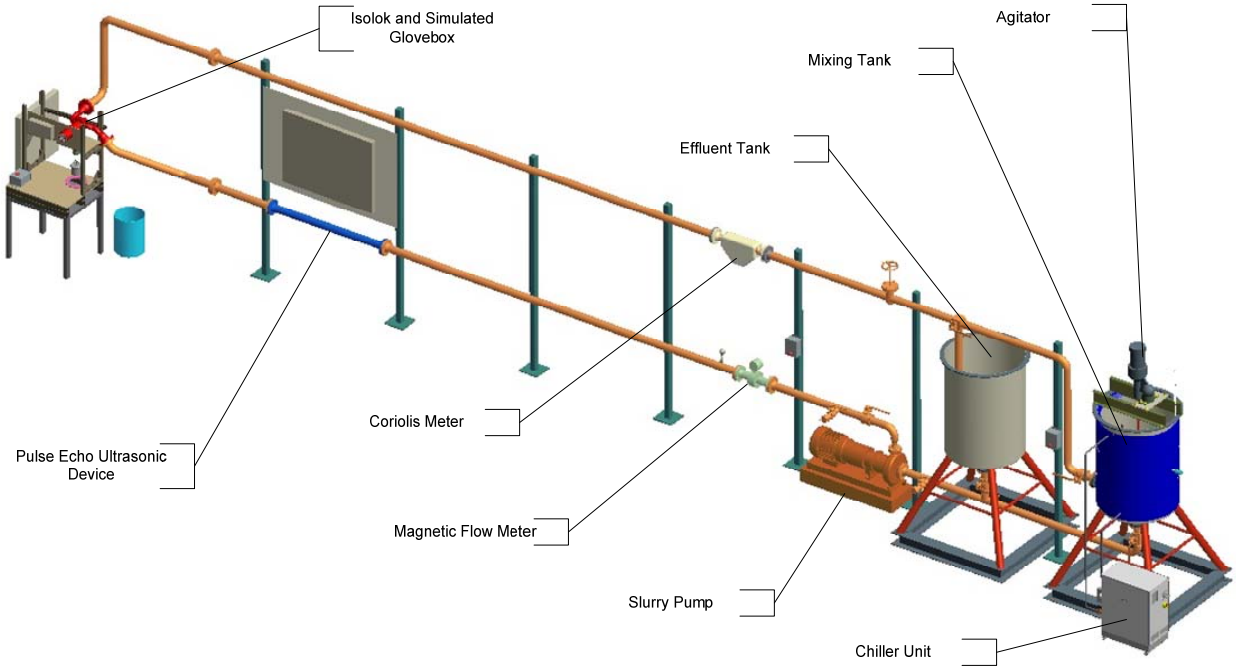


Figure 2-3. Schematic of Remote Sampler Demonstration Test Platform

3.0 TEST REQUIREMENTS

Test requirements and test guidance have been developed to meet the SSMD scaled performance and RSD system performance test objectives identified in Section 2.0.

In addition to this test plan, each testing contractor will develop operational procedures that include or reference the test configuration, test objectives, test requirements, and provisions for assuring that prerequisites and suitable environmental conditions are met, adequate instrumentation is available and operational, and that necessary monitoring is performed.

3.1 TEST SIMULANTS

The capability gap between the TOC and the WTP is defined by the TOC's capability to mix, sample, and transfer large and dense particles, and the WTP's capability to process these particles. Therefore, integral with defining the gap in capabilities is the selection of appropriately complex simulants, integrated with WTP simulant selection, and supported by accurate analytical techniques to characterize the material of interest. The Hanford waste simulants for DNFSB 2010-2 testing are developed and described in RPP-PLAN-51625. As detailed in RPP-PLAN-51625, particle size and density are expected to be the most important solids properties for predicting system performance. Liquid density and viscosity are expected to be important liquid phase properties. Unlike previous limits of performance test activities described in RPP-PLAN-52005, which included irregularly shaped base simulant particles and very large and dense spherical spike particles, the particles used in the scaled and system performance test activities are generally irregularly shaped base simulant particles.

The simulants used for SSMD scaled performance and RSD system performance test activities are consistent with DNFSB 2010-2 testing performed in accordance with RPP-PLAN-52005. Simulant selection considers parameters (e.g., particle size, density, viscosity, and yield stress) important to mixing, sampling, and transfer performance. Simulant properties such as hardness and abrasiveness, which are important to evaluating erosion and wear of the tank and pipe walls and the mixing and transfer equipment, are not primary considerations for understanding the capability of the system to mix, sample, and transfer slurries characteristic of Hanford tank waste. However, simulant selection does favor materials that result in less wear on the test equipment when alternatives that match the critical characteristics are available.

Although SSMD and RSD testing is Phase I technology development and generally performed to the subcontractors own quality assurance procedures, simulant procurement, preparation, and simulant property data collection are performed to enhanced quality assurance standards as defined in TFC-ESHQ-Q_ADM-C-01, *Graded Quality Assurance*. As such, additional level of controls beyond the providers published or stated attributes of the item, service, or process are needed to verify critical attributes of the simulants. Simulant materials procured as commercial grade items shall be prepared and qualified to match the critical characteristics of the simulants. The critical characteristics for the Newtonian base simulant materials are the particle size distribution and density of the materials. The particle size distributions and densities of the components in the composite slurry are used to calculate performance metrics (e.g., distribution of Archimedes numbers) for the composite to qualify the simulant for use. For the supernatant, the critical characteristics are the liquid density and liquid viscosity. For non-Newtonian

simulants the critical characteristics are the Bingham plastic yield stress and density. Bingham plastic consistency (i.e., plastic viscosity) is a secondary characteristic that is measured and reported. To qualify the supernatant and non-Newtonian slurry for use, the critical characteristics will be measured when the simulant batches are prepared.

Newtonian simulant batches of base material and supernatant are prepared according to prepared recipes. By specifying the mass fraction of each solids component, the density of each solids component, the density of the supernatant, the solids loading, and the batch volume, the required amounts of each solids component are fully defined. Supernatant and non-Newtonian slurry recipes are determined from test batches prepared to match the critical characteristics. The base simulant and supernatant simulant for Newtonian simulants and the non-Newtonian simulant described in this test plan are described below. Selection and justification of the simulants to be used in each test activity are provided in the test requirements for each test activity.

3.1.1 Base Simulant

As discussed in RPP-PLAN-51625, during simulant development for DNFSB 2010-2 test activities metrics were selected that are relevant to mixing and sampling and are similar to the metrics for the Hanford tank waste. The calculated values for the metrics are not used to set operating conditions for testing; metric comparisons are only used to demonstrate that the developed simulants are similar to the Hanford tank waste.

3.1.1.1 Base Simulant Description

The base simulant is the mixture of solid particles in the Newtonian slurry representing the Hanford tank waste. Report RPP-PLAN-51625 recommends three base simulants for WFD Mixing and Sampling Program test activities, low conceptual, typical conceptual, and high conceptual. The low conceptual base simulant is a single component base composed of gibbsite particles. As described in RPP-PLAN-51625, the low conceptual simulant is similar to the least challenging waste with respect to the distribution of Archimedes numbers and jet velocity needed to achieve complete solids suspension. Considering these same two metrics, the high conceptual simulant is more challenging than most of the measured waste and the typical conceptual simulant is in between these two and is similar to much more of the waste. The typical conceptual and high conceptual base simulants are complex (i.e., multicomponent mixtures) simulants composed of gibbsite particles, sand particles, zirconium oxide particles, and stainless steel particles. Differences in recommended particle sizes of gibbsite and sand, as well as differences in the mass fractions of each component mixture distinguish the typical and high conceptual simulants. Table 3-1 provides the composition of the base simulants recommended in RPP-PLAN-51625. The selected base simulant used in each test is specific to the objective of the test and justified in the Test Simulants sections (Sections 3.2.3 and 3.3.2) of the test plan.

In addition, following the recommendations in RPP-PLAN-51625, tests will also be performed using non-Newtonian slurry with a Bingham plastic yield stress between 3 and 10 Pa. Tests requiringnon-Newtonian, cohesive slurry will be made from kaolin clay. Based on initial laboratory work performed to develop simulant recipes at lab scale quantities and test batches prepared in the 43.2-inch diameter SSMD test vessel, a non-Newtonian slurry with a yield stress of 3 Pa and a density of about 1.16 g/ml is obtained by adding 22 wt%) kaolin clay to tap water.

A non-Newtonian slurry with a Bingham plastic yield stress of 10 Pa and a density of about 1.22 g/ml is obtained by adding 28 wt % kaolin clay to tap water. The method of mixing the kaolin into the simulant liquid has a big effect on the resulting simulant properties. Therefore, test samples shall be prepared to confirm the simulant preparation technique, simulant makeup, and the critical properties (i.e., the yield stress and density) of the test batch prior to testing. In addition, the Bingham plastic consistency shall also be measured and reported. Table 3-1 includes the properties for the non-Newtonian simulant. For a non-Newtonian slurry with a yield stress of 3 Pa and a higher density, sodium thiosulfate at 24-wt % can be added to 16-wt % kaolin clay in tap water. For a non-Newtonian slurry with a yield stress of 10 Pa and a higher density, sodium thiosulfate at 17-wt % can be added to 23.4 wt % kaolin clay in tap water.

Kaolin clay slurries with a targeted Bingham plastic yield stress of 3 Pa are determined to be acceptable in the range of 2 to 4.5 Pa. Slurries with a targeted Bingham plastic yield stress of 10 Pa are determined to be acceptable in the range of 7 to 13 Pa. This is based on the time-varying nature of a non-Newtonian simulant, and the necessary accuracy needed to resolve the effect of the yield stress on the capability of the system. Preparing consistent simulant batches from test to test will facilitate the analysis of the data between tests and is expected to be more important for the data analysis than performing tests at specific conditions (i.e., 3 and 10 Pa).

Table 3-1: Base Particulate Simulant Characteristics

Newtonian Base					
Compound	**Solid Density (g/ml)**	**Median Particle Size (micron)**	**Mass Fraction**		
			Low	**Typical**	**High**
Small Gibbsite	2.42	1.3	1.00	0.27	0
Large Gibbsite	2.42	10	0	0.44	0.03
Small Sand	2.65	57	0	0	0.35
Medium Sand	2.65	148	0	0.13	0
Large Sand	2.65	382	0	0	0.21
Zirconium Oxide	5.7	6	0	0.10	0.08
Stainless Steel	8.0	112	0	0.06	0.33
Non-Newtonian Base					
			Yield Stress		
			Slurry Density (g/ml)	**3 Pa**	**10 Pa**
Kaolin clay	NA	NA	~1.2	22 wt%	28 wt%
Kaolin clay w/ sodium thiosulfate	NA	NA	1.37	16 wt% Kaolin 24 wt% sodium thiosulfate	23.4 wt% Kaolin 17 wt% sodium thiosulfate

3.1.1.2 Base Simulant Qualification

As described in RPP-PLAN-51625, particle size distributions, particle density, and mass fractions of the components in the composite simulant can be used to determine the distributions of Archimedes numbers and jet velocities needed to achieve complete solids suspension for the composite simulant. As discussed in PNNL-20637 the Archimedes number is closely related to the settling velocity and is also a parameter in other mixing and transfer metrics such as pump intake, jet suspension velocity, critical shear stress for erosion, critical suspension velocity, suspended particle cloud height, and pipeline critical velocity. The calculation of the jet velocity needed to achieve complete solids suspension correlates the particle size and density to the jet velocity of a radial wall jet needed to suspend solids in a tank. Base simulant qualification is performed by comparing the distribution of Archimedes numbers and jet velocities needed to achieve complete solids suspension calculated for the procured simulants to the distributions for the recommended simulants documented in Figures 8-1 and 8-2 in RPP-PLAN-51625. To provide comparable results, performance metrics are calculated using the same assumptions used to calculate the metrics for the three conceptual simulants. Metrics are calculated using particle densities and particle size distributions obtained on samples from each procured lot. Because there is no expectation that procured material lots will not be mixed when testing is performed, particle size distributions from multiple lots of similar material may be averaged for the

qualification comparisons. For commercial grade material, the particle size distribution provided by the vendor is not adequate for simulant qualification and a particle size analysis of each procured lot shall be performed. Appendix C of RPP-PLAN-51625 includes additional performance metrics, such as the critical shear stress for erosion of non-cohesive particles, just suspended impeller speed, pulse jet mixer critical suspension velocity for non-cohesive solids, pulse jet mixer cloud height for non-cohesive solids, and pipeline critical transport velocity. The procured material will also be compared to the conceptual simulants using these metrics.

The metrics calculated for the conceptual simulants in RPP-PLAN-51625 include typical distributions for some of the components. Therefore, the calculated values represent target values and deviations from the conceptual simulants are anticipated. The appropriateness of candidate material will be evaluated before simulant procurement. For procurement purposes, in absence of samples from actual lots, vendor supplied information (e.g., particle size distributions and particle density) and targeted mass fractions can be used to calculate the performance metrics for comparison to the conceptual simulants. For simulant qualification, calculations will be based on laboratory analysis of samples taken from the procured material and actual weight measurements recorded during testing.

Tests using a non-Newtonian slurry with a Bingham plastic yield stress between 3 and 10 Pa will be made from kaolin clay. The yield stress will be measured to be within the tolerances specified in Section 3.1.1.1 prior to testing. The yield stress measurements will be performed on-site with a rheometer calibrated, controlled, and maintained in accordance with American Society of Mechanical Engineers (ASME) NQA-1-2004, Requirement 12, “Control of Measuring and Test Equipment”including addenda, or a later version. Bingham parameters will be determined using a set program that controls the shear rate to generate the rheogram. The program will include a pre-shear period and two evolutions over the shear rate range. Due to the slight rheopetic nature of the Kaolin clay slurries, Bingham parameters shall be determined on the second down curve used to generate the rheogram. Functional checks with reference standards covering the expected range of solutions used during testing shall be performed daily to ensure that the rheometer is being properly maintained. Corrective actions, commensurate with the significance of an out-of-calibration condition, shall be performed. Appropriate instrumentation for measuring the Bingham plastic parameters of the non-Newtonian fluid is a programmable rheometer capable of taking controlled shear rate and controlled shear stress measurements. The rheometer shall also have the capability to control sample temperatures. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, “Test Control” including addenda, or a later version. Yield stress measurements will be collected prior to the start of testing to ensure that the time varying qualities of the non-Newtonian slurry do not change significantly before testing is initiated. In addition, yield stress will also be measured at the completion of testing and during testing if necessary, to assess rheological changes that may occur during the course of testing.

3.1.2 Supernatant Simulant

Developing the supernatant composition for DNFSB 2010-2 test activities is informed from modeling Hanford waste processes. Hanford waste process modeling includes tank inventory, accounts for retrieval technologies, waste volume reduction (i.e., evaporation), and includes inventory blending during multiple tank-to-tank transfers. Therefore, an estimate for the

chemical composition of each feed batch is calculated and the results are used to select a suitable supernatant density and viscosity for DNFSB 2010-2 test activities.

3.1.2.1 Supernatant Simulant Description

The supernatant simulant is the liquid phase of the simulant slurry. For WFD Mixing and Sampling Program test activities, RPP-PLAN-51625 recommends four supernatant simulants (low density/low viscosity, low density/high viscosity, high density/low viscosity, and high density/high viscosity). These simulants are characterized by liquid density and liquid viscosity. The four supernatant characteristics are taken from Table 6-1 in RPP-PLAN-51625, which is summarized as the target simulant properties in Table 3-2. Table 3-2 also provides tested properties for simulants that have been prepared at 20°C (Centigrade) for each target simulant using non-hazardous, non-reactive components that are readily available at a reasonable cost, and in most instances have been used previously in related testing activities. These compositions are informed from chemical handbooks and previous testing, and were confirmed by preparing test batches at a laboratory scale. Due to strong temperature sensitivity, solutions that use glycerol to increase the liquid viscosity may require adjustments when the testing temperature differs from 20°C. When developing compositions for the liquid simulant, simpler combinations that matched the target density were preferred to facilitate batch production. In some instances, the preference for simpler compositions resulted in viscosity values that exceeded the target values but were considered acceptable for testing.

The targeted supernatant simulants are limiting supernatants and were developed for testing activities that attempt to mobilize large and dense particles during limits of performance testing. A supernatant that is more representative of typical Hanford supernatant is also included in Table 3-2. The liquid density for this supernatant is the median density from the same dataset used to derive the low and high density values in RPP-PLAN-51625. The dataset is the liquid density of the feed batches to the WTP calculated using the Hanford Tank Waste Operations Simulator model (RPP-RPT-48681, *Hanford Tank Waste Operations Simulator Model Data Package for the River Protection Project System Plan Rev. 6 Cases*). The typical supernatant is characterized as having a liquid density of about 1.29 g/ml and an estimated liquid viscosity of 3.3 cP. The viscosity of the supernatant is determined by the salt(s) used to attain the desired density, and is comparable to the value determined using the relationship in Figure 6-2 of RPP-PLAN-51625. An aqueous solution of 31.5 wt % sodium thiosulfate will produce a supernatant with properties similar to the targeted simulant.

The typical supernatant listed in Table 3-2 is a preferred simulant for SSMD scaled performance and RSD system performance testing. Using a limiting supernatant, which was developed to maximize the capability of each system to mix, transfer, and sample large and dense particles, as was the objective for limits of performance testing, is not necessary for SSMD scaled performance and RSD system performance testing. However, the selected supernatant simulant used in each test is specific to the objective of the test and justified in Section 3.1,Test Simulants section of this test plan.

Table 3-2 also includes a supernatant composition that was not discussed in RPP-PLAN-51625. This supernatant is used in lieu of the high density / high viscosity supernatant when the predicted flow regime (Section **Error! Reference source not found.**) at the inlet of the transfer

pump becomes laminar. The density and viscosity preparation tolerances for this modified high supernatant are the same those for the high density / high viscosity supernatant. The simulant can be prepared using sodium thiosulfate to adjust the density to the targeted value and then adding glycerol until the targeted viscosity is attained.

Table 3-2: Newtonian Liquid Supernatant Simulant Characteristics

Supernatant (density/viscosity)	Target Simulant Properties @ 20°C		Simulant Properties @ 20°C		Simulant Composition
	Density (g/ml)	Viscosity (cP)	Density (g/ml)	Viscosity (cP)	
Low/Low	1.1	1	1.098	1.62	12 wt% sodium thiosulfate
Low/High	1.1	8	1.135	8.03	53wt% glycerol
High/Low	1.37	1	1.370	2.00	37 wt% sodium bromide
High/High	1.37	15	1.368	14.6	33.4 wt% sodium thiosulfate and 19.5 wt% glycerol
Typical/Typical	1.29	3.3	1.284	3.60	31.5 wt% sodium thiosulfate
High / Modified High[a]	1.37	8	TBD	TBD	TBD wt% sodium thiosulfate and TBD wt% glycerol

[a] The high density supernatant with reduced viscosity is discussed in Section **Error! Reference source not found.**.

3.1.2.2 Supernatant Simulant Qualification

The simulant recipe for the supernatant simulant was developed in the laboratory, but will need to be scaled to the volume needed for each test. Small test batches prepared at testing temperatures should be prepared to confirm the relative amounts of each constituent needed to match the simulant properties using the procured materials at testing conditions. Upon confirmation of the recipe, adjusted as necessary, scale up to testing volumes will be performed and the liquid density and liquid viscosity will be measured at testing temperatures to confirm that the prepared batch is within the required range for simulant density and viscosity. Preparing consistent simulant batches from test to test will facilitate the analysis of the data between tests and is expected to be more important for the data analysis than performing tests at specific conditions.

Therefore, for low density/low viscosity fluids, 1.098 g/ml and 1.62 cP, respectively, and typical density and typical viscosity fluids, 1.284 g/ml and 3.60 cP, respectively, the acceptable range of liquid densities and viscosities is ±5% and ±0.5 cP, respectively. These two liquids will be attained using a sodium salt (e.g., sodium thiosulfate). The two properties cannot be adjusted independently using the single component and a broad tolerance is allowed for liquid viscosity. For higher density and viscosity fluids, the acceptable range for the density is also ±5%. The tolerance on the liquid viscosity at levels above 5 cP is ±20% when the measurement is determined at testing temperatures. High viscosities will be attained by adding glycerol. The viscosity of glycerol is dependent on concentration and temperature, increasing as concentration increases and temperature decreases. For a specified concentration, a temperature correlation will be developed so that the viscosity at the measured temperature can be used to evaluate the

viscosity at the testing temperature to determine if the prepared simulant meets the 20% tolerance on viscosity.

The liquid property measurements will be measured on-site with the appropriate instrumentation (e.g., hydrometer, viscometer, and rheometer) calibrated, controlled, and maintained in accordance with ASME NQA-1-2004, Requirement 12 including addenda, or a later version. Supernatant viscosity will be determined using a set program that controls the shear rate to generate the rheogram. The program will include a pre-shear period and two evolutions over the shear rate range. The viscosity shall be determined on the second down curve used to generate the rheogram. Functional checks with reference standards covering the expected range of solutions used during testing shall be performed daily to ensure that the instrument is being properly maintained. Corrective actions, commensurate with the significance of an out-of-calibration condition, shall be performed. Appropriate instrumentation for measuring liquid viscosity of the Newtonian fluid is a programmable rheometer capable of taking controlled shear rate and controlled shear stress measurements. The rheometer shall also have the capability to control sample temperatures. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, including addenda, or a later version. To ensure that the prepared simulant is appropriate for use, liquid properties will be measured prior to adding base simulant solids and therefore will be performed at the start of testing. In addition, viscosity will also be measured at the completion of testing, and during testing if necessary, to assess changes that may occur during the course of testing. The base solids in the samples collected during and after testing should be removed by filtering prior to collecting viscosity and density measurements.

3.1.3 Spike Particulates

Unlike limits of performance testing described in RPP-PLAN-52005, SSMD testing will not include large and dense spike particles. However, spiking the base simulant for RSD testing may be performed based on the limits of performance test work. It is possible that large particles of average density may interfere with the Isolok® Samplers ability to collect representative samples of the base material. Testing using spike materials that can be sampled reliably by the Isolok® sampler, as determined during limits of performance testing, will be considered for RSD system performance testing.

Report RPP-PLAN-51625 recommends four materials for the spike particulates, sand, stainless steel, tungsten carbide grit (WC), and tungsten grit. Sand is a simulant for large particles that have a density comparable to the average density of Hanford waste particles. Stainless steel, tungsten carbide, and tungsten, which have densities of approximately 8 g/ml, 14 g/ml, and 19 g/ml, respectively, are simulants for high-density Pu-containing compounds [e.g., plutonium oxide (~11 g/ml)] in the Hanford tank waste. The sand and stainless steel spike particulates are chemically similar to the components in the base simulant, and therefore must be distinguishable from the base materials to be quantified. The spike materials will be distinguishable by particle size; size exclusion (e.g., sieving) will be used to separate the spike particles from the chemically similar base materials. Soda-lime glass spheres will be used as a surrogate for very large sand particles. The glass spheres are chemically inert, have a density similar to sand, but have consistent sizes in 1,000 micron increments because they are manufactured products. Having a consistent shape will facilitate separation of the spike particles from the base by sieving.

Table 3-3 identifies the spike materials for consideration during RSD system performance testing. The spike materials are a subset of the spikes considered for limits of performance testing. Preliminary limits of performance testing that is underway (conducted in accordance with RPP-PLAN-52005) indicates that the performance of the Isolok® Sampler is unacceptable when particles with diameters of approximately 3000 microns, which approaches the diameter of the internal passages of the sample needle, are present in the slurry. The tabulated particles are only for consideration; limits of performance testing may determine that other particles included in the list cannot be repeatedly sampled by the system.

The sizes of the glass, stainless steel, and tungsten carbide spike particulates in Table 3-3 are for spheres, which are readily available in the sizes listed. Consistent with recommendations in SRNL-STI-2012-00062, *Properties Important to Mixing for WTP Large Scale Integrated Testing*, spherical particles are considered because, compared to irregularly shaped particles with more surface area per volume, spherical particles would settle faster from suspensions, creating a greater challenge to sample these particles. The spike particles listed are commercially available items that have an industrial purpose and are manufactured to size tolerances that exceed the tolerances necessary to distinguish the different sized spike particles from the base solids by sieving. Commercial sources for the listed particles manufacture the particles in either 1000-micron, 1/32-inch or 1/16-inch increments with size variations that typically do not exceed several microns. Qualification of the metal spike particles is limited to demonstrating that 99% of a one pound sample taken from each delivered lot is retained on the sieves used to separate that size from the other particles. Qualification of the glass spike particles, which are manufactured to a lower tolerance for shape, is limited to demonstrating that 98% of a one pound sample taken from each delivered lot is retained on the sieves used to separate that size from the other particles.

The spike materials listed in Table 3-3 have densities characteristic of Hanford tank waste and are provided for test planning purposes; the densities of procured spike materials may be different due to differences in manufacturing processes. Table 3-3 also includes three properties that are relevant to mixing, the Archimedes number, the free settling velocity, and the particle Reynolds number. The tabulated Archimedes numbers (Ar) are calculated according to Equation 3-1. The Archimedes number indicates general settling characteristic particles with higher Archimedes values tend to settle faster than particles with lower Archimedes values. The reported values are calculated for the typical density (1.29 g/ml) and typical viscosity (3.3 cP) supernatant. The tabulated free settling velocity, V_t is calculated in the same supernatant liquid according to Equation 3-2. The free settling velocities result in particle Reynolds numbers, Re_p, (Equation 3-3) in the Intermediate Law regime (between 0.3 and 1000).

$$Ar = \frac{\left(\frac{\rho_s}{\rho_l} - 1\right) g d^3}{v^2} \tag{3-1}$$

$$V_t = \left(\frac{4gd(\rho_s - \rho_l)}{3\rho_l \left(\frac{18.5}{Re^{0.6}}\right)} \right)^{0.5} \tag{3-2}$$

$$Re_p = \frac{\rho_l V_t d}{\mu} \quad (3\text{-}3)$$

Where ρ_s is the particle density, ρ_l is the liquid density, g is the gravitational constant, d is the particle diameter, v is the kinematic viscosity of the liquid, and μ is the dynamic viscosity of the liquid. The selected spike particulates, including particle size and spike concentration, used in each test are specific to the objective of the test and justified in Section 3.1, Test Simulants section of this test plan. Alternatives to the spike materials require the concurrence with the TOC technical representative(s) before the material is procured.

Table 3-3: Remote Sampler Demonstration System Performance Simulant Spike Candidates

Compound	Solid Density (g/ml)	Characteristic Particle Size (micron)	Archimedes Number[a]	Free Settling Velocity[a] (ft/s)	Particle Reynolds Number[a]
Borosilicate Glass	2.23	1000 2000	1090 8740	0.19 0.42	23 100
Soda-Lime Glass	2.52	1000 2000	1430 11,400	0.23 0.51	27 120
Stainless Steel (SS)	8.0	1587.5 (1/16") 2380 (3/32")	31,200 105,000	1.3 2.1	250 590
Tungsten Carbide (WC)	14.2	1587.5 (1/16") 2380 (3/32")	60,000 202,000	2.1 3.3	400 940

[a] Calculated for a fluid having a liquid density of 1.29 g/ml and a viscosity of 3.3 cP.

3.1.4 Flow Regime

The flow regime within the transfer line and at the pump suction inlet is determined by the Reynolds number (*Re*) (Equation 3-4).

$$Re = \frac{\rho V D}{\mu} \quad (3\text{-}4)$$

Where: ρ and μ are the density and viscosity of the fluid, respectively, V is the velocity of the flow and D is the pipe or inlet diameter. For Newtonian fluids, the transition regime between laminar and turbulent flow is between *Re* values of 2300 and 4000. For non-Newtonian fluids, the Reynolds number for the transition regime must be calculated. The critical Reynolds number (Re_c) of transition from laminar to turbulent flow for Bingham plastic flow in pipes is determined by Equations 3-5 to 3-7 (Hanks 1963).

$$Re_c = \frac{He}{8\xi_{oc}}\left(1 - \frac{4}{3}\xi_{oc} + \frac{1}{3}\xi_{oc}^4\right) \quad (3\text{-}5)$$

$$He = \frac{D^2 \rho \tau_y}{K^2} \tag{3-6}$$

$$\frac{\xi_{oc}}{(1-\xi_{oc})^3} = \frac{He}{16{,}800} \tag{3-7}$$

Where: *He* is the Hedstrom number, $\boldsymbol{\xi_{oc}}$ is the ratio of the yield stress (τ_y) and the wall shear stress at the point of transition from laminar to turbulent flow, and *K* is the Bingham plastic viscosity, which replaces μ in Equation 3-5 when the Reynolds number is determined for Bingham Plastic fluids. Table 3-4 shows the calculated flow regime for the proposed test conditions for SSMD Scaled Performance testing using a 13 wt% mass loading for Newtonian slurries.

Table 3-4: Flow Regime For Full and Scaled Systems

Scale	Inlet Size (in)	Pump Rate (gpm)	Inlet Velocity (ft/s)	Re	Re_c	Flow Regime
Typical Supernatant (Fluid Density = 1.284 g/ml, Viscosity = 3.6 cP)						
Full	2.25	140	11.3	70,200	2300	Turbulent
1:8	0.32	2.83	11.3	9,980	2300	Turbulent
1:21	0.28	2.17	11.3	8,740	2300	Turbulent
High Supernatant (Density = 1.37 g/ml, Viscosity = 14.6 cP)						
Full	2.25	140	11.3	18,500	2300	Turbulent
1:8	0.32	2.83	11.3	2,620	2300	Transition
1:21	0.28	2.17	11.3	2,300	2300	Transition
Typical Supernatant (Density = 1.284 g/ml, Viscosity = 3.6 cP)						
Full	2.25	90	7.3	45,100	2300	Turbulent
1:8	0.40	2.83	7.2	7,980	2300	Turbulent
1:21	0.35	2.17	7.2	6,990	2300	Turbulent
High Supernatant (Density = 1.37 g/ml, Viscosity = 14.6 cP)						
Full	2.25	90	7.3	11,900	2300	Turbulent
1:8	0.40	2.83	7.2	2,100	2300	Laminar
1:21	0.35	2.17	7.2	1,840	2300	Laminar
High Base/Modified High Supernatant (Density = 1.37 g/ml, Viscosity = 8.0 cP)						
Full	3.9	140	3.8	19,400	2300	Turbulent
1:8	0.55	2.83	3.8	2,760	2300	Transition
1:21	0.48	2.17	3.8	2,450	2300	Transition
Non-Newtonian with Base Solids (Density = 1.18 g/ml, Bingham Plastic Yield Stress = 3 Pa, Bingham Plastic Consistency = 5 cP)						
Full	2.25	140	11.3	46,400	11,700	Turbulent
1:8	0.32	2.83	11.3	6,600	3,270	Turbulent
1:21	0.28	2.17	11.3	5,780	3,070	Turbulent

For the standard operating conditions, the flow at the inlet is either transitioning from laminar to turbulent flow or fully turbulent at all scales. However, for the reduced capture velocity testing, the flow at the inlet for the Newtonian fluids becomes laminar in the scaled environment with Reynolds number values that drop below the transition value. In order to maintain the same pump out rate for the lower capture velocity (3.8 ft/s), the diameter of the inlet must be increased and the viscosity for the high density/high viscosity supernatant must be reduced to 8.0 cP to keep all tests in the transition regime and 4.8 cP to have turbulent conditions. Both the cyclical jet motion and the squared corners of the pump suction inlet will increase the turbulence at the inlet. However, keeping turbulent conditions at the inlet is not attainable for the lowest capture velocity tests when the high density/high supernatant is used. The test matrix either avoids this condition or minimizes the number of runs that are performed under these conditions.

3.2 SMALL-SCALE MIXING DEMONSTRATION SCALED PERFORMANCE

The SSMD scaled performance test activities documented in Section 3.2 are performed by Energy*Solutions* for WRPS.

The SSMD scaled performance activities described in this test plan will use the 1:21-and 1:8-scale tanks of the SSMD test platform (Figure 2-2) located at Monarch Machine & Tool Company, Inc. in Pasco, WA to evaluate the system performance when test conditions for mixing and transfer are varied. The operating parameters that will be varied during testing are the mixer jet nozzle velocity and transfer pump capture velocity. The mixer jet rotational rate will be adjusted for each change in nozzle velocity according to Equation -3-9 in Section 3.2.1. In addition to varying the nozzle velocity, transfer pump capture velocity and mixer jet rotational rate, the simulant properties, both solids composition and supernatant composition, will also be varied and include both Newtonian and non-Newtonian slurries. Tests conducted at both scales will use the same simulant compositions so that the results from the two scales can be compared to determine velocities that result in equal performance. Velocities that result in equal performance will be used to determine the scaling relationship that will be used to predict full-scale performance.

3.2.1 Scaling Approach

The SSMD scaling approach was described in detail in test plan RPP-PLAN-52005. The scaling approach for the nozzle velocity and mixer jet pump rotational rate is unchanged and for completeness it is reproduced in Appendix A. The SSMD scaling relationship for nozzle velocity (Equation3-8) is a function of the mixer jet pump nozzle velocities for the two scaled systems, U_{jet}, the tank diameters, d_{tank}, and the scale factor exponent a. The SSMD scaled performance test activities will collect performance data at two scales to determine an appropriate value for the scale factor exponent.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{a} \tag{3-8}$$

As discussed in Section 3.2.6, a performance metric (e.g., the difference between the pre-transfer sample concentration of a component *i* and the average concentration of component *i* in each

batch transfer) will be calculated for each test at each scale. Equation 3-8 will be used to determine the scale factor exponent that results in equivalent metric results between scales.

The SSMD scaling relationship for mixer jet pump rotational rates, ω_{tank}, (Equation 3-9) sets an equivalent number of mixer jet rotations in one turnover of the waste volume through the mixer jet pump. The resulting relationship is a function of the full-scale rotation rate, the geometric scaling factor (i.e., the ratio of the tank diameters), and the nozzle velocities for the two systems.

$$\omega_{tank2} = \frac{\omega_{tank1} U_{jet2}}{\left(\frac{d_{tank2}}{d_{tank1}}\right) U_{jet1}} \tag{3-9}$$

For SSMD scaled performance testing, a nozzle velocity will be selected and Equation 3-9 will be used to determine the rotational rate for the test.

3.2.2 Test Equipment and Instrumentation

Scaled performance testing will be performed using the established SSMD test platform at the Monarch Machine & Tool Company, Inc. facility in Pasco, Washington. A schematic of the SSMD test platform is shown in Figure 2-2. The SSMD test platform has been used for previous test activities and will continue to be used to address uncertainties in the WFD Mixing and Sampling Program. The SSMD test platform was constructed to perform mixer jet pump testing at two different scales, approximately 1:21 (43.2-inch diameter tank) and 1:8 (120-inch diameter tank). Both tanks will be used for scaled performance testing so that the scaling relationship can be evaluated to predict full-scale performance. The properties of the DSTs used to geometrically scale the test tanks and the scaled properties of the two-scaled tanks are provided in Table 3-5. The plan view of DST 241-AY-102 is shown in Figure 3-1 (from H-14-010506, Sheet 4, Rev 1).

The SSMD test platform will continue to be used to assess the capability of the system to mix tank waste simulants and deliver the solids to a receipt tank. The main components of the test platform include: a 3,000-gallon flush tank, a 120-gallon (43.2-inch diameter) clear acrylic test tank (TK-201), a 2,358-gallon (120-inch diameter) clear acrylic test tank (TK-301), dual rotating mixer jet pump assemblies, and the slurry transfer pumps for both TK-201 and TK-301. Flow from the tanks enters the two mixer jet pump suction inlets on the bottom of the mixer jet pump, and is combined into one flow stream as it is routed through the pump driving the system. The pump discharge is split with half of the flow returning to each mixer jet pump. As each mixer jet pump is rotating, the flow is discharged back into the tank through two opposing jet nozzles located on the side of the mixer jet pump just above the pump suction inlet. Between scales, the mixer jet pump assemblies and transfer pumps for each tank are independent. The slurry transfer pumps are not submersible pumps located inside acrylic tanks. The slurry transfer pumps are progressive cavity pumps located outside of the test tanks; the inlets of the pump are connected to suction lines that are placed within the tanks. The end of the suction lines inside each tank is fitted with a machined orifice matching the requirements in Table 3-4 and Table 3-5. The transfer pump suction inlet shall be placed consistent with the location of Riser 30. The scaled height of the pump suction inlet shall be equivalent to the height of the transfer pump inlet in the

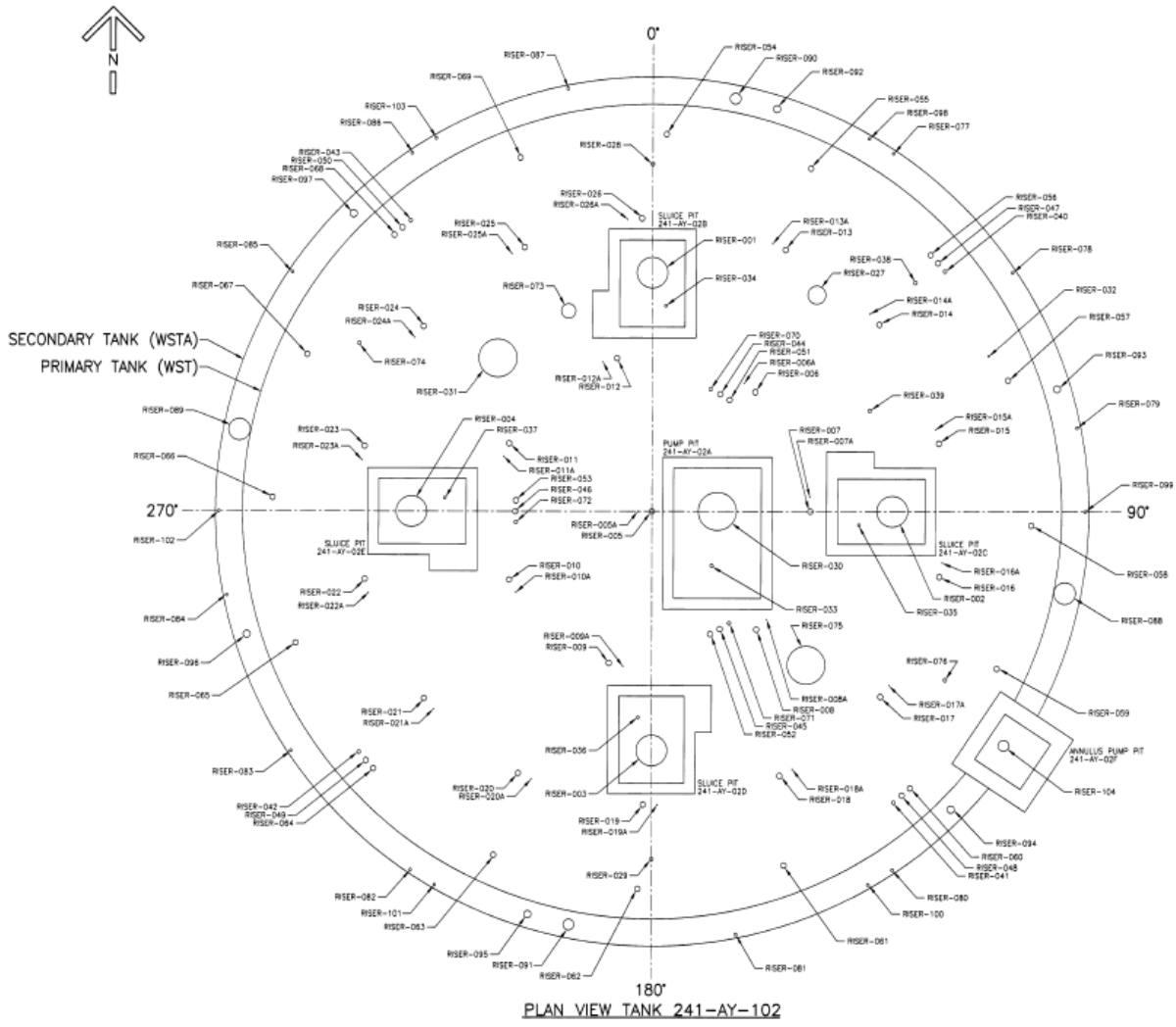
full-scale DST transfer system, which is 0.8 inches from the tank bottom in TK-301 and 0.28 inches from the tank bottom in TK-201 (see Table 3-5). Ancillary equipment, such as the support structure, the control system, video monitoring, and simulated piping to transfer and sample the material from the tank are also part of the test platform.

The transfer system piping, valving, and instrumentation (e.g., in-line Coriolis meters, and magnetic flow meters) will replicate the transfer system from previous SSMD testing reported in RPP-49740. The test configuration includes a closed recirculation loop from the tank. The recirculation loop accommodates sample collection. Flow control is automated using programmable logic controllers connected to a human–machine interface. System data, including date and time, slurry temperature, mixer jet pump rates and position, slurry flow rates, tank level, and specific gravity measurements in the transfer pump discharge, will be monitored and recorded using a data acquisition system.

The internal passageways of the mixer jet pumps driving pump and the slurry transfer pump are larger than the transfer lines; therefore, particles with a high settling velocity (e.g. stainless steel powder in the base simulant) may settle in the pump because the velocity through the pump is reduced below the critical velocity of the particles. Modifications to the pump orientation to minimize the collection of particles will be evaluated. The extent that particles can collect in the transfer pump shall be evaluated in developmental testing so that this condition can be captured as a source of error. In addition, the slurry lines shall be purged in between tests to reduce the potential that settled solids from one test contaminate the results of a subsequent test.

When operating in a recycle mode to stabilize the mixing tank prior to performing batch transfers, the transfer line shall be discharged back into the tank. During batch transfer operations the transfer line shall be discharged for sample collection or waste collection.

All measuring and test equipment, including gauges and instrumentation, used for testing activities shall be controlled, calibrated under conditions typical of the test environment, adjusted, and maintained to required accuracy limits. The condition and the reported accuracy of each instrument shall be documented in a test log.



Note: Mixer jet pumps will be in Riser-001 (0°) and Riser-003 (180°). Transfer pump will be in Riser-030 (90°)

Figure 3-1. Plan View Tank 241-AY-102

Table 3-5: Small-Scale Mixing Demonstration Tank Geometrically Scaled Properties

Property	Full-Scale DST (AY-102)	1:8 Scale	1:21 Scale
Diameter (in)	900	120	43.2
Scale Factor	1	0.1333	0.048
Fill Height (in)	343	45.7	16.5
Bottom Geometry	Flat w/12-inch corner radius	Flat w/1.6-inch corner radius	Flat w/0.6-inch corner radius
Fill Volume1 (gallons)	944,620	~2,200	~100
Mixer Jet Pump 1 Location[2]	Riser-001 0°, 22 feet	90°, 2.9 feet	90°, 0.96 feet (12.7 in as-built)
Mixer Jet Pump 2 Location[2]	Riser-003 180°, 22 feet	270°, 2.9 feet	270°, 0.96 feet (12.7 in as-built)
Mixer Jet Pump Suction Elevation[3] (in)	5±1	0.67±0.13	0.24±0.05
Mixer Jet Pump Suction Diameter (in)	11	1.47	0.53
Mixer Jet Pump Nozzle Diameter (in)	6	0.80	0.28
Mixer Jet Pump Nozzle Elevation[3] (in)	18	2.4	0.86
Mixer Jet Rotation Rate (rpm)	0.2	See Eq. 3-5	See Eq. 3-5
Transfer Pump Location[2]	Riser-030 90°, 6 feet	0°, 0.8 feet	0°, 0.29 feet
Transfer Pump Suction Inlet Diameter (in)[4]	2.25-2.40	0.32	0.25
Transfer Pump Suction Inlet Height (in)[4]	6	0.8	0.28
Transfer Line Diameter (in)	3.07 (3-inch Schedule 40)	½"-poly tubing	¼"-poly tubing
Tank Obstructions	Air Lift Circulators (ALCs)	Simulated ALCs (removable)	Simulated ALCs (removable)

[1] Fill volume is determined by linear scaling of the tank diameter and sludge volume height.

[2] The reference point for DST locations presented in this table defines 0° as the top (241-AY-102) or bottom (241-AW-105) of the tank in a plan view drawing of the tank. Provided distances are design distances from the center of the riser to the center of the tank.

[3] Elevation is relative to the tank bottom.

[4] The pump suction inlet diameter of the Full-Scale Transfer Pump is underdevelopment and the tabulated value is based on similar transfer pumps used on the Hanford site to convey waste. The inlet size on the 1:21 scale tank is not geometrically scaled. The resulting inlet size was too small to accommodate the particle sizes targeted.

3.2.3 Test Simulants

The simulants used in the SSMD scaled performance testing are selected in accordance with the recommendations in RPP-PLAN-51625. Simulant properties and qualifications are described in Section 3.1. Selecting particular simulants for SSMD scaled performance test activities is discussed below. The test matrix showing the combinations of base simulant and liquid supernatant is discussed in Section 3.2.4.

The SSMD scaled performance simulants shall include Newtonian and non-Newtonian simulants. For SSMD limits of performance testing, non-Newtonian testing was conducted with slurries of kaolin clay spiked with large and dense particles. For SSMD scaled performance testing the non-Newtonian solids will also be principally kaolin clay, but stainless steel and zirconium oxide will be added so that batch transfer performance can be quantified. Sodium thiosulfate will be added to increase the density of the non-Newtonian slurries when required in the test matrix.

The Newtonian simulant shall be a complex (i.e., multicomponent) simulant containing base particulates. The liquid phase shall be a supernatant simulant. Sodium thiosulfate will be added to increase the density of the Newtonian slurries when required in the test matrix. Glycerol will be added to increase the viscosity of the Newtonian slurries when required in the test matrix. Recipes for the simulants discussed below are tabulated in Table 3-1 and Table 3-2.

Although RPP-PLAN-51625 recommends three conceptual simulants for WFD Mixing and Sampling Program DNFSB 2010-2 testing, only two simulants are selected for SSMD scaled performance testing, the typical and the high conceptual simulants. The low conceptual simulant is composed entirely of small gibbsite particles, which are readily suspended at even the lowest operational velocities, and are therefore not interesting for determining equivalent performance between scales. Based on the distribution of Archimedes numbers and jet suspension velocities reported in Figures 8-1 and 8-2 in RPP-PLAN-51625, the typical and high conceptual simulants are representative of the typical conceptual simulant to suspend, and most challenging to suspend tank waste. Although the typical conceptual simulant recommends that two different sized gibbsite particles be used, batch consistency performance will be based on chemical analyses of the transferred material, which will not distinguish between the different sized materials and so the scaling analysis will not consider the effect of gibbsite size. A similar limitation is applied to sand in tests with the high conceptual simulant, which includes two different sized sands.

To investigate the effects of the supernatant density and viscosity, three supernatant compositions will be investigated, typical, high, and modified high. For the typical supernatant, the liquid density is 1.284 g/ml and the liquid viscosity is 3.60 cP. The typical supernatant is consistent with the typical density/typical viscosity recommendation in Table 3-2. For the high supernatant, the liquid density is 1.368 g/ml and the liquid viscosity is 14.6 cP. The high supernatant is consistent with the high density/high viscosity recommendation in Table 3-2. For the modified high supernatant, the liquid density is 1.368 g/ml and the liquid viscosity is 8 cP. The modified high supernatant is necessary to prevent laminar flowat the transfer pump inlet when a high density, Newtonian simulant is evaluated at lower capture velocities. The recipe for the modified high supernatant will be developed as a variant of the high density/high viscosity supernatant by adding less glycerol. The acceptable preparation tolerances are discussed in

Section 3.1.2. Liquid viscosity shall be evaluated at the operating temperature of the test tank, if the temperature of the sampled material differs from the bulk volume. The high values for liquid density and liquid viscosity are selected because higher densities and higher viscosities are expected to increase the buoyancy effecting solid particles in the mixing tank and reduce critical suspension and settling velocities. Increasing buoyancy and subsequently reducing the critical suspension velocity and settling velocities are expected to promote particle suspension, which will improve mixing within the tank. Although higher viscosities fluids may reduce the capability of the system to clear the solids from the bottom of the tank, SSMD scaled performance testing is evaluating transfer batch consistency with the pre-transfer samples and is not evaluating the capability of the system to mobilize all material from the tanks. Improved mixing within the tank is expected to yield a more representative pre-transfer sample and also result in better batch-to-batch consistency. To confirm this expected correlation, the three supernatant simulants will be used during testing.

The effect of solids loading on batch-to-batch consistency and batch consistency with the pre-transfer sample between scales is difficult to predict. Previous SSMD test results (RPP-49470) indicate that in three of four tests, the fraction of the initial amount of stainless steel transferred from the tank was within 10% of a comparable case with twice as much stainless steel initially present in the tank. In the fourth test, the fraction of stainless steel recovered was less than 50% of a comparable case with twice as much stainless steel initially present in the tank. In these same tests, the amount of zirconium oxide and gibbsite were held constant. The difference in the fraction of the initial amount of zirconium oxide transferred from the tank in each comparable test was within 10%. The differences in the fraction of initial gibbsite transferred out of the tank ranged from 15-to-30%. Therefore, the differences in the stainless steel recoveries are comparable to other solids with initial amounts that did not vary. With these results in mind, the effect of solids loading will not be investigated and will be held constant at 13wt% based on the ICD-19 allowable limit of 200 g/l. The mass loading is equivalent to 180 to 194 g/l depending on the composition of solids and supernatant selected. The effect of solids loading will be revisited during supplemental testing that includes scaled relationship confirmation runs with different mass loadings. These confirmation runs will be performed with lower mass loading values because the mass loading tested is at the upper range of the ICD-19 action level for solids loading.

In addition to the Newtonian tests discussed previously, tests will also be performed using a non-Newtonian slurry with a Bingham plastic yield stress. In order to produce quantitative data stainless steel and zirconium oxide will be added to the kaolin slurry. The amount of stainless steel and zirconium oxide added to the slurry will be equal to the amount added for a Newtonian test using the typical supernatant and typical base simulant with a solids loading of 13 wt%. The non-Newtonian tests will be conducted to test SSMD transfer performance with a non-Newtonian simulant and evaluate whether or not the transfer batch consistency with the pre-transfer sample for a mobilized non-Newtonian simulant scales according to the Newtonian scaling relationship. A fundamental difference between the Newtonian slurry and the Bingham plastic non-Newtonian slurry is the yield stress necessary to get the slurry to behave like a fluid. In a fully mixed tank (i.e., no caverns are formed) the Bingham plastic fluid that is available to be transferred from the tank has overcome the yield stress necessary to mobilize the fluid and is expected to behave like a Newtonian fluid. Therefore, transfer batch consistency with pre-transfer samples may be characterized by Newtonian scaling relationship. If caverns are

observed at the lowest nozzle velocities, then the batch transfer results may not be useful in the evaluation of the non-Newtonian data. If the second lowest nozzle velocity results in the formation of caverns, the velocity will be increased until cavern formation is eliminated. It is recognized that moderate to high yield stress fluids (greater than 5 Pa) may form stagnant areas within the tank that effect transfer performance so that using the same scaling relationship may not be applicable. However, current ICD-19 limits have a yield stress action level of 1 Pa, so that slurries that are expected to be challenging to mix, sample, and transfer (i.e., slurries with a yield stress exceeding 5 Pa) may not be suitable for delivery to the WTP. The SSMD scaled performance testing will begin to evaluate the scaling of non-Newtonian simulants using slurries with a Bingham plastic yield stress of 3 Pa and a density of approximately 1.16 g/ml. The 3 Pa limit was selected because it is similar to values that have been used in mixing tests in the past, and is expected to be manageable in the 120-inch diameter tank. Due to the anticipated formation of stagnant zone in the mixing tank when higher yield stress fluids are evaluated, it is unlikely that non-Newtonian slurry with a Bingham plastic yield stress of 10 Pa will scale equally as Newtonian slurry. The non-Newtonian slurry shall be prepared and measured in accordance with the recipes, methods, and tolerances discussed in Section 3.1.1.

3.2.4 Operating Parameters and Test Methods

The operating conditions for the SSMD scaled performance testing should be consistent with previous SSMD performance testing. The mixer jets shall rotate continuously clockwise with no rotational offset between mixer jet pumps; the streams will be synchronized to meet in the center of the tank. The rotational speed of the jets (ω) shall be set in accordance with Equation 3-9, but mixing performance using five different nozzle velocities will be evaluated. Five nozzle velocities have been selected to evaluate two bounding mixing conditions and three points in between these bounding conditions to characterize the behavior in between the bounds. The two bounding conditions evaluate velocities that result in bottom cleaning and very poor performance. A velocity with poor mixing performance is being evaluated because the determination for equal performance between scales does not require optimal performance.

Testing conditions that are bounding for both acceptable performance and poor performance will ensure that performance differences are observed during testing so that equal performance among scales is observed. Because equal performance is expected to be at velocities between these bounding conditions, three additional velocities approximately equally spaced from the end points will also be evaluated. Selecting two or more velocities in between the bounding conditions will provide additional data points for the functional model applied during analysis, and increase the confidence that the behavior between the bounding conditions is characterized by the fitted model. The five nozzle velocities that will be used during SSMD scaled performance testing are not determined in advance (as discussed below); however, the nozzle velocities used will be consistent with previous testing, which included nozzle velocities in the range of 22.3 ft/s (70 gpm) to 35.4 ft/s (111 gpm) in the larger test vessel (TK-301) and 16.9 ft/s (6.5 gpm) to 27.6 ft/s (10.6 gpm) in the smaller test vessel (TK-201).

Prior to performing batch transfers that remove material from the tank, the system shall be operated in a recirculation mode until a stable state is established. The stable state is indicated by a consistent mass flow rate reading from the Coriolis meter, after adjusting for cyclical variations caused by the rotating jets. Additionally at the stabilized state a steady cloud height

and mixer jet zone of influence should be observed. Previous operator experience indicates that approximately 10-20 rotations of the mixer jets pumps are sufficient to result in a stabilized state once the solids have been added and dispersed throughout the tank. Once the tank reaches the stable condition, pre-transfer samples will be collected as described in Section 3.2.5. Once the pre-transfer samples are collected, batch transfers will be initiated.

After the first batch transfer is completed, the system shall be reconfigured to recirculate the waste until a stable state condition is re-established. Once the stable state condition is re-established, the next batch transfer and sampling operation will be initiated and will proceed like the first batch transfer and sampling operation. The process will be repeated until five batch transfers have occurred. After the last batch transfer is completed, a description of the solids remaining in the tank, including a photographic or video record, will be prepared and the tank will be emptied.

The upper velocity for each tank will be determined in during testing. Prior to performing a batch transfer the nozzle velocity in each tank will be varied to determine the nozzle velocity required to prevent the formation of piles on the sides of the tank when the typical base simulant is mixed with the typical supernatant. If the nozzle velocity required to clear the bottom exceeds the capability of the system or results in unsafe operating conditions (e.g., splashing or tank shaking) then the velocity will be limited to a maximum that can be operated safely. The resulting velocity will be set as the maximum nozzle velocity used during SSMD scaled performance testing. The combination of the typical base simulant in the typical supernatant was selected because it is expected to be the easiest of the tested configurations to be suspended. This expectation is based on observation that the typical base simulant was developed to be easier to mix than the high base simulant. In addition, this expectation is also based on the radial wall jet velocity needed to achieve complete solids suspension discussed in PNNL-20637 (Equation 2.9).

Compared to the high base simulant in both the typical and high supernatants and the typical base simulant in the high supernatant, the predicted nozzle velocity needed to achieve complete solids suspension, keeping everything else equal, is the least for the typical base simulant in the typical supernatant. This expectation is also consistent with effective cleaning radius calculations that use Equation 5.8 in PNNL-20637, to estimate the effective cleaning radius for slurry containing five wt% 100-micron stainless steel particles using the Shields diagram to determine the critical shear stress for erosion. The formula can be used to show that the combination of the higher density and higher viscosity fluid, despite the increase in buoyancy by the higher density fluid, reduces the effective cleaning radius for the particles; the reduction in the effective cleaning radius due to the change in the viscosity over the planned range exceeds the benefit by the increased density. With the expectation that a velocity that effectively cleans the bottom of the tank is higher than that required for acceptable batch-to-batch consistency with the pre-transfer samples, selecting the velocity that achieves complete bottom cleaning for the easiest to suspend solids ensures that the system is not operated above necessary velocities for any scaled performance test.

The lower velocities for each tank are also determined during developmental testing and are based on a minimum effective cleaning radius criterion. Following the discussion for determining the upper nozzle velocity, it is expected that the high base simulant in the high

density and high viscosity supernatant would result in the lowest effective cleaning radius of the simulant combinations planned in the SSMD scaled performance testing. This simulant combination will be used to determine the minimum nozzle velocity to be used during testing. Previous experimental work shows that in the 1:8-scale system batch- to-batch consistency with the pre-transfer samples was poor when the nozzle velocity was 22.3 ft/s (data from RPP-49740). At this nozzle velocity, the effective cleaning radius was measured to be approximately 75% (approximately 55 inches from the mixer jet pump nozzle) of the distance need to achieve complete bottom clearing (i.e. the distance between the mixer jet pump nozzle and the edge of the tank along a diameter that is orthogonal to the diameter containing the mixer jet pumps). Therefore, developmental testing with the high base simulant in the high density and high viscosity supernatant will be used to determine the nozzle velocity at each scale that results in an effective cleaning radius that is 75% the length to achieve complete bottom clearing. Using the most difficult simulant combination will ensure that the nozzle velocity will be high enough to result in acceptable batch transfer performance during the other tests at this nozzle velocity. The resulting velocity for the 1:8-scale system may not be 22.3 ft/s due to differences from the previous tests for both the base solids being suspended and the composition of the supernatant.

Three velocities that are approximately equally spaced between the upper and lower set points will also be used during testing. Selecting specific intervals rather than specific scale factor exponents was preferred for the regression analysis that will correlate nozzle velocity to the performance metric considered.

Scaled performance testing will evaluate three capture velocities. The maximum capture velocity being evaluated (11.3 ft/s) is equated to the full-scale capture velocity that occurs at the maximum transfer rate (140 gpm). Operating at the maximum flow rate minimizes the waste transfer time. Operating at the maximum capture velocity at the pump suction inlet offers a greater opportunity to capture tank solids. At the maximum capture velocity, the fluid velocities at the transfer pump inlets at the scaled systems are equal. A lower capture velocity is also being evaluated to determine the sensitivity the capture velocity has on the test results. Selection of the lower capture velocity is based on past test experience and uncertainties in the WFD transfer pump design.

Previous reports indicate that the effects of varying the capture velocity are mixed. A recent study evaluating lower capture velocities at both scales (RPT-SSMD-EG-00006, *SSMD Platform Small Scale Mixing Demonstration Low Capture Velocity Follow On Results Report*) indicated that when the capture velocity in the small test vessel (TK-201) was lowered from 11.3 ft/s to 6.3 ft/s with a mixer jet pump flow rate of 27.6 ft/s (10.6 gpm), the cumulative amount of gibbsite transferred in five batches only differed from the predicted amount using the pre-transfer sample by 1% at the maximum capture velocity but was 12% over predicted by the pre-transfer sample at the reduced capture velocity. The cumulative amount of gibbsite transferred at the two capture velocities varied by less than 2%. In the large test vessel (TK-301) the results for gibbsite with a mixer jet pump velocity of 35.4 ft/s (111 gpm) were comparable for the higher capture velocity (11.7 ft/s) but were still over-predicted by 6% at the lower capture velocity (5.9 ft/s). The higher transfer velocity transferred 12% more gibbsite. The results for zirconium oxide were similar. Comparisons of stainless steel results in the small test vessel show that an equivalent amount of material was transferred at the two capture velocities but the amount transferred was over-predicted by the pre-transfer sample by 18-37%. In the large test vessel, the cumulative amount

of stainless steel transferred was within 1% of the predicted amount from the pre-transfer sample at the higher capture velocity, but was over-predicted by 37% at the lower capture velocity. With these results taken into consideration, the effects of the changes in the capture velocity remain uncertain and two different velocities at each scale will be evaluated.

An intermediate capture velocity is equal to the full-scale capture velocity at the lowest planned full-scale operating flow rate (90 gallons per minute) and is 7.3 ft/s when the transfer pump inlet is 2.25 inches in diameter. The alternative capture velocity will be maintained by increasing the diameter of the pump suction inlet while maintaining the same flow rate through the transfer tubing. This method for adjusting the capture velocity was selected to avoid reducing the flow through the transfer tubing downstream of the pump inlet, which may result in particle settling that could interrupt test operations. Inlet sizes for the modified conditions are listed in Table 3-4.

A low capture velocity will also be evaluated. The WFD transfer pump is currently being designed and recent communications with the supplier indicate that the pump suction inlet may need to be increased to 3.9 inches to accommodate the requirements specified for the pump. At 140 gpm, the capture velocity for a 3.9-inch inlet drops to 3.8 ft/s. As discussed in Section 3.1.4, this flow velocity results in laminar flow at the inlet of the scaled system when the high density/high viscosity supernatant is used. In lieu of using the high density / high viscosity supernatant under these conditions, tests will be conducted using a reduced viscosity fluid. Testing with the reduced viscosity fluid avoids scaled testing in the laminar flow regime when the flow in the full scale system would be turbulent.

Non-Newtonian tests will be performed using the same nozzle velocities but will only use the higher capture velocity.

Data collection for each test is described in Section 3.2.5.

The test matrix for SSMD scaled performance testing is provided in Table 3-6. In order to reduce the occurrence of systematic errors, such as instrument calibration drift and elevated temperatures as testing progresses to warmer days, the tests should be performed in a random order. In order to minimize contamination of subsequent tests when a random order is followed, the test platform (test tank, transfer lines, transfer equipment, and sample collection containers) shall be thoroughly flushed and cleaned prior to each test. The test matrix is not a full factorial analysis of the varied parameters, which include the five nozzle velocities, the two base simulant compositions, the three supernatant compositions, and the three capture velocities. Performing a full factorial analysis of the variables most important to determining the scaling relationship would allow for an inclusion of any interaction effects between the varied parameters. Performing a partial or fractional factorial analysis of the variables allows quantification of more important variables at the expense of quantifying interaction effects. The specific variations in the test conditions were selected using a computer algorithm. This method, known as a Bayesian D-optimal design algorithm, essentially selects the “best” test runs from the set of all possible combinations of the settings of the specified design factors, where “best” translates to small variability and small correlation of the coefficients in the design model. An additional constraint was applied that excluded test conditions that result in laminar flow conditions at the transfer pump inlet suction (Section **Error! Reference source not found.**). For SSMD scaled performance, the design model includes all of the linear (main) effects of the design factors. Additionally, the design algorithm includes the ability to provide a check for the presence of any

of the higher order interaction effects among the design factors. Note that a larger experiment is required to estimate each of the multiple-factor effects.

There are four additional tests for a non-Newtonian slurry. These tests are conducted with the same slurry composition at different nozzle velocities. In addition to these 20 tests at each scale, two replicate analyses will be performed at each scale. The replicates are performed at nozzle velocities that help to reduce the average predicted variance to give greater confidence in the collected data.

In addition to the 22 Newtonian and 4 non-Newtonian tests, four additional confirmation runs are planned. These runs will be performed once the SSMD scaled performance data is collected and analyzed. The confirmation runs will include a nozzle velocity variation. Analysis of the collected data will be used to determine the scale factor exponent for equivalent performance between scales (based on a pre-transfer sample and batch consistency metric). A set of runs using the scale factor exponent to determine the nozzle velocities for each scale will be performed to confirm the analysis. In addition, supplemental confirmation runs will be performed to evaluate parameters that were initially considered less important to assessing the scaling relationship and may include a mass loading variation, another capture velocity variation, and another supernatant variation. The configuration of the confirmation runs may change as the data analysis of the first 26 runs is conducted.

Table 3-6: Small-Scale Mixing Demonstration Scaled Performance Test Matrix

Test Number	Nozzle Velocity 1:21-Scale ft/s (gpm)[d]	Nozzle Velocity 1:8-Scale ft/s (gpm)[d]	Base Simulant Constituent	Supernatant/Non-Newtonian Simulant Properties[a]	Capture Velocity
1	V21-1	V8-1	High	Typical	3.8 ft/s
2[c]	V21-5	V8-5	High	Typical	3.8 ft/s
3	V21-1	V8-1	High	Typical	11.3 ft/s
4	V21-3	V8-3	High	Typical	11.3 ft/s
5	V21-5	V8-5	High	Typical	11.3 ft/s
6	V21-1	V8-1	Typical	Typical	3.8 ft/s
7	V21-5	V8-5	Typical	Typical	3.8 ft/s
8	V21-2	V8-2	Typical	Typical	7.3 ft/s
9	V21-1	V8-1	Typical	Typical	11.3 ft/s
10	V21-4	V8-4	Typical	Typical	11.3 ft/s
11	V21-5	V8-5	Typical	Typical	11.3 ft/s
12	V21-2	V8-2	High	Modified High	3.8 ft/s
13	V21-4	V8-4	High	Modified High	7.3 ft/s
14	V21-4	V8-4	Typical	Modified High	3.8 ft/s
15	V21-2	V8-2	Typical	Modified High	11.3 ft/s
16	V21-2	V8-2	Typical	Modified High	11.3 ft/s
17	V21-1	V8-1	High	High	11.3 ft/s
18	V21-3	V8-3	High	High	11.3 ft/s
19	V21-5	V8-5	High	High	11.3 ft/s
20[c]	V21-5	V8-5	High	High	11.3 ft/s
21	V21-1	V8-1	Typical	High	11.3 ft/s
22	V21-5	V8-5	Typical	High	11.3 ft/s
23	V21-1	V8-1	Non-Newtonian (kaolin clay)	Bingham Plastic Yield Stress = 3 Pa, Slurry Density ~ 1.16 g/ml	See Note b
24	V21-2	V8-2			
25	V21-4	V8-4			
26	V21-5	V8-5			

[a] High supernatant properties: density = 1.368 g/ml, viscosity = 14.6 cP; Modified high supernatant properties: density = 1.368 g/ml, viscosity = 8.0 cP; Typical supernatant properties: density = 1.29 g/ml, viscosity = 3.6 cP; non-Newtonian slurry properties, Bingham plastic yield stress = 3 Pa and density ~ 1.16 g/ml.

[b] For non-Newtonian tests, stainless steel and zirconium oxide will be added to the slurry at a mass equivalent to the typical base simulant and typical supernatant (Test #6-11). The capture velocity will be specified to be 11.3 ft/s.

[c] Test is a replicate.

[d] Within a scaled system, test velocities increase from Vx-1 to Vx-5.

3.2.5 Sample Collection and Chemical Analysis

Prior to performing each test, the simulants are prepared and qualified. The solid particulates are qualified for use prior to testing in accordance with Section 3.1.1.2. Base simulant qualification uses a laboratory determined particle size distribution and density for the procured materials to compare computed metrics for the simulants (e.g., distribution of Archimedes number, jet velocities necessary to achieve complete solids suspension, etc.) to the recommended composites from RPP-PLAN-51625. The liquid density and liquid viscosity of the supernatant of the Newtonian simulants and the Bingham plastic yield stress of the non-Newtonian simulant are qualified for use prior to adding base solids. Measurements of the supernatant density and viscosity will be performed on-site with a hydrometer and a rheometer as discussed in Section 3.1.2. Measurements of the Bingham plastic yield stress and Bingham plastic consistency of the non-Newtonian fluid will be performed on-site with a rheometer as discussed in Section 3.1.1. Data collection shall be performed in accordance with NQA-1-2004, Requirement 11including addenda, or a later version.

Prior to conducting the first batch transfer the tank contents are mixed at the operating conditions until mixing in the tank has stabilized. During tank stabilization, the transfer pump is engaged so that the specific gravity of the transferrable slurry can be monitored. The location of the Coriolis meter is downstream from the transfer pump. During tank stabilization the transfer pump discharge is re-circulated back into the tank. Monitoring the mass flow rate and slurry specific gravity will allow an assessment of the systems capability to mix and convey the complex simulant. Once the system has stabilized, two pre-transfer samples are collected. Similar to previous work, pre-transfer and batch transfer samples will be diversion samples through sample ports whose valves are programmatically controlled and correlated to the position of the mixer jet nozzles using encoders. Samples shall be collected downstream of the transfer pump but within the recirculation flow loop. Pre-transfer samples shall be collected in a manner that avoids bias and does not withdraw an excessive amount of material from the tank such that the conditions of the tank would be significantly altered. To avoid bias caused by the cyclical nature of the mixing system that directs the jet directly at the transfer pump twice per revolution, the pre-transfer samples shall be collected for an integer value of full rotations of the mixer jets. The mass and volume of the collected material for the pre-transfer samples shall be measured and recorded. If necessary, the collected sample will be subsampled prior to sending the sample off-site for analysis. Subsampling of collected samples shall be performed according to established procedures (summarized below) for batch samples during SSMD test activities. The collected samples will be analyzed for chemical composition to identify the concentration of the base simulant solids in the collected samples.

Once the pre-samples are collected and the tank contents are re-stabilized, batch transfers are initiated and slurry samples for each transfer batch are collected for chemical analysis. Samples for the 1:21-scale tank shall collect the entire volume of the transfer batch and this volume shall be sub-sampled for chemical analysis. For the 1:8-scale system, only part of the transfer batch will be collected for sampling. For the 1:8-scale system, four slurry samples will be collected during each transfer and the four slurry samples will be combined to form a representative sample for the entire transfer batch. Each of the four samples should be collected at regular intervals during the transfer. The duration for collecting each of the four samples will be equivalent and will be equal to an integer value of mixer jet full rotations. Because the mixer jet

pumps rotate at different speeds for different nozzle velocities, the subsample duration and hence volume of material collected during sampling varies between tests. The total volume of the slurry sample collected during a transfer for the 1:8-scale system should be similar to the full transfer batch volume for the 1:21-scale system. The mass and volume of the collected material for the batch transfer samples shall be measured and recorded. The collected volume is then sub-sampled for chemical analysis.

The collected volume from each pre-transfer sample (as necessary) and batch transfer may exceed the amount necessary for laboratory analysis and may be sub-sampled. The collected volume representing each transfer batch is settled in a large volume container. Settling in the non-Newtonian slurry may be hampered by the kaolin clay particles in the slurry. In previous testing, the collected material is clarified for 24 hours in a mixer barrel prior to decanting the liquid. This method will be refined during developmental testing to ensure that the subsamples can be collected in a reasonable amount of time and be representative of the content of the composited material. The mass and volume of the slurry is recorded. The liquid is decanted and the wetted solids are mixed prior to sub-sampling. Four representative and two archive samples are collected randomly from the solids. The four collected samples are shipped off-site for laboratory analysis; the two archive samples are retained on-site in a managed area to prevent a loss of sample integrity. Off-site analytical services are performed by a laboratory on the Hanford Evaluated Suppliers List that operates under a Quality Assurance program that has been evaluated against quality requirements in ASME NQA-1-2004 including addenda, or a later version. The four samples that were shipped for off-site analysis are analyzed for the mass of dry solids (Newtonian tests only) and the mass of each primary constituent in base simulant. Analytical data is required to be enhanced quality so that all sample collection, sample analysis, sample handling, and data reporting shall be traceable to the test performed. The sample results shall be reported in a Microsoft Excel[2] compatible format. Prior to the start of testing, analytical method development shall be performed to determine the sample preparation error associated with measuring the base material content in the presence of kaolin clay and the supernatant rheology modifiers. The analytical method is considered acceptable if it produces an unbiased result with a relative standard deviation of less than 10%.

In addition to collecting slurry samples for chemical analysis, other performance data will be collected. Each system in the SSMD test platform has the capability to record operational parameters such as test time, slurry temperature, mixer jet pump flow rate, mixer jet angular position, mixer jet pump rotational rate, tank level, slurry transfer rate and slurry specific gravity. This data is recorded by a data acquisition system and shall record data for the entire test duration. In addition, performance data shall also be recorded in the test log during testing. Performance data describing the dimensions of any accumulated material in the tank shall be collected throughout the test, noting specifically when changes in tank stability occur due to a change or process interruption. In addition, cloud height and effective cleaning radius measurements shall also be recorded in the test log. The effective cleaning radius can be determined while the mixer jets are running by measuring the distance from the edge of the mixer jet pump nozzle to the edge of the pile of solids that has stabilized on the sides of the tank. Multiple measurements shall be collected in each test to determine an average effective cleaning

[2] MS Excel® is a registered trademark of the Microsoft Corporation, Redmond, WA.

radius. Measurements shall be collected for each batch transfer to support an evaluation of changes in the system as the tank level is lowered.

3.2.6 Performance Analysis

Assessing the scaling relationship for the 1:21 and 1:8 scale systems will be performed using the analytical data collected during testing. For the purposes of the analysis of the mixing and transfer test data, an empirical model of performance will be used, which incorporates the theoretical scaling model shown in Equation 3-8. The purpose of the empirical model is to describe the relevant performance in each tank as a function of the factors that have been manipulated in the testing. Key to determining the scale factor exponent is determining the actual measure of performance that will be used. There are numerous performance measures that are typically used to quantify mixing performance (e.g., effective cleaning radius, cloud height).

While these are measures of the actual mixing phenomena in the tank, they may not adequately capture the behavior for a complex simulant. Additionally, they may not be indicative of performance related to material transfer out of the mixing tanks. For these reasons, different measures of mixing and transfer performance will be investigated for possible relevance. For example, using the measurements of constituent concentrations in each of the batch transfers, equivalent performance could be defined as occurring when the concentrations are most similar. An additional performance measure can be defined based on the amount of the constituent material transferred relative to the amount of the constituent in the tank when the transfer is started. A third measure of performance could be obtained as the difference between the constituent concentration in the batch transfer and in a pre-transfer sample, or as the ratio of the batch transfer amount to the pre-transfer sample. While each of these could be useful measures of performance, it's likely that they would each describe performance differently, providing perhaps different results. Note that these performance measures, based on measurements of each individual constituent, would result in an estimated scaling relationship for each simulant constituent. The data can be evaluated using all these metrics, but the latter two, which are very similar, represent the metric most useful for the WFD waste acceptance process.

The empirical model describes the relevant performance in each tank as a function of the factors that vary during testing. For jet velocity, a cubic polynomial will be used to represent the effect. Additionally, the two different base simulants, two different supernatants, and two different capture velocities used during testing, will be included in the model. While a full factorial design could be considered, resulting in 32 tests for each tank, it is cost prohibitive. A much smaller set of tests is planned and is based on the use of a Bayesian D-optimal design as discussed in Section 3.2.4. In the test planning phase, the complete empirical model associated with the full factorial design was considered as a starting point. This model was then reviewed, and higher-order terms that would be expected to be relatively small were removed, resulting in Equation 3-10 as a model for performance in a tank.

$$\begin{aligned} PM_k = {} & b_0 + b_1 U + b_2 BS + b_3 SN + b_4 CV + b_5 (BS \times SN) + b_6 (BS \\ & \times CV) + b_7 (SN \times CV) + b_8 U^2 + b_9 (U \times BS) + b_{10} (U \\ & \times SN) + b_{11} (U \times CV) + b_{12} (U \times BS \times SN) + b_{13} U^3 \\ & + b_{14} (U^2 \times BS) + b_{15} (U^2 \times SN) \end{aligned} \qquad (3\text{-}10)$$

Where PM_k indicates the transfer performance measure of individual simulant component k, U indicates jet nozzle velocity, BS indicates Base Simulant, SN indicates Supernatant, CV indicates Capture Velocity, and $b_0, , b_{15}$ represent the coefficients to be estimated in the model.

The basic experimental unit in Equation 3-10 is the tank. In actual testing, each tank will have pre-transfer samples taken from the recirculation loop, followed by five batch transfers out of the tank, with samples drawn from each batch transfer. Each of these samples will be analyzed for the concentration, expressed as a wt% of the solids of each simulant component. These weight percent measurements can then be used to construct the desired measure of transfer performance. Also, it was decided that each tank would run the same set of tests (at suitably chosen mixer jet velocities). For the purposes of analysis, Equation 3-10 is then expanded to include the tank scaling effect (based on Equation 3-8), as well as a batch effect, as shown in Equation 3-11.

For tank TK-201:

$$\begin{aligned} PM_k = {} & b_0 + b_1\left(U\left(\frac{T_2}{T_1}\right)^a\right) + b_2 BS + b_3 SN + b_4 CV + b_5(BS \times SN) \\ & + b_6(BS \times CV) + b_7(SN \times CV) + b_8\left(U\left(\frac{T_2}{T_1}\right)^a\right)^2 \\ & + b_9\left[\left(U\left(\frac{T_2}{T_1}\right)^a\right) \times BS\right] + b_{10}\left[\left(U\left(\frac{T_2}{T_1}\right)^a\right) \times SN\right] \\ & + b_{11}\left[\left(U\left(\frac{T_2}{T_1}\right)^a\right) \times CV\right] + b_{12}\left[\left(U\left(\frac{T_2}{T_1}\right)^a\right) \times BS \times SN\right] \\ & + b_{13}\left(U\left(\frac{T_2}{T_1}\right)^a\right)^3 + b_{14}\left[\left(U\left(\frac{T_2}{T_1}\right)^a\right)^2 \times BS\right] \\ & + b_{15}\left[\left(U\left(\frac{T_2}{T_1}\right)^a\right)^2 \times SN\right] + c_1 Batch \\ & + c_2\left[Batch\left(U\left(\frac{T_2}{T_1}\right)^a\right)\right] \end{aligned} \quad (3\text{-}11)$$

For tank TK-301:

$$\begin{aligned} PM_k = {} & b_0 + b_1 U + b_2 BS + b_3 SN + b_4 CV + b_5(BS \times SN) + b_6(BS \\ & \times CV) + b_7(SN \times CV) + b_8 U^2 + b_9(U \times BS) + b_{10}(U \\ & \times SN) + b_{11}(U \times CV) + b_{12}(U \times BS \times SN) + b_{13} U^3 \\ & + b_{14}(U^2 \times BS) + b_{15}(U^2 \times SN) + c_1 Batch + c_2(Batch \\ & \times U) \end{aligned}$$

Where *Batch* represents the batch transfer number, T_i represents the diameter of tank i, and a, b_0, b_{15}, c_1, c_2 represent the coefficients to be estimated in the model. Equation 3-11 can then be used to estimate the scale effect jointly with the effects of jet velocity, base simulant, capture velocity, and batch by fitting the nonlinear model to estimate the specified coefficients. Note that this analysis produces a set of coefficient estimates for each performance measure. In particular, if each simulant constituent is used to construct a performance measure, then each simulant constituent will have its own scaling relationship as determined by the model fitting. Also note that, for any specific performance measure, the coefficients for the jet velocity terms are the

same for both tanks; this enforces the assumption that the difference between tanks is accounted for by the scale effect. If the performance measure is constructed as a comparison of the batch transfers to the pre-transfer sample values, then the pre-transfer observations will not be included in the actual model fitting.

Equation 3-10 was constructed as an empirical model of performance in the tank. Interaction effects that are not important to the metric being evaluated may be included in the model but the regression analysis would result in a near-zero regression coefficient for the effect as an indication of the effect's lack of importance. If a more theoretical, physics-based model were available, it could be used rather than the empirical model shown. Depending on the complexity and form of a theoretical model, a different set of experimental tests may be required to provide the ability to adequately estimate the model coefficients. Equation 3-10 would be obtained in similar fashion, based on the theoretical model rather than the empirical model.

3.3 REMOTE SAMPLER DEMONSTRATION SYSTEM PERFORMANCE

The RSD system performance test activities documented in Section 3.3 are performed by Energy*Solutions* for WRPS. Pacific Northwest National Laboratory (PNNL) directs the operation of the UPE and interprets data collected by the device.

Previous work using the RSD flow loop indicated that, compared to a horizontal orientation, samples collected when the Isolok® Sampler was installed in a vertical section of piping more closely matched slurry samples collected from the discharge of the transfer line (RPP-RPT-51796, *Remote Sampler Demonstration (RSD) Phase I Sampling Results Report*). However, most of the initial testing was conducted in the horizontal orientation and supplemental testing in the vertical orientation was recommended. The RSD system performance will evaluate the Isolok® Sampler further in the vertical orientation. The RSD system performance testing will be performed with simulants that span a broader range of Hanford waste than has been previously tested. In addition, RSD system performance testing will continue to evaluate the mechanical handling system for automated sample collection and demonstrate the capability of the UPE. UPE demonstrations are supplemental to the testing activities performed by PNNL at their PDL-East facility in Richland, WA. Results of this previous testing can be found in PNNL-20350 *Hanford Tank Farms Waste Certification Flow Loop Phase IV: PulseEcho Sensor Evaluation* and PNNL-19441, *Test Loop Demonstration and Evaluation of Slurry Transfer Line Critical Velocity Measurement Instruments*.

3.3.1 Test Equipment and Instrumentation

Integrated flow loop testing for the Isolok® Sampler evaluations shall be performed using the RSD test platform constructed at the Monarch Machine & Tool Company, Inc. facility in Pasco, Washington. The flow loop was constructed at full scale, with the exception of the mixing and transfer system, to demonstrate the capabilities of the Isolok® Sampler, the mechanical handling system, and the UPE. The RSD test platform includes a mixing tank and mechanical (paddle-style) agitator, an effluent tank, a slurry pump, a Coriolis meter, the Isolok® Sampler, the integrated mechanical handling system, the UPE, a simulated glove box, and all associated piping/valving to connect these components. The mechanical handling system is a prototype automated handling system that accepts sample containers, places the containers into position for

collecting Isolok® samples, and drops the sample container with the collected sample in a location suitable for retrieval by an operator. The purpose of the mechanical handling system is to minimize operator exposure to the radiation environment at the sample location. A schematic of the flow loop is shown in Figure 2-3.

The mixing tank has an operating capacity of 180 gallons and will be mixed using an agitator (mixing blade) rotating in a down-flow configuration. The vessel will be cooled to maintain operating temperatures. Simulant will be drawn out of the mixing tank around a dispersion plate that creates a ½" circular gap over a three inch line located directly in the middle of the bottom of the tank. The dispersion plate minimizes channeling of simulant solids through the mixing tank. After leaving the tank, the simulant will be pumped through a centrifugal pump capable of operating between 2 and 8 ft/s. Then the waste will enter a straight section of horizontal 3" pipe, configured for operation of the PulseEcho critical velocity measurement equipment. The UPE will be located approximately 60-70 horizontal pipe diameters (15-18 feet) downstream of the last flow disturbance and has 15 pipe diameters (4 feet) of horizontal piping after the device. To ensure that the starting flow rate is sufficient to establish full suspension of the slurry solids and allow visual verification of the critical velocity the sections just prior to and just post UPE equipment are transparent. After leaving the UPE test section the simulant enters the Isolok® sampling section of the system; piping is reduced from 3"inner diameter. to 2" inner diameter and flow is upward in a vertical orientation; about 7 degrees from vertical. The sampler is a Sentry Isolok® MSE sampler, designed for viscous and thixotropic fluids. The Isolok® sampler takes many 5.3ml subsamples to obtain one sample, which can vary based on the size of the sample bottle employed. RSD sampling will employ 250ml sample bottles (requiring 47 subsamples). After leaving the sampler section, the pipe diameter is returned to 3" inner diameter and drains back to the mixing tank with a slope to aid in cleaning.

As the simulant returns to the mixing tank, it first passes through a Coriolis meter, where mass flow rate and specific gravity measurements are obtained, then through an automated full diversion valve. The diversion valve is located in the line a few feet before the mixing tank on the return line, is only operated for a few seconds at a time, allowing operators to take full diversion samples to obtain an accurate representation of the simulant as it flows through the pipe. The volume of a full diversion sample is approximately four gallons. The standard path of the simulant has the material returning to the mixing tank at the top.

The UPE and flow loop shall include data acquisition systems to collect data real time. The data acquisition system for the Coriolis meter may be separate from the system for the UPE, and shall monitor and record the mass flow rate and the specific gravity of the slurry.

Testing shall have three phases for data acquisition. The critical velocity of the simulant being tested will be determined. This may be performed either before samples are taken or after samples are taken, but due to the requirement to adjust the flow rate it cannot be performed during sampling. PNNL will have the lead for the PulseEcho portion of testing. Second, the Isolok® sampler shall be used to obtain characterization samples. Operation of the Isolok® sampler shall include the use of the mechanical handling system to the maximum extent possible, however if mechanical or software issues adversely interrupt testing, the test director may allow use of an Arbor press for Isolok® bottle loading and unloading. After completion of the Isolok® samples full diversion samples shall be taken.

The UPE and adjacent transparent sections will be used during RSD system performance testing to detect bulk particle settling, which will be correlated with an independently measured flow velocity to determine critical velocity of the simulant. Slurry flow velocities between 2 ft/s and 6 ft/s will be used to determine the critical flow velocities of the simulants. Measurements performed by the UPE are representative only of the fraction of the slurry that is present and circulating in the flow loop test section. The UPE transducer is externally attached to the bottom of the 2-ft long UPE spool piece (3-inch inner diameter schedule 40 stainless steel pipe) at a discrete location on the flow loop and is monitoring the conditions only at those locations. The assumption is that the conditions at this location are representative of those along the entire horizontal section of the flow loop. Data reported by the Coriolis meter will be correlated with the UPE data and the visual observations to determine critical velocity.

For testing purposes, evaluating the capability of the Isolok® system is independent of evaluating critical flow velocities. Actual in-field sampling of waste will require confirmation of critical velocity before slurry samples are collected so that re-sampling is minimized. Evaluating the capability of the Isolok® system to collect representative samples of the slurry is also independent of evaluating the mechanical handling of the collected samples. However for completeness testing should be performed with the fully integrated system including the Isolok® Sampler and the mechanical handling system to retrieve the prototypic sample containers.

All measuring and test equipment, including gauges and instrumentation, used for testing activities, shall be controlled,calibrated under conditions typical of the test environment, adjusted, and maintained to required accuracy limits. The condition and the reported accuracy of each instrument shall be documented in a test log.

3.3.2 Test Simulants

The simulants used in the RSD system performance testing are selected in accordance with the recommendations in RPP-PLAN-51625. Simulant properties and qualifications are described in Section 3.1. Selecting particular simulants for RSD system performance test activities is discussed below. The test matrix showing the combinations of base simulant and liquid supernatant is discussed in Section 3.3.3.

The RSD system performance simulants shall include Newtonian and non-Newtonian simulants. For SSMD and RSD limits of performance testing, non-Newtonian testing was conducted with slurries of kaolin clay spiked with large and dense particles. For RSD system performance testing the non-Newtonian solids will be principally kaolin clay, but additional solids will be added so that sampling performance can be quantified.

The Newtonian simulant shall be a complex simulant containing base particulates. The liquid phase shall be a supernatant simulant. The non-Newtonian simulant will be kaolin clay with supplemental solids. Sodium thiosulfate will be added to increase the density of the Newtonian and non-Newtonian slurries when required in the test matrix. Glycerol will be added to increase the viscosity of the Newtonian slurries when required in the test matrix. Recipes for the simulants discussed below are tabulated in Table 3-1 and Table 3-2.

Although RPP-PLAN-51625 recommends three conceptual simulants for WFD Mixing and Sampling Program DNFSB 2010-2 testing, only two simulants are selected for RSD system performance testing, the typical and the high conceptual simulants. The low conceptual simulant is composed entirely of small gibbsite particles, and is therefore not interesting for determining the capability of a multi-component sampler. Based on the distribution of Archimedes numbers and jet suspension velocities reported in Figures 8-1 and 8-2 in RPP-PLAN-51625, the typical and high conceptual simulants are representative of the typical and more challenging Hanford tank waste. Although the typical conceptual simulant recommends that two different sized gibbsite particles be used, sampler performance will be based on chemical analyses of the collected material, which will not distinguish between the different sized materials and so the performance analysis will not consider the effect of gibbsite size. A similar limitation is applied to sand in tests with the high conceptual simulant, which includes two different sized sands. Evaluating different solids compositions will also be used in the demonstration of the UPE. The high conceptual simulant is expected to have a higher critical settling velocity and this will be confirmed during the demonstrations of the UPE.

To investigate the performance of the sampler for a range of tank waste properties three supernatant compositions will also be investigated, low, typical, and high. For the low supernatant the liquid density is 1.098 g/ml and the liquid viscosity is 1.62 cP. For the typical supernatant, the supernatant density is 1.284 g/ml and the liquid viscosity is 3.60 cP. For the high supernatant, the liquid density is 1.368 g/ml and the liquid viscosity is 14.6 cP. Recipes for matching these supernatant properties with water, sodium thiosulfate, and glycerol are provided in Table 3-2. For the low density/low viscosity and typical density/typical viscosity supernatants, the tolerance on the liquid density is ±5% and the tolerance on the liquid viscosity is 0.5 cP. For the high supernatant the tolerance, the liquid density is ±5% and the tolerance on the liquid viscosity is ±20%. For the low and typical supernatant, the tolerance on the viscosity is different than the high supernatant, because the rheology change is expected to be achieved using a single sodium salt. The density and viscosity for a single sodium salt cannot be specified independently. If the temperature of the sampled material differs from the bulk volume, the liquid viscosity tolerance is evaluated at the operating temperature.. In addition to measuring viscosity at the beginning of each test, viscosity measurements are also collected at the completion of testing to identify any changes that occurred during testing.

The range of liquid density and liquid viscosity values are selected because higher densities and higher viscosity fluids are expected to increase the buoyancy, effecting solid particles in the slurry, reducing critical suspension, and settling velocities. Increasing buoyancy and subsequently reducing the critical suspension velocity and settling velocities is expected to promote particle suspension, which will improve mixing and transfer within the RSD flow loop. Improving the distribution of the solids in the flow loop is expected to yield more consistent results. Previous RSD testing in water and a non-Newtonian slurry indicated that the relative standard deviation (i.e., the standard deviation divided by the mean) of samples collected by both the Isolok® Sampler and through the full-diversion method was typically higher for stainless steel and bismuth oxide compared to the relatively easy to suspend solids, gibbsite and zirconium oxide.

In the prepared samples, stainless steel and bismuth oxide represented the more challenging (higher Archimedes numbers) components in the tank waste. During RSD system performance

test activities, different supernatant compositions will be tested and the sample results will be compared for each supernatant type to determine if the relative standard deviation of the more challenging particles is reduced in higher density/higher viscosity fluids. Evaluating different supernatant compositions will also be used in the demonstration of the UPE. The slurry is expected to have a lower critical settling velocity at higher densities. This will be confirmed during the demonstrations of the UPE.

To investigate the effects of solids loading, the weight percent of the base simulant will also be varied. Two solids loading levels will be evaluated, 9 wt% and 13 wt %. The 13 wt % is based on the ICD-19 allowable limit of 200 g/l. The mass loading is equivalent to 155 to 194 g/l depending on the composition of solids and supernatant selected. The 9 wt% is based on a lower 125 g/l loading and is equivalent to 105 to 131 g/l depending on the composition of solids and supernatant selected. The resulting slurry density ranges between 1.16 g/l and 1.49 g/ml; the latter being very near the action level identified in ICD-19. Previous RSD testing performed tests with very low (0.1 wt %) amounts of the densest materials (stainless steel and bismuth oxide). The results indicated that these tests were among the worst for sample variability and bias (RPP-RPT-51796). Comparable tests during RSD system performance will include stainless steel at 0.5 wt% (stainless steel is 6% of the typical conceptual simulant solids, which will be included at 9 wt% of the slurry (i.e., 6%×9%=0.5%). Successful testing with simulants that vary over the anticipated range of solids loadings will add confidence that the sampler can collect representative samples of the transferred material regardless of the slurry content.

In addition to the Newtonian tests discussed previously, tests shall also be performed using non-Newtonian slurry with a Bingham plastic yield stress. Kaolin clay slurries will be used as the non-Newtonian simulant. Base particulate solids of stainless steel and zirconium oxide will be added to the slurry to provide a component that can be quantified in the collected samples. The mass of the base solids added will match the equivalent mass of these components when the high conceptual simulant is prepared at 13 wt% solids in the typical density/typical viscosity supernatant. The resulting base particulate solids loading considered the amount of solids necessary to evaluate the UPE. Phase IV testing with the 10-MHz transducer, as described in PNNL-20350, was capable of detecting settling of 14-micron stainless steel particles without false indications at lower mass loadings (2 wt% or higher). The minimum detectable concentrations are expected to change as a function of particle size.

The non-Newtonian tests will be conducted to evaluate the performance of the integrated flow loop with a non-Newtonian simulant and evaluate whether or not a sampler performance is either degraded or improved for non-Newtonian simulant compared to a Newtonian simulant. Previous work indicates that the relative standard deviation for the Isolok® Sampler was comparable for Newtonian and non-Newtonian simulants, but that the bias was less for the non-Newtonian simulant (RPP-RPT-51796). However, the previous work was performed with the Isolok® Sampler in the horizontal configuration. Non-Newtonian work was not performed in the vertical configuration. RSD system performance testing will begin to evaluate the non-Newtonian simulants with the Isolok® Sampler oriented vertically using a slurry with a Bingham plastic yield stress between 3 Pa and 10 Pa. A tolerance of -1 Pa to +1.5 Pa is added to the yield stress measurement for the 3 Pa slurry and a 30% tolerance is added to the 10 Pa slurry because of dynamic changes in the slurry viscosity as it is prepared and mixed. Kaolin clay slurries are slightly rheopectic and may thicken when mixed and transferred.

For tests requiring non-Newtonian, cohesive slurry, kaolin clay shall be used to increase the Bingham plastic yield stress of the simulant to values up to 10 Pa, as measured at the beginning of testing. Bingham parameter measurements shall also be collected at the end of each test to quantify any changes in the test conditions that occur during testing. If necessary, as indicated by measurements that exceed the specified tolerance at the end of testing, supplemental measurements should be taken to monitor changes in the slurry as mixing progresses. The 10 Pa limit was selected in accordance with recommendations in RPP-PLAN-51625. A 3 Pa kaolin clay mixture has a density around 1.16 g/ml and the 10 Pa slurry will have a density of about 1.22 g/ml. Bingham parameter measurements shall be performed prior to testing and at subsequent startups if the slurry is idle for more than 8 hours in between testing.

Testing using a spike particle from the RSD limits of performance test activities is also performed to determine if the large particles that can be sampled by the sampler affect the performance of the sampler to collect a representative sample. For RSD system performance testing a spike particle, for example 1000-micron diameter soda lime glass spheres (see Table 3-3), will be added to a base simulant. The quantity of the spike particle added to the test tank shall be 5 wt % of the total solids added during a test sequence. The 5 wt % value was selected so that an adequate number of particles are present in each test and does not reflect any expected condition in the uncharacterized waste. The size and quantity of the spike material added is subject to change as RSD limits of performance test results are collected and analyzed.

3.3.3 Operating Parameters and Test Methods

When the performance of the Isolok® Sampler is evaluated, the RSD platform shall be configured to adequately suspend the simulant in the mixing tank and transfer the contents to the inlet of the transfer pump. The speed of the mechanical agitators necessary to produce a consistent slurry shall be evaluated during developmental testing. The slurry specific gravity will be monitored by a Coriolis meter as the agitator speed in increased. The agitator speed that yields a stabilized slurry (values that fluctuate by no more than 5% during 10 tank turnovers) for the most challenging simulant should be maintained for all tests. To maintain turbulent flow in the transfer line for Isolok® sample collection in the vertical configuration, the transfer pump flow rate shall be maintained at the maximum transfer flow rate considered for waste feed delivery, 140 ± 5 gallons per minute.

Once the RSD flow loop has stabilized, as evidenced by stable mass flow rates and specific gravity readings from the Coriolis meter, the Isolok® Sampler shall be used to collect ten 250 ml samples. Five of the collected samples will be analyzed for chemical content and the remaining five samples will be retained as archives. After the last Isolok® sample is collected, two full diversion samples shall be collected. The full diversion sample opens a valve in the transfer line downstream of the Isolok® Sampler and captures the discharge to characterize the slurry in the transfer line. Sample collection and analysis is described in Section 3.3.4.

As discussed previously, the testing conditions that are varied for Newtonian slurries include the composition of the base simulant, the composition of the supernatant, and the base simulant solids loading. Two variations of base simulant are used, the typical and high conceptual simulants. Three variations of supernatant are used, the low density/low viscosity, typical density/typical viscosity and high density/high viscosity supernatants. The third testing

condition that is varied is the mass loading of the base simulant. Two variations, 9 wt% and 13 wt%, are used during testing. For RSD system performance tests with a non-Newtonian slurry, two tests will be performed. The Bingham plastic yield stress values for the first test will be 3 Pa and 10 Pa for the second test. Recipes for producing the correct slurry are provided in Table 3-1. Preparation tolerances for the kaolin slurry are discussed in Section 3.1.1. In order to quantify the performance of the Isolok® Sampler, base solids will be added to the slurry. The mass of the base solids, stainless steel, and zirconium oxide, will match the equivalent mass of these components when the high conceptual simulant is prepared in the typical density/typical viscosity supernatant.

A verification test will be conducted with large spike particles to determine if the presence of large particles affects the performance of the sampler. In RSD limits of performance testing, spike particles that could be captured by the Isolok® Sampler are evaluated. For a spike particle that could be captured by the Isolok® Sampler, the presence of the spike particle may affect the performance of the system to collect the base particulates. This verification test will use a spike particle that could be repeatedly captured during RSD limits of performance testing to evaluate whether or not the base solids are still representatively sampled in the presence of the larger particles. The spike particle will be added at 5 wt% of the solids for a 9 wt% solids loading of the typical conceptual simulant in the typical density and typical viscosity supernatant.

The test matrix for RSD system performance testing is provided in Table 3-7. In order to reduce the occurrence of systematic errors, such as instrument calibration drift and elevated temperatures as testing progresses to warmer days, the tests should be performed in a random order. In order to minimize contamination of subsequent tests when a random order is followed, the test platform (mixing tank, transfer lines, and sampling equipment) shall be thoroughly flushed and cleaned prior to each test. A full factorial analysis is planned with additional tests for non-Newtonian slurries and a verification run. Replicate analyses are not included in the test matrix. During Isolok® testing, five samples are collected in series and submitted for compositional analysis. The collection of multiple samples over the duration of the test reduces the need for replicate analyses. Furthermore, process operations that contribute to test variability (e.g., simulant preparation, mixing, and variable flow conditions) are mitigated by comparing Isolok® samples to full-diversion tests that are subjected to the same sources of error.

Table 3-7: Remote Sampler Demonstration System Performance Test Matrix

Test Sequence	Base Simulant Constituents	Supernatant Simulant Composition[a]	Base Simulant Mass Loading/non-Newtonian Bingham Plastic Yield Stress
1	Typical	Low	9 wt%
2	Typical	Typical	9 wt%
3	Typical	High	9 wt%
4	Typical	Low	13 wt%
5	Typical	Typical	13wt%
6	Typical	High	13 wt%
7	High	Low	9 wt%
8	High	Typical	9 wt%
9	High	High	9 wt%
10	High	Low	13 wt%
11	High	Typical	13wt%
12	High	High	13 wt%
13	Non-Newtonian	N/A	3 Pa[b]
14	Non-Newtonian	N/A	10 Pa[b]
15	Typical	Typical	13 wt% with 5 wt% of the solids included as spike particles

[a] Low supernatant properties: density = 1.098 g/ml, viscosity = 1.62 cP; Typical supernatant properties: density = 1.284 g/ml, viscosity = 3.6 cP; High supernatant properties: density = 1.368 g/ml, viscosity = 14.6 cP

[b] Non-Newtonian tests include quantification of added stainless steel and zirconium oxide solids. The amount of these solids added to the slurry is equivalent to the amount of these solids in Test #11.

The slurry used to evaluate the capability of the Isolok® Sampler to collect representative samples of broader types of Hanford tank waste will also be used to demonstrate the UPE. At an

appropriate time during testing, as determine by the test director, the UPE will be demonstrated using the same simulant compositions. The slurry will be re-circulated through the flow loop at 140 gpm ±5 gpm (6 ft/s) until the specific gravity of the slurry stabilizes. Visual observations through the transparent test sections will be made to ensure that the solids in the transparent sections of the flow loop are not stratified at the starting velocity; if solids are stratified or focused and axial flow is evident, then the flow velocity would be increased as necessary to fully suspend the solid particles. The UPE will be used to constantly monitor particle motion in the UPE test section; however, reportable data will only be recorded once the flow has stabilized at each flow velocity increment. The velocity will be incrementally reduced by up to 1 ft/s increments until solids suspension begins to become challenged and stratification or focused axial motion becomes evident. If a stationary bed forms prior to visual determination of solids suspension becoming challenged and stratification or focused axial motion occurring, deposited solids will be re-suspended and the previous slurry velocity set will be revisited. Then the velocity reduction increments will be dropped to 0.1 ft/s until particle settling results in a stationary bed or until the flow reaches 2 ft/s, the performance limit of the RSD slurry pump. The velocity resulting in a stationary bed is identified as the critical velocity. ICD-19 establishes an action level for the critical velocity at 4 ft/s. Previous testing (PNNL-20350) indicates that the critical velocity determined by the UPE is generally within 0.3 ft/s of the visually determined critical velocity and tends to be conservative (predicts a stationary bed before it is visually observed). The previous testing also indicates that the difference between the two measurement techniques increases with increasing complexity of the simulant. For the UPE demonstrations using the multicomponent simulants discussed in Section 3.3.2, the difference in the critical velocity determined using the UPE and visual observations shall be within ±0.3 ft/s. It is not necessary to determine critical velocities that are below 2 ft/s, the minimum flow velocity from the RSD flow loop transfer pump.

Prior to each velocity reduction, the flow loop is allowed to stabilize and the flow behavior at the stabilized condition is recorded on video and documented in a video log along with the video file name and system operating conditions. Upon identification of the critical velocity, the slurry in the transfer line is re-suspended by increasing the flow velocity. The system is allowed to stabilize and a full-diversion sample is collected to represent the slurry in the transfer line during the demonstration of the UPE.

3.3.4 Sample Collection and Chemical Analysis

The RSD system performance testing shall establish the capability of the vertically oriented Isolok® Sampler to collect representative samples of the slurry in the flow loop. Samples are considered *representative* when the mean square of the sampling error, which is determined for each component of the simulant and includes an estimate of bias and variability, is less than the standard of representativeness. For RSD testing, the standard of representativeness is 10% relative to the average full diversion sample concentrations. The standard of representativeness is determined from sample size graphs presented in 2450-WTP-RPT-MGT-11-014, *Initial Data Quality Objectives for WTP Feed Acceptance Criteria*. According to sample size graphs and the empirical cumulative distribution functions for the waste feed determined by Hanford waste modeling activities, the waste feed is most likely to exceed the WAC for the 95% confidence level for the ratio of fissile U to total U (see Figures 7-12 and 7-13 in 2450-WTP-RPT-MGT-11-014). When 10% sampling uncertainty is assumed, the required number of samples needed to

ensure that the feed batch does not exceed the waste acceptance criterion is less than the maximum currently planned to be collected (10) for approximately 70% of the waste feed. Improving sampling performance or collecting additional samples would be necessary to ensure that the waste acceptance criterion is not exceeded for the balance of the waste.

Prior to performing each test, the simulants are prepared and qualified. The solid particulates are qualified for use prior to testing in accordance with Section 3.1.1.2. The liquid density and liquid viscosity of the supernatant of the Newtonian simulants are qualified for use prior to adding base solids. Measurements of the supernatant density and viscosity of the supernatants and the Bingham parameters for the non-Newtonian simulants will be performed on-site with a hydrometer and a rheometer as discussed in Sections 3.1.1and 3.1.2. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, Test Control in including addenda, or a later version.

Once the simulants are qualified and added to the flow loop, the flow in the flow loop is stabilized, as indicated by the mass flow readings on the Coriolis meter and the Isolok® Sampler is exercised. The Isolok® Sampler is used to collect ten 250 ml samples of slurry in clean sample containers. The mechanical handling system should be used during sample collection to repeatedly exercise the equipment to establish reliability and help identify maintenance requirements. After the Isolok® samples are collected; two full diversion samples are collected. Five of the collected Isolok® samples and one of the two full diversion samples are sent off-site for compositional analysis. Analytical services are performed by a laboratory that operates under a Quality Assurance program that has been evaluated against quality requirements in ASME NQA-1-2004 including addenda, or a later version. These samples shall be analyzed for total slurry volume, total slurry mass, and the mass of each solid constituent (excluding kaolin for non-Newtonian tests). The remaining samples are retained on-site in a managed area of the facility as archive samples to be analyzed as necessary. Analytical data is required to be enhanced quality so that all sample collection, sample analysis, sample handling, and data reporting shall be traceable to the test performed. The sample results shall be reported in a Microsoft Excel compatible format.

The method for collecting the full-diversion sample will be consistent with previous RSD testing activities. The full diversion sample will be performed at the end of each test. The full diversion sample will be approximately 3-5 gallons, and will be taken by placing a 5 gallon bucket into the process stream that is being diverted into the effluent tank (TK-102). Holding the bucket there for 1-2 seconds will yield sufficient volume (approximately 4 gallons). Once the sample has been completed, the bucket will be removed and the process stream will be diverted back to the mixing tank (TK-101). A proper human machine interface has been field mounted to provide adequate protection to personnel and provide a level consistency needed for sample collection. The mass and volume of the collected sample are measured and recorded. The sample is then clarified for a minimum of 24 hours. After the solids have settled, the liquid is decanted and the mass and volume of the decanted liquid is measured and recorded. The wet solids are then loaded into multiple one liter containers for shipping. For each test, the full diversion solids are re-combined, homogenized, and sub-sampled by the analytical laboratory. The purpose of this sample is to have direct representation of the material in the certification loop during testing activities.

The full diversion sample provides the basis for evaluating the performance of the Isolok® Sampler. Rather than compare sample results to initial simulant makeup content, which may be skewed by mixing in the tank, the comparison sample will be collected from the stream used to collect the Isolok® samples. Differences between the concentration of each component in the full diversion sample and the initial concentration will be attributed to settling in the transfer line and/or inadequate mixing in the mixing tank. Whether or not solids settle in the transfer line at the full-scale flow rate used to collect Isolok® samples will be evaluated when the UPE is demonstrated. Differences between the concentration of each component in the Isolok® samples and the full diversion samples are attributed to the capability of the Isolok® system to collect representative slurry samples from the flow loop assuming that the full-diversion sample is representative of the stream during Isolok® sample collection. To evaluate this assumption, variability in five full diversion samples will be quantified using the high conceptual base simulant in the typical density and typical viscosity supernatant. The difference between the Isolok® sample concentrations and the full diversion sample concentration will be expressed as a percent error (bias). In addition, correlations between the percent errors and the test properties that were changed will be analyzed for correlations. The relative standard deviation between the five collected Isolok® samples will also be calculated to evaluate correlations between sample consistency and the changed test conditions.

The performance of the UPE will be monitored by PNNL. Depending on the capability of the system and test schedule to accommodate collecting samples, full-diversion samples should also be collected before and after each demonstration of the UPE. Collected samples should be analyzed using the same analytical techniques developed for the Isolok® test samples. However, because the same simulants are used during Isolok® testing, full-diversion samples of the material are being collected to characterize the material in the transfer line. Video of the flow behavior at each velocity increment will be recorded. The flow data monitored by the Coriolis meter in the flow loop will be recorded on a data acquisition system for the duration of the test. A separate data acquisition system will be used to capture the signals reported by the ultrasonic transducers during demonstrations of the UPE. The results of the UPE demonstration will be analyzed by PNNL subject matter experts and will be summarized in a test report prepared by PNNL.

4.0 TEST COORDINATION

All testing equipment operations are performed by trained and qualified subcontracted personnel under the supervision of a Test Director. An operations plan, including test run sheets, will be prepared that describes the precautions and limitations, the testing sequences, testing prerequisites, startup conditions, and test procedures in stepwise detail. The TOC technical representative(s) must concur with the operations plan. The Test Director coordinates testing activities including ensuring that all test conditions required for the startup of testing have been performed and all test records (e.g., Test Log, Test Deficiency Reports, Test Change Requests, etc.) are maintained. The Test Director is also responsible for coordinating test activities with the Quality Assurance representative to ensure testing is performed in accordance with the approved quality assurance plan. While tests are conducted, the Test Director will also determine which changes do not adversely affect the acceptance criteria and/or methods by which the acceptance criteria are to be accomplished and are considered "inconsequential" or "minor" and approve these test changes. All other changes require concurrence with the TOC technical representative(s) before the change(s) is/are implemented.

4.1 PRECAUTIONS AND LIMITATIONS

The Job Hazards Analysis is the process for identifying, evaluating, controlling, and communicating potential hazards associated with the work being performed, including modifications to test facilities and test equipment. Testing for the SSMD scaled performance and RSD system performance are being performed in test facilities constructed to perform the testing. Each test facility is governed by a facility specific Job Hazards Analysis documented in a Job Hazards Analysis checklist or equivalent document. Changing conditions that modify the test facility or equipment to accommodate testing will be evaluated in a revision to the Job Hazards Analysis before the modifications to the facility or equipment are performed. Workers performing work in the test facility governed by the Job Hazards Analysis shall review the document hazards and acknowledge that they understand the hazards associated with the work being performed and will abide by controls (e.g., don required personal protective equipment, obey posted signs and placards) put in place to mitigate or eliminate the hazards.

Any special precautions that must be taken or test limitations will be documented in the operations plan specifically prepared for each activity and will be communicated to workers before the start of work during a Pre-Job briefing.

4.2 SEQUENCE OF TESTING

Any special requirements for the testing sequence that are not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

4.3 PLANT CONDITIONS

Any special requirements for the plant conditions, including connecting to site utilities and site restoration that are not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

4.4 SPECIAL EQUIPMENT

Any special equipment required to conduct the tests that is not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

5.0 DATA COLLECTION AND TEST RESULTS REPORTING

Testing shall be conducted in accordance with an approved operations plan and an approved data collection and accuracy plan that are prepared in accordance with this test plan. All test activities shall be performed according to test run sheets. All major testing activities shall be documented in a test log. Test deficiencies shall be reported in a Test Deficiency record.

Test data identified in Section 3.0 , including test durations and test conditions, shall be recorded in the test log. Applicable data not recorded by a data acquisition system shall be recorded on the run sheet or recorded in the test log. All electronic data collected by a data acquisition system shall be content reviewed for error and anomalies. Electronic records shall be submitted to the TOC for evaluation.

All laboratory analysis results shall be accompanied by a chain of custody report that was prepared when the samples were collected. The chain of custody shall identify the samples by a unique name, describe the sample type and list the analyses to be performed. The chain of custody shall also document the preparers name and shall acknowledge receipt at the analytical laboratory. All laboratory analysis results shall be submitted to the TOC technical representative in an MS Excel compatible format.

Test result reports shall be prepared for each test activity. Test activities shall be documented in a test data package that is submitted to the TOC by Energy*Solutions*. The TOC shall perform the required analysis and document the findings in a test report that is reviewed by Energy*Solutions*. PNNL will review the data collected by the UPE and document the evaluation in a separate test report.

6.0 REFERENCES

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WRPS-1201374-OS, 2012, "One System DNFSB 2010-2 Sub-Recommendation 5 Test Plan Summit Meeting Minutes", April 17, 2012, Washington River Protection Solutions, LLC, Richland, Washington.

APPENDIX A. SMALL-SCALE MIXING SCALING PHILOSOPHY

The WFD Mixing and Sampling Program is performing both full-scale and small scale tests to evaluate mixing, sampling, and transfer performance between the Hanford HLW feed staging tanks and the receipt tanks at the WTP. Full-scale tests using prototypic equipment and operating conditions are being used to demonstrate the performance capabilities of the HLW sampling and transfer system that will be used to characterize the waste prior to transferring it to the WTP. Full-scale testing of components provides experimental data that can be used to evaluate the performance of the integrated system without the need to consider scale. Sampling and transfer testing at full-scale is manageable both fiscally and operationally. However, after considering economics, schedules, and operating complexities, performing full-scale tests of the mixing system was not practical. Therefore, it has been determined that mixing tests would be performed at small scales and full-scale performance will be evaluated using scale-up relationships. Operating at smaller scales is desirable because it reduces the cost of materials (i.e. simulants), labor, and time necessary to perform tests. For example, a full-scale transfer of 950,000 gallons of HLW at the maximum transfer flow rate (140 gpm) would take nearly five days of continuous operation. Using smaller scales, the transfer could be completed in a single work shift. However, operating at smaller scales requires that scaling relationships be understood to predict full-scale performance adequately.

The SSMD test platform contains two scaled systems that are geometrically similar to the DST and transfer system that will be used for first delivery to the WTP (DST 241-AY-102). The scaled properties are provided in Table 3-5. Full-scale DST properties are provided for 241-AY-102 and 241-AW-105. The SSMD test platform was constructed according to scale from 241-AY-102. According to ORP-11242 Rev. 6, *River Protection Project System Plan*, 241-AW-105 will participate in numerous feed transfers to the WTP receipt tank, accounting for about 24% of the total waste volume that will be transferred to the WTP from the 13 feed staging tanks (SVF-2110, T*RANSFER_PLOTS_4MINTIMESTEP(6MELTERS)-MMR-11-031-6.5-8.3R1-2011-03-18-AT-01-31-58_V7.XLSM*). Therefore, DST 241-AW-105 has been selected as the model tank for investigating solids accumulation.

The dimensions of the scaled test tanks and placement of the mixing and transfer equipment (e.g., tank diameter, bottom configuration, waste volume, mixer jet and transfer pump spatial locations, mixer jet nozzle diameter, mixer jet pump suction diameter and general tank obstructions) are directly scaled (i.e., proportional) to a full-scale DST filled with actual or anticipated volumes of waste. However, scaling is not full similitude. Consistent with general industry practice for mixing studies and previous testing with the SSMD platform, simulant properties, including particle sizes are not scaled. In addition, to mitigating line plugging with the unscaled simulant, the scaled dimensions for the transfer pump suction inlet diameter and transfer line conduit diameter are also not in direct proportion to a full-scale system. To avoid plugging, the diameter of the pipe should be 3 to 10 times the size of the particles being transferred. Hanford waste simulants are 10s to 100s of microns in size; therefore, the smallest diameter piping that was considered for the scaled systems was ¼-inch (6350 microns), which is much larger than would be used if the pipe diameter was proportionally scaled.

Similarly, scaling the flow rate through a proportionally scaled transfer pump inlet was also not practical for flow hydraulic concerns. For the 1:8 scale system, a proportionally scaled system would pump 12–19 gallons of slurry per minute through an approximate 0.3-inch diameter inlet yielding a transfer velocity of at least 54 feet per second (ft/s), well above the expected capture

velocities in the full-scale system. The range for the transfer pump flow rates at each scale is specified to equate the fluid velocity through the inlet. The size and shape of the inlet and the fluid velocity through the inlet establish the velocity gradient into the pump inlet. Particles that enter the area of influence of the pump suction will only be captured by the pump if the pump suction, together with any upward motion induced by mixing, is sufficient to overcome any opposing motion due to particle settling and mixing. For the anticipated range of 90—140 gallons per minute, the fluid velocity through the 2.25 to 2.4 inch diameter inlet ranges between 6.4 and 11.3 feet per second. Because the particles are not scaled, the velocities through the inlet of the scaled systems are equated to full-scale velocities to get equivalent particle capture performance. The transfer pump flow rate is calculated as the product of the fluid velocity, 6.4 and 11.3 feet per second, and the pump suction inlet area in the scaled system.

If the scaling relationship is known, data collection from small-scale experiments performed at two or more different scales can be used to predict full-scale performance. Scaled performance experiments can be conducted at multiple scales to establish or refine scaling relationships. In order to develop scaling relationships, equivalent performance within the scaled systems must be established for known operating conditions. Developing the scaling relationship is performed by using generally accepted scaling relationships, which can be theoretically based or empirically determined from similar experiments, to establish a test matrix for the scales of interest. For SSMD scaled performance testing, the generally accepted scaling relationship used for equivalent mixing among scales, as relates to the distribution of solids throughout the mixed volume, is the equal power-per-unit-volume relationship. The power required to mix a tank with a jet, P_{mix}, can be determined from the kinetic energy supplied by the jet, as shown in Equation A-1.

$$P_{mix} = \left(\frac{\pi}{4} d_{jet}^2 U_{jet}\right)\left(\frac{1}{2}\rho U_{jet}^2\right) = \frac{\pi}{8}\rho d_{jet}^2 U_{jet}^3 \quad \text{(A-1)}$$

Where: ρ is the fluid density, U_{jet} is the nozzle velocity of the jet and d_{jet} is the jet nozzle diameter.

For the equal power-per-volume scaling relationship, the power computed by Equation A-1 is divided by the mixing volume, V, as shown in Equation A-2. Note: the mixing volume is the waste simulant slurry volume, not the capacity of the tank. The mixing volume is characterized by the tank diameter, d_{tank}, and the height, h_{slurry} of the slurry in the tank as it is mixed.

$$\frac{P_{mix}}{V} = \frac{\frac{\pi}{8}\rho d_{jet}^2 U_{jet}^3}{\frac{\pi}{4} d_{tank}^2 h_{slurry}} \quad \text{(A-2)}$$

For two scaled mixing systems with similar geometric properties mixing the same simulant, the nozzle diameter, tank diameter and slurry height from one tank are scaled from the other tank using the scaling factor, SF. The scaling factor is the ratio of the scaled tank diameter and the full-scale tank diameter. Setting the power-per-volume equation equal for the two scales, denoted with subscripts 1 and 2, and substituting in the scaling relationship ($SF=d_{tank2}/d_{tank1}$) is shown in Equation A-3. The simplification of Equation A-3 is shown in Equation A-4.

$$\frac{P_{mix1}}{V_{tank1}} = \frac{\frac{\pi}{8}\rho d_{jet1}^2 U_{jet1}^3}{\frac{\pi}{4} d_{tank1}^2 h_{slurry1}} = \frac{P_{mix2}}{V_{tank2}} = \frac{\frac{\pi}{8}\rho d_{jet2}^2 U_{jet2}^3}{\frac{\pi}{4} d_{tank2}^2 h_{slurry2}} = \frac{\frac{\pi}{8}\rho SF^2 d_{jet1}^2 U_{jet2}^3}{\frac{\pi}{4} SF^2 d_{tank1}^2 SF h_{slurry1}} \quad \text{(A-3)}$$

$$U_{jet1}^3 = \frac{U_{jet2}^3}{SF} \quad \text{(A-4)}$$

The scaling factor exponent for equal power per volume conditions in the SSMD test platform is 1/3, as shown in Equation A-5.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{\frac{1}{3}} \quad \text{(A-5)}$$

Equation A-5 assumes that equal performance is attained when the applied power to mix is directly proportional to the volume to be mixed. The mixer jet pumps are being designed to sustain a flow rate of 5,200 gallons per minute from each of two 6-inch diameter nozzles on each mixer jet. The nozzle velocity exiting the full-scale pump is about 59 ft/s. Using a 1/3 scale factor exponent, nozzle velocities of approximately 30 ft/s and 21 ft/s are determined for the 1:8 and 1:21 scale systems, respectively.

Initially scaling between the two scales in the SSMD test platform was performed to demonstrate that the scaled tanks could be scaled from the full-scale system using the equal power-per-volume scale factor exponent. While this relationship is suitable for mixing, it may not be suitable for other performance metrics, such as the effective cleaning radius, off-bottom suspension, or particle transfer. Equal performance between scales is not just limited to mixing, it could also consider the transfer pumps ability to capture and convey the slurry solids. Therefore, the equal power per unit volume relationship with a scale factor exponent of 1/3 may not be the best relationship to use to scale the integrated system. Equation A-6 replaces the 1/3 scale factor exponent with an unknown value, a, that can be determined for different performance metrics.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{a} \quad \text{(A-6)}$$

The scale factor exponent can be determined through scaled testing. For example, as reported in RPP-RPT-48233, *Independent Analysis of Small-Scale Mixing Demonstration Test*, the mixing data from nine mixer jet pump flow rates at 1:8-scale and 1:21-scale illustrated that equal mixing performance of zirconium oxide in water, as defined by equivalent slurry densities at equal scaled heights, was attained with flow rates of 102.0 gallons per minute (32.6 ft/s) and 9.0

gallons per minute (21.9 ft/s), respectively. The scale factor exponent for the point where mixing performance at the two scales became equal was determined to be 0.39. It is noted that the metric evaluated equal mixing, not adequate mixing as defined by a consistent density at all heights within the tank. The latter was achieved at higher nozzle velocities and equivalent mixing between the scales was maintained at the higher velocities. At the identified flow rates the specific gravity of the zirconium oxide slurry used in the tests was higher at lower heights in both tanks, indicating that the solids (presumably the larger particles) were not being dispersed throughout the entire tank volume. The results also indicate that with increasing nozzle velocities (decreasing scale factor exponent values), mixing performance becomes adequate and plateaus.

Because there is uncertainty in the appropriate scale factor for the performance of the integrated system with simulants that are characteristic of other Hanford tanks, future tests will be performed using two scales and a range of different mixer jet pump nozzle velocities. In addition, the program will begin to evaluate the appropriateness of applying the same scaling relationships to Newtonian and non-Newtonian slurries. Equal performance, as measured by a specific performance metric (e.g., distribution of solids, effective cleaning radius, off-bottom suspension, or particle transfer), will be used to refine previous scaling work.

The rotation rate for the mixer jet pump, ω, is also a scaled property of the integrated system. Similar to work described in Section 2.1.2 of PNNL-14443, *Recommendations for Advanced Design Mixer Pump Operation in Savannah River Site Tank 18F,* the scaling parameter for the mixer jet pump rotational rate equates the number of revolutions that occur in the time required to circulate an entire tank volume through the mixer jet pump inlet (PNNL-14443 Section 2.1.2).

Because the tank diameter and tank height are geometrically scaled from the full-scale, the volume of the scaled tanks, *V*, are related as shown in Equation A-7.

$$V_{tank2} = \frac{\pi}{4} d_{tank2}^2 h_{slurry2} = \frac{\pi}{4} (SF\ d_{tank1})^2 SF\ h_{slurry1} = SF^3 V_{tank1} \quad \text{(A-7)}$$

The time required to circulate an entire tank volume through the mixer jet pump inlet, the turnover time (Θ), is the ratio of the tank volume and the mixer jet pump volumetric flow rate, which is itself a function of the nozzle velocity and the nozzle area. Equation A-8 shows this relationship.

$$\Theta_{tank1} = \frac{V_{tank1}}{Q_{tank1}} = \frac{V_{tank1}}{A_{nozzle1} U_{jet1}} \quad \text{(A-8)}$$

The turnover time for Tank 2 can be related to the turnover time for Tank 1 using the geometric scaling factor when the tank diameter, waste height, and mixer jet nozzle diameter are geometrically scaled as shown in Equation A-9.

$$\Theta_{tank2} = \frac{V_{tank2}}{Q_{tank2}} = \frac{SF^3 V_{tank1}}{A_{nozzle,2} U_{jet2}} = \frac{SF^3 V_{tank1}}{SF^2 A_{nozzle1} U_{jet2}} = \frac{SF U_{jet1} \Theta_{tank1}}{U_{jet2}} \quad \text{(A-9)}$$

Setting the scaling condition (ωΘ) equal between the two tanks yields the angular velocity scaling relationship (Equations A-10 and A-11).

$$\omega_{tank1}\theta_{tank1} = \omega_{tank2}\theta_{tank2} = \omega_{tank2}\frac{SF U_{jet1}\Theta_{tank1}}{U_{jet2}} \quad \text{(A-10)}$$

Therefore,

$$\omega_{tank2} = \frac{\omega_{tank1} U_{jet2}}{SF \quad U_{jet1}} \quad \text{(A-11)}$$

Where: *SF* is the ratio of the tank diameters at the two scales.

Compared to full-scale conditions, as the scale factor exponent decreases, the nozzle velocity and rotational rate for a smaller scale system increase. However, the nozzle velocity for a smaller scale system is generally less than the full-scale nozzle velocity and the rotational rate is usually faster than the full scale rotational rate. Therefore, the nozzle velocity in the smaller scale system equals the full scale nozzle velocity when the scale factor exponent value equals 0 and the rotational rate for a smaller scale system equals the full scale rotational rate when the scale factor exponent value equals unity.

In SRNL-STI-2010-00521, *Demonstration of Mixer Jet Pump Rotational Sensitivity on Mixing and Transfers of the AY-102 Tank*, the effect of the rotational velocity of the mixer jets was evaluated at 1:22-scale and shown to have little effect on the amount of solids transferred in each transfer batch. However, it is noted that the nozzle velocity of the mixer jet was selected so that no "dead zones" were observed in the tank during testing. The testing did not assess whether or not the rotational rate would influence the amount of solids transferred if solids were allowed to accumulate in "dead zones". PNNL-14443 showed that the effective cleaning radius of a mixer jet decreased with increasing mixer jet rotational velocity and decreasing mixer jet nozzle velocity. It can be reasoned that performance metrics aimed at bottom cleaning or metrics that are strongly influenced by the solids on the bottom of the tank would need to evaluate the impact of both mixer jet rotational rate and nozzle velocity.

WRPS-1202839 OS

Enclosure 3

LSIMS ERT DOCUMENT REVIEW RECORD		
	REVIEW NUMBER:	ERT-18 Feed Test Plan 2
	DOCUMENT NUMBER:	RPP-PLAN-52623, Rev A
	DOCUMENT TITLE:	Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan

Comment			Comments and Recommendations:	Resolution:
Number	Reviewer	Type*		
1	LMP	E	Page 1-2, last sentence: "In November 2011…" can likely be deleted; essentially the same information is provided a page later in the last paragraph of Section 1.2 with the benefit of having described DNFSB 2010-2 first.	The sentence has been deleted and the order of the discussion has been revised.
2	LMP	E	Section 1.3: This section seems slightly out of place here; it might be better placed in Section 2 after you introduce the idea that this test plan focuses specifically on scaling. If left in Section 1, then it would be beneficial to explain here that this is the test plan for scaled performance.	Moved to new subsection in Section 3.2.
3	LMP	**M**	**As discussed in the 6/27/12 telecon, if the scaling factor "a" in Equations 1-1 and 1-2 are not the same, don't use the same symbol to describe them.**	Equation 1-2 (now Equation 3-4) has been replaced with an equation that does not include the scaling factor exponent, the derivation of which is corrected in Appendix A. $\omega_{tank2} = \frac{\omega_{tank1} U_{jet2}}{\left(\frac{d_{tank2}}{d_{tank1}}\right) U_{jet1}}$
4	LMP	E	Page 2-1, first bullet: What does it mean to "optimize requirements"?	A reassessment of the ICD-19 requirements based on WTP Limits of Performance testing and Tank Farm capability test results. This optimization will be performed using the DQO process.
5	LMP	E	Table 2-1 seems to omit transfer pump capture velocity as an independent variable.	Agreed. The text has been updated to include transfer pump capture velocity.
6	LMP	E	Table 2-2: The table refers to "changes in the operating conditions," which seems to suggest things like flow rate. What you're really changing is simulant composition and loading. Suggest you say that instead for clarity.	Agreed. Changed as suggested.
7	LMP	E	Page 3-2 implies that tests will be done with a 10 Pa yield stress fluid (it even says how to make one), but Section 3.2.3 says you won't.	RSD system performance testing will use a 10 Pa slurry, SSMD scaled performance testing will not.
8	LMP	**M**	**Page 3-10: Per the telecon, sentence on how nozzle rotational rate is determined is confusing or misleading given confusion about "a".**	Changed to "The mixer jet rotational rate will be adjusted for each change in nozzle velocity according to Equation 1-2."

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9	LMP	**M**	**Page 3-10: Per the telecon, don't just say that "it is assumed that equivalent flow regimes are maintained"; justify the assumption.**	Flow regime is discussed in newly added Section in 3.1.
10	LMP	E	Page 3-15: Could we just say the smaller and larger test vessels rather than TK-201 and TK-301?	Added as suggested to improve clarity.
11	LMP	O	I like the approach described on Page 3-18 of coming back and conducting additional confirmation runs.	Acknowledged.
12	LMP	O	What will be done with the "other performance data" like cloud height, ECR, etc. (Page 3-21)? Is it easy to determine cloud height in these systems? Is it meaningful in the presence of small particles and a multicomponent simulant?	The other data is collected for information and is useful for understanding changes in the performance of the system while the data is being analyzed. It gives indications of anomalies and can be used to perform evaluations based on metrics other than transfer batch consistency. Given that the transfer velocities will likely to be high enough to suspend the lightest particles into a cloud, cloud height measurements may not be useful in terms of predicting performance among scales.
13	LMP	**M**	**As discussed in the 6/27/12 telecon, Section 3.2.6 is not accurately and effectively communicating your performance analysis approach. Please provide a better description of your approach for analyzing the data and determining the scaling factor a. The fact that individual constituent concentrations are being considered seems missing. Also: have performance metrics been selected? The text seems a bit tentative in that regard.**	The section has been updated. In addition a new report is being prepared to address this topic.
14	LMP	E	Page 3.26: Please define the term relative standard deviation.	Added "(i.e., the standard deviation divided by the mean)"
15	LMP	E	Page 3-27 implies that sampling will proceed as five Isolock samples followed by two diversion samples, then five more Isolocks. Page 3-30 (at the bottom and then continuing onto the next page) implies it will be ten Isolock, then two full diversion.	Corrected. "After the fifth" has been changed to "After the last" and included a statement that 5 of the 10 collected are analyzed for chemical content and the other 5 are archived.
16	EKH		General: Words such as "should," "confidently," etc. are not appropriate for	ASME NQA-1-2004 states that "should" denotes guidance and "shall" denotes

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			test plans. Definitive words should be used.	requirements. A review of each occurrence has been conducted and changes to "shall" and "will" have been performed when considered appropriate. Without the opportunity to verify full-scale performance until much later in the program, confidence is needed to support decision made based on scaled testing data.
17	EKH		General: Simulant type and characterization requirements should be in one section of the document. There is way too much repeating of such information and it is not consistent.	Repitition has been reduced by back referencing to one location.
18	EKH		General: Here are the four questions to the ERT members and my response: • Are the major points of the document communicated well to the intended audience? Document is not very easy to read. The intended audience might be the test teams, hence they know what they are looking for. • Does the document provide a clear set of test objectives and requirements? It is somewhat piecemeal throughout the document. The simulant requirements and sample characterization should be in one section and not scattered and repeated throughout. • Are the proposed approaches to testing sufficiently defined and technically defensible? Not sure how defensible the use of the diversion samples are in this test plan. The heterogeneity of the various processes (mixing and transfer) can lead to unknown and unquantified errors in the diversion samples themselves. Mike might have historical data to show that the diversion sample has been quantified with errors. Making the diversion sample	 An effort has been made to improve readability and reduce redundancy. An effort has been made to reduce repetition through backwards referencing. In SSMD testing diversion samples from the transfer line represent what can be captured, sampled, and transferred to the WTP. For RSD testing, full-diversion samples represent what is the transfer line rather than what is in mixing vessel. Mixing in the vessel was less than homogeneous in original testing but changes were implemented to improve mixing in the vessel. Comparing Isolok samples to the contents of the mixing

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			the gold standard must have been quantified previously. • (a) Is simulant selection appropriate? (b) Does the document meet its intent of "qualifying" the simulants proposed? (a) Yes. (b) Not clear on certain aspects. See detailed comments below.	vessel or initial recipes introduces an error that can only be quantified by collecting full diversion samples to determine the differences between what is in the pipe and what is in the mixing vessel. See comment responses below.
19	EKH	E/O	Page i, Executive Summary, first paragraph, third sentence: What are you comparing or assessing this data with respect to the present WAC requirements?	Added bulk density, solids loading, yield stress, slurry viscosity, and uranium and plutonium action levels to Paragraph 2.
20	EKH	E/O	Page i, Executive Summary, second and third paragraphs: These paragraphs should not be in the summary. If you want to keep them, they should be placed at the end.	Agreed. The paragraphs have been removed.
21	EKH	E/O	Page ii, Executive Summary, fifth paragraph: The last sentence should be the second sentence. It tells the reader what this document is about!	The Executive summary has been rewritten/reordered to improve clarity.
22	EKH	E/O	Page ii, Executive Summary, last paragraph, last sentence, "… mixer jet nozzle velocity…": What about different mixer pump rotational speeds? It is a variable being studied in this test plan.	Different rotational speeds will be used during testing in accordance with (revised) Equation 1-2 (see response to comment #3). Deviations from this relationship will not be investigated.
23	EKH	E/O	Page ii, Executive Summary, last paragraph, last sentence, "… the yield strength…": Yield strength is related to settled solids properties, not sheared material properties. If you mean the Bingham Plastic yield stress, state it. I would also include plastic viscosity, it potentially could be a player and may be required to perform necessary calculations.	Bingham yield stress is the correct term that should have been used and the change has ben made.
24	EKH	**M**	**Page 1-3, Section 1.3, first paragraph, last sentence, "… scale factor exponent…": Scaling must be performed in the same flow region and it must be clear that this will be the case when scaling.**	Flow regime is discussed in newly added Section in 3.1.
25	EKH	E/O	Page 1-3, Section 1.3, first paragraph: Make it clear in this section that Equation 1-1 will be used to scale both Newtonian and non-Newtonian (NN) fluids. Typically the Bingham Plastic yield stress is used for scaling NN fluids.	The Bingham yield stress is important for determining what material can be suspended; however, SSMD testing is not focused on mobilizing material from the tank bottom as much as it is focused on quantifing what is suspended and

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				transferred. If the low yield stress slurry (currently 3x ICD-19 action level) behaves like a Newtonian fluid once it is suspended, then the scaling relationship for Newtonian fluids may be acceptable for predicting batch transfer consistency of the non-Newtonian slurries.
26	EKH	E/O	Page 1-3, Equation 1-1: Would be helpful in this section to verify on what matrix(es) the scaling factors will be based on. Just a simple paragraph will do and you can reference another section in this document for additional details.	Moved to Section 3.2.1. Added example of the metric comparing concentrations in pre-transfer samples and in batch transfers. Other metrics related to batch transfer consistency could be used.
27	EKH	E/O	Page 2-1, Section 2.0, third paragraph, second sentence: Specify here which requirements of ICD-19 will be assessed, since this is part of this test plan.	Added " With the exception of measuring critical velocity for comparison to ICD-19 limits, testing will not specifically target sampling for comparison to ICD-19 requirements. Instead, testing will be performed with simulants that are characteristic of Hanford waste in terms of bulk density, solids loading, yield stress and slurry viscosity. Testing will also be performed with slurries containing dense particles (8 mg/l) having particle sizes exceeding 100 microns for assessing the capability of sampling fissile material for comparisons to ICD-19 requirements for uranium and plutonium (e.g., Pu to metals loading ratio and $U_{Fissile}$ to U_{Total} ratio)."
28	EKH	E/O	Page 2-2, Section 2.0, last paragraph, first sentence, "… confidently.": How confident is confidently? To what level of confidence is required?	Confidence in the RSD platform is consistent with the WAC DQO, which requires a 90% condience level as the starting point for the decision rules for the non-criticality constituents and a 95% confidence level for criticality safety limits.
29	EKH	E/O	Page 2-2, Section 2.0, last paragraph, second sentence, "… WTP WAC DQO …": What are the WTP WAC DQO sampling confidence requirements? Specify which ones this task is investigating such that the reader does not have to read all the documents. A table will do.	See response to #27. Also added sampling requirements accuracy based on WAC-DQO to section 3.3.4. Isolok sample representativeness is based on the 95% confidence level for the ratio of fissile uranium to total uranium (see Figures 7-12 and 7-13 in 2450-WTP-RPT-MGT-11-014) and 10% sampling uncertainty.

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30	EKH	E/O	Page 2-4, Section 2.1, first paragraph, fifth sentence: I thought that the MJP rotational speed will be varied in this task? If so, should it also be stated?	The rotational rates will be varied, but not to evaluate a different scaling relationship. Once a nozzle velocity is specified, the rotational rate is then calculated using this nozzle velocity and the scaling relationship.
31	EKH	E/O	Page 2-4, Section 2.1, first paragraph, last two sentences: OK, given the other variables, will they (e.g., rheology, density, capture velocity, MJP rotation rate) not impact this model or is this model specific to the test conditions?	Although thebiggest influence on the scaling parameter is expected to be the nozzle velocity, the model will include the other parameters varied in the different test conditions.
32	EKH	E/O	Page 2-5, Table 2-1, first row, "Success Criteria" column, first paragraph, last sentence: Page 2-4 states batch chemical composition will be used, not physical. Which is correct? Same comment for success criteria below.	The physical properties could be used for component separation (e.g., magnetism) prior to chemical analysis. This has been clarified in the success criteria.
33	EKH	E/O	Page 2-7, Section 2.2, first paragraph, first sentence, "… feed.": Do you mean what is in the transfer line, since you are going to pull a diversion sample? Typically feed means what is in the mixing vessel.	Feed is intended to mean the contents of the vessel that can be suspended and transferred and hence is also what is in the transfer line.
34	EKH	E/O	Page 2-7, Section 2.2, second paragraph, first sentence, "… reliable …": This needs to be more definitive with respect to what you mean by reliable? How reliable?	Changed to "… the sampler to obtain samples that have the same content as the slurry within the waste characterization flow loop."
35	EKH	E/O	Page 3-2, Section 3.1, third paragraph, sixth sentence, "… Bingham yield stress …": Should be Bingham Plastic yield stress. The same goes for consistency (though this is typically called plastic viscosity in literature, other than in the DOE complex, which seems to intertwine the words so that everybody can be confused at the same level). This wording of using just Bingham is throughout the document.	Accepted. Change made throughout.
36	EKH	E/O	Page 3-2, Section 3.1.1.1, second paragraph, fifth sentence, "Test samples shall …": How are these test samples to be prepared? Are you going to use a bench top piece of equipment? Please specify what will be used.	Samples have been prepared to confirm the recipe using the 43.2-in diameter SSMD vessel. The same slurries are also prepared during LOP tests activities.

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37	EKH	E/O	Page 3-2, Section 3.1.1.1, second paragraph, fifth sentence, "… yield stress …": "Bingham Plastic properties" is all that is needed to be stated.	Bingham Plastic consistency has not been specified as a critical property although it is measured and reported.
38	EKH	E/O	Page 3-3, Section 3.1.1.1, second paragraph, sixth sentence: Can be captured above.	The Bingham Plastic consistency is not a critical propertiy defined in RPP-PLAN-51625. Although it is not a critical parameter, the Bingham Plastic consistency will be measured and compared to the range of values for Hanford tank waste (typically <10 cP).
39	EKH	E/O	Page 3-3, Section 3.1.1.1, second paragraph, eighth sentence, "… yield stress …": Highly recommend that the same type of rheology protocol WTP has been using to characterize fluids be used, so as to compare data between the two organizations.	LSIT rheology testing will be determined off-site, but at a nearby laboratory. This arrangement was not practical for work in Pasco that needs real-time input to adjust simulant composition.
40	EKH	E/O	Page 3-3, Section 3.1.1.1, third paragraph, second sentence, "… time varying nature of a non-Newtonian …": This time varying effect is based on the type of shearing applied to the Kaolin slurry and time of shearing. Data I've seen to date indicates for kaolin slurries that they become thicker when continuously mixed, but it does reach a somewhat steady state condition based on the mixing system.	Acknowledged. The intent will be to keep the properties consistent between tests so comparable results are obtained more so than observing behavior at exactly 3 and 10 Pa.
41	EKH	E/O	Page 3-3, Section 3.1.1.1, third paragraph, second sentence, "… necessary accuracy needed to resolve …": What does this mean?	Added statement "Preparing consistent simulant batches from test to test will facilitate the analysis of the data between tests and is expected to be more important for the data analysis than performing tests at specific conditions (i.e., 3 and 10 Pa)."
42	EKH	E/O	Page 3-5, Section 3.1.1.2, third paragraph, third sentence, "… calibrated …": Calibrating a rheometer is typically performed by the vendor. I'm assuming you are functional checking the operability of the rheometer using NIST traceable viscosity oil standards that looks at the integrated rheological system. Calibration takes a lot more effort.	This is correct. Clarification has been added.
43	EKH	E/O	Page 3-5, Section 3.1.1.2, third paragraph, fourth sentence, "… controlled shear rate and controlled …": Highly recommend you pick the method, rate or stress. WTP protocol has	The program that is run uses rate to determine the viscosity and yield stress.

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			been rate. This question is applicable to other sections in this document.	
44	EKH	E/O	Page 3-5, Section 3.1.1.2, third paragraph, fifth sentence, "… should …": This should be a must. If you're going to use NIST traceable oil standards, they are temperature sensitive.	Agreed. Changed to "shall". The procured rheometer has this capability and
45	EKH	E/O	Page 3-5, Section 3.1.1.2, third paragraph, last sentence: Highly recommend that you perform yield stress measurement after testing is complete, as a minimum.	Acknowledged. Taking measurements at the end of testing is included in the test plan.
46	EKH	E/O	Page 3-7, Section 3.1.2.2, first paragraph, third sentence: This should be deleted due to specifics stated below for the simulants.	Accepted. Changed small test batch preparation to a "should" because Limits of Performance testing will confirm recipes for full batches of the most difficult to prepare fluids.
47	EKH	E/O	Page 3-7, Section 3.1.2.2, first paragraph, fifth sentence, "… 0.5 cP …": +/- 0.5.	Accepted.
48	EKH	E/O	Page 3-7, Section 3.1.2.2, first paragraph, eighth sentence, "… density is also ±5%.": Is this measurement to occur at test temperature? If so state it; if not, is a correction needed?	Accepted.
49	EKH	E/O	Page 3-10, Section 3.2, second paragraph, third sentence: The scaling factor n, given in the first paragraph on Page 2-4, has to be determined based on a mathematical model. Hence how do you determine the rotational rate if n has not been determined?	See response to Comment #3.
50	EKH	E/O	Page 3-10, Section 3.2, third paragraph, last sentence: You need to verify that you are in the same flow regime prior to starting the test. If you are not in the correct flow regime (this should be done way ahead of time), then you must increase the velocity so that pertinent data is obtained.	Flow regime is discussed in newly added Section in 3.1.
51	EKH	E/O	Page 3-11, Section 3.2.1, third paragraph: Has it been determined from previous tests that this is the case? If so, how would this impact the transfer batch results?	We are using a new, larger pump for Limits of Performance and Scaled Performance tests. The impact of this has not yet been evaluated because base material thatr may settle is not quantified in LOP testing and spike particles that would settle are captured in a collection device prior to entering the pump in LOP testing. This is a new concern for Scaled Performance testing that will need to be worked out during development testing.

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				Added that developmental testing will be performed to evaluate the consequences on the base simulant.
52	EKH	E/O	Page 3-12, Table 3-4, footnote 4, second sentence: Can this impact the results since the tank contents for a given batch size will be transferred faster than when appropriately scaled? Will the effective capture area increase due to this increase in suction inlet diameter?	The capture velocity is a variable in scaled performance testing to determine the significance of the capture velocity and capture area. Previously reported work, as discussed in 3.2.4, was inclusive about the effect of capture area. Also capture velocity decisions in the smallest scale were also informed by previous SRNL work (SRNL-STI-2009-00717) thatconcluded that gibbsite and silicon carbide transferred was consistent regardless batch transfer conditions because the tested rates provided the velocity that was needed to lift the particles and prevent the, from settling in the transfer lines.
53	EKH	E/O	Page 3-13, Section 3.2.3, fourth paragraph, third sentence: Add these figures into this text, since this drives your assessment on simulant solids selection.	RPP-PLAN-51625 is the simulant selection document for the TOC's DNFSB 2010-2 work scope and thus is not driving the assessment, rather it is the assessment.
54	EKH	E/O	Page 3-13, Section 3.2.3, fifth paragraph, fifth and sixth sentences: This is inconsistent with Section 3.2. It states that for viscosities greater than 5 cP, the tolerance is +/-20%. You need to capture the 3.6 cP requirement into Section 3.2 to be consistent in using the +/-20%.	Reduced tolerance to 0.5 cP here and in 3.1.2.2 for the same reason as specified for the 1.6 cP fluid. Also added a note in Section 3.1.2.2 that consistency is more important that attaining a specific value.
55	EKH	E/O	Page 3-13, Section 3.2.3, fifth paragraph, ninth sentence: Note that increased viscosity will also impact jet performance by reducing its level of turbulence and this could impact the ability of the jet to lift particles further from the jet as compared to a thinner fluid, impacting the ECR.	This is acknowledged near the end of the paragraph.
56	EKH	E/O	Page 3-14, Section 3.2.3, seventh paragraph, third sentence: Given a range of jet mixer pump velocities you will be testing, the lower velocities may create caverns.	Acknowledged. Added an allowance to only test with caverns at the lowest velocity. The second lowest velocity will be increased until caverns are eliminated.
57	EKH	E/O	Page 3-14, Section 3.2.3, seventh paragraph, last sentence, "… slightly rheopetic …": Given it is slightly rheopetic, will the up or	PNNL (Phil Gauglitz) has recommended that the second of two down curves be used. Added note in Section 3.1.1.2.

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			down or both curve from a flow curve measurement be used to assess the Bingham Plastic parameters?	
58	EKH	E/O	Page 3-14, Section 3.2.3, eighth paragraph, first two sentences: As stated earlier, the same rheological protocol should be used to assess the NN fluids, e.g., same program and curve fitting range for a given set of rheological conditions.	Acknowledged. The same rheometer program is used regardless of fluid type.
59	EKH	E/O	Page 3-15, Section 3.2.3, eighth paragraph, last sentence, "… should …": Must?	This has been changed toa requirement.
60	EKH	E/O	Page 3-15, Section 3.2.4, first paragraph, third sentence: See previous comments on this subject.	See response to Comment #3.
61	EKH	**M**	**Page 3-17, Section 3.2.4, eighth paragraph: By increasing the suction line on the 1:21 scale, the pump out rate would be faster than if it were linearly scaled. For instance, if the suction diameter was linearly scaled, it would be 0.1152 inches in diameter and the given that velocity is maintained, the flowrate in this case would be between 0.2 to 0.36 GPM or about 5 times as slow. Could this 5X in flowrate impact the results? If not, why? Provide an explanation in this section the differences in pump down and if it does or does not impact the results for the 1:21 scale.**	Pump out rate and capture velocity decisions in the smallest scale are described in the response to Comment #52.
62	EKH	E/O	Page 3-17, Section 3.2.4, eleventh paragraph, first sentence, "… should …": Must?	The "should" occurences have been reviewed and converted to "shall" or "will" when appropriate.
63	EKH	E/O	Page 3-17, Section 3.2.4, eleventh paragraph, second sentence, "… transfer and sampling …": Not clear. Will a diversion sample be pulled as well? In either case, state if a diversion sample is pulled.	Added "batch" before transfer. SSMD samples are composited from four diversion samples collected during the transfer of the batch.
64	EKH	E/O	Page 3-17, Section 3.2.4, eleventh paragraph, second sentence, "… should …": Will?	The "should" occurences have been reviewed and converted to "shall" or "will" when appropriate.
65	EKH	E/O	Page 3-17, Section 3.2.4, eleventh paragraph, last sentence, "… should …": Must?	The "should" occurences have been reviewed and converted to "shall" or "will" when appropriate.
66	EKH	E/O	Page 3-19, Table 3-6, footnote b: This footnote is out of place. This discussion should be in the text where the NN simulant is being discussed and in more detail.	Text has been added to Section 3.2.3 Test Simulants.

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			Simulant specification should not be in a table!	
67	EKH	E/O	Page 3-20, Section 3.2.5, first paragraph, fourth through last sentences: See previous comments on rheometer and measurements.	Text has been replaced with a reference to Section 3.1.1 and 3.1.2.
68	EKH	E/O	Page 3-20, Section 3.2.5, second paragraph, twelfth sentence, "… reported.": Recorded?	Accepted.
69	EKH	E/O	Page 3-21, Section 3.2.5, third paragraph, eighth sentence: Add after slurry the word "sample". Change the word should to something else more definitive.	Accepted.
70	EKH	E/O	Page 3-21, Section 3.2.5, third paragraph, ninth sentence, "… reported.": Recorded?	Accepted.
71	EKH	E/O	Page 3-21, Section 3.2.5, fourth paragraph, first sentence: Do you expect the same as described here will be used for the NN fluids? If so state it; if not state how you will handle the NN fluid?	In previous testing a cement mixer has been used to assist clarification of the solids. This approach will be tested with the kaolin slurry and refined during developmental testing. Added text discussing this aspect of the testing.
72	EKH	E/O	Page 3-21, Section 3.2.5, fourth paragraph, fifth sentence, "… settled solids.": I recommend you use another word. Settled solids can mean you will have problems in sampling.	Settled has been deleted. The solids are initially settled during clarification but then the solids are mixed vigorously after the liquid has been decanted.
73	EKH	E/O	Page 3-21, Section 3.2.5, fourth paragraph, eighth sentence, "… mass of dry solids …": At what temperature?	The procedure for measuring the solids content is being developed by the laboratory but the work is not yet completed.
74	EKH	**M**	**Page 3-21, Section 3.2.5, fourth paragraph, eighth sentence: Question, since the supernate is not water, will the total solids include the solids in the supernate as well? Or do the solids in the supernate evaporate at the elevated drying temperatures? Do you need to calculated the undissolved solids in the sample? Are the solids in the supernate analyzed as part of the solids via the acid dissolution process? Are the NN slurries treated in the same manner?**	The procedure for measuring the solids content is being developed by the laboratory but the work is not yet completed. Since the solids of concern are very insoluble in water, the dried solids content can be determined on a washed solution that removes the dissolved sodium thiosulfate. Base simulant quantification interference by kaolin and sodium thiosulfate is also being investigated by the lab.
75	EKH	**M**	**Page 3-22, Section 3.2.6, second paragraph, "… M_{PT} is the mass collected …": Why isn't the actual mass and volume of the batched materials used? Why is this pre-transfer sample more appropriate? What variability is there in the pre-transfer sample?**	The pre-transfer sample is more important because it represents the sample that will be collected from the DSTs and compared to waste acceptance criteria as the slurry that can be transferred from the tank. The initial content of the tank is not suitable for

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				comparison because the mixing does not homogenize the tanks and heels are formed so that it is expected that the transferable slurry will differ from the initial content.
76	EKH	E/O	Page 3-25, Section 3.3.2, fifth paragraph, first seven sentences: Make sure you are consistent between sections of this document with respect to tolerances.	Reviewed for consistency with changes added to address comment #54.
77	EKH	E/O	Page 3-26, Section 3.3.2, eighth paragraph, fourth sentence: Clarification. The mass of solids to add to the 13 wt% Newtonian simulant is X and its composition is given in Table 3-1. Given the mass fraction of S/S and Zr in Table 3-1, will these factions then be used to determine the amount of these solids to be added based on X? Or will the mass of X be added and split between S/S and Zr based on normalizing the mass fractions of S/S and Zr in Table 3-1?	180 gallons of Newtonian slurry composed of the high base solids @ 13 wt% in a typical supernatant uses ~90 lbs SS and ~22 lbs ZrO. Therefore, ~90 lbs SS and ~22 lbs ZrO will be added to the non-Newtonian slurry for testing.
78	EKH	E/O	Page 3-26, Section 3.3.2, ninth paragraph, second sentence, "… (RPP-RPT-51796).": I read RPP-RPT-51796; not sufficient data was provided for the Fe_2O_3 such as PSD. Additionally, no description was provided in how the yield stress measurement was made other than a curve provided at the end of the document that is unique (have not seen such a curve other than in material science), showing only stress and displacement. The Bingham Plastic yield stress is determined from a flow curve; there is no other way to obtain this data and this would be the data you need for pipe flow. Additionally, calculations should have been performed to determine the condition of flow (e.g., laminar or turbulent). If the flow is highly turbulent, then the yield stress has no impact in keeping the solids suspended.	Acknowledged. The performance of the Isolok in the vertical configuration will provide new performance data for non-Newtonian slurries. The critical transition velocity (Hanks 1963) of a 1.22 g/ml, 10 Pa, 10 cP slurry in a 3-inch diameter pipe is 4.7 ft/s (105 gpm). Testing at 140 gpm will be turbulent for all test conditions.
79	EKH	**M**	**Page 3-26, Section 3.3.2, ninth paragraph, second sentence, "… (RPP-RPT-51796).": Pipe flow calculations to determine the condition of flow has to be done for this task. See comment 78 above.**	See response to comment #78.
80	EKH	E/O	Page 3-27, Section 3.3.3, second paragraph, second sentence, "… two full diversion samples …": How much volume is being	Full diversion samples are collected for 2-3 seconds in a 5 gallon bucket. Two diversion samples are less than 10

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			collected?	gallons at 140 gpm (~5% of the 180 gallons of prepared slurry)
81	EKH	E/O	Page 3-28, Section 3.3.3, fourth paragraph, last sentence: Testing at SRS and VSL based the sample of the isolok (or sampler system used) as compared to the tank contents. The homogeneity of the tank was characterized. The method you use is different. What is the variability in the diversion samples? This is a reason why you do verification runs, to determine this error, since you are not sampling the mixing system or the batched quantities as a basis of comparison. Also note that the flow conditions for the Isolok and diversion samples are different, one is located vertically and just upstream of a bend and the other is located horizontally, where the flow is fully developed.	It is assumed that the full diversion sample is representative of the pipe content and is not transient. The variability in the full diversion sample will be quantitifed in predevelopment testing by collecting 5 full diversion samples at different times and comparing the chemical content of each sample. This will be used to quantify the error in the basis used to evaluate Isolok performance. For the purposes of testing, the most challenging simulant to suspend will be used to quantify the error. This is expected to be the high base simulant in the typical supernatant.
82	EKH	E/O	Page 3-28, Section 3.3.3, fifth paragraph, fifth sentence, "… equivalent mass of these components …": This is clear here, but not on Page 3-26.	Adjusted previous language to be consistent.
83	EKH	E/O	Page 3-30, Section 3.3.3, seventh paragraph, third and fourth sentences: Shouldn't the fully suspended criteria be verified prior to sampling activities as well?	While ensuring that the pipeline flow is fully suspended is desirable, tests are conducted at the maximum flow rate accepted under ICD-19. Sampler performance will be evaluated regardless of whether or not forced axial flow or stratification is observed. On the other hand, PulseEcho determinations require a visual difference in the flow behavior to verify the data reported by the device.
84	EKH	E/O	Page 3-30, Section 3.3.4, first paragraph, sixth through ninth sentences: See previous comments on rheology measurements.	Text has been replaced with a reference to Section 3.1.1 and 3.1.2.
85	EKH	E/O	Page 3-31, Section 3.3.4, third paragraph, fourth sentence: How are you going to separate the solid constituents of interest from the kaolin so that this assessment can be performed? Would it be just as easy to analyze the kaolin as well or does kaolin effect the acid digestion of solids for this analysis? You would have to baseline the kaolin using the acid digestion method to determine what its composition.	Separation of ZrO and SS will be performed in the laboratory, not at the test facility. ZrO and SS where selected as base components because the kaolin was not expected to interfere with their preparation and analysis. This is currently being confirmed in the lab and an analtyical method will be established prior to the start of testing.
86	EKH	E/O	Page 3-31, Section 3.3.4, fourth paragraph,	The mass and volume of the full-

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			last three sentences: Are masses weighed? If so, state when masses and volumes are measured.	diversion sample has not previously been recorded. DNFSB 2010-2 testing is requesting these measurements at the time that they are collected and this has been added to the test plan.
87	EKH	E/O	Page 3-31, Section 3.3.4, fifth paragraph, third sentence, "… settling in the transfer line …": You shouldn't have settling occurring in the transfer line, it really throws a wrench in your assessment. You better make sure that this is not occurring prior to starting the sampling sequence of tests.	There has been no specific effort to select simulants that would not settle in the transfer line at testing flow rates. The simulants were selected to be representative of a range of Hanford tank waste. Solid settling at full flow conditions will be observed during PulseEcho testing. Observations will determine if solid settling is a source of difference between the full diversion sample and the initial makeup.
88	EKH	E/O	Page 3-31, Section 3.3.4, fifth paragraph: See previous questions on the use of the full diversion sample as the basis.	See response to comment #81.
89	EKH	E/O	Page A-5, Appendix A, partial paragraph at top of page, last sentence, "… plateaus.": Interesting; seems that excessive velocity buys you nothing! This could be also be used as a reference point, where the plateau occurs.	Higher velocities should increase the amount of the most challenging to suspend particles captured. However, if the amount of these particles is small relative to the readily suspendible material, then increased velcoties will only have a marginal impact on the performance for the metrics being evaluated.
90	EKH	E/O	Page A-5, Appendix A, paragraph below Equation A-7, first sentence: Question, is the equal tank turnover times the appropriate scaling relationship to determine pump rotational speed? Have other relationships been considered, and if so, which ones and why were they excluded?	Other than SRNL-STI-2010-00521, our efforts have not previously considered other rotational rate scaling relationships. The jet propogation rate method proposed by R. Hemrajani (see Comment #91) results in the same relationship.
91	RRH		General: • The objectives are clearly stated, but experimental program and data interpretation seem to indicate inconsistency. For example, primary objective is transfer of majority of solids and mixing to suspend solids is secondary. The two are connected because if mixing is poor, desired transfer of solids would not be possible. Therefore good mixing in the vessel should be considered as a pre-requisite	The primary objective of testing is not transfer of the majority of solids. While this is highly desirable, the objective of testing is to demonstrate whether or not the tank farm system can collect representative samples of the feed that is to be delivered.

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			for transfer. • Definition of 'f' in Equation 3-4 compares solids transferred with solids in the sample. Meaningful metric for transfer should include comparing solids transferred with solids present in the vessel. Also it should be ensured that flow rate of transfer should provide higher than critical velocity to prevent any settling. • The document assumes that scaling factor for mixing and transfer is the same. Since physical concepts of the two operations are different, scaling factors are likely to be different. • We discussed the use of parameter 'a' in Equation 1-2. Since it confuses the scaling factor in Equation 1-1, a different parameter should be used in Equation 1-2. Also, mixer jet pump rotational rate 'w' can be set based on time for jet propagation which depends on jet velocity. For a different scale 'w' is also inversely proportional to vessel diameter for geometrically similar jet nozzles. • At several locations in the document a statement of "certain degree of suspension" is used. This is vague and should be defined for quantification. • Please use consistent units throughout the document based on common practice, e.g., vessel dia. (ft), height (ft), nozzle dia. (in.) etc.	TOC WFD Mixing and Sampling Program is interested in minimizing the variability in the transfer batchesand minimizing the number of samples that must be collected to characterize the feed that can be transferred from the tank. The analysis will determine a scaling factor for the coupled process of mixing and transfer assuming that the fundamental relationship generally applied to mixing is appropriate. The equation has been corrected. The corrected expression yields the same result as the jet propogation rate relationship. Updated to 100% of particles suspended. The document has been reviewed for unit consistency.
92	RRH	E	Page 1-1, last paragraph: It is correctly mentioned that WAC requirements are emerging. It would be helpful to elaborate a bit on this, e.g., what do we know at this time and plans for firming them up.	Reassemment of the WAC is on on-going process that will be conducted after DNFSB 2010-2 testing results are analyzed. What we know to date is already documented in ICD-19 and the WFD DQO. The emerging changes have not been identified because the TOC and WTP limits of performance have not yet been established. Revisions to the WAC is captured in a separate DNFSB 2010-2 comittment.
93	RRH	O	Page 1-2, Section 1.2: Indicates that previous testing addressed PSDD of AY-102 vessel and the planned study will expand the	This is the specific topic of previous DNFSB 2010-2 deliverable RPP-PLAN-51625, which developed the simulants

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			range of waste physical properties. It would help to describe how different are properties of waste in other tanks.	that are used in all DNFSB 2010-2 WFD testing.
94	RRH	E	Page 1-3, second paragraph, starting with "While the initial work …": The message is very confusing. Please modify the statement and perhaps break it down in 2 to 3 sentences.	The text has been revised as suggested.
95	RRH	**M**	**Page 1-3, Equation 1-1: The definition of U_{jet} should be based on "Equivalent Performance," which can be ECR, Cloud Height, or Solids Transfer.**	The scaling discussion has been revised.
96	RRH	O	Page 3-4, Table 3-1: • It would help to add a column for Ar and/or settling velocity. • The 'High' simulant contains 0.03 fraction of 10 microns/2.42 g/ml particles. This doesn't appear to be significant and perhaps can be eliminated.	The distribution of Ar and settling velocity for each of the simulant combinations (in water) is provided in previous DNFSB 2010-2 deliverable RPP-PLAN-51625, which developed the simulants that are used in all DNFSB 2010-2 WFD testing.
97	RRH	**M**	**Page 3-4, last paragraph: Figure 8-2 in the Report 51625 is for Njs for solids suspension in agitated tanks (Zwietering). Since the mixing system in DSTs is not an agitator, the use of Zwietering correlation is inappropriate.**	Figure 8-2 is based on the mixer jet work of Kale and Patwardhan (2005). Note this metric is used to compare the behavior of the simulants to the behavior of known tank waste under equal conditions to show that the simulant is similar to the tank waste based on the properties that are considered by the metric.
98	RRH	E	Page 3-5, third paragraph: It is mentioned that rheology of the fluid will be measured before and after the test. But there is no mention of what action is planned if the rheology changes significantly.	No action will be taken. I considered adjusting the recipe for future work, but this introduces an inconsistency that would make comparsions at different nozzle velcoities (SSMD) or with different simulants (RSD) difficult. I have added a discussion that consistency between tests is more important than performing tests at a specific yield stress or viscosity.
99	RRH	O	Page 3-6, Table 3-2: There are five liquid supernatant options. I believe two options of Low Density/Low Viscosity and Low Density/High Viscosity would cover conservative options.	Testing will cover three of the five options, low/low, typical/typical., and high/high. The intent is to represent the range of Hanford tank waste, including the supernatants.
100	RRH	E	Page 3-7, last sentence: Use of tungsten grit is not mentioned in the Report 51625. Please check.	Tungsten grit and tungsten carbide grit are both included as spike particles in Section 8.3 of RPP-PLAN-51625.

***Type:** **E** – Editorial, addresses word processing errors that do not adversely impact the integrity of the document.
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

LSIMS ERT DOCUMENT REVIEW RECORD		
	REVIEW NUMBER:	ERT-18 Feed Test Plan 2
	DOCUMENT NUMBER:	RPP-PLAN-52623, Rev A
	DOCUMENT TITLE:	Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan

101	RRH	E	Page 3-8, third paragraph: Last three sentences are very confusing and perhaps should be explained more clearly.	Edited for clarity.
102	RRH	E	Page 3-9 • Equations 3-2 and 3-3: Re is particle Reynolds number, should be denoted as Re_p. • Table 3-3: A column for Re_p would help to establish applicability of 'Intermediate Law' regime.	Made the correction for Re_p. Added.
103	RRH	**M**	**Page 3-10, second paragraph: The basis of 'equivalent flow regime' causes some confusion, as full scale-flow regime will be "Turbulent". Selection of test vessels and operating conditions should be based on the same turbulent flow regime. Operation under different flow regimes could potentially lead to different functionalities in correlations.**	Flow regime is discussed in newly added Section in 3.1.
104	RRH	E	Page 3-12, Table 3-4 • It would help to include pump jet mixer rotation rate of two full-scale DSTs. • Specification of Mixer Jet Pumps in various vesels can best be described in sketches of plan view. • Most parameters are based on geometric similarity, except Transfer Pump Suction Inlet Diameter and Transfer Line Diameter.	Added full-scale RPM. Added plan view of AY-102.
105	RRH	O	Page 3-15, Section 3.2.4: It is stated that mixer jets will operate with no rotational offset. Limited tests should be carried out to demonstrate this because offset may be beneficial for avoiding solids accumulation at the collision points.	This is planned for FY 2013.
106	RRH	E	Page 3-20, Section 3.2.5: This section is written as an ongoing test program (use of present tense). I understand that this program is yet to start.	Updated tense. This work will be done.
107	RRH	**M**	**Page 3-20, last paragraph: It mentions that pre-transfer samples will be collected for a integer value of half rotations of mixer jets. In the conference call with authors it was agreed that the samples will be taken during a full rotation. Also you may want to describe expected size of the samples.**	In the small tank, the entire transfer batch will be collected for sampling / subsampling (~15 gallons). In the large tank the collected volume will be as close to the same as possible. However, the duration of sampling depends on the rotational rate, which depends on the nozzle velocities which have yet to be

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LSIMS ERT DOCUMENT REVIEW RECORD	REVIEW NUMBER:	ERT-18 Feed Test Plan 2
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	DOCUMENT TITLE:	Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan

				determined. The expected range is close to 0.65 to 1.0 RPM. At 2.8 gpm with four intervals of smapling per batch collected over 1 revolution each, this amounts to 11.2 gallons (@ 1rpm) to 17.2 gallons (@ 0.65 rpm)
108	RRH	O	Page 3-22, Equations 3-5 and 3-6: Fitting a polynomial does not use any basis of physics of solids suspension and slurry transfer. The form of a correlation should be investigated based on other research in these areas.	An empirical model was selected because it is not known how the multiple physics-based models needed to describe the complex mixing behavior interact with one another.
109	RRH	O	Page 3-23, Section 3.3.1: It mentions that slurry velocities between 2 ft/s and 6 ft/s will be used. You may want to estimate critical velocity using literature correlations to decide this range.	The range is determined by the capability of the system. 6 ft/s is equivalent to the maximum feed delivery rate of 140 gpm. 2 ft/s is the minimum rate of the pump and is well below the region of interest, which is 4 ft/s. Critical velocities of the simulants will be calculated for the test report and compared to the observed values determined visually and from the PulseEcho system.
110	RRH	**M**	**Page 3-24, third paragraph: "Mechanical Handling" should be described along with equipment to be evaluated.**	Added brief description of the handling system. A separate effort was performed outside of the DNFSB 2010-2 workscope to initially evaluate the MHS. This was done under a separate test plan. The results of the earlier MHS testing, LOP testing and System Performance testing will be included in the RSD test report.
111	RVC		The relationship between jet discharge velocity and mixer head rotation rate continues to be controversial and difficult to follow. It is mandatory that this be clarified and well stated in the final document before concurrence can be given.	The rotational rate scaling relationship recommended in supplemental discussions with the ERT is based on an effective cleaning radius. In an analysis of the functional relationship, it was shown the the functional relationship for scaling reduces to the same functional relationship that is already being evaluated during testing. Therefore, the relationship between the jet discharge velocity and mixer head roational rate (see response to Comment #3) is used to determine the rotational rate when a different nozzle velocity is used.
112	RKG		Comments have been addressed by other members of the ERT.	Acknowledged.

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ERT-18 Feed Test Plan 2

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 Mixing and Sampling Program System Performance Test Plan* (ERT-18)

Date: August 7, 2012

Dear Mr. Skwarek:

The Large-Scale Integrated Mixing System Expert Review Team (ERT) reviewed the One system ERT-18 response letter dated July 19, 2012 and subsequently held three technical clarification conference calls with your technical staff. During these discussions we mutually agreed to additional document modifications that clarified our understanding and incorporated our recommendations related to scaled performance testing. The ERT concurs with the attached version (Revision E) of "Waste Feed Delivery Mixing and Sampling Program System Performance Test Plan." The WRPS disposition of ERT comments documented in ERT-18 Feed Test Plan 2 is satisfactory.

This letter closes review ERT-18.

EXECUTIVE SUMMARY

The primary purpose of the Tank Operations Contractor Mixing and Sampling Program is to mitigate the technical risks associated with the ability of the tank farms waste feed delivery systems to mix and sample High-Level Waste feed adequately to meet the Hanford Waste Treatment and Immobilization Plant Waste Acceptance Criteria. The Tank Operations Contractor will conduct tests to determine the range of waste physical properties that can be retrieved and transferred. Using two geometrically scaled tanks, testing and analysis will determine the scale-up relationship for a full-scale, feed staging tank based on batch transfer consistency with pre-transfer samples (i.e., replicating the waste acceptance process). The capability of the tank farm mixing, sampling, and transfer systems to obtain representative samples to assess properties important for the waste acceptance criteria comparison will also be determined. This test plan is the second of three test plan documents that are being prepared to address Defense Nuclear Facilities Safety Board DNFSB 2010-2, Sub-Recommendation 5, Commitment 5.5.3.6, "Test Plan to establish Tank Farm performance capability" and addresses the technical approach and test requirements for the scaled/system performance test activities being performed to support waste feed delivery.

The tests being conducted to define the capabilities of the mixing, sampling, and transfer system are focused on three areas: limits of performance, solids accumulation, and scaled/system performance. Limits of performance testing and developmental work supporting solids accumulation are currently being conducted under the first of the three test plans, RPP-PLAN-52005, *One System Waste Feed Delivery Mixing and Sampling Program Limits of Performance and Solids Accumulation Scouting Studies Test Plan*. Additional solids accumulation testing will be conducted under a future test plan. Scaled/system performance is performed in accordance with this test plan. Scaled/system performance testing will be conducted to demonstrate mixing, sampling, and transfer performance using simulants representing a broad spectrum of Hanford waste. Testing will be performed with simulants that are characteristic of Hanford waste and approach or exceed waste acceptance criteria action levels in terms of bulk density, solids loading, yield stress, and slurry viscosity. Testing with simulants that approach the Hanford Waste Treatment and Immobilization Plant design basis ensures that the system is capable of identifying waste that may be outside the envelope of acceptance. Testing will also be performed with slurries containing dense particles (8 g/ml) having particle sizes exceeding 100-microns for assessing the capability of sampling fissile material for comparisons to requirements with action limits for uranium (U) and plutonium (Pu); (e.g., Pu to metals loading ratio and $U_{Fissile}$ to U_{Total} ratio). These tests will use both the Small-Scale Mixing Demonstration and Remote Sampler Demonstration test platforms used in previous Waste Feed Delivery Mixing and Sampling Program test activities; however, the operating conditions and simulants tested will be expanded to collect additional performance data.

For each test activity covered in this test plan, the test objectives along with success criteria are identified. The necessary equipment to conduct the tests and collect the necessary data is identified and described. The simulants that are appropriate for testing are identified and qualified in accordance with the recommendations in RPP-PLAN-51625, *Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing*. Testing with different simulants is included to explore the capabilities of the individual systems. Because the test objectives for the Small-Scale Mixing Demonstration scaled performance and

Remote Sampler Demonstration system performance activities are similar, the test matrices evaluate similar test conditions (e.g., base simulant components, supernatant properties, and mass loadings). The most important properties identified for scaled/system performance work include variations to: mixer jet nozzle velocity (Small-Scale Mixing Demonstration only), transfer pump capture velocity (Small-Scale Mixing Demonstration only), Newtonian slurry solids simulant composition, supernatant density and viscosity, Newtonian solid simulant mass loading, and the Bingham plastic yield stress of a non-Newtonian slurry simulant.

Small-Scale Mixing Demonstration scaled performance testing will be conducted to:

- Use Newtonian simulants in the 1:8- and 1:21-scale Small-Scale Mixing Demonstration platform to build confidence in the pre-transfer sampling representativeness and the predictions of full-scale performance.

- Evaluate the suitability of using the scaled relationship determined for Newtonian slurries to mobilized non-Newtonian slurries.

Mixing and transfer data at two scales will be collected and analyzed to increase the confidence in the scale up relationship for mixing, sampling, and transfer. Specifically, thirty tests, including replicates and verification runs, will be conducted in the 1:21 and 1:8 scale mixing tanks in the Small-Scale Mixing Demonstration test platform. Scaled testing will be conducted with five different nozzle velocities, three different transfer pump capture velocities, two different Newtonian simulant compositions, and three different supernatant compositions. Scaled testing will also be conducted using a non-Newtonian simulant at four different nozzle velocities.

Remote Sampler Demonstration system performance testing will be conducted to:

- Demonstrate, with different simulant compositions (Newtonian and non-Newtonian), the capability of the Isolok® Sampler to collect representative samples in the vertical configuration.

- Demonstrate the Ultrasonic PulseEcho system for monitoring bulk solids settling in the flow loop.

- Define operational steps for the Isolok® Sampler and describe functional requirements for supporting systems necessary for field deployment.

Remote Sampler Demonstration test data will be collected and analyzed to provide additional confidence in the systems capabilities to sample a wider range of Hanford waste characteristics. System testing includes 15 tests that include different combinations of two Newtonian simulant compositions, two solids loadings, and three supernatant compositions. System testing will also include non-Newtonian simulants with two different Bingham plastic yield stresses. Testing will also include the Ultrasonic PulseEcho system that detects bulk particle settling in the flow loop and can be used to determine critical settling velocities of the transferable slurry.

CONTENTS

FIGURES

TABLES

TERMS

Abbreviations and Acronyms

ASME	American Society of Mechanical Engineers
BNI	Bechtel National, Inc.
DOE	U.S. Department of Energy
DNFSB	Defense Nuclear Facilities Safety Board
DST	double-shell tank
DQO	data quality objective
HLW	high-level waste
ICD	Interface Control Document
MDT	SRNL mixing demonstration tank
ORP	Office of River Protection
Pu	plutonium
PNNL	Pacific Northwest National Laboratory
RPP	River Protection Project
RSD	Remote Sampler Demonstration
SF	scale factor
SRNL	Savannah River National Laboratory
SSMD	Small-Scale Mixing Demonstration
TOC	Tank Operations Contract
UPE	Ultrasonic Pulse Echo system
U	uranium
WC	Tungsten carbide grit
WAC	waste acceptance criteria
WFD	Waste Feed Delivery
WRPS	Washington River Protection Solutions, LLC
WTP	Hanford Waste Treatment and Immobilization Plant

Units

°C	degrees Celsius
cP	centipoise
ft	feet
in	inch
g	gram
gpm	gallons per minute
l	liter
Hz	hertz
MHz	megahertz
ml	milliliter
Pa	Pascal
s	second

1.0 INTRODUCTION

1.1 INTRODUCTION

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 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-12-64 and TOC-12-65 per the TFC-PLN-39, Rev. G, *Risk Management Plan*, which address sampling methods and emerging changes to WAC requirements. The root of the mixing and sampling risk is the ability to collect samples that are characteristic of the tank waste, including the rapidly settling solids in the HLW for the purpose of demonstrating compliance with the WTP waste acceptance requirements. In addition, in November 2011, the U.S. Department of Energy (DOE) issued the implementation plan for the Defense Nuclear Facility Safety Board (DNFSB) Recommendation 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.

Report RPP-PLAN-41807, *Waste Feed Delivery Mixing and Sampling Program Plan and Test Requirements* defines the three test requirements for continued the WFD Mixing and Sampling Program testing to address DNFSB concerns as follows:

- Limits of performance - determine the range of waste physical properties that can be mixed, sampled, and transported under varying modes of operation. These tests will use both the Remote Sampler Demonstration (RSD) platform and the Small-Scale Mixing Demonstration (SSMD) platform. In addition, a test using a full-scale slurry transfer pump will be performed.
- Solids accumulation - perform scaled testing to understand the accumulation and distribution of the remaining solids in a double-shell tank (DST) during multiple fill, mix, and transfer operations that are typical of the HLW feed delivery mission. These tests include activities at the Savannah River National Laboratory (SRNL) Mixing Demonstration Tank (MDT) and the SSMD platform.
- Scaled/system performance - demonstrate mixing, sampling, and transfer performance using a realistic simulant representing a broad spectrum of Hanford waste to meet WTP WAC Data Quality Objectives (DQO) sampling confidence requirements. These tests will use both the SSMD and the RSD platforms. The RSD platform is full scale; therefore, RSD system performance testing activities will collect additional system performance data at full scale.

This represents a broadening of objectives from earlier SSMD and RSD testing. The simulants and operating conditions in this earlier testing were intended to simulate the particle size, density distribution, and operating configuration of Hanford DST 241-AY-102, the first tank waste to be delivered to WTP. The particle size distribution for the SSMD simulant for DST 241-AY-102 (1% is 0.39 microns, 50% is 13.2 microns, 95% is 200 microns, and 99% is 394 microns) is

documented in PNNL-20637, *Comparison of Waste Feed Delivery Small-Scale Mixing Demonstration Simulant to Hanford Waste*. The range of particle sizes in the simulant was smaller than the particle size distribution for the 95% confidence limit for 95% of the population (1% is 2 microns, 50% is 22 microns, 95% is 460 microns, and 99% is 700 microns) used in the waste feed transfer system analysis used in the WTP design basis, RPP-9805, *Values of Particle Size, Particle Density, and Slurry Viscosity to Use in Waste Feed Delivery Transfer System Analysis*. Simulants and operating conditions will need to be developed to represent the complete range of physical properties for the broader spectrum of Hanford waste tanks, and to address specific testing requirements summarized above.

The TOC will conduct tests to determine the range of waste physical properties that can be retrieved and transferred to WTP, and determine the capability of tank farm staging tank sampling systems to provide samples that will characterize the tank waste to determine compliance with the WAC. These tests will reduce the technical risk associated with the overall mixing, sampling, and transferring of HLW feed to WTP so that all WAC requirements are met.

This test plan is the second of three test plan documents that will be prepared to address DNFSB 2010-2 Sub-Recommendation Commitment 5.5.3.6, "Test Plan to establish Tank Farm performance capability". The first, RPP-PLAN-52005, *One System Waste Feed Delivery Mixing and Sampling Program Limits of Performance and Solids Accumulation Scouting Studies Test Plan* addresses the technical approach and test requirements for the SSMD Limits of Performance, RSD Limits of Performance, Full-Scale Transfer Pump Limits of Performance, and SSMD Solids Accumulation Scouting Studies being performed to support feed delivery to the WTP. This test plan identifies and describes the test objectives, test requirements, and test methods for the SSMD Scaled Performance and RSD System Performance test activities. The testing approach is guided by input from internal subject matter experts and external consultants familiar with the objectives of the test program (WRPS-1105293, *Small-Scale Mixing Demonstration Optimization Workshop Meeting Minutes* and WRPS-1201374-OS, *One System DNFSB 2010-2 Sub-Recommendation 5 Test Plan Summit Meeting Minutes*). The third test plan will cover additional testing related to the accumulation of solids in a waste feed tank. Additional information is being generated as part of parallel work that may result in further refinements to the test program. This parallel work includes Commitment 5.5.3.2, which estimates, based on current information, the range of waste physical properties that can be transferred to WTP and Commitments 5.7.3.1 and 5.7.3.4, which identify potential new WAC requirements based on known technical issues, preliminary documented safety analyses, and process capabilities and compatibilities.

1.2 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* (also known as ICD-19). 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.

The objective of the WFD Mixing and Sampling Program continues to be the mitigation of the technical risks associated with the ability of the tank farms WFD systems to mix and sample HLW feed adequately to meet the WTP WAC. Initial work for the SSMD and RSD projects has demonstrated the concept functionality for the first feed tank to deliver consistent feed delivery batches. However, uncertainties related to scale-up, simulant representativeness, data uncertainty, optimizing system performance, applicability to all feed tanks, feed conditioning, and understanding emerging WTP solids handling risks still need to be addressed.

DNFSB Recommendation 2010-2 has raised WTP safety issues related to tank farms ability to mix, sample, and transfer solids. In response, DOE developed an implementation plan to resolve these issues (DOE Rev. 0 2010-2). As discussed in Section 1.0, this test plan is one of multiple test plan documents that will be prepared to address Commitment 5.5.3.6 of the Implementation Plan. This test plan is being prepared to address any outstanding key uncertainties pertaining to the bounds of the SSMD and RSD equipment performance identified during the TOC Mixing and Sampling workshop held in Richland, Washington October 10–12, 2011 (WRPS-1105293).

To ensure that tank farms and WTP mixing and sampling systems are integrated and compatible (i.e., execution of the One System approach) and that the uncertainties identified to date are addressed, the WFD Mixing and Sampling Program has been expanded to include the following:

- Define DST mixing, sampling, and transfer system limits of performance with respect to the ability to transfer waste to the WTP that exceeds any limitations of the WTP mixing and transfer systems. The capability of the Tank Farm's WFD system, including a consideration of data uncertainty, will be characterized using simulants with varying physical properties that are important to mixing, sampling and transfer (solid particulates sizes and densities, yield stress, and viscosity), and may not be properties that will be directly measured and compared to WAC requirements.
- Define 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 (see Section 3.3.4 for definition) slurry samples and in-line critical velocity measurements from a fully mixed waste feed staging tank.
- Develop sufficient data and methodology to predict full-scale DST mixing, sampling, and transfer system performance confidently; such that a gap analysis against WTP feed receipt system performance can be completed adequately.

The first task listed above is the subject of the test plan RPP-PLAN-52005. Initial work supporting the second task is also included in RPP-PLAN-52005 and follow-on work will be documented in a subsequent test plan. The latter two tasks are the subject of this test plan.

2.0 SCOPE

The original objective of the 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 WAC. Testing focuses on the ability to achieve adequate mixing and representative sampling and on minimizing variability between batches transferred to WTP. Testing to date (RPP-49740, *Small-Scale Mixing Demonstration Sampling and Batch Transfers Results Report*) has demonstrated the potential ability to adequately mix, deliver, and sample DST 241-AY-102 simulated waste using prototypic DST mixing and transfer systems. However, waste in DST 241-AY-102 did not represent the most challenging waste expected over the feed delivery mission and testing using simulants representing more challenging wastes will be conducted.

While test data collected to date has provided some insight to mixing, sampling, and transfer performance (e.g., RPP-50557, *Tank Waste Mixing and Sampling Update*), more data is needed to predict full-scale performance that covers the range of physical properties of Hanford waste confidently. The objective of SSMD scaled performance activities is to test mixing and transfer performance at two scales using simulants representing a broad spectrum of Hanford waste to meet WTP WAC DQO sampling confidence requirements. Testing will continue to be performed at two scales in accordance the recommendations developed at the initial planning workshop, which provided guidance that a decision regarding a third scale should be held until after performance at the smaller scales is demonstrated (Section 4.2 of RPT-1741-0001, *Tank Farm Mixing Demonstration Planning Workshop*). The objective of RSD system performance activities is to evaluate the performance of the RSD, including the Isolok[1]® Sampler system and Ultrasonic PulseEcho system Ultrasonic Pulse Echo system (UPE) in a configuration that addresses field deployment constraints.

The current WFD Mixing and Sampling Program being executed to address the issues is being performed in a phased approach that will:

- Demonstrate the tank farms capability to mix, sample, and transfer HLW
- Demonstrate the viability of systems to meet waste acceptance requirements in small-scale or full-scale environments, and upon successful demonstration
- Exhibit system capability in a full-scale DST (i.e., a DST that will be providing hot commissioning feed to WTP).

Three major areas of testing that will be executed by the WFD Mixing and Sampling Program to demonstrate capability and viability include limits of performance, solids accumulation, and scaled/system performance. The test requirements for all limits of performance scope and the initial solids accumulation development work are described in RPP-PLAN-52005. This test plan documents the test requirements for the SSMD scaled performance and RSD system performance activities. A subsequent test plan will provide the test requirements for SSMD solids accumulation performance evaluation scope.

Isolok® is a registered trademark of the Sentry Equipment Corp. of Oconomowoc, Wisconsin.

Figure 2-1 shows test sequence and portrays how information learned from early testing activities is used to develop the test plans for subsequent scope.

This plan defines test requirements to address Tank Farm mixing, sampling, characterization, and transfer system capability, to predict full-scale performance and demonstrate the capability of the RSD to collect representative waste samples to meet the expanded requirements associated with DNFSB Recommendation 2010-2. Testing will be performed with Hanford waste simulants that approach or exceed ICD-19 WAC action levels in terms of bulk density, solids loading, yield stress, and slurry viscosity. Testing with simulants that approach the WTP design basis ensures that the system is capable of identifying waste that may be outside the envelope of acceptance. Testing will also be performed with slurries containing dense particles (8 mg/l) having particles sizes exceeding 100 microns for assessing the capability of sampling fissile material for comparisons to ICD-19 requirements with action limits for U and Pu (e.g., Pu to metals loading ratio and $U_{Fissile}$ to U_{Total} ratio). As described in RPP-PLAN-41807, the objectives of the test activities are to develop a scaling relationship to predict full-scale performance and determine the range of waste physical properties that can be retrieved and transferred to the WTP. They will also determine the capability of the tank farm staging, tank sampling systems to obtain samples that can be characterized to assess the bounding physical properties important for the WAC.

The Waste Feed Delivery (WFD) Mixing and Sampling Program testing is evaluating the feasibility of a baseline design for waste feed delivery. Testing is developmental and is not evaluating a field deployable design against specific functional characteristics and performance requirements. Testing is performed in accordance with Phase I testing described in TFC-PLAN-90, *Technology Development Management Plan*. Phase I development testing addresses a TOC technology need when existing processes are inadequate, inefficient, or not proven for the intended application. During Phase I testing functional criteria and performance requirements for the promising technology are defined, a prototype working model is constructed, and the prototype is evaluated against the performance criteria. Phase I development implements a graded application of the quality assurance program requirements. Upon successful completion of Phase I testing, which may be an iterative process, additional development (Phase II) may be pursued. Phase II development and testing is performed to a higher quality assurance standard and invokes TOC approved procedures and quality assurance requirements for design control, including design verification, and qualification testing. The WFD Mixing and Sampling Program test planning, test review, test control, and test results reporting requirements are communicated through this test plan and are guided by testing principles described in TFC-ENG-DESIGN-C-18, *Testing Practices*. The WFD Mixing and Sampling Program testing falls outside the scope of TFC-PLAN-26, *Test Program Plan*, which defines additional requirements for oversight, development, and the conduct of factory acceptance, construction acceptance, and operational acceptance tests for demonstrating the operability and integrity of new or modified tank farm facilities and systems.

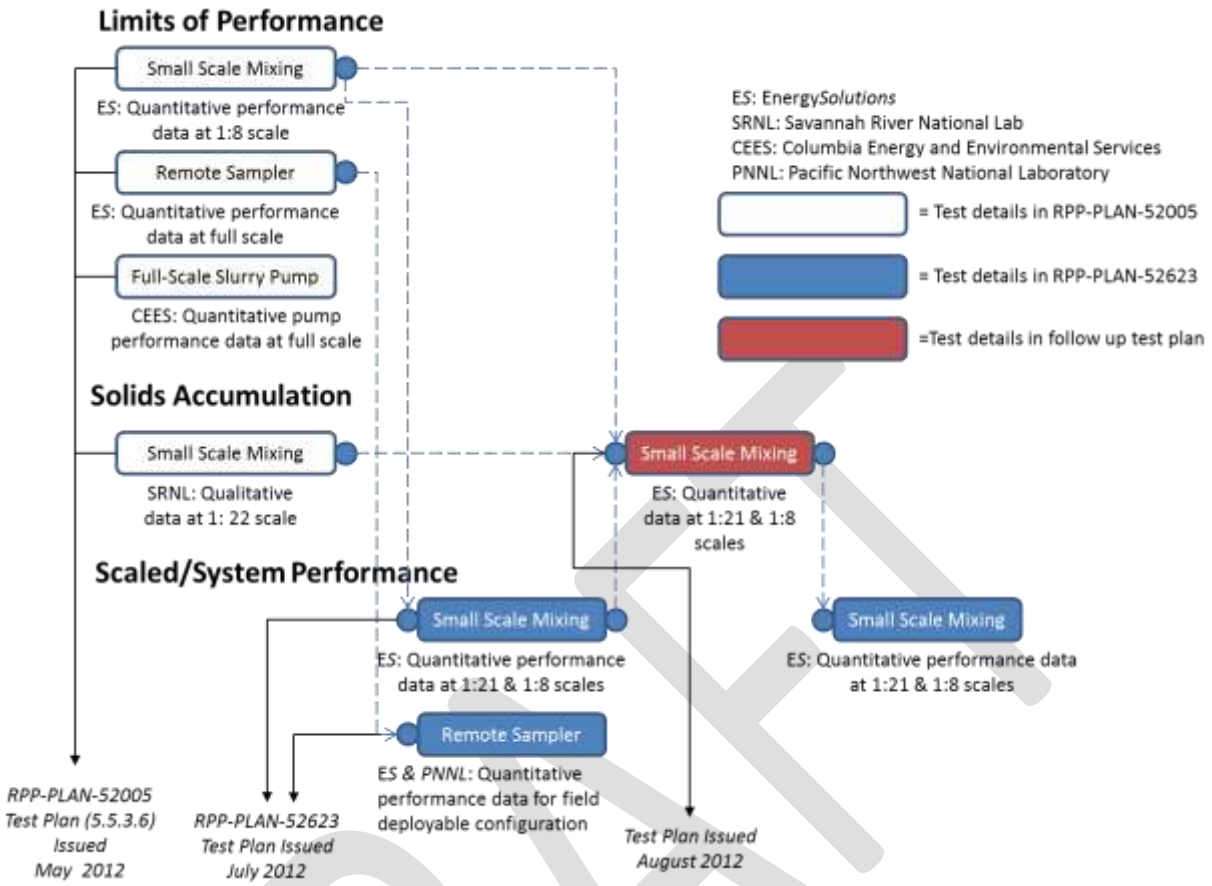


Figure 2-1. WFD Mixing and Sampling Program Test Sequence

2.1 SMALL-SCALE MIXING DEMONSTRATION SCALED PERFORMANCE TEST OBJECTIVES

The overall objective of the WFD Mixing and Sampling Program is to build confidence in the capability of the full-scale mixing and transfer system to deliver feed batches that are consistent with pre-transfer samples collected to characterize the feed. The SSMD scaled performance testing will extend previous work using simulants that are more representative of a broader distribution of Hanford tank wastes. In order to achieve this objective, small scale mixing and transfer testing will be conducted to collect the data necessary to build confidence in the mixing and transfer scaling relationship (Equation 3-8 in Section 3.2.1). Specifically, chemical composition data for each of five transfer batches will be collected at two different scales. Multiple tests, varying the mixer jet pump nozzle velocity, the simulant composition and/or the transfer pump capture velocity (also known as suction velocity or the average velocity across the pump suction inlet opening) will be performed at each scale. The batch composition data will then be converted into a metric for evaluating batch consistency with the pre-transfer sample. This metric will then be fit to an empirical model that includes a functional dependency on the varied parameters and will incorporate the theoretical scaling model shown in Equation 3-8 in Section 3.2.1. The scaling relationship is determined when the models predict equivalent performance, as related to batch consistency with the pre-transfer sample or other performance metric.

Using the SSMD test platform, which includes both a 1:21 and 1:8-scale mixing and transfer system (see Figure 2-2), a series of tests will be conducted at two scales and batch transfer data, including the chemical composition of each transfer batch, will be collected and analyzed to improve the knowledge and understanding of the scaled mixing systems. The primary performance metric that will be evaluated is transfer batch chemical composition consistency with the pre-transfer samples that are collected to characterize the transferrable slurry. Additionally, system performance information related to limits of performance and solids accumulation (e.g., effective cleaning radius, dimensions of the mounding solids in the "dead-zone(s)", and cloud height) will also be collected for each test condition to support DNFSB 2010-2 Deliverable 5.5.3.1, *Initial gap analysis between WTP WAC and tank farm sampling and transfer capability*. The test objectives are summarized in Table 2-1.

Additionally, tests using a non-Newtonian simulant that includes solids represented in the Newtonian slurry (e.g., stainless steel and zirconium oxide) will be conducted and batch transfer data for the added solids will be collected. The data will be analyzed to determine if the scaled relationship developed for the Newtonian slurry is suitable for predicting full-scale performance of non-Newtonian slurry that is mobilized during mixing and transfer.

Test plan details, including a discussion of the requirements for test equipment, simulants, operating parameters, test matrix, sample collection, and data analysis are provided in Section 3.2.

Table 2-1. Small-Scale Mixing Demonstration Scaled Performance Test Objectives

Objective	Success Criteria
Use Newtonian simulants in the 1:8- and 1:21-scale SSMD platform to build confidence in the pre-transfer sampling representativeness and the predictions of full-scale performance.	Mixing and transfer tests are performed with Newtonian slurries at multiple jet nozzle velocities. The slurry contains moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste. These particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Mixing and transfer tests are performed with Newtonian slurries at multiple jet nozzle velocities with variations in the base (solids) simulant, supernatant compositions, and transfer pump capture velocities. Performance data (i.e., sample composition of each transfer batch) is collected at two scales and is used to refine the scaling relationship for the integrated mixer jet pump and slurry transfer system. The sensitivity of the scaling relationship to the varied parameters is evaluated. The scaling relationship is refined and used to predict waste transfer performance at full-scale.
Use non-Newtonian simulants in the 1:8- and 1:21-scale SSMD platform to evaluate the suitability of using the scaled relationship determined for Newtonian slurries to mobilized non-Newtonian slurries.	Mixing and transfer tests are performed with non-Newtonian slurries at multiple jet nozzle velocities. Additional solids, including moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste are added to the slurry. These particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Performance data (i.e., sample composition of each transfer batch) is collected at two scales and is used to evaluate the suitability of the scaling relationship developed for Newtonian slurries to mobilized non-Newtonian slurries.

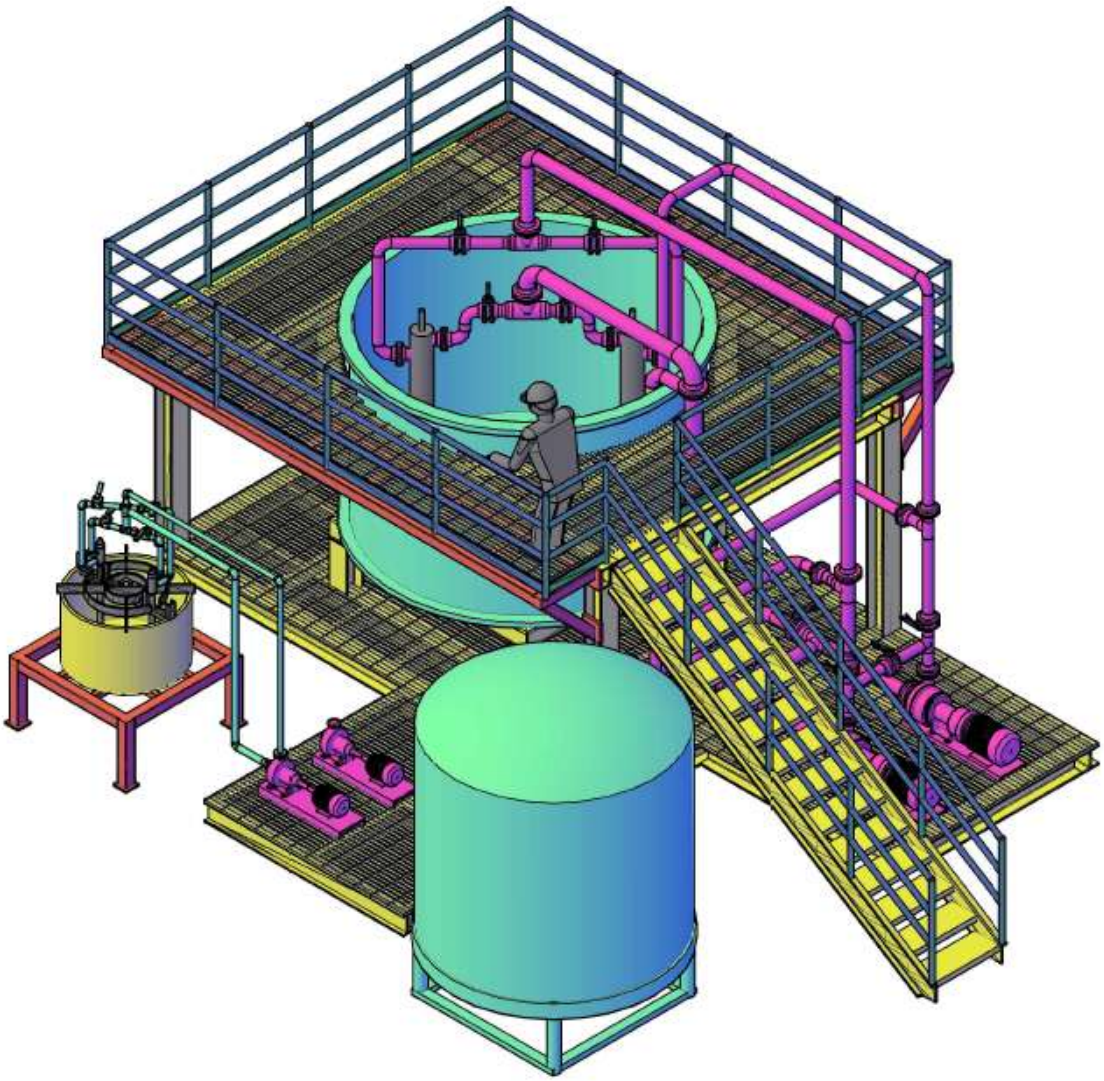


Figure 2-2. Schematic of Small-Scale Mixing Demonstration Test Platform

2.2 REMOTE SAMPLER DEMONSTRATION SYSTEM PERFORMANCE TEST OBJECTIVES

While the SSMD test activities support the overall objective of the WFD Mixing and Sampling Program to build confidence in the capability of the full-scale mixing and transfer system to deliver feed batches, the RSD test activities are performed to build confidence that the collected pre-transfer samples are *representative* (see Section 3.3.4 for explanation of *representative*) of the feed. The objective of RSD system performance activities is to evaluate the performance of the RSD, including the UPE, with simulants that represent a broader distribution of Hanford tank wastes.

The objective of RSD system performance test activities is to continue to optimize the RSD configuration of the Isolok® Sampler system (see Figure 2-3) to demonstrate the ability of the sampler to obtain samples that have the same content as the slurry within the waste characterization flow loop. Operating parameters that will be investigated include variations in simulant composition (base solids and supernatant) and simulant mass loading. Additionally, RSD system performance testing will use the UPE with the 10 MHz transducer for monitoring bulk solids settling (i.e., the onset of critical velocity) in the flow loop. Using transparent sections located both upstream and downstream of the UPE (transparent sections are not shown in Figure 2-3), bulk particle settling will also be visually observed to evaluate the performance accuracy of the UPE. Critical velocity evaluations will expand upon testing performed during RSD limits of performance testing (RPP-PLAN-52005). In addition, the system design will be evaluated against field deployable constraints and limitations.

The test objectives are summarized in Table 2-2.

Table 2-2: Remote Sampler Demonstration System Performance Test Objectives

Objective	Success Criteria
Demonstrate, with different simulant compositions (Newtonian and non-Newtonian), the capability of the Isolok® Sampler to collect representative samples in the vertical configuration.	Isolok® sampling tests in the vertical configuration are performed in the RSD flow loop with a base simulant that contains moderately sized (approximately 100 microns), dense particles to represent hard to transfer waste particles in the Hanford tank waste, a supernatant simulant and some challenging spike particles. Base and spike particles are distinguishable in collected samples by a physical or chemical property that can be exploited for separation and subsequent quantification. Collected samples are analyzed for chemical composition and quantified relative to a full diversion sample. Sampler performance is evaluated by comparing the mean square of the sampling error to a standard of representativeness of 10% relative to the full diversion samples. Correlations relating the relative difference between the Isolok® samples and full diversion samples are evaluated with respect to the changes in the test conditions (i.e., variations in the liquid and solid simulant composition and loading).
Demonstrate the Ultrasonic PulseEcho system for monitoring bulk solids settling in the flow loop.	Identify critical velocity of simulants based on bulk particle settling as detected by the Pacific Northwest National Laboratory (PNNL) Ultrasonic PulseEcho system and visual monitoring of the settled slurry in the adjacent transparent sections. The critical settling velocity determined visually and using the Ultrasonic PulseEcho system are within 0.3 ft/s for critical settling velocities exceeding 2 ft/s.
Define operational steps for the Isolok® Sampler and describe functional requirements for supporting systems necessary for field deployment.	Develop operational protocols for the Isolok® Sampler system that allow consistent and integrated sample collection of HLW slurries coming from a mixed DST, and document results in a report. Identify field deployment considerations for the remote sampling system, based on the experience gained during the RSD activities.

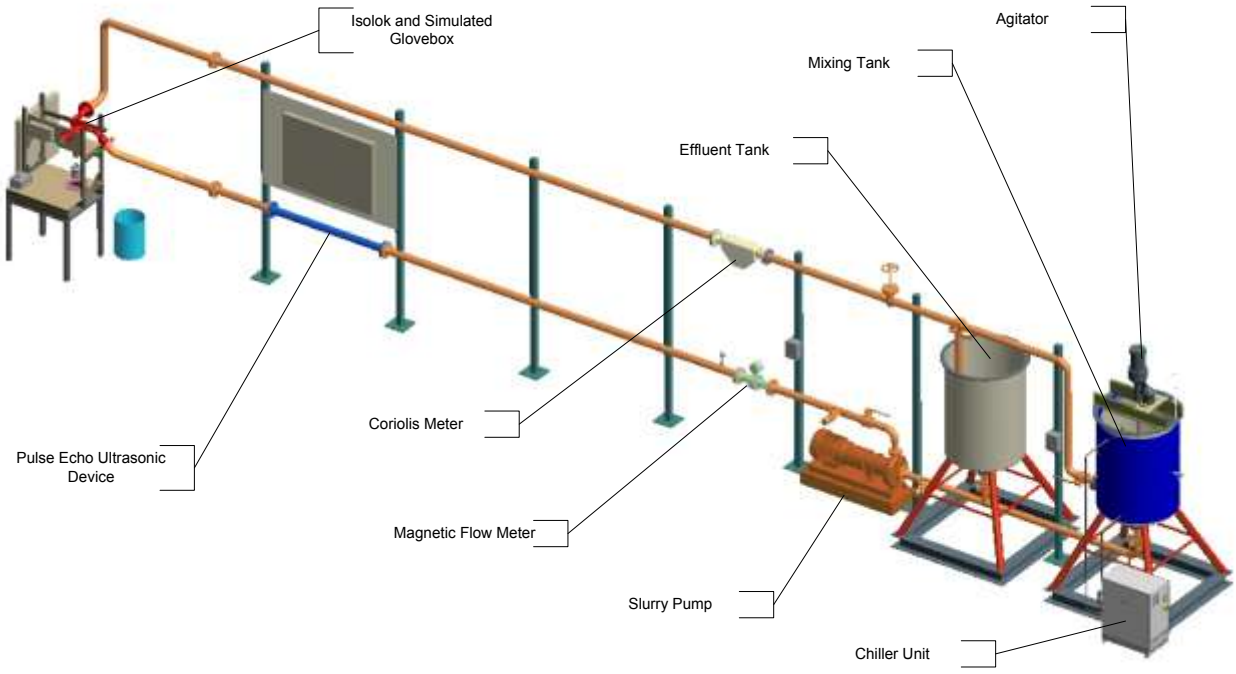


Figure 2-3. Schematic of Remote Sampler Demonstration Test Platform

3.0 TEST REQUIREMENTS

Test requirements and test guidance have been developed to meet the SSMD scaled performance and RSD system performance test objectives identified in Section 2.0.

In addition to this test plan, each testing contractor will develop operational procedures that include or reference the test configuration, test objectives, test requirements, and provisions for assuring that prerequisites and suitable environmental conditions are met, adequate instrumentation is available and operational, and that necessary monitoring is performed.

3.1 TEST SIMULANTS

The capability gap between the TOC and the WTP is defined by the TOC's capability to mix, sample, and transfer large and dense particles, and the WTP's capability to process these particles. Therefore, integral with defining the gap in capabilities is the selection of appropriately complex simulants, integrated with WTP simulant selection, and supported by accurate analytical techniques to characterize the material of interest. The Hanford waste simulants for DNFSB 2010-2 testing are developed and described in RPP-PLAN-51625. As detailed in RPP-PLAN-51625, particle size and density are expected to be the most important solids properties for predicting system performance. Liquid density and viscosity are expected to be important liquid phase properties. Unlike previous limits of performance test activities described in RPP-PLAN-52005, which included irregularly shaped base simulant particles and very large and dense spherical spike particles, the particles used in the scaled and system performance test activities are generally irregularly shaped base simulant particles.

The simulants used for SSMD scaled performance and RSD system performance test activities are consistent with DNFSB 2010-2 testing performed in accordance with RPP-PLAN-52005. Simulant selection considers parameters (e.g., particle size, density, viscosity, and yield stress) important to mixing, sampling, and transfer performance. Simulant properties such as hardness and abrasiveness, which are important to evaluating erosion and wear of the tank and pipe walls and the mixing and transfer equipment, are not primary considerations for understanding the capability of the system to mix, sample, and transfer slurries characteristic of Hanford tank waste. However, simulant selection does favor materials that result in less wear on the test equipment when alternatives that match the critical characteristics are available.

Although SSMD and RSD testing is Phase I technology development and generally performed to the subcontractors own quality assurance procedures, simulant procurement, preparation, and simulant property data collection are performed to enhanced quality assurance standards as defined in TFC-ESHQ-Q_ADM-C-01, *Graded Quality Assurance*. As such, additional level of controls beyond the providers published or stated attributes of the item, service, or process are needed to verify critical attributes of the simulants. Simulant materials procured as commercial grade items shall be prepared and qualified to match the critical characteristics of the simulants. The critical characteristics for the Newtonian base simulant materials are the particle size distribution and density of the materials. The particle size distributions and densities of the components in the composite slurry are used to calculate performance metrics (e.g., distribution of Archimedes numbers) for the composite to qualify the simulant for use. For the supernatant, the critical characteristics are the liquid density and liquid viscosity. For non-Newtonian

simulants the critical characteristics are the Bingham plastic yield stress and density. Bingham plastic consistency (i.e., plastic viscosity) is a secondary characteristic that is measured and reported. To qualify the supernatant and non-Newtonian slurry for use, the critical characteristics will be measured when the simulant batches are prepared.

Newtonian simulant batches of base material and supernatant are prepared according to prepared recipes. By specifying the mass fraction of each solids component, the density of each solids component, the density of the supernatant, the solids loading, and the batch volume, the required amounts of each solids component are fully defined. Supernatant and non-Newtonian slurry recipes are determined from test batches prepared to match the critical characteristics. The base simulant and supernatant simulant for Newtonian simulants and the non-Newtonian simulant described in this test plan are described below. Selection and justification of the simulants to be used in each test activity are provided in the test requirements for each test activity.

3.1.1 Base Simulant

As discussed in RPP-PLAN-51625, during simulant development for DNFSB 2010-2 test activities metrics were selected that are relevant to mixing and sampling and are similar to the metrics for the Hanford tank waste. The calculated values for the metrics are not used to set operating conditions for testing; metric comparisons are only used to demonstrate that the developed simulants are similar to the Hanford tank waste.

3.1.1.1 Base Simulant Description

The base simulant is the mixture of solid particles in the Newtonian slurry representing the Hanford tank waste. Report RPP-PLAN-51625 recommends three base simulants for WFD Mixing and Sampling Program test activities, low conceptual, typical conceptual, and high conceptual. The low conceptual base simulant is a single component base composed of gibbsite particles. As described in RPP-PLAN-51625, the low conceptual simulant is similar to the least challenging waste with respect to the distribution of Archimedes numbers and jet velocity needed to achieve complete solids suspension. Considering these same two metrics, the high conceptual simulant is more challenging than most of the measured waste and the typical conceptual simulant is in between these two and is similar to much more of the waste. The typical conceptual and high conceptual base simulants are complex (i.e., multicomponent mixtures) simulants composed of gibbsite particles, sand particles, zirconium oxide particles, and stainless steel particles. Differences in recommended particle sizes of gibbsite and sand, as well as differences in the mass fractions of each component mixture distinguish the typical and high conceptual simulants. Table 3-1 provides the composition of the base simulants recommended in RPP-PLAN-51625. The selected base simulant used in each test is specific to the objective of the test and justified in the Test Simulants sections (Sections 3.2.3 and 3.3.2) of the test plan.

In addition, following the recommendations in RPP-PLAN-51625, tests will also be performed using non-Newtonian slurry with a Bingham plastic yield stress between 3 and 10 Pa. Tests requiringnon-Newtonian, cohesive slurry will be made from kaolin clay. Based on initial laboratory work performed to develop simulant recipes at lab scale quantities and test batches prepared in the 43.2-inch diameter SSMD test vessel, a non-Newtonian slurry with a yield stress of 3 Pa and a density of about 1.16 g/ml is obtained by adding 22 wt%) kaolin clay to tap water.

A non-Newtonian slurry with a Bingham plastic yield stress of 10 Pa and a density of about 1.22 g/ml is obtained by adding 28 wt % kaolin clay to tap water. The method of mixing the kaolin into the simulant liquid has a big effect on the resulting simulant properties. Therefore, test samples shall be prepared to confirm the simulant preparation technique, simulant makeup, and the critical properties (i.e., the yield stress and density) of the test batch prior to testing. In addition, the Bingham plastic consistency shall also be measured and reported. Table 3-1 includes the properties for the non-Newtonian simulant. For a non-Newtonian slurry with a yield stress of 3 Pa and a higher density, sodium thiosulfate at 24-wt % can be added to 16-wt % kaolin clay in tap water. For a non-Newtonian slurry with a yield stress of 10 Pa and a higher density, sodium thiosulfate at 17-wt % can be added to 23.4 wt % kaolin clay in tap water.

Kaolin clay slurries with a targeted Bingham plastic yield stress of 3 Pa are determined to be acceptable in the range of 2 to 4.5 Pa. Slurries with a targeted Bingham plastic yield stress of 10 Pa are determined to be acceptable in the range of 7 to 13 Pa. This is based on the time-varying nature of a non-Newtonian simulant, and the necessary accuracy needed to resolve the effect of the yield stress on the capability of the system. Preparing consistent simulant batches from test to test will facilitate the analysis of the data between tests and is expected to be more important for the data analysis than performing tests at specific conditions (i.e., 3 and 10 Pa).

Table 3-1: Base Particulate Simulant Characteristics

Newtonian Base					
Compound	**Solid Density (g/ml)**	**Median Particle Size (micron)**	**Mass Fraction**		
			Low	**Typical**	**High**
Small Gibbsite	2.42	1.3	1.00	0.27	0
Large Gibbsite	2.42	10	0	0.44	0.03
Small Sand	2.65	57	0	0	0.35
Medium Sand	2.65	148	0	0.13	0
Large Sand	2.65	382	0	0	0.21
Zirconium Oxide	5.7	6	0	0.10	0.08
Stainless Steel	8.0	112	0	0.06	0.33
Non-Newtonian Base					
			Yield Stress		
			Slurry Density (g/ml)	**3 Pa**	**10 Pa**
Kaolin clay	NA	NA	~1.2	22 wt%	28 wt%
Kaolin clay w/ sodium thiosulfate	NA	NA	1.37	16 wt% Kaolin 24 wt% sodium thiosulfate	23.4 wt% Kaolin 17 wt% sodium thiosulfate

3.1.1.2 Base Simulant Qualification

As described in RPP-PLAN-51625, particle size distributions, particle density, and mass fractions of the components in the composite simulant can be used to determine the distributions of Archimedes numbers and jet velocities needed to achieve complete solids suspension for the composite simulant. As discussed in PNNL-20637 the Archimedes number is closely related to the settling velocity and is also a parameter in other mixing and transfer metrics such as pump intake, jet suspension velocity, critical shear stress for erosion, critical suspension velocity, suspended particle cloud height, and pipeline critical velocity. The calculation of the jet velocity needed to achieve complete solids suspension correlates the particle size and density to the jet velocity of a radial wall jet needed to suspend solids in a tank. Base simulant qualification is performed by comparing the distribution of Archimedes numbers and jet velocities needed to achieve complete solids suspension calculated for the procured simulants to the distributions for the recommended simulants documented in Figures 8-1 and 8-2 in RPP-PLAN-51625. To provide comparable results, performance metrics are calculated using the same assumptions used to calculate the metrics for the three conceptual simulants. Metrics are calculated using particle densities and particle size distributions obtained on samples from each procured lot. Because there is no expectation that procured material lots will not be mixed when testing is performed, particle size distributions from multiple lots of similar material may be averaged for the qualification comparisons. For commercial grade material, the particle size distribution provided by the vendor is not adequate for simulant qualification and a particle size analysis of each procured lot shall be performed. Appendix C of RPP-PLAN-51625 includes additional performance metrics, such as the critical shear stress for erosion of non-cohesive particles, just suspended impeller speed, pulse jet mixer critical suspension velocity for non-cohesive solids, pulse jet mixer cloud height for non-cohesive solids, and pipeline critical transport velocity. The procured material will also be compared to the conceptual simulants using these metrics.

The metrics calculated for the conceptual simulants in RPP-PLAN-51625 include typical distributions for some of the components. Therefore, the calculated values represent target values and deviations from the conceptual simulants are anticipated. The appropriateness of candidate material will be evaluated before simulant procurement. For procurement purposes, in absence of samples from actual lots, vendor supplied information (e.g., particle size distributions and particle density) and targeted mass fractions can be used to calculate the performance metrics for comparison to the conceptual simulants. For simulant qualification, calculations will be based on laboratory analysis of samples taken from the procured material and actual weight measurements recorded during testing.

Tests using a non-Newtonian slurry with a Bingham plastic yield stress between 3 and 10 Pa will be made from kaolin clay. The yield stress will be measured to be within the tolerances specified in Section 3.1.1.1 prior to testing. The yield stress measurements will be performed on-site with a rheometer calibrated, controlled, and maintained in accordance with American Society of Mechanical Engineers (ASME) NQA-1-2004, Requirement 12, “Control of Measuring and Test Equipment”including addenda, or a later version. Bingham parameters will be determined using a set program that controls the shear rate to generate the rheogram. The program will include a pre-shear period and two evolutions over the shear rate range. Due to the slight rheopetic nature of the Kaolin clay slurries, Bingham parameters shall be calculated using the second down curve used to generate the rheogram. Functional checks with reference standards covering the

expected range of solutions used during testing shall be performed daily to ensure that the rheometer is being properly maintained. Corrective actions, commensurate with the significance of an out-of-calibration condition, shall be performed. Appropriate instrumentation for measuring the Bingham plastic parameters of the non-Newtonian fluid is a programmable rheometer capable of taking controlled shear rate and controlled shear stress measurements. The rheometer shall also have the capability to control sample temperatures. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, "Test Control" including addenda, or a later version. Bingham parameters will be determined prior to the start of testing to ensure that the time varying qualities of the non-Newtonian slurry do not change significantly before testing is initiated. In addition, Bingham parameters will also be determined at the completion of testing and during testing if necessary, to assess rheological changes that may occur during the course of testing.

3.1.2 Supernatant Simulant

Developing the supernatant composition for DNFSB 2010-2 test activities is informed from modeling Hanford waste processes. Hanford waste process modeling includes tank inventory, accounts for retrieval technologies, waste volume reduction (i.e., evaporation), and includes inventory blending during multiple tank-to-tank transfers. Therefore, an estimate for the chemical composition of each feed batch is calculated and the results are used to select a suitable supernatant density and viscosity for DNFSB 2010-2 test activities.

3.1.2.1 Supernatant Simulant Description

The supernatant simulant is the liquid phase of the simulant slurry. For WFD Mixing and Sampling Program test activities, RPP-PLAN-51625 recommends four supernatant simulants (low density/low viscosity, low density/high viscosity, high density/low viscosity, and high density/high viscosity). These simulants are characterized by liquid density and liquid viscosity. The four supernatant characteristics are taken from Table 6-1 in RPP-PLAN-51625, which is summarized as the target simulant properties in Table 3-2. Table 3-2 also provides tested properties for simulants that have been prepared at 20°C (Centigrade) for each target simulant using non-hazardous, non-reactive components that are readily available at a reasonable cost, and in most instances have been used previously in related testing activities. These compositions are informed from chemical handbooks and previous testing, and were confirmed by preparing test batches at a laboratory scale. Due to strong temperature sensitivity, solutions that use glycerol to increase the liquid viscosity may require adjustments when the testing temperature differs from 20°C. When developing compositions for the liquid simulant, simpler combinations that matched the target density were preferred to facilitate batch production. In some instances, the preference for simpler compositions resulted in viscosity values that exceeded the target values but were considered acceptable for testing.

The targeted supernatant simulants are limiting supernatants and were developed for testing activities that attempt to mobilize large and dense particles during limits of performance testing. A supernatant that is more representative of typical Hanford supernatant is also included in Table 3-2. The liquid density for this supernatant is the median density from the same dataset used to derive the low and high density values in RPP-PLAN-51625. The dataset is the liquid density of the feed batches to the WTP calculated using the Hanford Tank Waste Operations Simulator

model (RPP-RPT-48681, *Hanford Tank Waste Operations Simulator Model Data Package for the River Protection Project System Plan Rev. 6 Cases*). The typical supernatant is characterized as having a liquid density of about 1.29 g/ml and an estimated liquid viscosity of 3.3 cP. The viscosity of the supernatant is determined by the salt(s) used to attain the desired density, and is comparable to the value determined using the relationship in Figure 6-2 of RPP-PLAN-51625. An aqueous solution of 31.5 wt % sodium thiosulfate will produce a supernatant with properties similar to the targeted simulant.

The typical supernatant listed in Table 3-2 is a preferred simulant for SSMD scaled performance and RSD system performance testing. Using a limiting supernatant, which was developed to maximize the capability of each system to mix, transfer, and sample large and dense particles, as was the objective for limits of performance testing, is not necessary for SSMD scaled performance and RSD system performance testing. However, the selected supernatant simulant used in each test is specific to the objective of the test and justified in Section 3.1,Test Simulants section of this test plan.

Table 3-2 also includes a supernatant composition that was not discussed in RPP-PLAN-51625. This supernatant is used in lieu of the high density / high viscosity supernatant when the predicted flow regime (Section 3.1.4) at the inlet of the transfer pump becomes laminar. The density and viscosity preparation tolerances for this modified high supernatant are the same those for the high density / high viscosity supernatant. The simulant can be prepared using sodium thiosulfate to adjust the density to the targeted value and then adding glycerol until the targeted viscosity is attained.

Table 3-2: Newtonian Liquid Supernatant Simulant Characteristics

Supernatant (density/viscosity)	**Target Simulant Properties @ 20°C**		**Simulant Properties @ 20°C**		**Simulant Composition**
	Density (g/ml)	**Viscosity (cP)**	**Density (g/ml)**	**Viscosity (cP)**	
Low/Low	1.1	1	1.098	1.62	12 wt% sodium thiosulfate
Low/High	1.1	8	1.135	8.03	53wt% glycerol
High/Low	1.37	1	1.370	2.00	37 wt% sodium bromide
High/High	1.37	15	1.368	14.6	33.4 wt% sodium thiosulfate and 19.5 wt% glycerol
Typical/Typical	1.29	3.3	1.284	3.60	31.5 wt% sodium thiosulfate
High / Modified High[a]	1.318	8	TBD	TBD	TBD wt% sodium thiosulfate and TBD wt% glycerol

[a] The high density supernatant with reduced viscosity is discussed in Section 3.1.4.

3.1.2.2 Supernatant Simulant Qualification

The simulant recipe for the supernatant simulant was developed in the laboratory, but will need to be scaled to the volume needed for each test. Small test batches prepared at testing temperatures should be prepared to confirm the relative amounts of each constituent needed to

match the simulant properties using the procured materials at testing conditions. Upon confirmation of the recipe, adjusted as necessary, scale up to testing volumes will be performed and the liquid density and liquid viscosity will be measured at testing temperatures to confirm that the prepared batch is within the required range for simulant density and viscosity. Preparing consistent simulant batches from test to test will facilitate the analysis of the data between tests and is expected to be more important for the data analysis than performing tests at specific conditions.

Therefore, for low density/low viscosity fluids, 1.098 g/ml and 1.62 cP, respectively, and typical density and typical viscosity fluids, 1.284 g/ml and 3.60 cP, respectively, the acceptable range of liquid densities and viscosities is ±5% and ±0.5 cP, respectively. These two liquids will be attained using a sodium salt (e.g., sodium thiosulfate). The two properties cannot be adjusted independently using the single component and a broad tolerance is allowed for liquid viscosity. For higher density and viscosity fluids, the acceptable range for the density is also ±5%. The tolerance on the liquid viscosity at levels above 5 cP is ±20% when the measurement is determined at testing temperatures. High viscosities will be attained by adding glycerol. The viscosity of glycerol is dependent on concentration and temperature, increasing as concentration increases and temperature decreases. For a specified concentration, a temperature correlation will be developed so that the viscosity at the measured temperature can be used to evaluate the viscosity at the testing temperature to determine if the prepared simulant meets the 20% tolerance on viscosity.

The liquid property measurements will be measured on-site with the appropriate instrumentation (e.g., hydrometer, viscometer, and rheometer) calibrated, controlled, and maintained in accordance with ASME NQA-1-2004, Requirement 12 including addenda, or a later version. Supernatant viscosity will be determined using a set program that controls the shear rate to generate the rheogram. The program will include a pre-shear period and two evolutions over the shear rate range. The viscosity shall be determined on the second down curve used to generate the rheogram. Functional checks with reference standards covering the expected range of solutions used during testing shall be performed daily to ensure that the instrument is being properly maintained. Corrective actions, commensurate with the significance of an out-of-calibration condition, shall be performed. Appropriate instrumentation for measuring liquid viscosity of the Newtonian fluid is a programmable rheometer capable of taking controlled shear rate and controlled shear stress measurements. The rheometer shall also have the capability to control sample temperatures. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, including addenda, or a later version. To ensure that the prepared simulant is appropriate for use, liquid properties will be measured prior to adding base simulant solids and therefore will be performed at the start of testing. In addition, viscosity will also be measured at the completion of testing, and during testing if necessary, to assess changes that may occur during the course of testing. The base solids in the samples collected during and after testing should be removed by filtering prior to collecting viscosity and density measurements.

3.1.3 Spike Particulates

Unlike limits of performance testing described in RPP-PLAN-52005, SSMD testing will not include large and dense spike particles. However, spiking the base simulant for RSD testing may

be performed based on the limits of performance test work. It is possible that large particles of average density may interfere with the Isolok® Samplers ability to collect representative samples of the base material. Testing using spike materials that can be sampled reliably by the Isolok® sampler, as determined during limits of performance testing, will be considered for RSD system performance testing.

Report RPP-PLAN-51625 recommends four materials for the spike particulates, sand, stainless steel, tungsten carbide grit (WC), and tungsten grit. Sand is a simulant for large particles that have a density comparable to the average density of Hanford waste particles. Stainless steel, tungsten carbide, and tungsten, which have densities of approximately 8 g/ml, 14 g/ml, and 19 g/ml, respectively, are simulants for high-density Pu-containing compounds [e.g., plutonium oxide (~11 g/ml)] in the Hanford tank waste. The sand and stainless steel spike particulates are chemically similar to the components in the base simulant, and therefore must be distinguishable from the base materials to be quantified. The spike materials will be distinguishable by particle size; size exclusion (e.g., sieving) will be used to separate the spike particles from the chemically similar base materials. Soda-lime glass spheres will be used as a surrogate for very large sand particles. The glass spheres are chemically inert, have a density similar to sand, but have consistent sizes in 1,000 micron increments because they are manufactured products. Having a consistent shape will facilitate separation of the spike particles from the base by sieving.

Table 3-3 identifies the spike materials for consideration during RSD system performance testing. The spike materials are a subset of the spikes considered for limits of performance testing. Preliminary limits of performance testing that is underway (conducted in accordance with RPP-PLAN-52005) indicates that the performance of the Isolok® Sampler is unacceptable when particles with diameters of approximately 3000 microns, which approaches the diameter of the internal passages of the sample needle, are present in the slurry. The tabulated particles are only for consideration; limits of performance testing may determine that other particles included in the list cannot be repeatedly sampled by the system.

The sizes of the glass, stainless steel, and tungsten carbide spike particulates in Table 3-3 are for spheres, which are readily available in the sizes listed. Consistent with recommendations in SRNL-STI-2012-00062, *Properties Important to Mixing for WTP Large Scale Integrated Testing*, spherical particles are considered because, compared to irregularly shaped particles with more surface area per volume, spherical particles would settle faster from suspensions, creating a greater challenge to sample these particles. The spike particles listed are commercially available items that have an industrial purpose and are manufactured to size tolerances that exceed the tolerances necessary to distinguish the different sized spike particles from the base solids by sieving. Commercial sources for the listed particles manufacture the particles in either 1000-micron, 1/32-inch or 1/16-inch increments with size variations that typically do not exceed several microns. Qualification of the metal spike particles is limited to demonstrating that 99% of a one pound sample taken from each delivered lot is retained on the sieves used to separate that size from the other particles. Qualification of the glass spike particles, which are manufactured to a lower tolerance for shape, is limited to demonstrating that 98% of a one pound sample taken from each delivered lot is retained on the sieves used to separate that size from the other particles.

The spike materials listed in Table 3-3 have densities characteristic of Hanford tank waste and are provided for test planning purposes; the densities of procured spike materials may be different due to differences in manufacturing processes. Table 3-3 also includes three properties that are relevant to mixing, the Archimedes number, the free settling velocity, and the particle Reynolds number. The tabulated Archimedes numbers (Ar) are calculated according to Equation 3-1. The Archimedes number indicates general settling characteristic particles with higher Archimedes values tend to settle faster than particles with lower Archimedes values. The reported values are calculated for the typical density (1.29 g/ml) and typical viscosity (3.3 cP) supernatant. The tabulated free settling velocity, V_t is calculated in the same supernatant liquid according to Equation 3-2. The free settling velocities result in particle Reynolds numbers, Re_p, (Equation 3-3) in the Intermediate Law regime (between 0.3 and 1000).

$$Ar = \frac{\left(\frac{\rho_s}{\rho_l} - 1\right) g d^3}{v^2} \tag{3-1}$$

$$V_t = \left(\frac{4gd(\rho_s - \rho_l)}{3\rho_l \left(\frac{18.5}{Re^{0.6}}\right)} \right)^{0.5} \tag{3-2}$$

$$Re_p = \frac{\rho_l V_t d}{\mu} \tag{3-3}$$

Where ρ_s is the particle density, ρ_l is the liquid density, g is the gravitational constant, d is the particle diameter, v is the kinematic viscosity of the liquid, and μ is the dynamic viscosity of the liquid. The selected spike particulates, including particle size and spike concentration, used in each test are specific to the objective of the test and justified in Section 3.1, Test Simulants section of this test plan. Alternatives to the spike materials require the concurrence with the TOC technical representative(s) before the material is procured.

Table 3-3: Remote Sampler Demonstration System Performance Simulant Spike Candidates

Compound	Solid Density (g/ml)	Characteristic Particle Size (micron)	Archimedes Number[a]	Free Settling Velocity[a] (ft/s)	Particle Reynolds Number[a]
Borosilicate Glass	2.23	1000 2000	1090 8740	0.19 0.42	23 100
Soda-Lime Glass	2.52	1000 2000	1430 11,400	0.23 0.51	27 120
Stainless Steel (SS)	8.0	1587.5 (1/16”) 2380 (3/32”)	31,200 105,000	1.3 2.1	250 590
Tungsten Carbide (WC)	14.2	1587.5 (1/16”) 2380 (3/32”)	60,000 202,000	2.1 3.3	400 940

[a] Calculated for a fluid having a liquid density of 1.29 g/ml and a viscosity of 3.3 cP.

3.1.4 Flow Regime

The flow regime within the transfer line and at the pump suction inlet is determined by the Reynolds number (*Re*) (Equation 3-4).

$$Re = \frac{\rho V D}{\mu} \tag{3-4}$$

Where: ρ and μ are the density and viscosity of the fluid, respectively, *V* is the velocity of the flow and *D* is the pipe or inlet diameter. For Newtonian fluids, the transition regime between laminar and turbulent flow is between *Re* values of 2300 and 4000. For non-Newtonian fluids, the Reynolds number for the transition regime must be calculated. The critical Reynolds number (Re_c) of transition from laminar to turbulent flow for Bingham plastic flow in pipes is determined by Equations 3-5 to 3-7 (Hanks 1963).

$$Re_c = \frac{He}{8\xi_{oc}}\left(1 - \frac{4}{3}\xi_{oc} + \frac{1}{3}\xi_{oc}^4\right) \tag{3-5}$$

$$He = \frac{D^2 \rho \tau_y}{K^2} \tag{3-6}$$

$$\frac{\xi_{oc}}{(1-\xi_{oc})^3} = \frac{He}{16{,}800} \tag{3-7}$$

Where: *He* is the Hedstrom number, ξ_{oc} is the ratio of the yield stress (τ_y) and the wall shear stress at the point of transition from laminar to turbulent flow, and *K* is the Bingham plastic viscosity, which replaces μ in Equation 3-5 when the Reynolds number is determined for Bingham Plastic fluids.

Table 3-4 shows the calculated flow regime for the proposed test conditions for SSMD Scaled Performance testing using a 13 wt% mass loading for Newtonian slurries.

For the standard operating conditions, the flow at the inlet is either transitioning from laminar to turbulent flow or fully turbulent at all scales. However, for the reduced capture velocity testing with the high density / high viscosity supernatant, the flow at the inlet for the Newtonian fluids becomes laminar in the scaled environment with Reynolds number values that drop below the transition value. In order to maintain the same pump out rate for the lower capture velocity (3.8 ft/s), the diameter of the inlet must be increased. In order to maintain flow conditions above the laminar regime, the supernatant viscosity must be reduced to 8.0 cP to keep all tests above laminar conditions. Using a linear relationship between the viscosity and density (see Figure 6-2 in RPP-PLAN-51625), the resulting density for the 8 cP supernatant is 1.318 g/ml. This additional simulant will be included in the test matrix for SSMD scaled performance when the design must be constrained to avoid laminar flow conditions. Both the cyclical jet motion and the squared corners of the pump suction inlet will increase the turbulence at the inlet. However, keeping turbulent conditions at the inlet is not attainable for the lowest capture velocity tests

when the high density/high viscosity supernatant is used. The test matrix either avoids this condition or minimizes the number of runs that are performed under these conditions.

Table 3-4: Flow Regime For Full and Scaled Systems

Scale	Inlet Size (in)	Pump Rate (gpm)	Inlet Velocity (ft/s)	Re	Re_c	Flow Regime
Typical Supernatant (Fluid Density = 1.284 g/ml, Viscosity = 3.6 cP)						
Full	2.25	140	11.3	70,200	2300	Turbulent
1:8	0.32	2.83	11.3	9,980	2300	Turbulent
1:21	0.28	2.17	11.3	8,740	2300	Turbulent
High Supernatant (Density = 1.37 g/ml, Viscosity = 14.6 cP)						
Full	2.25	140	11.3	18,500	2300	Turbulent
1:8	0.32	2.83	11.3	2,620	2300	Transition
1:21	0.28	2.17	11.3	2,300	2300	Transition
Typical Supernatant (Density = 1.284 g/ml, Viscosity = 3.6 cP)						
Full	2.25	90	7.3	45,100	2300	Turbulent
1:8	0.40	2.83	7.2	7,980	2300	Turbulent
1:21	0.35	2.17	7.2	6,990	2300	Turbulent
High Supernatant (Density = 1.37 g/ml, Viscosity = 14.6 cP)						
Full	2.25	90	7.3	11,900	2300	Turbulent
1:8	0.40	2.83	7.2	2,100	2300	Laminar
1:21	0.35	2.17	7.2	1,840	2300	Laminar
High Base/Modified High Supernatant (Density = 1.318 g/ml, Viscosity = 8.0 cP)						
Full	3.9	140	3.8	18,700	2300	Turbulent
1:8	0.55	2.83	3.8	2,680	2300	Transition
1:21	0.48	2.17	3.8	2,350	2300	Transition
Non-Newtonian with Base Solids (Density = 1.18 g/ml, Bingham Plastic Yield Stress = 3 Pa, Bingham Plastic Consistency = 5 cP)						
Full	2.25	140	11.3	46,400	11,700	Turbulent
1:8	0.32	2.83	11.3	6,600	3,270	Turbulent
1:21	0.28	2.17	11.3	5,780	3,070	Turbulent

3.2 SMALL-SCALE MIXING DEMONSTRATION SCALED PERFORMANCE

The SSMD scaled performance test activities documented in Section 3.2 are performed by Energy*Solutions* for WRPS.

The SSMD scaled performance activities described in this test plan will use the 1:21-and 1:8-scale tanks of the SSMD test platform (Figure 2-2) located at Monarch Machine & Tool Company, Inc. in Pasco, WA to evaluate the system performance when test conditions for mixing and transfer are varied. The operating parameters that will be varied during testing are

the mixer jet nozzle velocity and transfer pump capture velocity. The mixer jet rotational rate will be adjusted for each change in nozzle velocity according to Equation -3-9 in Section 3.2.1. In addition to varying the nozzle velocity, transfer pump capture velocity and mixer jet rotational rate, the simulant properties, both solids composition and supernatant composition, will also be varied and include both Newtonian and non-Newtonian slurries. Tests conducted at both scales will use the same simulant compositions so that the results from the two scales can be compared to determine velocities that result in equal performance. Velocities that result in equal performance will be used to determine the scaling relationship that will be used to predict full-scale performance.

3.2.1 Scaling Approach

The SSMD scaling approach was described in detail in test plan RPP-PLAN-52005. The scaling approach for the nozzle velocity and mixer jet pump rotational rate is unchanged and for completeness it is reproduced in Appendix A. The SSMD scaling relationship for nozzle velocity (Equation3-8) is a function of the mixer jet pump nozzle velocities for the two scaled systems, U_{jet}, the tank diameters, d_{tank}, and the scale factor exponent a. The SSMD scaled performance test activities will collect performance data at two scales to determine an appropriate value for the scale factor exponent.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{a} \tag{3-8}$$

As discussed in Section 3.2.6, a performance metric (e.g., the difference between the pre-transfer sample concentration of a component *i* and the average concentration of component *i* in each batch transfer) will be calculated for each test at each scale. Equation 3-8 will be used to determine the scale factor exponent that results in equivalent metric results between scales.

The SSMD scaling relationship for mixer jet pump rotational rates, ω_{tank}, (Equation 3-9) sets an equivalent number of mixer jet rotations in one turnover of the waste volume through the mixer jet pump. The resulting relationship is a function of the full-scale rotation rate, the geometric scaling factor (i.e., the ratio of the tank diameters), and the nozzle velocities for the two systems.

$$\omega_{tank2} = \frac{\omega_{tank1} U_{jet2}}{\left(\frac{d_{tank2}}{d_{tank1}}\right) U_{jet1}} \tag{3-9}$$

For SSMD scaled performance testing, a nozzle velocity will be selected and Equation 3-9 will be used to determine the rotational rate for the test.

3.2.2 Test Equipment and Instrumentation

Scaled performance testing will be performed using the established SSMD test platform at the Monarch Machine & Tool Company, Inc. facility in Pasco, Washington. A schematic of the

SSMD test platform is shown in Figure 2-2. The SSMD test platform has been used for previous test activities and will continue to be used to address uncertainties in the WFD Mixing and Sampling Program. The SSMD test platform was constructed to perform mixer jet pump testing at two different scales, approximately 1:21 (43.2-inch diameter tank) and 1:8 (120-inch diameter tank). Both tanks will be used for scaled performance testing so that the scaling relationship can be evaluated to predict full-scale performance. The properties of the DSTs used to geometrically scale the test tanks and the scaled properties of the two-scaled tanks are provided in Table 3-5. The plan view of DST 241-AY-102 is shown in Figure 3-1 (from H-14-010506, Sheet 4, Rev 1).

The SSMD test platform will continue to be used to assess the capability of the system to mix tank waste simulants and deliver the solids to a receipt tank. The main components of the test platform include: a 3,000-gallon flush tank, a 120-gallon (43.2-inch diameter) clear acrylic test tank (TK-201), a 2,358-gallon (120-inch diameter) clear acrylic test tank (TK-301), dual rotating mixer jet pump assemblies, and the slurry transfer pumps for both TK-201 and TK-301. Flow from the tanks enters the two mixer jet pump suction inlets on the bottom of the mixer jet pump, and is combined into one flow stream as it is routed through the pump driving the system. The pump discharge is split with half of the flow returning to each mixer jet pump. As each mixer jet pump is rotating, the flow is discharged back into the tank through two opposing jet nozzles located on the side of the mixer jet pump just above the pump suction inlet. Between scales, the mixer jet pump assemblies and transfer pumps for each tank are independent. The slurry transfer pumps are not submersible pumps located inside acrylic tanks. The slurry transfer pumps are progressive cavity pumps located outside of the test tanks; the inlets of the pump are connected to suction lines that are placed within the tanks. The end of the suction lines inside each tank is fitted with a nozzle with the desired opening, maintains this length for 1-2 inches, and then quickly transitions to the internal diameter of the transfer line, which is 3/8-inch. The suction nozzle is not fully prototypic. The non-prototypic configuration was selected as an economical alternative to developing a scaled version of the multistage submersible transfer pump and strainer, which is still being designed. The nozzle fitting is sized to achieve the desired suction and approximate, at scale, the zone of influence around the inlet of the transfer pump. The nozzle length is not intended to result in fully developed flow at the capture velocity because this is not the expected condition for flow into the full-scale submersible transfer pump, which enters through the inlet opening and is then subjected to the inner passage ways through the centrifugal pump. The exact configuration of the passage ways through the transfer pump for waste feed delivery is still under development. The desired opening is machined to match the requirements in Table 3-4 and Table 3-5. The transfer pump suction inlet shall be placed consistent with the location of Riser 30. The scaled height of the pump suction inlet shall be equivalent to the height of the transfer pump inlet in the full-scale DST transfer system, which is 0.8 inches from the tank bottom in TK-301 and 0.28 inches from the tank bottom in TK-201 (see Table 3-5). Ancillary equipment, such as the support structure, the control system, video monitoring, and simulated piping to transfer and sample the material from the tank are also part of the test platform.

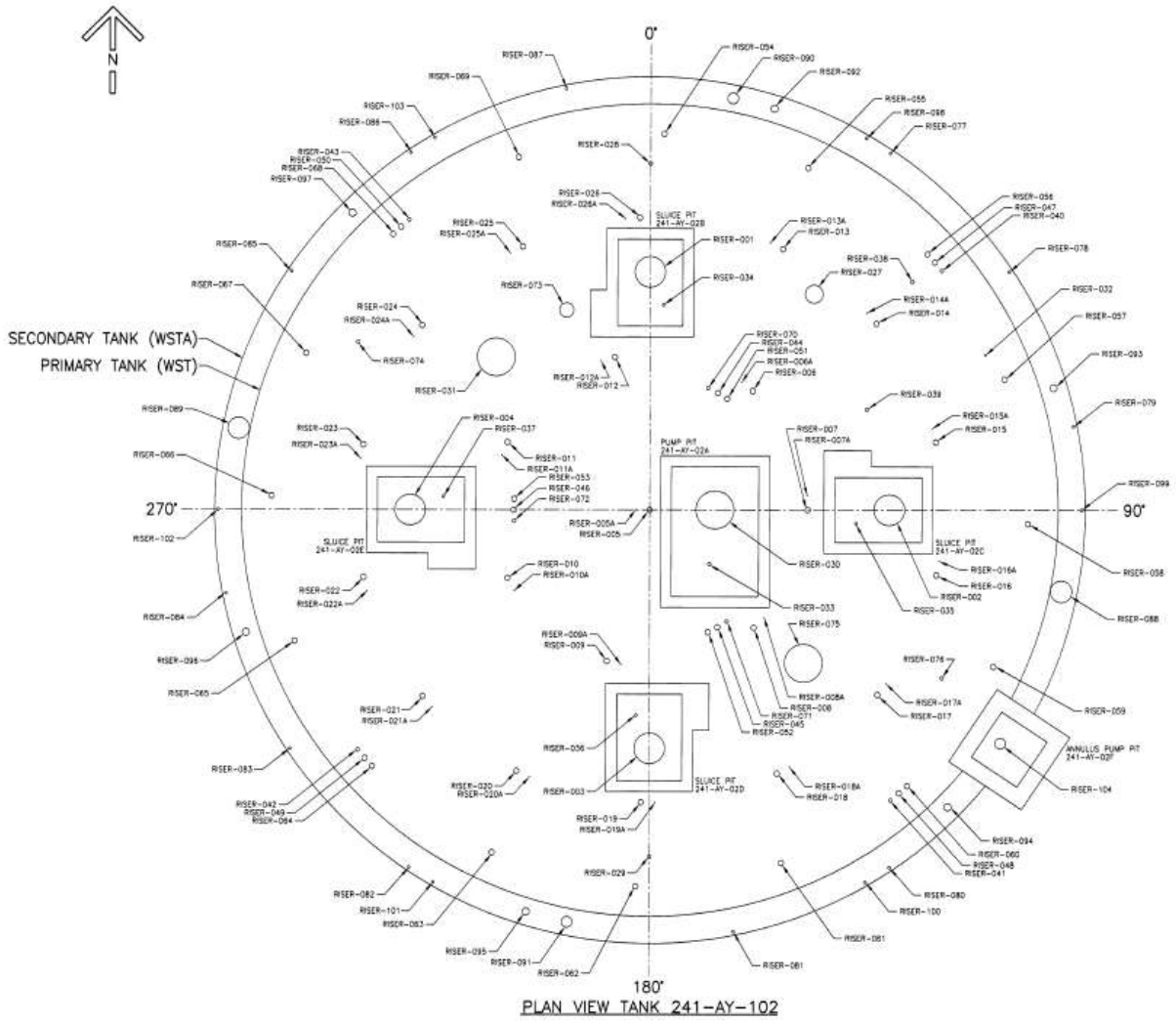
The transfer system piping, valving, and instrumentation (e.g., in-line Coriolis meters, and magnetic flow meters) will replicate the transfer system from previous SSMD testing reported in RPP-49740. The test configuration includes a closed recirculation loop from the tank. The recirculation loop accommodates sample collection. Flow control is automated using programmable logic controllers connected to a human–machine interface. System data, including date and time, slurry temperature, mixer jet pump rates and position, slurry flow rates,

tank level, and specific gravity measurements in the transfer pump discharge, will be monitored and recorded using a data acquisition system.

The internal passageways of the mixer jet pumps driving pump and the slurry transfer pump are larger than the transfer lines; therefore, particles with a high settling velocity (e.g. stainless steel powder in the base simulant) may settle in the pump because the velocity through the pump is reduced below the critical velocity of the particles. Modifications to the pump orientation to minimize the collection of particles will be evaluated. The extent that particles can collect in the transfer pump shall be evaluated in developmental testing so that this condition can be captured as a source of error. In addition, the slurry lines shall be purged in between tests to reduce the potential that settled solids from one test contaminate the results of a subsequent test.

When operating in a recycle mode to stabilize the mixing tank prior to performing batch transfers, the transfer line shall be discharged back into the tank. During batch transfer operations the transfer line shall be discharged for sample collection or waste collection.

All measuring and test equipment, including gauges and instrumentation, used for testing activities shall be controlled, calibrated under conditions typical of the test environment, adjusted, and maintained to required accuracy limits. The condition and the reported accuracy of each instrument shall be documented in a test log.



Note: Mixer jet pumps will be in Riser-001 (0°) and Riser-003 (180°). Transfer pump will be in Riser-030 (90°)

Figure 3-1. Plan View Tank 241-AY-102

Table 3-5: Small-Scale Mixing Demonstration Tank Geometrically Scaled Properties

Property	**Full-Scale DST (AY-102)**	**1:8 Scale**	**1:21 Scale**
Diameter (in)	900	120	43.2
Scale Factor	1	0.1333	0.048
Fill Height (in)	343	45.7	16.5
Bottom Geometry	Flat w/12-inch corner radius	Flat w/1.6-inch corner radius	Flat w/0.6-inch corner radius
Fill Volume1 (gallons)	944,620	~2,200	~100
Mixer Jet Pump 1 Location[2]	Riser-001 0°, 22 feet	90°, 2.9 feet	90°, 0.96 feet (12.7 in as-built)
Mixer Jet Pump 2 Location[2]	Riser-003 180°, 22 feet	270°, 2.9 feet	270°, 0.96 feet (12.7 in as-built)
Mixer Jet Pump Suction Elevation[3] (in)	5±1	0.67±0.13	0.24±0.05
Mixer Jet Pump Suction Diameter (in)	11	1.47	0.53
Mixer Jet Pump Nozzle Diameter (in)	6	0.80	0.28
Mixer Jet Pump Nozzle Elevation[3] (in)	18	2.4	0.86
Mixer Jet Rotation Rate (rpm)	0.2	See Eq. 3-5	See Eq. 3-5
Transfer Pump Location[2]	Riser-030 90°, 6 feet	0°, 0.8 feet	0°, 0.29 feet
Transfer Pump Suction Inlet Diameter (in) [4]	2.25-3.9	0.32-0.55	0.25-0.48
Transfer Pump Suction Inlet Height (in) [4]	6	0.8	0.28
Transfer Line Diameter (in)	3.07 (3-inch Schedule 40)	½”-poly tubing (0.375-inch inner diameter)	½”-poly tubing (0.375-inch inner diameter)
Tank Obstructions	Air Lift Circulators (ALCs)	Simulated ALCs (removable)	Simulated ALCs (removable)

[1] Fill volume is determined by linear scaling of the tank diameter and sludge volume height.

[2] The reference point for DST locations presented in this table defines 0° as the top of 241-AY-102 in a plan view drawing of the tank. Provided distances are design distances from the center of the riser to the center of the tank.

[3] Elevation is relative to the tank bottom.

[4] The pump suction inlet diameter of the Full-Scale Transfer Pump is underdevelopment and the tabulated range of values is based on similar transfer pumps used on the Hanford site to convey waste and preliminary design information. The inlet size on the 1:21 scale tank is not geometrically scaled. The resulting inlet size was too small to accommodate the particle sizes targeted.

3.2.3 Test Simulants

The simulants used in the SSMD scaled performance testing are selected in accordance with the recommendations in RPP-PLAN-51625. Simulant properties and qualifications are described in Section 3.1. Selecting particular simulants for SSMD scaled performance test activities is discussed below. The test matrix showing the combinations of base simulant and liquid supernatant is discussed in Section 3.2.4.

The SSMD scaled performance simulants shall include Newtonian and non-Newtonian simulants. For SSMD limits of performance testing, non-Newtonian testing was conducted with slurries of kaolin clay spiked with large and dense particles. For SSMD scaled performance testing the non-Newtonian solids will also be principally kaolin clay, but stainless steel and zirconium oxide will be added so that batch transfer performance can be quantified. Sodium thiosulfate will be added to increase the density of the non-Newtonian slurries when required in the test matrix.

The Newtonian simulant shall be a complex (i.e., multicomponent) simulant containing base particulates. The liquid phase shall be a supernatant simulant. Sodium thiosulfate will be added to increase the density of the Newtonian slurries when required in the test matrix. Glycerol will be added to increase the viscosity of the Newtonian slurries when required in the test matrix. Recipes for the simulants discussed below are tabulated in Table 3-1 and Table 3-2.

Although RPP-PLAN-51625 recommends three conceptual simulants for WFD Mixing and Sampling Program DNFSB 2010-2 testing, only two simulants are selected for SSMD scaled performance testing, the typical and the high conceptual simulants. The low conceptual simulant is composed entirely of small gibbsite particles, which are readily suspended at even the lowest operational velocities, and are therefore not interesting for determining equivalent performance between scales. Based on the distribution of Archimedes numbers and jet suspension velocities reported in Figures 8-1 and 8-2 in RPP-PLAN-51625, the typical and high conceptual simulants are representative of the typical conceptual simulant to suspend, and most challenging to suspend tank waste. Although the typical conceptual simulant recommends that two different sized gibbsite particles be used, batch consistency performance will be based on chemical analyses of the transferred material, which will not distinguish between the different sized materials and so the scaling analysis will not consider the effect of gibbsite size. A similar limitation is applied to sand in tests with the high conceptual simulant, which includes two different sized sands.

To investigate the effects of the supernatant density and viscosity, three supernatant compositions will be investigated, typical, high, and modified high. For the typical supernatant, the liquid density is 1.284 g/ml and the liquid viscosity is 3.60 cP. The typical supernatant is consistent with the typical density/typical viscosity recommendation in Table 3-2. For the high supernatant, the liquid density is 1.368 g/ml and the liquid viscosity is 14.6 cP. The high supernatant is consistent with the high density/high viscosity recommendation in Table 3-2. For the modified high supernatant, the liquid density is 1.318 g/ml and the liquid viscosity is 8 cP. The modified high supernatant is necessary to prevent laminar flow at the transfer pump inlet when a higher density, Newtonian simulant is evaluated at lower capture velocities. The recipe for the modified high supernatant will be developed as a variant of the high density/high viscosity supernatant by adding less glycerol and sodium thiosulfate. The acceptable preparation

tolerances are discussed in Section 3.1.2. Liquid viscosity shall be evaluated at the operating temperature of the test tank, if the temperature of the sampled material differs from the bulk volume. The high values for liquid density and liquid viscosity are selected because higher densities and higher viscosities are expected to increase the buoyancy effecting solid particles in the mixing tank and reduce critical suspension and settling velocities. Increasing buoyancy and subsequently reducing the critical suspension velocity and settling velocities are expected to promote particle suspension, which will improve mixing within the tank. Although higher viscosities fluids may reduce the capability of the system to clear the solids from the bottom of the tank, SSMD scaled performance testing is evaluating transfer batch consistency with the pre-transfer samples and is not evaluating the capability of the system to mobilize all material from the tanks. Improved mixing within the tank is expected to yield a more representative pre-transfer sample and also result in better batch-to-batch consistency. To confirm this expected correlation, the three supernatant simulants will be used during testing.

The effect of solids loading on batch-to-batch consistency and batch consistency with the pre-transfer sample between scales is difficult to predict. Previous SSMD test results (RPP-49470) indicate that in three of four tests, the fraction of the initial amount of stainless steel transferred from the tank was within 10% of a comparable case with twice as much stainless steel initially present in the tank. In the fourth test, the fraction of stainless steel recovered was less than 50% of a comparable case with twice as much stainless steel initially present in the tank. In these same tests, the amount of zirconium oxide and gibbsite were held constant. The difference in the fraction of the initial amount of zirconium oxide transferred from the tank in each comparable test was within 10%. The differences in the fraction of initial gibbsite transferred out of the tank ranged from 15-to-30%. Therefore, the differences in the stainless steel recoveries are comparable to other solids with initial amounts that did not vary. With these results in mind, the effect of solids loading will not be investigated and will be held constant at 13wt% based on the ICD-19 allowable limit of 200 g/l. The mass loading is equivalent to 180 to 194 g/l depending on the composition of solids and supernatant selected. The effect of solids loading will be revisited during supplemental testing that includes scaled relationship confirmation runs with different mass loadings. These confirmation runs will be performed with lower mass loading values because the mass loading tested is at the upper range of the ICD-19 action level for solids loading.

In addition to the Newtonian tests discussed previously, tests will also be performed using a non-Newtonian slurry with a Bingham plastic yield stress. In order to produce quantitative data stainless steel and zirconium oxide will be added to the kaolin slurry. The amount of stainless steel and zirconium oxide added to the slurry will be equal to the amount added for a Newtonian test using the typical supernatant and typical base simulant with a solids loading of 13 wt%. The non-Newtonian tests will be conducted to test SSMD transfer performance with a non-Newtonian simulant and evaluate whether or not the transfer batch consistency with the pre-transfer sample for a mobilized non-Newtonian simulant scales according to the Newtonian scaling relationship. A fundamental difference between the Newtonian slurry and the Bingham plastic non-Newtonian slurry is the yield stress necessary to get the slurry to behave like a fluid. In a fully mixed tank (i.e., no caverns are formed) the Bingham plastic fluid that is available to be transferred from the tank has overcome the yield stress necessary to mobilize the fluid and is expected to behave like a Newtonian fluid. Therefore, transfer batch consistency with pre-transfer samples may be characterized by Newtonian scaling relationship. If caverns are

observed at the lowest nozzle velocities, then the batch transfer results may not be useful in the evaluation of the non-Newtonian data. If the second lowest nozzle velocity results in the formation of caverns, the velocity will be increased until cavern formation is eliminated. It is recognized that moderate to high yield stress fluids (greater than 5 Pa) may form stagnant areas within the tank that effect transfer performance so that using the same scaling relationship may not be applicable. However, current ICD-19 limits have a yield stress action level of 1 Pa, so that slurries that are expected to be challenging to mix, sample, and transfer (i.e., slurries with a yield stress exceeding 5 Pa) may not be suitable for delivery to the WTP. The SSMD scaled performance testing will begin to evaluate the scaling of non-Newtonian simulants using slurries with a Bingham plastic yield stress of 3 Pa and a density of approximately 1.16 g/ml. The 3 Pa limit was selected because it is similar to values that have been used in mixing tests in the past, and is expected to be manageable in the 120-inch diameter tank. Due to the anticipated formation of stagnant zone in the mixing tank when higher yield stress fluids are evaluated, it is unlikely that non-Newtonian slurry with a Bingham plastic yield stress of 10 Pa will scale equally as Newtonian slurry. The non-Newtonian slurry shall be prepared and measured in accordance with the recipes, methods, and tolerances discussed in Section 3.1.1.

3.2.4 Operating Parameters and Test Methods

The operating conditions for the SSMD scaled performance testing should be consistent with previous SSMD performance testing. The mixer jets shall rotate continuously clockwise with no rotational offset between mixer jet pumps; the streams will be synchronized to meet in the center of the tank. The rotational speed of the jets (ω) shall be set in accordance with Equation 3-9, but mixing performance using five different nozzle velocities will be evaluated. Five nozzle velocities have been selected to evaluate two bounding mixing conditions and three points in between these bounding conditions to characterize the behavior in between the bounds. The two bounding conditions evaluate velocities that result in bottom cleaning and very poor performance. A velocity with poor mixing performance is being evaluated because the determination for equal performance between scales does not require optimal performance.

Testing conditions that are bounding for both acceptable performance and poor performance will ensure that performance differences are observed during testing so that equal performance among scales is observed. Because equal performance is expected to be at velocities between these bounding conditions, three additional velocities approximately equally spaced from the end points will also be evaluated. Selecting two or more velocities in between the bounding conditions will provide additional data points for the functional model applied during analysis, and increase the confidence that the behavior between the bounding conditions is characterized by the fitted model. The five nozzle velocities that will be used during SSMD scaled performance testing are not determined in advance (as discussed below); however, the nozzle velocities used will be consistent with previous testing, which included nozzle velocities in the range of 22.3 ft/s (70 gpm) to 35.4 ft/s (111 gpm) in the larger test vessel (TK-301) and 16.9 ft/s (6.5 gpm) to 27.6 ft/s (10.6 gpm) in the smaller test vessel (TK-201).

Prior to performing batch transfers that remove material from the tank, the system shall be operated in a recirculation mode until a stable state is established. The stable state is indicated by a consistent mass flow rate reading from the Coriolis meter, after adjusting for cyclical variations caused by the rotating jets. Additionally at the stabilized state a steady cloud height

and mixer jet zone of influence should be observed. Previous operator experience indicates that approximately 10-20 rotations of the mixer jets pumps are sufficient to result in a stabilized state once the solids have been added and dispersed throughout the tank. Once the tank reaches the stable condition, pre-transfer samples will be collected as described in Section 3.2.5. Once the pre-transfer samples are collected, batch transfers will be initiated.

After the first batch transfer is completed, the system shall be reconfigured to recirculate the waste until a stable state condition is re-established. Once the stable state condition is re-established, the next batch transfer and sampling operation will be initiated and will proceed like the first batch transfer and sampling operation. The process will be repeated until five batch transfers have occurred. After the last batch transfer is completed, a description of the solids remaining in the tank, including a photographic or video record, will be prepared and the tank will be emptied.

The upper velocity for each tank will be determined in during testing. Prior to performing a batch transfer the nozzle velocity in each tank will be varied to determine the nozzle velocity required to prevent the formation of piles on the sides of the tank when the typical base simulant is mixed with the typical supernatant. If the nozzle velocity required to clear the bottom exceeds the capability of the system or results in unsafe operating conditions (e.g., splashing or tank shaking) then the velocity will be limited to a maximum that can be operated safely. The resulting velocity will be set as the maximum nozzle velocity used during SSMD scaled performance testing. The combination of the typical base simulant in the typical supernatant was selected because it is expected to be the easiest of the tested configurations to be suspended. This expectation is based on observation that the typical base simulant was developed to be easier to mix than the high base simulant. In addition, this expectation is also based on the radial wall jet velocity needed to achieve complete solids suspension discussed in PNNL-20637 (Equation 2.9).

Compared to the high base simulant in both the typical and high supernatants and the typical base simulant in the high supernatant, the predicted nozzle velocity needed to achieve complete solids suspension, keeping everything else equal, is the least for the typical base simulant in the typical supernatant. This expectation is also consistent with effective cleaning radius calculations that use Equation 5.8 in PNNL-20637, to estimate the effective cleaning radius for slurry containing five wt% 100-micron stainless steel particles using the Shields diagram to determine the critical shear stress for erosion. The formula can be used to show that the combination of the higher density and higher viscosity fluid, despite the increase in buoyancy by the higher density fluid, reduces the effective cleaning radius for the particles; the reduction in the effective cleaning radius due to the change in the viscosity over the planned range exceeds the benefit by the increased density. With the expectation that a velocity that effectively cleans the bottom of the tank is higher than that required for acceptable batch-to-batch consistency with the pre-transfer samples, selecting the velocity that achieves complete bottom cleaning for the easiest to suspend solids ensures that the system is not operated above necessary velocities for any scaled performance test.

The lower velocities for each tank are also determined during developmental testing and are based on a minimum effective cleaning radius criterion. Following the discussion for determining the upper nozzle velocity, it is expected that the high base simulant in the high

density and high viscosity supernatant would result in the lowest effective cleaning radius of the simulant combinations planned in the SSMD scaled performance testing. This simulant combination will be used to determine the minimum nozzle velocity to be used during testing. Previous experimental work shows that in the 1:8-scale system batch- to-batch consistency with the pre-transfer samples was poor when the nozzle velocity was 22.3 ft/s (data from RPP-49740). At this nozzle velocity, the effective cleaning radius was measured to be approximately 75% (approximately 55 inches from the mixer jet pump nozzle) of the distance need to achieve complete bottom clearing (i.e. the distance between the mixer jet pump nozzle and the edge of the tank along a diameter that is orthogonal to the diameter containing the mixer jet pumps). Therefore, developmental testing with the high base simulant in the high density and high viscosity supernatant will be used to determine the nozzle velocity at each scale that results in an effective cleaning radius that is 75% the length to achieve complete bottom clearing. Using the most difficult simulant combination will ensure that the nozzle velocity will be high enough to result in acceptable batch transfer performance during the other tests at this nozzle velocity. The resulting velocity for the 1:8-scale system may not be 22.3 ft/s due to differences from the previous tests for both the base solids being suspended and the composition of the supernatant.

Three velocities that are approximately equally spaced between the upper and lower set points will also be used during testing. Selecting specific intervals rather than specific scale factor exponents was preferred for the regression analysis that will correlate nozzle velocity to the performance metric considered.

Scaled performance testing will evaluate three capture velocities. The capture velocity is also referred to as the suction velocity and is defined as the average velocity across the pump suction inlet opening area. The capture velocity is adjusted by changing cross-sectional area of the nozzle for the pump suction inlet (see Section 3.2.2). The maximum capture velocity being evaluated (11.3 ft/s) is equated to the full-scale capture velocity that occurs at the maximum transfer rate (140 gpm). Operating at the maximum flow rate minimizes the waste transfer time. Operating at the maximum capture velocity at the pump suction inlet offers a greater opportunity to capture tank solids. At the maximum capture velocity, the fluid velocities at the transfer pump inlets at the scaled systems are equal. A lower capture velocity is also being evaluated to determine the sensitivity the capture velocity has on the test results. Selection of the lower capture velocity is based on past test experience and uncertainties in the WFD transfer pump design.

Previous reports indicate that the effects of varying the capture velocity are mixed. A recent study evaluating lower capture velocities at both scales (RPT-SSMD-EG-00006, *SSMD Platform Small Scale Mixing Demonstration Low Capture Velocity Follow On Results Report*) indicated that when the capture velocity in the small test vessel (TK-201) was lowered from 11.3 ft/s to 6.3 ft/s with a mixer jet pump flow rate of 27.6 ft/s (10.6 gpm), the cumulative amount of gibbsite transferred in five batches only differed from the predicted amount using the pre-transfer sample by 1% at the maximum capture velocity but was 12% over predicted by the pre-transfer sample at the reduced capture velocity. The cumulative amount of gibbsite transferred at the two capture velocities varied by less than 2%. In the large test vessel (TK-301) the results for gibbsite with a mixer jet pump velocity of 35.4 ft/s (111 gpm) were comparable for the higher capture velocity (11.7 ft/s) but were still over-predicted by 6% at the lower capture velocity (5.9 ft/s). The higher transfer velocity transferred 12% more gibbsite. The results for zirconium oxide were similar.

Comparisons of stainless steel results in the small test vessel show that an equivalent amount of material was transferred at the two capture velocities but the amount transferred was over-predicted by the pre-transfer sample by 18-37%. In the large test vessel, the cumulative amount of stainless steel transferred was within 1% of the predicted amount from the pre-transfer sample at the higher capture velocity, but was over-predicted by 37% at the lower capture velocity. With these results taken into consideration, the effects of the changes in the capture velocity remain uncertain and two different velocities at each scale will be evaluated.

An intermediate capture velocity is equal to the full-scale capture velocity at the lowest planned full-scale operating flow rate (90 gallons per minute) and is 7.3 ft/s when the transfer pump inlet is 2.25 inches in diameter. The alternative capture velocity will be maintained by increasing the cross-sectional area of the pump suction inlet (see Section 3.2.2) while maintaining the same flow rate through the transfer tubing. This method for adjusting the capture velocity was selected to avoid reducing the flow through the transfer tubing downstream of the pump inlet, which may result in particle settling that could interrupt test operations. Inlet sizes for the modified conditions are listed in Table 3-4 and Table 3-5.

A low capture velocity will also be evaluated. The WFD transfer pump is currently being designed and recent communications with the supplier indicate that the pump suction inlet may need to be increased to 3.9 inches to accommodate the requirements specified for the pump. At 140 gpm, the capture velocity for a 3.9-inch inlet drops to 3.8 ft/s. As discussed in Section 3.1.4, this flow velocity results in laminar flow at the inlet of the scaled system when the high density/high viscosity supernatant is used. In lieu of using the high density / high viscosity supernatant under these conditions, tests will be conducted using a reduced viscosity fluid. Testing with the reduced viscosity fluid avoids scaled testing in the laminar flow regime when the flow in the full scale system would be turbulent.

Non-Newtonian tests will be performed using the same nozzle velocities but will only use the higher capture velocity.

Data collection for each test is described in Section 3.2.5.

The test matrix for SSMD scaled performance testing is provided in Table 3-6. In order to reduce the occurrence of systematic errors, such as instrument calibration drift and elevated temperatures as testing progresses to warmer days, the tests should be performed in a random order. In order to minimize contamination of subsequent tests when a random order is followed, the test platform (test tank, transfer lines, transfer equipment, and sample collection containers) shall be thoroughly flushed and cleaned prior to each test. The test matrix is not a full factorial design for the varied parameters, which include the five nozzle velocities, the two base simulant compositions, the three supernatant compositions, and the three capture velocities. Performing a full factorial design for the variables most important to determining the scaling relationship would allow for an inclusion of any interaction effects between the varied parameters. Performing a partial or fractional factorial design for the variables allows quantification of more important variables at the expense of quantifying interaction effects. The specific variations in the test conditions were selected using a computer algorithm. This method, known as a Bayesian I-optimal design algorithm, essentially selects the “best” test runs from the set of all possible combinations of the settings of the specified design factors, where “best” translates to small

variability of predictions. An additional constraint was applied that excluded test conditions that result in laminar flow conditions at the transfer pump inlet suction (Section3.1.4).

In addition to these 18 tests at each scale, four replicate tests will be performed at each scale. The replicates are performed at nozzle velocities that help to reduce the average predicted variance to give greater confidence in the collected data. There are four additional tests for a non-Newtonian slurry. These tests are conducted with the same slurry composition at different nozzle velocities.

In addition to the 22 Newtonian and 4 non-Newtonian tests, four additional confirmation runs are planned. These runs will be performed once the SSMD scaled performance data is collected and analyzed. The confirmations runs that will be performed will be selected once the initial data analysis is completed to determine what additional runs may be necessary. Examples of confirmation runs that will be considered include a nozzle velocity variation. Analysis of the collected data will be used to determine the scale factor exponent for equivalent performance between scales (based on a pre-transfer sample and batch consistency metric). A set of runs using the scale factor exponent to determine the nozzle velocities for each scale will be performed to confirm the analysis. The nozzle velocity verification runs could be performed with different simulant variations. In addition, supplemental confirmation runs may be performed to evaluate parameters that were initially considered less important to assessing the scaling relationship and may include a mass loading variation, another capture velocity variation, and another supernatant variation. The configuration of the confirmation runs may change as the data analysis of the first 26 runs is conducted.

Table 3-6: Small-Scale Mixing Demonstration Scaled Performance Test Matrix

Test Number	Nozzle Velocity 1:21-Scale ft/s (gpm)[d]	Nozzle Velocity 1:8-Scale ft/s (gpm)[d]	Base Simulant Constituent	Supernatant/Non-Newtonian Simulant Properties[a]	Capture Velocity
1	V21-1	V8-1	High	Typical	7.3 ft/s
2	V21-3	V8-3	High	Typical	7.3 ft/s
3	V21-2	V8-2	Typical	Typical	7.3 ft/s
4	V21-5	V8-5	Typical	Typical	7.3 ft/s
5[c]	V21-5	V8-5	Typical	Typical	7.3 ft/s
6	V21-2	V8-2	High	Modified High	3.8 ft/s
7[c]	V21-2	V8-2	High	Modified High	3.8 ft/s
8	V21-4	V8-4	High	Modified High	3.8 ft/s
9	V21-1	V8-1	High	Modified High	7.3 ft/s
10	V21-5	V8-5	High	Modified High	7.3 ft/s
11	V21-3	V8-3	High	Modified High	11.3 ft/s
12[c]	V21-3	V8-3	High	Modified High	11.3 ft/s
13	V21-3	V8-3	Typical	Modified High	3.8 ft/s
14	V21-1	V8-1	Typical	Modified High	7.3 ft/s
15	V21-5	V8-5	Typical	Modified High	7.3 ft/s
16	V21-3	V8-3	Typical	Modified High	11.3 ft/s
17[c]	V21-3	V8-3	Typical	Modified High	11.3 ft/s
18	V21-1	V8-1	High	High	11.3 ft/s
19	V21-3	V8-3	High	High	11.3 ft/s
20	V21-5	V8-5	High	High	11.3 ft/s
21	V21-2	V8-2	High	High	11.3 ft/s
22	V21-4	V8-2	Typical	High	11.3 ft/s
23	V21-1	V8-4	Non-Newtonian (kaolin clay)	Bingham Plastic Yield Stress = 3 Pa, Slurry Density ~ 1.16 g/ml	See Note b
24	V21-2	V8-2			
25	V21-4	V8-4			
26	V21-5	V8-5			

[a] High supernatant properties: density = 1.368 g/ml, viscosity = 14.6 cP; Modified high supernatant properties: density = 1.318 g/ml, viscosity = 8.0 cP; Typical supernatant properties: density = 1.29 g/ml, viscosity = 3.6 cP; non-Newtonian slurry properties, Bingham plastic yield stress = 3 Pa and density ~ 1.16 g/ml.

[b] For non-Newtonian tests, stainless steel and zirconium oxide will be added to the slurry at a mass equivalent to the typical base simulant and typical supernatant (Test #6-11). The capture velocity will be specified to be 11.3 ft/s.

[c] Test is a replicate.

[d] Within a scaled system, test velocities increase from Vx-1 to Vx-5.

3.2.5 Sample Collection and Chemical Analysis

Prior to performing each test, the simulants are prepared and qualified. The solid particulates are qualified for use prior to testing in accordance with Section 3.1.1.2. Base simulant qualification uses a laboratory determined particle size distribution and density for the procured materials to compare computed metrics for the simulants (e.g., distribution of Archimedes number, jet velocities necessary to achieve complete solids suspension, etc.) to the recommended composites from RPP-PLAN-51625. The liquid density and liquid viscosity of the supernatant of the Newtonian simulants and the Bingham plastic yield stress of the non-Newtonian simulant are qualified for use prior to adding base solids. Measurements of the supernatant density and viscosity will be performed on-site with a hydrometer and a rheometer as discussed in Section 3.1.2. Measurements of the Bingham plastic yield stress and Bingham plastic consistency of the non-Newtonian fluid will be performed on-site with a rheometer as discussed in Section 3.1.1. Data collection shall be performed in accordance with NQA-1-2004, Requirement 11including addenda, or a later version.

Prior to conducting the first batch transfer the tank contents are mixed at the operating conditions until mixing in the tank has stabilized. During tank stabilization, the transfer pump is engaged so that the specific gravity of the transferrable slurry can be monitored. The location of the Coriolis meter is downstream from the transfer pump. During tank stabilization the transfer pump discharge is re-circulated back into the tank. Monitoring the mass flow rate and slurry specific gravity will allow an assessment of the systems capability to mix and convey the complex simulant. Once the system has stabilized, two pre-transfer samples are collected. Similar to previous work, pre-transfer and batch transfer samples will be diversion samples through sample ports whose valves are programmatically controlled and correlated to the position of the mixer jet nozzles using encoders. Samples shall be collected downstream of the transfer pump but within the recirculation flow loop. Pre-transfer samples shall be collected in a manner that avoids bias and does not withdraw an excessive amount of material from the tank such that the conditions of the tank would be significantly altered. To avoid bias caused by the cyclical nature of the mixing system that directs the jet directly at the transfer pump twice per revolution, the pre-transfer samples shall be collected for an integer value of full rotations of the mixer jets. The mass and volume of the collected material for the pre-transfer samples shall be measured and recorded. If necessary, the collected sample will be subsampled prior to sending the sample off-site for analysis. Subsampling of collected samples shall be performed according to established procedures (summarized below) for batch samples during SSMD test activities. The collected samples will be analyzed for chemical composition to identify the concentration of the base simulant solids in the collected samples.

Once the pre-samples are collected and the tank contents are re-stabilized, batch transfers are initiated and slurry samples for each transfer batch are collected for chemical analysis. Samples for the 1:21-scale tank shall collect the entire volume of the transfer batch and this volume shall be sub-sampled for chemical analysis. For the 1:8-scale system, only part of the transfer batch will be collected for sampling. For the 1:8-scale system, four slurry samples will be collected during each transfer and the four slurry samples will be combined to form a representative sample for the entire transfer batch. Each of the four samples should be collected at regular intervals during the transfer. The duration for collecting each of the four samples will be equivalent and will be equal to an integer value of mixer jet full rotations. Because the mixer jet

pumps rotate at different speeds for different nozzle velocities, the subsample duration and hence volume of material collected during sampling varies between tests. The total volume of the slurry sample collected during a transfer for the 1:8-scale system should be similar to the full transfer batch volume for the 1:21-scale system. The mass and volume of the collected material for the batch transfer samples shall be measured and recorded. The collected volume is then sub-sampled for chemical analysis.

The collected volume from each pre-transfer sample (as necessary) and batch transfer may exceed the amount necessary for laboratory analysis and may be sub-sampled. The collected volume representing each transfer batch is settled in a large volume container. Settling in the non-Newtonian slurry may be hampered by the kaolin clay particles in the slurry. In previous testing, the collected material is clarified for 24 hours in a mixer barrel prior to decanting the liquid. This method will be refined during developmental testing to ensure that the subsamples can be collected in a reasonable amount of time and be representative of the content of the composited material. The mass and volume of the slurry is recorded. The liquid is decanted and the wetted solids are mixed prior to sub-sampling. Four representative and two archive samples are collected randomly from the solids. The four collected samples are shipped off-site for laboratory analysis; the two archive samples are retained on-site in a managed area to prevent a loss of sample integrity. Off-site analytical services are performed by a laboratory that operates under a Quality Assurance program that has been evaluated against quality requirements in ASME NQA-1-2004 including addenda, or a later version. The four samples that were shipped for off-site analysis are analyzed for the mass of dry solids (Newtonian tests only) and the mass of each primary constituent in base simulant. Analytical data is required to be enhanced quality so that all sample collection, sample analysis, sample handling, and data reporting shall be traceable to the test performed. The sample results shall be reported in a Microsoft Excel[2] compatible format. Prior to the start of testing, analytical method development shall be performed to determine the sample preparation error associated with measuring the base material content in the presence of kaolin clay and the supernatant rheology modifiers. The analytical method is considered acceptable if it produces an unbiased result with a relative standard deviation of less than 10%.

In addition to collecting slurry samples for chemical analysis, other performance data will be collected. Each system in the SSMD test platform has the capability to record operational parameters such as test time, slurry temperature, mixer jet pump flow rate, mixer jet angular position, mixer jet pump rotational rate, tank level, slurry transfer rate and slurry specific gravity. This data is recorded by a data acquisition system and shall record data for the entire test duration. In addition, performance data shall also be recorded in the test log during testing. Performance data describing the dimensions of any accumulated material in the tank shall be collected throughout the test, noting specifically when changes in tank stability occur due to a change or process interruption. In addition, cloud height and effective cleaning radius measurements shall also be recorded in the test log. The effective cleaning radius can be determined while the mixer jets are running by measuring the distance from the edge of the mixer jet pump nozzle to the edge of the pile of solids that has stabilized on the sides of the tank. Multiple measurements shall be collected in each test to determine an average effective cleaning

[2] MS Excel® is a registered trademark of the Microsoft Corporation, Redmond, WA.

radius. Measurements shall be collected for each batch transfer to support an evaluation of changes in the system as the tank level is lowered.

3.2.6 Performance Analysis

Particle movement in stirred tanks is described by multiple physical phenomena related to particle fluid interactions. Some examples of these physical principles include: particle settling, settled particle mobilization, fluid jet decay and propagation, and turbulence affects on particle movement. Because the primary performance metric for this testing, representative pre-sampling of the transferred batches, involves a complex interaction of these fundamental physical phenomena, estimating performance at different scales will be related to the observed behavior of the primary metric at the two test tank scales. Assessing the scaling relationship for the 1:21 and 1:8 scale systems will be performed using the analytical data collected during testing.

The objective is to identify the operating conditions where the two scaled tanks perform equivalently. This will allow definition of a mathematical scaling relationship between the two tanks that can then be applied of other geometrically scaled tanks. Once the scaling relationship is established, the full-scale mixer pump jet velocity can be scaled down to identify the equivalent small-scale tank conditions and therefore allow full-scale performance to be estimated based on the small scale results. Conceptually, to define tank performance equivalence, a test run could be performed at a specified jet nozzle velocity in one scaled tank. Then a test run could be performed in the second scaled tank, where only the jet nozzle velocity and rotational rate were adjusted to provide performance equivalent to that in the first tank. Based on the theoretical scaling model shown in Equation 3-8, the scaling exponent could then be calculated for the two scaled tanks and velocities used. Multiple test runs could be performed in similar fashion on both scales, and the resulting calculated scale exponents could be combined to provide a scale exponent based on the set of tests. However, for batch transfer testing, performance is not quantified until after the batches have been transferred from the mixing tank and the samples have been analyzed at an off-site laboratory, which makes it impractical to perform the testing in this conceptual fashion. As a conceptual alternative, a set of test runs could be made at one scale, over a range of jet nozzle velocities, followed by a set of test runs made over a range of jet nozzle velocities in the second tank. Then these test runs would be "paired-up" to identify the test runs at the two scales which produced the most similar performance. The scale exponent could then be calculated, using Equation 3-8, for each similar pair. If a suitably large number of velocities are chosen for each scaled tank, then it would be likely that multiple estimates of the scale exponent could be obtained. This could also be performed graphically, where the transfer performance values could be plotted against the jet nozzle velocity for each tank scale, and a curve drawn. By using the scaled jet nozzle velocity for one of the scaled tanks for specified values of the scale exponent, the value of the scale exponent which visually makes the curves "closest" could be determined. The scale exponent can essentially be used as a fitting parameter, which would be constrained to values that are typical for mixing (e.g., 0.2 to 0.4), to change the shape of one of the performance curves to most closely match the other curve.

While conceptually this approach makes sense, it requires a sufficient number of tests at each scale to either make direct pairing of equivalent performance likely, or to draw a performance curve for each scale. Additionally, the determination of when the curves are "closest" is

subjective. Both of these concerns can be addressed through a more rigorous statistical approach of fitting a regression model, which incorporates the theoretical scaling model, to the test data. In the simplest form for a specified tank, the regression model is assumed to be a simple polynomial, e.g., cubic, function of the jet nozzle velocity, shown in Equation 3-10.

$$PM_k = b_0 + b_1 U + b_2 U^2 + b_3 U^3 \quad (3\text{-}10)$$

Where PM_k indicates the transfer performance measure of individual simulant component *k*, *U* indicates jet nozzle velocity, and $b_0$through b_3 represent the coefficients to be estimated in the model.

Fitting this polynomial to the data collected for each tank scale is essentially drawing the curve for each tank scale. As explained previously, the desire is to identify a scale exponent, based on the theoretical scaling model, which makes the two curves "closest". In the context of the regression model, this is accomplished by incorporating the Equation 3-8 into the Equation 3-10, resulting in Equation 3-11.

$$PM_k = b_0 + b_1\left(U\left(\frac{T_2}{T_i}\right)^a\right) + b_2\left(U\left(\frac{T_2}{T_i}\right)^a\right)^2 + b_3\left(U\left(\frac{T_2}{T_i}\right)^a\right)^3 \quad (3\text{-}11)$$

Where PM_k indicates the transfer performance measure of individual simulant component *k*, *U* indicates jet nozzle velocity, T_i represents the diameter of tank *i*, and *a*, b_0, b_3 represent the coefficients to be estimated in the model.

There are two important points to note in Equation 3-11. First, the coefficients for the nozzle jet velocity terms are the same, regardless of the tank. This implies that the transfer performance relationship to velocity is the same in both scales, other than the scale effect which depends on velocity. Second, the scale effect is determined by the scale exponent. When the tank is T_2, the scaling model term is equal to one, and the model becomes independent of the scaling exponent for this tank; when the tank is T_1, the nozzle jet velocity for that tank is adjusted according to the scaling exponent. Mathematically, the scaling exponent is determined to make the performance curves "closest", using a non-linear regression procedure.

In the scaled performance testing, other factors are being investigated that may impact the transfer performance. However, they are not expected to impact the scaling of performance; the theoretical scaling model only depends on nozzle jet velocity. Conceptually, incorporating these other factors results in drawing the performance versus velocity curves for each of the different conditions, and then determining the scale exponent that makes the sets of curves for the two different tanks "closest". Clearly, as the number of additional conditions increases, it becomes more difficult to visually compare the multiple sets of curves to identify the scale exponent. Once again, this difficulty can be addressed through a more rigorous statistical approach of fitting a regression model, which incorporates the theoretical scaling model, to the test data.

For the scaled performance testing, the other factors that are being investigated include the supernatant liquid (defined by the density and viscosity), the base simulant material (defined by the amount and type of the constituents), and the transfer line capture velocity. These additional

factors then need to be included in the regression model to account for their anticipated effects on transfer performance. This is shown in Equation 3-12.

$$
\begin{aligned}
PM_k = {} & b_0 + b_1\left(U\left(\frac{T_2}{T_i}\right)^a\right) + b_2\left(U\left(\frac{T_2}{T_i}\right)^a\right)^2 + b_3\left(U\left(\frac{T_2}{T_i}\right)^a\right)^3 + b_4 BS \\
& + b_5 SN + b_6 SN^2 + b_7 CV + b_8\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\
& + b_9\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] + b_{10}[BS \times SN] \\
& + b_{11}[BS \times SN^2] + b_{12}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\
& + b_{13}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] + b_{14}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] \\
& + b_{15}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right]
\end{aligned}
\tag{3-12}
$$

Where PM_k indicates the transfer performance measure of individual simulant component *k*, *U* indicates jet nozzle velocity, *BS* indicates Base Simulant, *SN* indicates Supernatant, *CV* indicates Capture Velocity, T_i represents the diameter of tank *i*, and *a,* and $b_0$through b_{15} represent the coefficients to be estimated in the model.

Equation 3-12 is the result of reviewing the possible effects which might be considered, and selecting those that are deemed most likely to be significant, considering the number of test runs that can be performed. The starting point for this evaluation is a full factorial design, i.e., all combinations of the desired settings of each of the factors. For the nozzle jet velocity, fitting a cubic polynomial requires at least four settings of velocity; the supernatant liquid has three different formulations; there are two different base simulant combinations; two different capture velocities were selected. A full factorial design for these factors and levels would require 48 tests; the associated model contains 48 terms. Within that model are main (linear) effects of each factor, as well as higher-order effects of multiple factors. In particular, for jet nozzle velocity, there will be squared and cubed terms, as well as these terms in combination with other higher-order effects of other factors. In many cases, these higher-order effects are smaller relative to the lower-order effects. Assuming they are negligible allows for a smaller fraction of the factorial design to be used, resulting in fewer test runs, at the corresponding risk of confounding if the higher-order effects really are large. Confounding occurs when the two different effects cannot be estimated separately; the calculated effect is actually the sum of the two confounded terms.

With a maximum of 22 tests available at each scale, which means that 44 data points are collected for the analysis, and the desire to have four replicates to better estimate variability, this suggests that the maximum number of effects that can be estimated is 18. However, it is also desirable to have at least two less model terms than discrete test runs, to allow for an estimate of variability based on the model fit. This then leads to a model which has no more than 16 terms. Looking at each of the factors, the model needs to include terms for the cubic in nozzle jet velocity, and the main effects for each of the other factors. This results in an initial model

containing eight terms, which then allows for eight additional higher-order terms. Considering the factors and their expected effects, interaction effects involving the base simulant, the supernatant, and the nozzle jet velocity are expected to be larger; the effect of capture velocity is expected to be small, based on limited earlier testing. Within the limitations identified previously, this results in Equation 3-12.

When considering the design of the test matrix for the scaled performance testing, a simplified version of Equation 3-12 was used as the design model. Since it was decided that each scale tank would run the same set of tests, at suitably chosen jet nozzle velocities, the model is simplified by ignoring the scaling model component. As mentioned previously, it was desired to run 18 unique test cases and four replicates, for a total of 22 test cases, for each scale tank. Additionally, imposing the restriction that the capture velocity used must not result in being in the laminar flow regime (see Section 3.1.4) results in excluding a portion of the possible test conditions, precluding the use of the original considerations in the factorial design. Excluding those possible test conditions also leads to using more than two levels of the supernatant and capture velocity in the testing, in order to adequately fit the model over the constrained region. To satisfy the various constraints, both budget and physical, on the testing, a Bayesian I-optimal design was chosen, as discussed in Section 3.2.4. This design, generated by a computer algorithm, essentially selects the "best" test runs from the set of all possible combinations of the settings of the specified design factors, where "best" translates to small variability of predictions. The Bayesian I-optimal algorithm generates a design specific to the design model, a simplified form of Equation 3-12, with the additional property of providing some general protection against the possibility of other identified effects. These other identified effects, known as potential terms, were specified as the remaining terms associated with the full factorial design discussed previously.

The basic experimental unit used in Equations 3-10 through 3-12 is the tank. In actual testing, each tank will have pre-transfer samples taken from the recirculation loop, followed by five batch transfers out of the tank, with samples drawn from each batch transfer. Each of these samples will be analyzed for the concentration, expressed as a wt% of the solids of each simulant component. These weight percent measurements can then be used to construct the desired measure of transfer performance. For the purposes of analysis, Equation 3-12 is then expanded to include a batch effect, and an interaction between batch and jet nozzle velocity, as shown in Equation 3-13.

$$
\begin{aligned}
PM_k = {} & b_0 + b_1\left(U\left(\frac{T_2}{T_i}\right)^a\right) + b_2\left(U\left(\frac{T_2}{T_i}\right)^a\right)^2 + b_3\left(U\left(\frac{T_2}{T_i}\right)^a\right)^3 + b_4 BS \\
& + b_5 SN + b_6 SN^2 + b_7 CV + b_8\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\
& + b_9\left[BS \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] + b_{10}[BS \times SN] \\
& + b_{11}[BS \times SN^2] + b_{12}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] \\
& + b_{13}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right] + b_{14}\left[SN \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] \\
& + b_{15}\left[SN^2 \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)^2\right] + b_{16} Batch \\
& + b_{17}\left[Batch \times \left(U\left(\frac{T_2}{T_i}\right)^a\right)\right]
\end{aligned}
\tag{3-13}
$$

Where PM_k indicates the transfer performance measure of individual simulant component *k*, *Batch* represents the batch transfer number, *U* indicates jet nozzle velocity, *BS* indicates Base Simulant, *SN* indicates Supernatant, *CV* indicates Capture Velocity, T_i represents the diameter of tank *i*, and *a*, and $b_0$though b_{17} represent the coefficients to be estimated in the model.

For the purposes of the analysis of the mixing and transfer test data, an empirical model of performance will be used, which incorporates the theoretical scaling model shown in Equation 3-8. The purpose of the empirical model is to describe the relevant performance in each tank as a function of the factors that have been manipulated in the testing. Key to determining the scale factor exponent is determining the actual measure of performance that will be used. There are numerous performance measures that are typically used to quantify mixing performance (e.g., effective cleaning radius, cloud height). While these are measures of the actual mixing phenomena in the tank, they may not adequately capture the behavior for a complex simulant. that is being transferred from the mixing tanks in multiple batches. For this reason, different measures of mixing and transfer performance will be investigated for possible relevance. For example, using the measurements of constituent concentrations in each of the batch transfers, equivalent performance could be defined as occurring when the concentrations are most similar. An additional performance measure can be defined based on the amount of the constituent material transferred relative to the amount of the constituent in the tank when the transfer is started. A third measure of performance could be obtained as the difference between the constituent concentration in the batch transfer and in a pre-transfer sample, or as the ratio of the batch transfer amount to the pre-transfer sample. While each of these could be useful measures of performance, it's likely that they would each describe performance differently, providing perhaps different results. Note that these performance measures, based on measurements of each individual constituent, would result in an estimated scaling relationship for each simulant constituent. The data can be evaluated using all these metrics, but the latter two, which are very similar, represent the metric most useful for the WFD waste acceptance process.

3.3 REMOTE SAMPLER DEMONSTRATION SYSTEM PERFORMANCE

The RSD system performance test activities documented in Section 3.3 are performed by Energy*Solutions* for WRPS. Pacific Northwest National Laboratory (PNNL) directs the operation of the UPE and interprets data collected by the device.

Previous work using the RSD flow loop indicated that, compared to a horizontal orientation, samples collected when the Isolok® Sampler was installed in a vertical section of piping more closely matched slurry samples collected from the discharge of the transfer line (RPP-RPT-51796, *Remote Sampler Demonstration (RSD) Phase I Sampling Results Report*). However, most of the initial testing was conducted in the horizontal orientation and supplemental testing in the vertical orientation was recommended. The RSD system performance will evaluate the Isolok® Sampler further in the vertical orientation. The RSD system performance testing will be performed with simulants that span a broader range of Hanford waste than has been previously tested. In addition, RSD system performance testing will continue to evaluate the mechanical handling system for automated sample collection and demonstrate the capability of the UPE. UPE demonstrations are supplemental to the testing activities performed by PNNL at their PDL-East facility in Richland, WA. Results of this previous testing can be found in PNNL-20350 *Hanford Tank Farms Waste Certification Flow Loop Phase IV: PulseEcho Sensor Evaluation* and PNNL-19441, *Test Loop Demonstration and Evaluation of Slurry Transfer Line Critical Velocity Measurement Instruments*.

3.3.1 Test Equipment and Instrumentation

Integrated flow loop testing for the Isolok® Sampler evaluations shall be performed using the RSD test platform constructed at the Monarch Machine & Tool Company, Inc. facility in Pasco, Washington. The flow loop was constructed at full scale, with the exception of the mixing and transfer system, to demonstrate the capabilities of the Isolok® Sampler, the mechanical handling system, and the UPE. The RSD test platform includes a mixing tank and mechanical (paddle-style) agitator, an effluent tank, a slurry pump, a Coriolis meter, the Isolok® Sampler, the integrated mechanical handling system, the UPE, a simulated glove box, and all associated piping/valving to connect these components. The mechanical handling system is a prototype automated handling system that accepts sample containers, places the containers into position for collecting Isolok® samples, and drops the sample container with the collected sample in a location suitable for retrieval by an operator. The purpose of the mechanical handling system is to minimize operator exposure to the radiation environment at the sample location. A schematic of the flow loop is shown in Figure 2-3.

The mixing tank has an operating capacity of 180 gallons and will be mixed using an agitator (mixing blade) rotating in a down-flow configuration. The vessel will be cooled to maintain operating temperatures. Simulant will be drawn out of the mixing tank around a dispersion plate that creates a ½” circular gap over a three inch line located directly in the middle of the bottom of the tank. The dispersion plate minimizes channeling of simulant solids through the mixing tank. After leaving the tank, the simulant will be pumped through a centrifugal pump capable of operating between 2 and 8 ft/s. Then the waste will enter a straight section of horizontal 3” pipe, configured for operation of the PulseEcho critical velocity measurement equipment. The UPE will be located approximately 60-70 horizontal pipe diameters (15-18 feet) downstream of the

last flow disturbance and has 15 pipe diameters (4 feet) of horizontal piping after the device. To ensure that the starting flow rate is sufficient to establish full suspension of the slurry solids and allow visual verification of the critical velocity the sections just prior to and just post UPE equipment are transparent. After leaving the UPE test section the simulant enters the Isolok® sampling section of the system; piping is reduced from 3"inner diameter. to 2" inner diameter and flow is upward in a vertical orientation; about 7 degrees from vertical. The sampler is a Sentry Isolok® MSE sampler, designed for viscous and thixotropic fluids. The Isolok® sampler takes many 5.3ml subsamples to obtain one sample, which can vary based on the size of the sample bottle employed. RSD sampling will employ 250ml sample bottles (requiring 47 subsamples). After leaving the sampler section, the pipe diameter is returned to 3" inner diameter and drains back to the mixing tank with a slope to aid in cleaning.

As the simulant returns to the mixing tank, it first passes through a Coriolis meter, where mass flow rate and specific gravity measurements are obtained, then through an automated full diversion valve. The diversion valve is located in the line a few feet before the mixing tank on the return line, is only operated for a few seconds at a time, allowing operators to take full diversion samples to obtain an accurate representation of the simulant as it flows through the pipe. The volume of a full diversion sample is approximately four gallons. The standard path of the simulant has the material returning to the mixing tank at the top.

The UPE and flow loop shall include data acquisition systems to collect data real time. The data acquisition system for the Coriolis meter may be separate from the system for the UPE, and shall monitor and record the mass flow rate and the specific gravity of the slurry.

Testing shall have three phases for data acquisition. The critical velocity of the simulant being tested will be determined. This may be performed either before samples are taken or after samples are taken, but due to the requirement to adjust the flow rate it cannot be performed during sampling. PNNL will have the lead for the PulseEcho portion of testing. Second, the Isolok® sampler shall be used to obtain characterization samples. Operation of the Isolok® sampler shall include the use of the mechanical handling system to the maximum extent possible, however if mechanical or software issues adversely interrupt testing, the test director may allow use of an Arbor press for Isolok® bottle loading and unloading. After completion of the Isolok® samples full diversion samples shall be taken.

The UPE and adjacent transparent sections will be used during RSD system performance testing to detect bulk particle settling, which will be correlated with an independently measured flow velocity to determine critical velocity of the simulant. Slurry flow velocities between 2 ft/s and 6 ft/s will be used to determine the critical flow velocities of the simulants. Measurements performed by the UPE are representative only of the fraction of the slurry that is present and circulating in the flow loop test section. The UPE transducer is externally attached to the bottom of the 2-ft long UPE spool piece (3-inch inner diameter schedule 40 stainless steel pipe) at a discrete location on the flow loop and is monitoring the conditions only at those locations. The assumption is that the conditions at this location are representative of those along the entire horizontal section of the flow loop. Data reported by the Coriolis meter will be correlated with the UPE data and the visual observations to determine critical velocity.

For testing purposes, evaluating the capability of the Isolok® system is independent of evaluating critical flow velocities. Actual in-field sampling of waste will require confirmation of critical velocity before slurry samples are collected so that re-sampling is minimized. Evaluating the capability of the Isolok® system to collect representative samples of the slurry is also independent of evaluating the mechanical handling of the collected samples. However for completeness testing should be performed with the fully integrated system including the Isolok® Sampler and the mechanical handling system to retrieve the prototypic sample containers.

All measuring and test equipment, including gauges and instrumentation, used for testing activities, shall be controlled, calibrated under conditions typical of the test environment, adjusted, and maintained to required accuracy limits. The condition and the reported accuracy of each instrument shall be documented in a test log.

3.3.2 Test Simulants

The simulants used in the RSD system performance testing are selected in accordance with the recommendations in RPP-PLAN-51625. Simulant properties and qualifications are described in Section 3.1. Selecting particular simulants for RSD system performance test activities is discussed below. The test matrix showing the combinations of base simulant and liquid supernatant is discussed in Section 3.3.3.

The RSD system performance simulants shall include Newtonian and non-Newtonian simulants. For SSMD and RSD limits of performance testing, non-Newtonian testing was conducted with slurries of kaolin clay spiked with large and dense particles. For RSD system performance testing the non-Newtonian solids will be principally kaolin clay, but additional solids will be added so that sampling performance can be quantified.

The Newtonian simulant shall be a complex simulant containing base particulates. The liquid phase shall be a supernatant simulant. The non-Newtonian simulant will be kaolin clay with supplemental solids. Sodium thiosulfate will be added to increase the density of the Newtonian and non-Newtonian slurries when required in the test matrix. Glycerol will be added to increase the viscosity of the Newtonian slurries when required in the test matrix. Recipes for the simulants discussed below are tabulated in Table 3-1 and Table 3-2.

Although RPP-PLAN-51625 recommends three conceptual simulants for WFD Mixing and Sampling Program DNFSB 2010-2 testing, only two simulants are selected for RSD system performance testing, the typical and the high conceptual simulants. The low conceptual simulant is composed entirely of small gibbsite particles, and is therefore not interesting for determining the capability of a multi-component sampler. Based on the distribution of Archimedes numbers and jet suspension velocities reported in Figures 8-1 and 8-2 in RPP-PLAN-51625, the typical and high conceptual simulants are representative of the typical and more challenging Hanford tank waste. Although the typical conceptual simulant recommends that two different sized gibbsite particles be used, sampler performance will be based on chemical analyses of the collected material, which will not distinguish between the different sized materials and so the performance analysis will not consider the effect of gibbsite size. A similar limitation is applied to sand in tests with the high conceptual simulant, which includes two different sized sands. Evaluating different solids compositions will also be used in the demonstration of the UPE. The

high conceptual simulant is expected to have a higher critical settling velocity and this will be confirmed during the demonstrations of the UPE.

To investigate the performance of the sampler for a range of tank waste properties three supernatant compositions will also be investigated, low, typical, and high. For the low supernatant the liquid density is 1.098 g/ml and the liquid viscosity is 1.62 cP. For the typical supernatant, the supernatant density is 1.284 g/ml and the liquid viscosity is 3.60 cP. For the high supernatant, the liquid density is 1.368 g/ml and the liquid viscosity is 14.6 cP. Recipes for matching these supernatant properties with water, sodium thiosulfate, and glycerol are provided in Table 3-2. For the low density/low viscosity and typical density/typical viscosity supernatants, the tolerance on the liquid density is ±5% and the tolerance on the liquid viscosity is 0.5 cP. For the high supernatant the tolerance, the liquid density is ±5% and the tolerance on the liquid viscosity is ±20%. For the low and typical supernatant, the tolerance on the viscosity is different than the high supernatant, because the rheology change is expected to be achieved using a single sodium salt. The density and viscosity for a single sodium salt cannot be specified independently. If the temperature of the sampled material differs from the bulk volume, the liquid viscosity tolerance is evaluated at the operating temperature.. In addition to measuring viscosity at the beginning of each test, viscosity measurements are also collected at the completion of testing to identify any changes that occurred during testing.

The range of liquid density and liquid viscosity values are selected because higher densities and higher viscosity fluids are expected to increase the buoyancy, effecting solid particles in the slurry, reducing critical suspension, and settling velocities. Increasing buoyancy and subsequently reducing the critical suspension velocity and settling velocities is expected to promote particle suspension, which will improve mixing and transfer within the RSD flow loop. Improving the distribution of the solids in the flow loop is expected to yield more consistent results. Previous RSD testing in water and a non-Newtonian slurry indicated that the relative standard deviation (i.e., the standard deviation divided by the mean) of samples collected by both the Isolok® Sampler and through the full-diversion method was typically higher for stainless steel and bismuth oxide compared to the relatively easy to suspend solids, gibbsite and zirconium oxide.

In the prepared samples, stainless steel and bismuth oxide represented the more challenging (higher Archimedes numbers) components in the tank waste. During RSD system performance test activities, different supernatant compositions will be tested and the sample results will be compared for each supernatant type to determine if the relative standard deviation of the more challenging particles is reduced in higher density/higher viscosity fluids. Evaluating different supernatant compositions will also be used in the demonstration of the UPE. The slurry is expected to have a lower critical settling velocity at higher densities. This will be confirmed during the demonstrations of the UPE.

To investigate the effects of solids loading, the weight percent of the base simulant will also be varied. Two solids loading levels will be evaluated, 9 wt% and 13 wt %. The 13 wt % is based on the ICD-19 allowable limit of 200 g/l. The mass loading is equivalent to 155 to 194 g/l depending on the composition of solids and supernatant selected. The 9 wt% is based on a lower 125 g/l loading and is equivalent to 105 to 131 g/l depending on the composition of solids and supernatant selected. The resulting slurry density ranges between 1.16 g/l and 1.49 g/ml; the

latter being very near the action level identified in ICD-19. Previous RSD testing performed tests with very low (0.1 wt %) amounts of the densest materials (stainless steel and bismuth oxide). The results indicated that these tests were among the worst for sample variability and bias (RPP-RPT-51796). Comparable tests during RSD system performance will include stainless steel at 0.5 wt% (stainless steel is 6% of the typical conceptual simulant solids, which will be included at 9 wt% of the slurry (i.e., 6%×9%=0.5%). Successful testing with simulants that vary over the anticipated range of solids loadings will add confidence that the sampler can collect representative samples of the transferred material regardless of the slurry content.

In addition to the Newtonian tests discussed previously, tests shall also be performed using non-Newtonian slurry with a Bingham plastic yield stress. Kaolin clay slurries will be used as the non-Newtonian simulant. Base particulate solids of stainless steel and zirconium oxide will be added to the slurry to provide a component that can be quantified in the collected samples. The mass of the base solids added will match the equivalent mass of these components when the high conceptual simulant is prepared at 13 wt% solids in the typical density/typical viscosity supernatant. The resulting base particulate solids loading considered the amount of solids necessary to evaluate the UPE. Phase IV testing with the 10-MHz transducer, as described in PNNL-20350, was capable of detecting settling of 14-micron stainless steel particles without false indications at lower mass loadings (2 wt% or higher). The minimum detectable concentrations are expected to change as a function of particle size.

The non-Newtonian tests will be conducted to evaluate the performance of the integrated flow loop with a non-Newtonian simulant and evaluate whether or not a sampler performance is either degraded or improved for non-Newtonian simulant compared to a Newtonian simulant. Previous work indicates that the relative standard deviation for the Isolok® Sampler was comparable for Newtonian and non-Newtonian simulants, but that the bias was less for the non-Newtonian simulant (RPP-RPT-51796). However, the previous work was performed with the Isolok® Sampler in the horizontal configuration. Non-Newtonian work was not performed in the vertical configuration. RSD system performance testing will begin to evaluate the non-Newtonian simulants with the Isolok® Sampler oriented vertically using a slurry with a Bingham plastic yield stress between 3 Pa and 10 Pa. A tolerance of -1 Pa to +1.5 Pa is added to the yield stress measurement for the 3 Pa slurry and a 30% tolerance is added to the 10 Pa slurry because of dynamic changes in the slurry viscosity as it is prepared and mixed. Kaolin clay slurries are slightly rheopectic and may thicken when mixed and transferred.

For tests requiring non-Newtonian, cohesive slurry, kaolin clay shall be used to increase the Bingham plastic yield stress of the simulant to values up to 10 Pa, as measured at the beginning of testing. Bingham parameter measurements shall also be collected at the end of each test to quantify any changes in the test conditions that occur during testing. If necessary, as indicated by measurements that exceed the specified tolerance at the end of testing, supplemental measurements should be taken to monitor changes in the slurry as mixing progresses. The 10 Pa limit was selected in accordance with recommendations in RPP-PLAN-51625. A 3 Pa kaolin clay mixture has a density around 1.16 g/ml and the 10 Pa slurry will have a density of about 1.22 g/ml. Bingham parameter measurements shall be performed prior to testing and at subsequent startups if the slurry is idle for more than 8 hours in between testing.

Testing using a spike particle from the RSD limits of performance test activities is also performed to determine if the large particles that can be sampled by the sampler affect the performance of the sampler to collect a representative sample. For RSD system performance testing a spike particle, for example 1000-micron diameter soda lime glass spheres (see Table 3-3), will be added to a base simulant. The quantity of the spike particle added to the test tank shall be 5 wt % of the total solids added during a test sequence. The 5 wt % value was selected so that an adequate number of particles are present in each test and does not reflect any expected condition in the uncharacterized waste. The size and quantity of the spike material added is subject to change as RSD limits of performance test results are collected and analyzed.

3.3.3 Operating Parameters and Test Methods

When the performance of the Isolok® Sampler is evaluated, the RSD platform shall be configured to adequately suspend the simulant in the mixing tank and transfer the contents to the inlet of the transfer pump. The speed of the mechanical agitators necessary to produce a consistent slurry shall be evaluated during developmental testing. The slurry specific gravity will be monitored by a Coriolis meter as the agitator speed in increased. The agitator speed that yields a stabilized slurry (values that fluctuate by no more than 5% during 10 tank turnovers) for the most challenging simulant should be maintained for all tests. To maintain turbulent flow in the transfer line for Isolok® sample collection in the vertical configuration, the transfer pump flow rate shall be maintained at the maximum transfer flow rate considered for waste feed delivery, 140 ± 5 gallons per minute.

Once the RSD flow loop has stabilized, as evidenced by stable mass flow rates and specific gravity readings from the Coriolis meter, the Isolok® Sampler shall be used to collect ten 250 ml samples. Five of the collected samples will be analyzed for chemical content and the remaining five samples will be retained as archives. After the last Isolok® sample is collected, two full diversion samples shall be collected. The full diversion sample opens a valve in the transfer line downstream of the Isolok® Sampler and captures the discharge to characterize the slurry in the transfer line. Sample collection and analysis is described in Section 3.3.4.

As discussed previously, the testing conditions that are varied for Newtonian slurries include the composition of the base simulant, the composition of the supernatant, and the base simulant solids loading. Two variations of base simulant are used, the typical and high conceptual simulants. Three variations of supernatant are used, the low density/low viscosity, typical density/typical viscosity and high density/high viscosity supernatants. The third testing condition that is varied is the mass loading of the base simulant. Two variations, 9 wt% and 13 wt%, are used during testing. For RSD system performance tests with a non-Newtonian slurry, two tests will be performed. The Bingham plastic yield stress values for the first test will be 3 Pa and 10 Pa for the second test. Recipes for producing the correct slurry are provided in Table 3-1. Preparation tolerances for the kaolin slurry are discussed in Section 3.1.1. In order to quantify the performance of the Isolok® Sampler, base solids will be added to the slurry. The mass of the base solids, stainless steel, and zirconium oxide, will match the equivalent mass of these components when the high conceptual simulant is prepared in the typical density/typical viscosity supernatant.

A verification test will be conducted with large spike particles to determine if the presence of large particles affects the performance of the sampler. In RSD limits of performance testing, spike particles that could be captured by the Isolok® Sampler are evaluated. For a spike particle that could be captured by the Isolok® Sampler, the presence of the spike particle may affect the performance of the system to collect the base particulates. This verification test will use a spike particle that could be repeatedly captured during RSD limits of performance testing to evaluate whether or not the base solids are still representatively sampled in the presence of the larger particles. The spike particle will be added at 5 wt% of the solids for a 9 wt% solids loading of the typical conceptual simulant in the typical density and typical viscosity supernatant.

The test matrix for RSD system performance testing is provided in Table 3-7. In order to reduce the occurrence of systematic errors, such as instrument calibration drift and elevated temperatures as testing progresses to warmer days, the tests should be performed in a random order. In order to minimize contamination of subsequent tests when a random order is followed, the test platform (mixing tank, transfer lines, and sampling equipment) shall be thoroughly flushed and cleaned prior to each test. A full factorial analysis is planned with additional tests for non-Newtonian slurries and a verification run. Replicate analyses are not included in the test matrix. During Isolok® testing, five samples are collected in series and submitted for compositional analysis. The collection of multiple samples over the duration of the test reduces the need for replicate analyses. Furthermore, process operations that contribute to test variability (e.g., simulant preparation, mixing, and variable flow conditions) are mitigated by comparing Isolok® samples to full-diversion tests that are subjected to the same sources of error.

Table 3-7: Remote Sampler Demonstration System Performance Test Matrix

Test Sequence	Base Simulant Constituents	Supernatant Simulant Composition[a]	Base Simulant Mass Loading/non-Newtonian Bingham Plastic Yield Stress
1	Typical	Low	9 wt%
2	Typical	Typical	9 wt%
3	Typical	High	9 wt%
4	Typical	Low	13 wt%
5	Typical	Typical	13wt%
6	Typical	High	13 wt%
7	High	Low	9 wt%
8	High	Typical	9 wt%
9	High	High	9 wt%
10	High	Low	13 wt%
11	High	Typical	13wt%
12	High	High	13 wt%
13	Non-Newtonian	N/A	3 Pa[b]
14	Non-Newtonian	N/A	10 Pa[b]
15	Typical	Typical	13 wt% with 5 wt% of the solids included as spike particles

[a] Low supernatant properties: density = 1.098 g/ml, viscosity = 1.62 cP; Typical supernatant properties: density = 1.284 g/ml, viscosity = 3.6 cP; High supernatant properties: density = 1.368 g/ml, viscosity = 14.6 cP

[b] Non-Newtonian tests include quantification of added stainless steel and zirconium oxide solids. The amount of these solids added to the slurry is equivalent to the amount of these solids in Test #11.

The slurry used to evaluate the capability of the Isolok® Sampler to collect representative samples of broader types of Hanford tank waste will also be used to demonstrate the UPE. At an appropriate time during testing, as determine by the test director, the UPE will be demonstrated using the same simulant compositions. The slurry will be re-circulated through the flow loop at 140 gpm ±5 gpm (6 ft/s) until the specific gravity of the slurry stabilizes. Visual observations through the transparent test sections will be made to ensure that the solids in the transparent sections of the flow loop are not stratified at the starting velocity; if solids are stratified or focused and axial flow is evident, then the flow velocity would be increased as necessary to fully suspend the solid particles. The UPE will be used to constantly monitor particle motion in the UPE test section; however, reportable data will only be recorded once the flow has stabilized at each flow velocity increment. The velocity will be incrementally reduced by up to 1 ft/s increments until solids suspension begins to become challenged and stratification or focused axial motion becomes evident. If a stationary bed forms prior to visual determination of solids suspension becoming challenged and stratification or focused axial motion occurring, deposited solids will be re-suspended and the previous slurry velocity set will be revisited. Then the velocity reduction increments will be dropped to 0.1 ft/s until particle settling results in a stationary bed or until the flow reaches 2 ft/s, the performance limit of the RSD slurry pump. The velocity resulting in a stationary bed is identified as the critical velocity. ICD-19 establishes an action level for the critical velocity at 4 ft/s. Previous testing (PNNL-20350) indicates that the critical velocity determined by the UPE is generally within 0.3 ft/s of the visually determined critical velocity and tends to be conservative (predicts a stationary bed before it is visually observed). The previous testing also indicates that the difference between the two measurement techniques increases with increasing complexity of the simulant. For the UPE demonstrations using the multicomponent simulants discussed in Section 3.3.2, the difference in the critical velocity determined using the UPE and visual observations shall be within ±0.3 ft/s. It is not necessary to determine critical velocities that are below 2 ft/s, the minimum flow velocity from the RSD flow loop transfer pump.

Prior to each velocity reduction, the flow loop is allowed to stabilize and the flow behavior at the stabilized condition is recorded on video and documented in a video log along with the video file name and system operating conditions. Upon identification of the critical velocity, the slurry in the transfer line is re-suspended by increasing the flow velocity. The system is allowed to stabilize and a full-diversion sample is collected to represent the slurry in the transfer line during the demonstration of the UPE.

3.3.4 Sample Collection and Chemical Analysis

The RSD system performance testing shall establish the capability of the vertically oriented Isolok® Sampler to collect representative samples of the slurry in the flow loop. Samples are considered *representative* when the mean square of the sampling error, which is determined for each component of the simulant and includes an estimate of bias and variability, is less than the standard of representativeness. For RSD testing, the standard of representativeness is 10% relative to the average full diversion sample concentrations. The standard of representativeness is determined from sample size graphs presented in 2450-WTP-RPT-MGT-11-014, *Initial Data Quality Objectives for WTP Feed Acceptance Criteria*. According to sample size graphs and the empirical cumulative distribution functions for the waste feed determined by Hanford waste modeling activities, the waste feed is most likely to exceed the WAC for the 95% confidence

level for the ratio of fissile U to total U (see Figures 7-12 and 7-13 in 2450-WTP-RPT-MGT-11-014). When 10% sampling uncertainty is assumed, the required number of samples needed to ensure that the feed batch does not exceed the waste acceptance criterion is less than the maximum currently planned to be collected (10) for approximately 70% of the waste feed. Improving sampling performance or collecting additional samples would be necessary to ensure that the waste acceptance criterion is not exceeded for the balance of the waste.

Prior to performing each test, the simulants are prepared and qualified. The solid particulates are qualified for use prior to testing in accordance with Section 3.1.1.2. The liquid density and liquid viscosity of the supernatant of the Newtonian simulants are qualified for use prior to adding base solids. Measurements of the supernatant density and viscosity of the supernatants and the Bingham parameters for the non-Newtonian simulants will be performed on-site with a hydrometer and a rheometer as discussed in Sections 3.1.1and 3.1.2. Data collection shall be performed in accordance with ASME NQA-1-2004, Requirement 11, Test Control in including addenda, or a later version.

Once the simulants are qualified and added to the flow loop, the flow in the flow loop is stabilized, as indicated by the mass flow readings on the Coriolis meter and the Isolok® Sampler is exercised. The Isolok® Sampler is used to collect ten 250 ml samples of slurry in clean sample containers. The mechanical handling system should be used during sample collection to repeatedly exercise the equipment to establish reliability and help identify maintenance requirements. After the Isolok® samples are collected; two full diversion samples are collected. Five of the collected Isolok® samples and one of the two full diversion samples are sent off-site for compositional analysis. Analytical services are performed by a laboratory that operates under a Quality Assurance program that has been evaluated against quality requirements in ASME NQA-1-2004 including addenda, or a later version. These samples shall be analyzed for total slurry volume, total slurry mass, and the mass of each solid constituent (excluding kaolin for non-Newtonian tests). The remaining samples are retained on-site in a managed area of the facility as archive samples to be analyzed as necessary. Analytical data is required to be enhanced quality so that all sample collection, sample analysis, sample handling, and data reporting shall be traceable to the test performed. The sample results shall be reported in a Microsoft Excel compatible format.

The method for collecting the full-diversion sample will be consistent with previous RSD testing activities. The full diversion sample will be performed at the end of each test. The full diversion sample will be approximately 3-5 gallons, and will be taken by placing a 5 gallon bucket into the process stream that is being diverted into the effluent tank (TK-102). Holding the bucket there for 1-2 seconds will yield sufficient volume (approximately 4 gallons). Once the sample has been completed, the bucket will be removed and the process stream will be diverted back to the mixing tank (TK-101). A proper human machine interface has been field mounted to provide adequate protection to personnel and provide a level consistency needed for sample collection. The mass and volume of the collected sample are measured and recorded. The sample is then clarified for a minimum of 24 hours. After the solids have settled, the liquid is decanted and the mass and volume of the decanted liquid is measured and recorded. The wet solids are then loaded into multiple one liter containers for shipping. For each test, the full diversion solids are re-combined, homogenized, and sub-sampled by the analytical laboratory. The purpose of this

sample is to have direct representation of the material in the certification loop during testing activities.

The full diversion sample provides the basis for evaluating the performance of the Isolok® Sampler. Rather than compare sample results to initial simulant makeup content, which may be skewed by mixing in the tank, the comparison sample will be collected from the stream used to collect the Isolok® samples. Differences between the concentration of each component in the full diversion sample and the initial concentration will be attributed to settling in the transfer line and/or inadequate mixing in the mixing tank. Whether or not solids settle in the transfer line at the full-scale flow rate used to collect Isolok® samples will be evaluated when the UPE is demonstrated. Differences between the concentration of each component in the Isolok® samples and the full diversion samples are attributed to the capability of the Isolok® system to collect representative slurry samples from the flow loop assuming that the full-diversion sample is representative of the stream during Isolok® sample collection. To evaluate this assumption, variability in five full diversion samples will be quantified using the high conceptual base simulant in the typical density and typical viscosity supernatant. The difference between the Isolok® sample concentrations and the full diversion sample concentration will be expressed as a percent error (bias). In addition, correlations between the percent errors and the test properties that were changed will be analyzed for correlations. The relative standard deviation between the five collected Isolok® samples will also be calculated to evaluate correlations between sample consistency and the changed test conditions.

The performance of the UPE will be monitored by PNNL. Depending on the capability of the system and test schedule to accommodate collecting samples, full-diversion samples should also be collected before and after each demonstration of the UPE. Collected samples should be analyzed using the same analytical techniques developed for the Isolok® test samples. However, because the same simulants are used during Isolok® testing, full-diversion samples of the material are being collected to characterize the material in the transfer line. Video of the flow behavior at each velocity increment will be recorded. The flow data monitored by the Coriolis meter in the flow loop will be recorded on a data acquisition system for the duration of the test. A separate data acquisition system will be used to capture the signals reported by the ultrasonic transducers during demonstrations of the UPE. The results of the UPE demonstration will be analyzed by PNNL subject matter experts and will be summarized in a test report prepared by PNNL.

4.0 TEST COORDINATION

All testing equipment operations are performed by trained and qualified subcontracted personnel under the supervision of a Test Director. An operations plan, including test run sheets, will be prepared that describes the precautions and limitations, the testing sequences, testing prerequisites, startup conditions, and test procedures in stepwise detail. The TOC technical representative(s) must concur with the operations plan. The Test Director coordinates testing activities including ensuring that all test conditions required for the startup of testing have been performed and all test records (e.g., Test Log, Test Deficiency Reports, Test Change Requests, etc.) are maintained. The Test Director is also responsible for coordinating test activities with the Quality Assurance representative to ensure testing is performed in accordance with the approved quality assurance plan. While tests are conducted, the Test Director will also determine which changes do not adversely affect the acceptance criteria and/or methods by which the acceptance criteria are to be accomplished and are considered "inconsequential" or "minor" and approve these test changes. All other changes require concurrence with the TOC technical representative(s) before the change(s) is/are implemented.

4.1 PRECAUTIONS AND LIMITATIONS

The Job Hazards Analysis is the process for identifying, evaluating, controlling, and communicating potential hazards associated with the work being performed, including modifications to test facilities and test equipment. Testing for the SSMD scaled performance and RSD system performance are being performed in test facilities constructed to perform the testing. Each test facility is governed by a facility specific Job Hazards Analysis documented in a Job Hazards Analysis checklist or equivalent document. Changing conditions that modify the test facility or equipment to accommodate testing will be evaluated in a revision to the Job Hazards Analysis before the modifications to the facility or equipment are performed. Workers performing work in the test facility governed by the Job Hazards Analysis shall review the document hazards and acknowledge that they understand the hazards associated with the work being performed and will abide by controls (e.g., don required personal protective equipment, obey posted signs and placards) put in place to mitigate or eliminate the hazards.

Any special precautions that must be taken or test limitations will be documented in the operations plan specifically prepared for each activity and will be communicated to workers before the start of work during a Pre-Job briefing.

4.2 SEQUENCE OF TESTING

Any special requirements for the testing sequence that are not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

4.3 PLANT CONDITIONS

Any special requirements for the plant conditions, including connecting to site utilities and site restoration that are not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

4.4 SPECIAL EQUIPMENT

Any special equipment required to conduct the tests that is not identified in Section 3.0 will be documented in the operations plan specifically prepared for each activity.

5.0 DATA COLLECTION AND TEST RESULTS REPORTING

Testing shall be conducted in accordance with an approved operations plan and an approved data collection and accuracy plan that are prepared in accordance with this test plan. All test activities shall be performed according to test run sheets. All major testing activities shall be documented in a test log. Test deficiencies shall be reported in a Test Deficiency record.

Test data identified in Section 3.0 , including test durations and test conditions, shall be recorded in the test log. Applicable data not recorded by a data acquisition system shall be recorded on the run sheet or recorded in the test log. All electronic data collected by a data acquisition system shall be content reviewed for error and anomalies. Electronic records shall be submitted to the TOC for evaluation.

All laboratory analysis results shall be accompanied by a chain of custody report that was prepared when the samples were collected. The chain of custody shall identify the samples by a unique name, describe the sample type and list the analyses to be performed. The chain of custody shall also document the preparers name and shall acknowledge receipt at the analytical laboratory. All laboratory analysis results shall be submitted to the TOC technical representative in an MS Excel compatible format.

Test result reports shall be prepared for each test activity. Test activities shall be documented in a test data package that is submitted to the TOC by Energy*Solutions*. The TOC shall perform the required analysis and document the findings in a test report that is reviewed by Energy*Solutions*. PNNL will review the data collected by the UPE and document the evaluation in a separate test report.

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APPENDIX A. SMALL-SCALE MIXING SCALING PHILOSOPHY

The WFD Mixing and Sampling Program is performing both full-scale and small scale tests to evaluate mixing, sampling, and transfer performance between the Hanford HLW feed staging tanks and the receipt tanks at the WTP. Full-scale tests using prototypic equipment and operating conditions are being used to demonstrate the performance capabilities of the HLW sampling and transfer system that will be used to characterize the waste prior to transferring it to the WTP. Full-scale testing of components provides experimental data that can be used to evaluate the performance of the integrated system without the need to consider scale. Sampling and transfer testing at full-scale is manageable both fiscally and operationally. However, after considering economics, schedules, and operating complexities, performing full-scale tests of the mixing system was not practical. Therefore, it has been determined that mixing tests would be performed at small scales and full-scale performance will be evaluated using scale-up relationships. Operating at smaller scales is desirable because it reduces the cost of materials (i.e. simulants), labor, and time necessary to perform tests. For example, a full-scale transfer of 950,000 gallons of HLW at the maximum transfer flow rate (140 gpm) would take nearly five days of continuous operation. Using smaller scales, the transfer could be completed in a single work shift. However, operating at smaller scales requires that scaling relationships be understood to predict full-scale performance adequately.

The SSMD test platform contains two scaled systems that are geometrically similar to the DST and transfer system that will be used for first delivery to the WTP (DST 241-AY-102). The scaled properties are provided in Table 3-5. Full-scale DST properties are provided for 241-AY-102. The SSMD test platform was constructed according to scale from 241-AY-102.

The dimensions of the scaled test tanks and placement of the mixing and transfer equipment (e.g., tank diameter, bottom configuration, waste volume, mixer jet and transfer pump spatial locations, mixer jet nozzle diameter, mixer jet pump suction diameter and general tank obstructions) are directly scaled (i.e., proportional) to a full-scale DST filled with actual or anticipated volumes of waste. However, scaling is not full similitude. Consistent with general industry practice for mixing studies and previous testing with the SSMD platform, simulant properties, including particle sizes are not scaled. In addition, to mitigating line plugging with the unscaled simulant, the scaled dimensions for the transfer pump suction inlet diameter and transfer line conduit diameter are also not in direct proportion to a full-scale system. To avoid plugging, the diameter of the pipe should be 3 to 10 times the size of the particles being transferred. Hanford waste simulants are 10s to 100s of microns in size; therefore, the smallest diameter piping that was considered for the scaled systems was ¼-inch (6350 microns), which is much larger than would be used if the pipe diameter was proportionally scaled.

Similarly, scaling the flow rate through a proportionally scaled transfer pump inlet was also not practical for flow hydraulic concerns. For the 1:8 scale system, a proportionally scaled system would pump 12–19 gallons of slurry per minute through an approximate 0.3-inch diameter inlet yielding a transfer velocity of at least 54 feet per second (ft/s), well above the expected capture velocities in the full-scale system. The range for the transfer pump flow rates at each scale is specified to equate the fluid velocity through the inlet. The size and shape of the inlet and the fluid velocity through the inlet establish the velocity gradient into the pump inlet. Particles that enter the area of influence of the pump suction will only be captured by the pump if the pump suction, together with any upward motion induced by mixing, is sufficient to overcome any opposing motion due to particle settling and mixing. For the anticipated range of 90—140

gallons per minute, the fluid velocity through the 2.25 to 2.4 inch diameter inlet ranges between 6.4 and 11.3 feet per second. Because the particles are not scaled, the velocities through the inlet of the scaled systems are equated to full-scale velocities to get equivalent particle capture performance. The transfer pump flow rate is calculated as the product of the fluid velocity, 6.4 and 11.3 feet per second, and the pump suction inlet area in the scaled system.

If the scaling relationship is known, data collection from small-scale experiments performed at two or more different scales can be used to predict full-scale performance. Scaled performance experiments can be conducted at multiple scales to establish or refine scaling relationships. In order to develop scaling relationships, equivalent performance within the scaled systems must be established for known operating conditions. Developing the scaling relationship is performed by using generally accepted scaling relationships, which can be theoretically based or empirically determined from similar experiments, to establish a test matrix for the scales of interest. For SSMD scaled performance testing, the generally accepted scaling relationship used for equivalent mixing among scales, as relates to the distribution of solids throughout the mixed volume, is the equal power-per-unit-volume relationship. The power required to mix a tank with a jet, P_{mix}, can be determined from the kinetic energy supplied by the jet, as shown in Equation A-1.

$$P_{mix} = \left(\frac{\pi}{4} d_{jet}^2 U_{jet}\right)\left(\frac{1}{2}\rho U_{jet}^2\right) = \frac{\pi}{8}\rho d_{jet}^2 U_{jet}^3 \quad \text{(A-1)}$$

Where: ρ is the fluid density, U_{jet} is the nozzle velocity of the jet and d_{jet} is the jet nozzle diameter.

For the equal power-per-volume scaling relationship, the power computed by Equation A-1 is divided by the mixing volume, V, as shown in Equation A-2. Note: the mixing volume is the waste simulant slurry volume, not the capacity of the tank. The mixing volume is characterized by the tank diameter, d_{tank}, and the height, h_{slurry} of the slurry in the tank as it is mixed.

$$\frac{P_{mix}}{V} = \frac{\frac{\pi}{8}\rho d_{jet}^2 U_{jet}^3}{\frac{\pi}{4} d_{tank}^2 h_{slurry}} \quad \text{(A-2)}$$

For two scaled mixing systems with similar geometric properties mixing the same simulant, the nozzle diameter, tank diameter and slurry height from one tank are scaled from the other tank using the scaling factor, SF. The scaling factor is the ratio of the scaled tank diameter and the full-scale tank diameter. Setting the power-per-volume equation equal for the two scales, denoted with subscripts 1 and 2, and substituting in the scaling relationship ($SF=d_{tank2}/d_{tank1}$) is shown in Equation A-3. The simplification of Equation A-3 is shown in Equation A-4.

$$\frac{P_{mix1}}{V_{tank1}} = \frac{\frac{\pi}{8}\rho d_{jet1}^2 U_{jet1}^3}{\frac{\pi}{4} d_{tank1}^2 h_{slurry1}} = \frac{P_{mix2}}{V_{tank2}} = \frac{\frac{\pi}{8}\rho d_{jet2}^2 U_{jet2}^3}{\frac{\pi}{4} d_{tank2}^2 h_{slurry2}} = \frac{\frac{\pi}{8}\rho SF^2 d_{jet1}^2 U_{jet2}^3}{\frac{\pi}{4} SF^2 d_{tank1}^2 SF h_{slurry1}} \quad \text{(A-3)}$$

$$U_{jet1}^3 = \frac{U_{jet2}^3}{SF} \quad \text{(A-4)}$$

The scaling factor exponent for equal power per volume conditions in the SSMD test platform is 1/3, as shown in Equation A-5.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{\frac{1}{3}} \quad \text{(A-5)}$$

Equation A-5 assumes that equal performance is attained when the applied power to mix is directly proportional to the volume to be mixed. The mixer jet pumps are being designed to sustain a flow rate of 5,200 gallons per minute from each of two 6-inch diameter nozzles on each mixer jet. The nozzle velocity exiting the full-scale pump is about 59 ft/s. Using a 1/3 scale factor exponent, nozzle velocities of approximately 30 ft/s and 21 ft/s are determined for the 1:8 and 1:21 scale systems, respectively.

Initially scaling between the two scales in the SSMD test platform was performed to demonstrate that the scaled tanks could be scaled from the full-scale system using the equal power-per-volume scale factor exponent. While this relationship is suitable for mixing, it may not be suitable for other performance metrics, such as the effective cleaning radius, off-bottom suspension, or particle transfer. Equal performance between scales is not just limited to mixing, it could also consider the transfer pumps ability to capture and convey the slurry solids. Therefore, the equal power per unit volume relationship with a scale factor exponent of 1/3 may not be the best relationship to use to scale the integrated system. Equation A-6 replaces the 1/3 scale factor exponent with an unknown value, a, that can be determined for different performance metrics.

$$U_{jet2} = U_{jet1}\left(\frac{d_{tank2}}{d_{tank1}}\right)^{a} \quad \text{(A-6)}$$

The scale factor exponent can be determined through scaled testing. For example, as reported in RPP-RPT-48233, *Independent Analysis of Small-Scale Mixing Demonstration Test*, the mixing data from nine mixer jet pump flow rates at 1:8-scale and 1:21-scale illustrated that equal mixing performance of zirconium oxide in water, as defined by equivalent slurry densities at equal scaled heights, was attained with flow rates of 102.0 gallons per minute (32.6 ft/s) and 9.0

gallons per minute (21.9 ft/s), respectively. The scale factor exponent for the point where mixing performance at the two scales became equal was determined to be 0.39. It is noted that the metric evaluated equal mixing, not adequate mixing as defined by a consistent density at all heights within the tank. The latter was achieved at higher nozzle velocities and equivalent mixing between the scales was maintained at the higher velocities. At the identified flow rates the specific gravity of the zirconium oxide slurry used in the tests was higher at lower heights in both tanks, indicating that the solids (presumably the larger particles) were not being dispersed throughout the entire tank volume. The results also indicate that with increasing nozzle velocities (decreasing scale factor exponent values), mixing performance becomes adequate and plateaus.

Because there is uncertainty in the appropriate scale factor for the performance of the integrated system with simulants that are characteristic of other Hanford tanks, future tests will be performed using two scales and a range of different mixer jet pump nozzle velocities. In addition, the program will begin to evaluate the appropriateness of applying the same scaling relationships to Newtonian and non-Newtonian slurries. Equal performance, as measured by a specific performance metric (e.g., distribution of solids, effective cleaning radius, off-bottom suspension, or particle transfer), will be used to refine previous scaling work.

The rotation rate for the mixer jet pump, ω, is also a scaled property of the integrated system. Similar to work described in Section 2.1.2 of PNNL-14443, *Recommendations for Advanced Design Mixer Pump Operation in Savannah River Site Tank 18F*, the scaling parameter for the mixer jet pump rotational rate equates the number of revolutions that occur in the time required to circulate an entire tank volume through the mixer jet pump inlet (PNNL-14443 Section 2.1.2).

Because the tank diameter and tank height are geometrically scaled from the full-scale, the volume of the scaled tanks, *V*, are related as shown in Equation A-7.

$$V_{tank2} = \frac{\pi}{4} d_{tank2}^2 h_{slurry2} = \frac{\pi}{4} (SF\ d_{tank1})^2 SF\ h_{slurry1} = SF^3 V_{tank1} \quad \text{(A-7)}$$

The time required to circulate an entire tank volume through the mixer jet pump inlet, the turnover time (Θ), is the ratio of the tank volume and the mixer jet pump volumetric flow rate, which is itself a function of the nozzle velocity and the nozzle area. Equation A-8 shows this relationship.

$$\Theta_{tank1} = \frac{V_{tank1}}{Q_{tank1}} = \frac{V_{tank1}}{A_{nozzle1} U_{jet1}} \quad \text{(A-8)}$$

The turnover time for Tank 2 can be related to the turnover time for Tank 1 using the geometric scaling factor when the tank diameter, waste height, and mixer jet nozzle diameter are geometrically scaled as shown in Equation A-9.

$$\Theta_{tank2} = \frac{V_{tank2}}{Q_{tank2}} = \frac{SF^3 V_{tank1}}{A_{nozzle,2} U_{jet2}} = \frac{SF^3 V_{tank1}}{SF^2 A_{nozzle1} U_{jet2}} = \frac{SF U_{jet1} \Theta_{tank1}}{U_{jet2}} \quad \text{(A-9)}$$

Setting the scaling condition (ωΘ) equal between the two tanks yields the angular velocity scaling relationship (Equations A-10 and A-11).

$$\omega_{tank1}\theta_{tank1} = \omega_{tank2}\theta_{tank2} = \omega_{tank2} \frac{SF U_{jet1} \Theta_{tank1}}{U_{jet2}} \quad \text{(A-10)}$$

Therefore,

$$\omega_{tank2} = \frac{\omega_{tank1} U_{jet2}}{SF \quad U_{jet1}} \quad \text{(A-11)}$$

Where: *SF* is the ratio of the tank diameters at the two scales.

Compared to full-scale conditions, as the scale factor exponent decreases, the nozzle velocity and rotational rate for a smaller scale system increase. However, the nozzle velocity for a smaller scale system is generally less than the full-scale nozzle velocity and the rotational rate is usually faster than the full scale rotational rate. Therefore, the nozzle velocity in the smaller scale system equals the full scale nozzle velocity when the scale factor exponent value equals 0 and the rotational rate for a smaller scale system equals the full scale rotational rate when the scale factor exponent value equals unity.

In SRNL-STI-2010-00521, *Demonstration of Mixer Jet Pump Rotational Sensitivity on Mixing and Transfers of the AY-102 Tank*, the effect of the rotational velocity of the mixer jets was evaluated at 1:22-scale and shown to have little effect on the amount of solids transferred in each transfer batch. However, it is noted that the nozzle velocity of the mixer jet was selected so that no "dead zones" were observed in the tank during testing. The testing did not assess whether or not the rotational rate would influence the amount of solids transferred if solids were allowed to accumulate in "dead zones". PNNL-14443 showed that the effective cleaning radius of a mixer jet decreased with increasing mixer jet rotational velocity and decreasing mixer jet nozzle velocity. It can be reasoned that performance metrics aimed at bottom cleaning or metrics that are strongly influenced by the solids on the bottom of the tank would need to evaluate the impact of both mixer jet rotational rate and nozzle velocity.