High-Level Waste Feed Certification in Hanford Double-Shell Tanks – 10083

Michael G. Thien*, Beric E. Wells**, Duane J. Adamson***

* Washington River Protection Solutions, Richland, Washington 99352
**Pacific Northwest National Laboratory, Richland, Washington 99352
***Savannah River National Laboratory, Aiken, South Carolina 29808

ABSTRACT

The ability to effectively mix, sample, certify, and deliver consistent batches of High Level Waste (HLW) feed from the Hanford Double Shell Tanks (DST) to the Waste Treatment and Immobilization Plant (WTP) presents a significant mission risk with potential to impact mission length and the quantity of HLW glass produced. DOE's River Protection Project (RPP) mission modeling and WTP facility modeling assume that individual 3785 cubic meter (1 million gallon) HLW feed tanks are homogenously mixed, representatively sampled, and consistently delivered to the WTP. It has been demonstrated that homogenous mixing of HLW sludge in Hanford DSTs is not likely achievable with the baseline design thereby causing representative sampling and consistent feed delivery to be more difficult. Inconsistent feed to the WTP could cause additional batch-to-batch operational adjustments that reduce operating efficiency and have the potential to increase the overall mission length. The Hanford mixing and sampling demonstration program will identify DST mixing performance capability, will evaluate representative sampling techniques, and will estimate feed batch consistency. An evaluation of demonstration program results will identify potential mission improvement considerations that will help ensure successful mission completion. This paper will discuss the history, progress, and future activities that will define and mitigate the mission risk.

INTRODUCTION

Hanford HLW will be staged in 3785 cubic meter (1 million gallon), underground DSTs prior to delivery to the WTP for treatment. HLW is a combination of liquid and undissolved solids that settle and form sludge in the bottom of the DSTs. The underground DSTs are approximately 23 meters (75 feet) in diameter and 12 meters (40 feet) high with equipment access provided through risers located in the dome of the tank. The baseline design for transferring the HLW to the WTP for treatment includes the use of two 300-horsepower centrifugal mixer pumps with two opposed nozzles each to mobilize the sludge particles, and the use of one submerged inlet centrifugal transfer pump to deliver the HLW slurry through pipelines to the WTP. Mixer pump testing performed in Hanford's AZ-101 DST in 2000 demonstrated the ability of these pumps to mobilize the majority of the settled sludge off the bottom of the DST such that it could be moved to the transfer pump for transfer to the WTP or other DSTs [1]. As the WTP design progressed and the WTP feed certification process became more detailed, performance expectations for the mixer pumps evolved to include the ability to homogeneously distribute the solids throughout the million-gallon DST. An evaluation of the AZ-101 mixer pump test data concluded that only about 30% of the solids by mass in AZ-101 were evenly distributed across approximately 90% of the tank volume [2].

The HLW feed certification and delivery strategy includes mixing, certifying a 3785 cubic meter (1 million gallon) staged DST as compliant with WTP requirements, and then transferring multiple 600 cubic meter (160,000 gallon) batches to the WTP [3] (See Figure 1). The level of accuracy for certifying waste feed is still under development but the feed must be shown to meet the regulatory, safety basis, and operational requirements within the yet-to-be-defined tolerance band. Traditional tank farms methods of sampling DSTs which consist of individual grab sample (liquids) or core sample (settled solids) events while the tanks are quiescent (not being mixed), are not adequate for providing a representative slurry sample of the waste that would be transferred to the WTP. DST sampling capability is needed that can collect slurry samples while the DSTs are being mixed that are representative of the feed that will be delivered to the WTP.

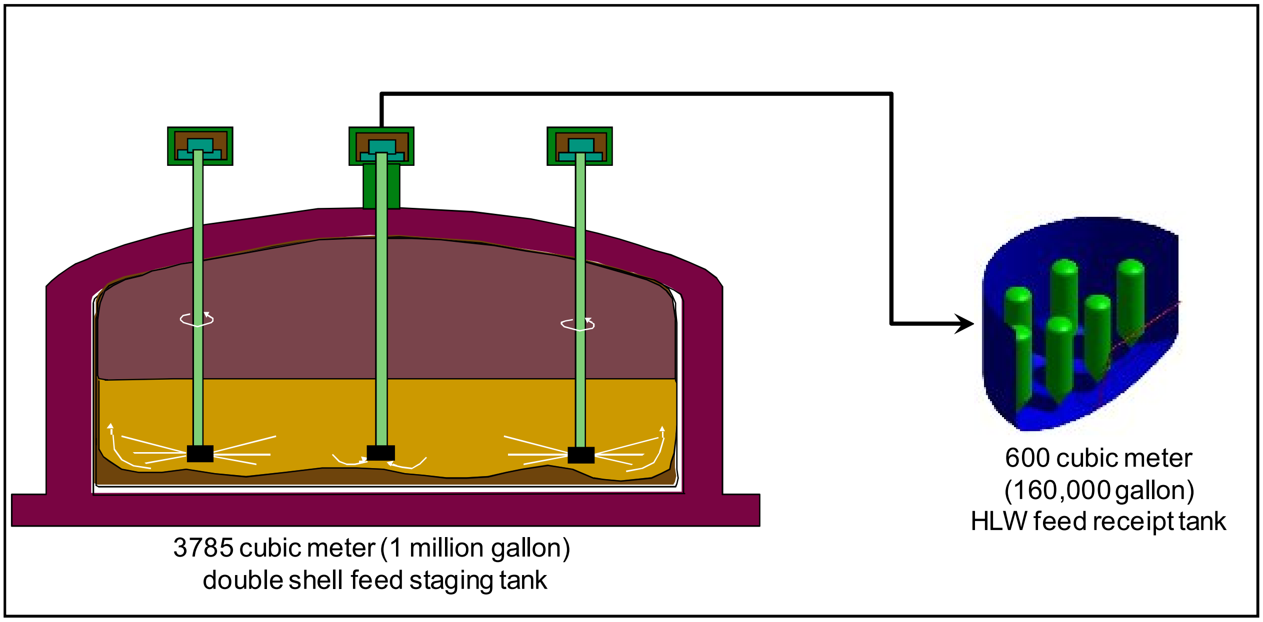

Figure 1. WTP Feed Delivery Concept

Over the last fifteen years, much information has been compiled within the DOE complex that is related to the ability of submerged jet pumps to mobilize solids that have settled to bottom of tanks. This information is a result of development and demonstration activities plus many years of tank retrieval and cleanout experience at the Savannah River and Hanford Sites. An effective cleaning radius (ECR) correlation from scaled mixer pump tests for Hanford tanks, based on jet velocity, jet nozzle diameter, and sediment shear strength has been recommended [4].

While there is significant experience with mobilizing settled solids from the bottom of tanks there is little understanding about how these solids are distributed within the volume of the tank after they have been mobilized. This distribution of solids, or mixing, has typically not been an area of interest because the objective of retrieval and cleanout activities is focused on moving the solids to a location where they can be pumped out of the tank regardless of the characterization or batch-to-batch content consistency of the transferred slurry. In the case of feed delivery to a processing plant (i.e., WTP), the characterization and batch content consistency of the transferred slurry become more important as the receiving processes have specific acceptance requirements for the feed that are driven by design, operational, or safety considerations. One might expect that SRS feed batching and mixing operations prior to delivery to the vitrification plant (Defense Waste Processing Facility [DWPF]) to be similar to the Hanford feed delivery situation. Significant differences between SRS and Hanford feed staging and delivery scenarios exist.

These differences include:

- Different tank configurations (SRS tanks have large central columns – Hanford tanks are completely open)
- Different mixer pump configurations (SRS uses four 300-HP mixer pumps located 90 degrees apart – Hanford uses two 300-HP mixer pumps located 180 degrees apart)
- Different waste characteristics (SRS waste comes from two main processes and is relatively consistent from tank to tank – Hanford waste comes from upwards of 54 processes [5] and relatively diverse from tank to tank)
- Different processing plants (SRS waste is feeding a plant focused on producing High Level Waste glass – Hanford is feeding a pretreatment facility with multiple chemical and physical separation steps that occur prior to feeding either High Level Waste or Low Activity Waste vitrification facilities)

Complicating the WTP feed delivery scenario is the Pretreatment Facility design requirements that limit the amount and type of solids the receipt tanks can accommodate. This creates a scenario where the feed tank certification requirements are significantly more onerous than that experienced with SRS transfers to DWPF or Hanford transfers between tanks in the tank farms. Accurately characterizing the contents of a million gallon feed tank containing an excess of five feet of settled solids and then delivering the mixed slurry in consistent batches is a formidable challenge that is not well understood.

MIXING DEMONSTRATION STRATEGY

While RPP mission planning assumptions suggest homogenous individual DST mixing and consistent batch delivery is required, an optimized solution may exist that relies on selection of a representative transfer pump location within a mixed DST and relaxed expectations for consistency between feed batches delivered to the WTP. Implementing this strategy requires a more thorough understanding of undissolved solids distribution within the dynamic environment of a mixed DST and requires an evaluation of WTP operational tolerances and mission impacts of variability between feed batches. Understanding these issues and defining an acceptable feed certification and delivery scenario has the potential to eliminate the need for significant Hanford project expenses that would otherwise be needed to upgrade DST mixing performance or construct a dedicated feed delivery mixing facility.

The mixing demonstration strategy is built around the following progressive concepts:

- Demonstrate DST mixing phenomena with small scale ‘scouting studies’
- Develop small scale DST mixing correlations using two different small scale mixing platforms
- Demonstrate representative sampling capability on small scale mixing platforms
- Clarify WTP receipt requirements versus WTP operational preferences
- Use computer modeling calibrated to small scale results to estimate full scale performance
- Develop in-field characterization module to collect samples and directly measure critical velocity
- Validate performance in full scale WTP commissioning tank

SMALL SCALE SCOUTING DEMONSTRATIONS

A small scale, fully functional, clear tank was constructed at Savannah River National Laboratory (SRNL) to demonstrate the complexity of the Hanford DST mixing phenomena and to develop an understanding of the basic parameters that have a significant effect on the effectiveness of tank mixing.

Demonstration Platform

The mixing demonstration tank was built around an existing transparent acrylic tank with an ID of 103 centimeters and a height of 76 centimeters. A geometrically scaled replica of DST AY-102 was built that included two functional mixer pumps and internal tank obstructions replicating the 22 air lift circulators, a heating coil, and a centrally located transfer pump. All other AY-102 components were considered insignificant when scaled down to the approximately 1/22nd scale represented by this tank. The internal obstructions were designed such that they could be easily removed or installed in the tank as one assembly. [6] The mixer pumps were designed with a slurry pump located external to the tank that drew its suction from the bottom center of the mixer pump assembly and discharged through an outer annulus that carried the slurry to two scaled discharge nozzles located near the bottom of the mixer pump assembly and 180° apart. The mixer pump assembly was able to rotate through a full 360 degrees of rotation at variable speeds. Figure 2 contains a drawing of the mixer pump assembly and Figure 3 contains a picture of the assembled mixing platform with settled simulant.

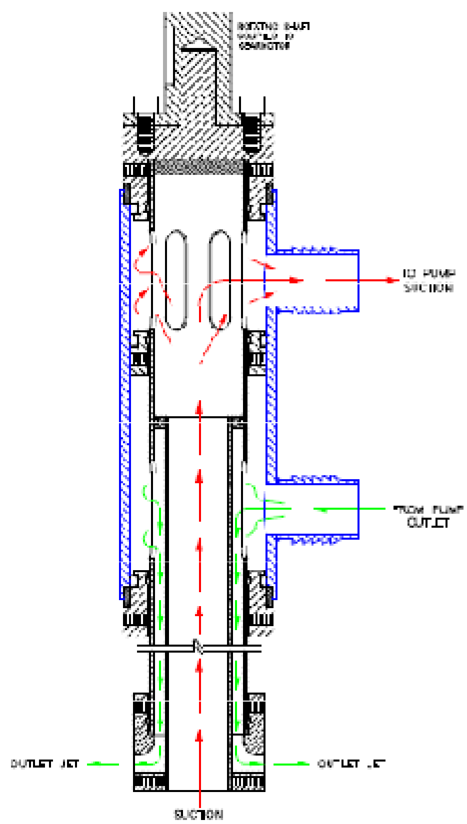

Figure 2. Scaled Mixer Pump Details

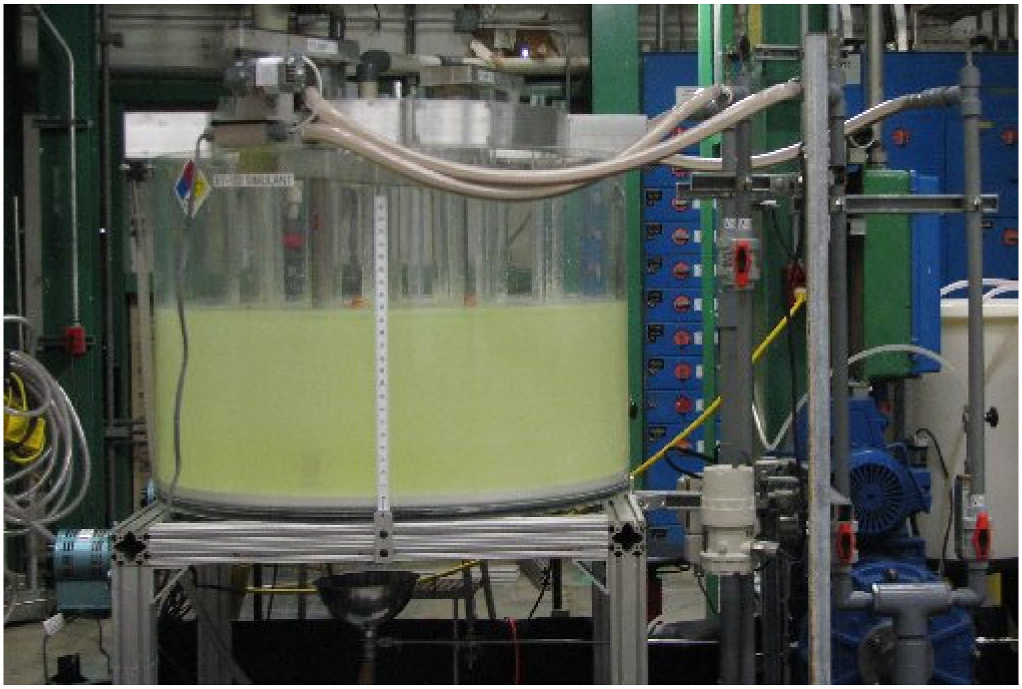

Figure 3. Mixing Demonstration Platform

The simulant used for the visual scouting studies was chosen to conservatively reflect the particle size distribution in AY-102 while providing visual distinction of the mixing phenomena occurring within the tank. The simulant was composed of a clear fluid, a light colored particulate of relative small size particles, and a dark colored particulate of relatively large size. The clear fluid was a simulant that represented an average Hanford tank supernate waste and was left over from Fractional Crystalization Pilot Project testing performed earlier at SRNL. Gibbsite was selected to represent the majority of the typical Hanford solids because of its white milky color and a 30 µm particle size that is somewhat larger than the average Hanford waste particle size. Silica Carbide (SiC) was selected to represent the larger, more difficult to mix particles because of its black color and a 50 to 165 µm particle size that represents the upper percentile of particles found in Hanford waste. The particulate simulant was added in a quantity reflective of the settled solids in AY-102 but was purposely "overloaded" with a higher percentage of the more difficult to mix SiC particles to ensure visual distinction could be made of the observed mixing behavior.

Mixing Demonstration

The mixing demonstration platform was operated in early 2009 to gain an understanding of the mixing phenomena occurring in a Hanford DST and to qualitatively determine the significance the internal tank obstructions have on the mixing performance. A series of mixing demonstrations were performed across a spectrum of mixer pump flow rates with and without the obstructions present in the tank. The mixer pump flow rate was varied in increments from zero flow up to 38 liters/minute (10 gal/minute), a value that provided equivalent scaled mixing power calculated as a function of pump power per tank volume.

The mixing platform performed exceptionally well and allowed collection of effective cleaning radius data, cloud height, and a wealth of qualitative visual mixing phenomena all correlated with mixer pump flow rate.

As expected, an increase in the effective cleaning radius and cloud height correlated well with an increase in mixer pump flow rate. The most significant data was the wealth of visual observation that provides insight into the mixing phenomena. The following observations were made:

Mixing Mechanism: Based on visual observations the smaller gibbsite particles are mixed in a turbulent cloud-like structure that transforms the tank into a milky looking mixture as mixer pump flow rate is increased. Visual observation of the larger (and denser) SiC particles indicated the primary mixing mechanism is the “welling up” of the particles at the tank walls. As the SiC particles get moved across the bottom of the tank by the mixer pump jets, they impact the walls of the tank and the horizontal velocity is translated into vertical motion that carries the particles up to the surface where the particles then spread around the surface and begin to settle back down to the bottom of the tank.

Tank Homogeneity: Tank homogeneity was not achieved. Even at high mixer pump flow rates there could always be observed areas of darker color (more SiC) and areas of lighter color. Observations of the tank bottom demonstrated the fast settling nature of SiC where the tank bottom was saturated with the larger SiC particles except the area where the mixer pumps had just swept clean. This phenomenon is demonstrated in Figure 4.

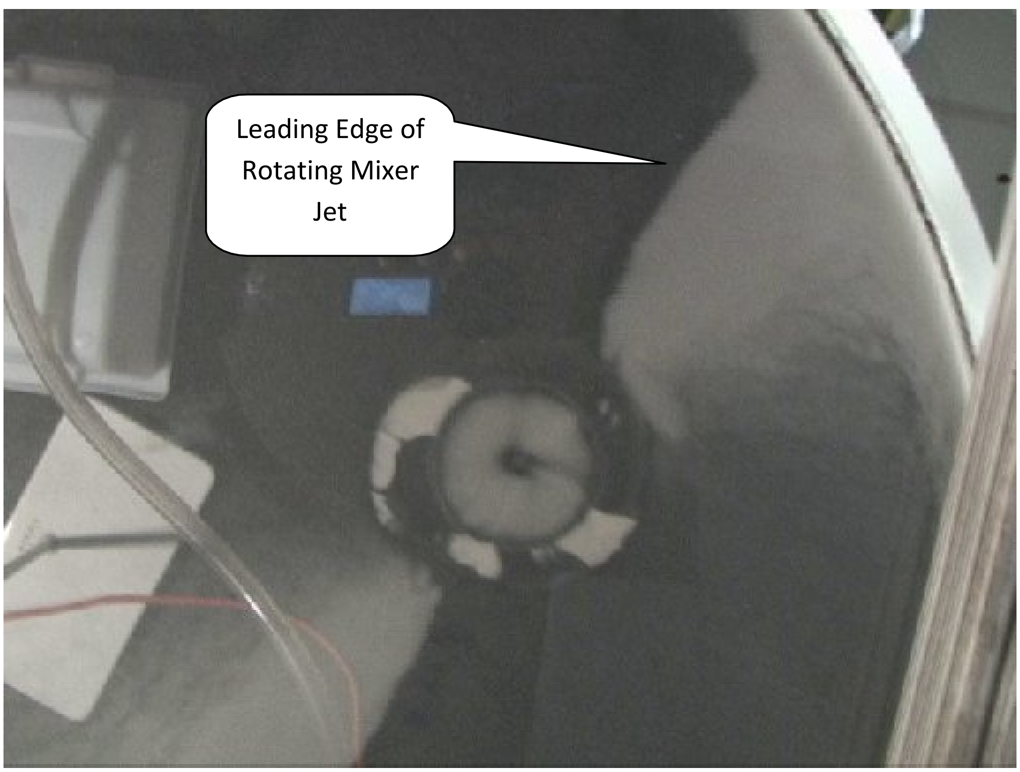

Figure 4. Mixer Pump Clearing of Tank Bottom

Obstruction Impact: The observed mixing phenomena appeared to be independent of the obstructions in the tank. It should be noted that observations were only able to be made on the outside surfaces of the tank and flow patterns internal to the tank could not be observed. This observation reinforces the theory that the primary mixing mechanism for the larger particles is the "welling up" of the particles at the tank walls.

Batch Transfer Demonstration

After completion of the initial mixing demonstrations in early 2009, the mixing platform was modified to evaluate the consistency of simulated WTP feed delivery batches. A scaled transfer was added with the ability to transfer the tank contents to one of six batch receipt tanks. The batch receipt tanks were constructed of transparent material so a visual measurement of the settled solids could be made. The objective of the batch transfer demonstrations was to determine the variability in solids that are transferred in each scaled 600,000 L (160,000 gallon) HLW feed batch transferred to the WTP. Figure 5 includes the six batch transfer tanks and demonstrates the ability to visually distinguish the amount of SiC solids (dark solids settled to the bottom) and gibbsite solids (white solids settled in the upper transparent section) transferred in each batch.[7]

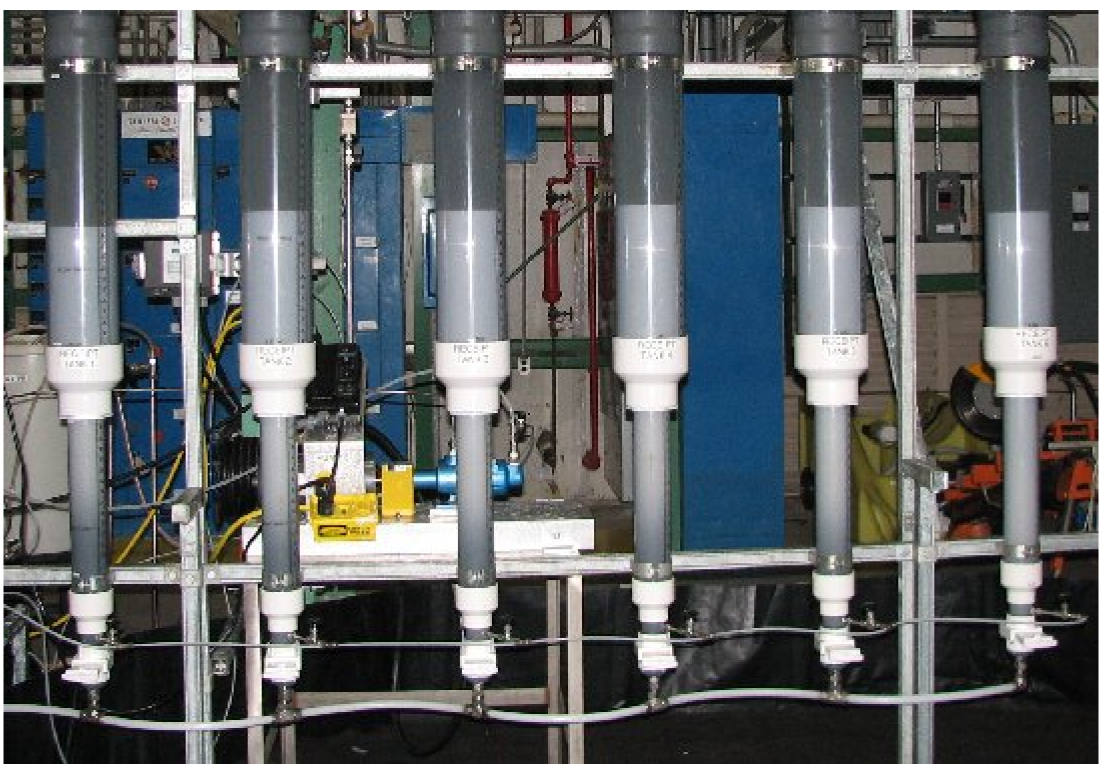

Figure 5. Batch Transfer Tanks

The following mixing tank parameters were varied during the batch transfer demonstration:

- Transfer pump flow rate
- Transfer pump radial location
- Transfer pump elevation
- Mixer pump flow rate
- Mixer pump rotation rate

The results of the batch transfer demonstration revealed far less batch variability in the amount of solids transferred than initially expected. Batch consistency was calculated as a function of the average deviation each transfer batch volume differed from the mean volume transferred for all batches in a particular test, expressed as a consistency percentage. For example, if all batches were identical then a batch consistency of 100% is calculated. Even in the cases with reduced mixer pump flow where the tank was intentionally under mixed, the batch-to-batch consistency was surprisingly high. Figure 6 demonstrates that the batch-to-batch consistency of the SiC transferred for each test was near or above 90% for all tests.

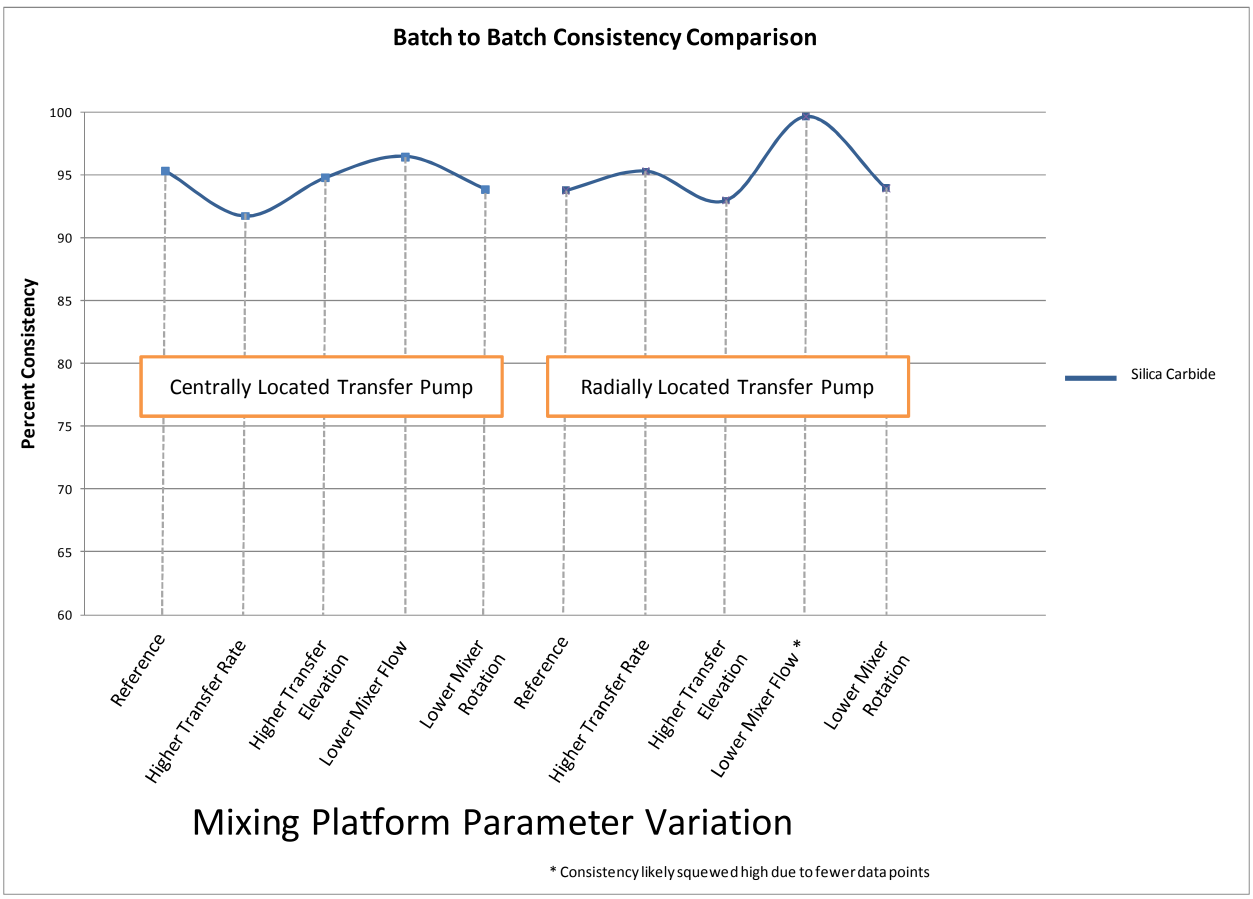

Figure 6. Batch Transfer Consistency

While these demonstrations still need to be duplicated in a more precisely controlled and instrumented demonstration and at multiple scales, they are encouraging. These batch transfer demonstration results suggest that the transfer pump suction in a mixed tank sees a consistent amount of solids over the time increment it takes to transfer five batches out of the tank. This batch consistency is maintained even in conditions where the tank is not mixed thoroughly or the transfer pump has been moved to alternate locations. This consistency supports the concept that characterization of the tank contents that will be transferred out of the tank (e.g., to the WTP) can be made based on samples collected directly from the transfer pump discharge piping.

Particle size distribution measurements of SiC samples taken from the bottom of batch one receipt vessel, the bottom of batch five receipt vessel, and the pile of remaining solids in the mixing tank showed no significant difference between the three locations.

SMALL SCALE MIXING DEMONSTRATION

The small scale mixing demonstration work currently in progress is focused on demonstrating at a small scale the baseline tank farm system capabilities to mix 3800 cubic meter (1 million gallon) DSTs. The objective of this demonstration work is to understand the mixing capabilities of the baseline equipment at two different scales and to define appropriate sample collection locations within the tank to ensure a representative feed certification can be achieved. Using computational fluid dynamic (CFD) modeling that will be calibrated to the observed performance in the two small scale demonstration platforms, scale-up correlations will be developed to allow prediction of full scale DST mixing and sampling performance.

The two-scaled mixing platforms will be significantly more instrumented than the SRNL based scouting platform described above. This will allow for collection of necessary flow and particulate concentration data that is necessary to calibrate the CFD models. The small scale mixing platform tanks will be approximately 1 meter (41 inches) and 3 meters (10 feet) in diameter with the remaining dimensions geometrically scaled to match the full scale DSTs. This work is currently in the design and fabrication stages today in the Tri-Cities (Washington) and is expected to continue through the end of 2011.

CERTIFICATION LOOP

Prior to delivering HLW to the WTP, each batch of staged HLW must be sampled and certified to meet the WTP waste acceptance criteria. Waste sampling and certification must be of sufficient rigor to satisfy WTP regulatory, safety, and operational requirements. Sampling a 3800 cubic meter (1 million gallon) DST to provide for confident certification that all requirements are met is a large challenge. The baseline concept to meet this certification challenge was developed during a Waste Feed Delivery Value Engineering Study [8] in January of 2009. The certification loop concept is based on the principle that the waste in the tank that will be transferred to the WTP will come directly from the transfer pump discharge and therefore characterization of waste to be transferred is most appropriately done on samples taken from the transfer pump discharge rather than core or grab sample events that may not be representative of transferred waste. A piping loop could be used to recirculate HLW slurry from the transfer pump discharge back to the originating tank while it is being mixed. Samples taken directly from this recirculation would be most representative of waste to be transferred to the WTP.

A challenging and perhaps one of the more limiting WTP waste acceptance criteria parameters is the critical velocity of the slurry. Critical velocity is defined as the velocity of a slurry above which particulates will remain mobilized in the carrier solution and be transported down the pipe. [9] Critical velocity is important for WTP receipt to ensure that solids in HLW feed will remain suspended and not accumulate in plant piping. Traditional methods for estimating slurry critical velocity involve collecting small samples of the slurry and then sending the samples to an analytical laboratory to evaluate rheological properties (i.e., viscosity, shear strength, particle size, particle density, etc.) which are then applied to one of several theoretical critical velocity equations. Errors in critical velocity calculations are introduced by the analytical testing, the combination of multiple attributes, and perhaps most importantly the appropriateness of the selected critical velocity equation to the particular flow conditions that exist. If critical velocity could be measured directly to give a true performance parameter of the HLW slurry, much uncertainty could be removed. Combining the ability to directly measure critical velocity with the concept of a recirculation flow loop driven by the transfer pump creates an elegant solution to the WTP waste certification process.

The flow loop developed by Pacific Northwest National Laboratory (PNNL) to address WTP External Flowsheet Review Team M-1 issues [8] was successfully used to study slurry flow and develop slurry flow correlations directly related to solids deposition. WRPS has initiated work that modifies the existing M-1 flow loop to identify instruments capable of measuring deposition of solids in a pipe. This ongoing work is evaluating three primary instruments to determine applicability for tank farm field deployment. A range of bounding Hanford tank farm slurries will be pumped through the flow loop (Figure 7) at sequentially reduced flow velocities until deposition of solids in the test section piping is detected. Instrument response from pulse-echo ultrasound, ultrasonic attenuation, and ultrasonic doppler velocimitery instruments (Figure 8) will be recorded and correlated against reference measurements from a transparent pipe section and differential pressure monitoring.[10] The data collected from this flow loop demonstration will be used to select one or more instruments that are suitable for deployment in a Hanford tank farm field environment to measure Hanford DST slurry critical velocity as it is recirculated through the certification loop concept described above.

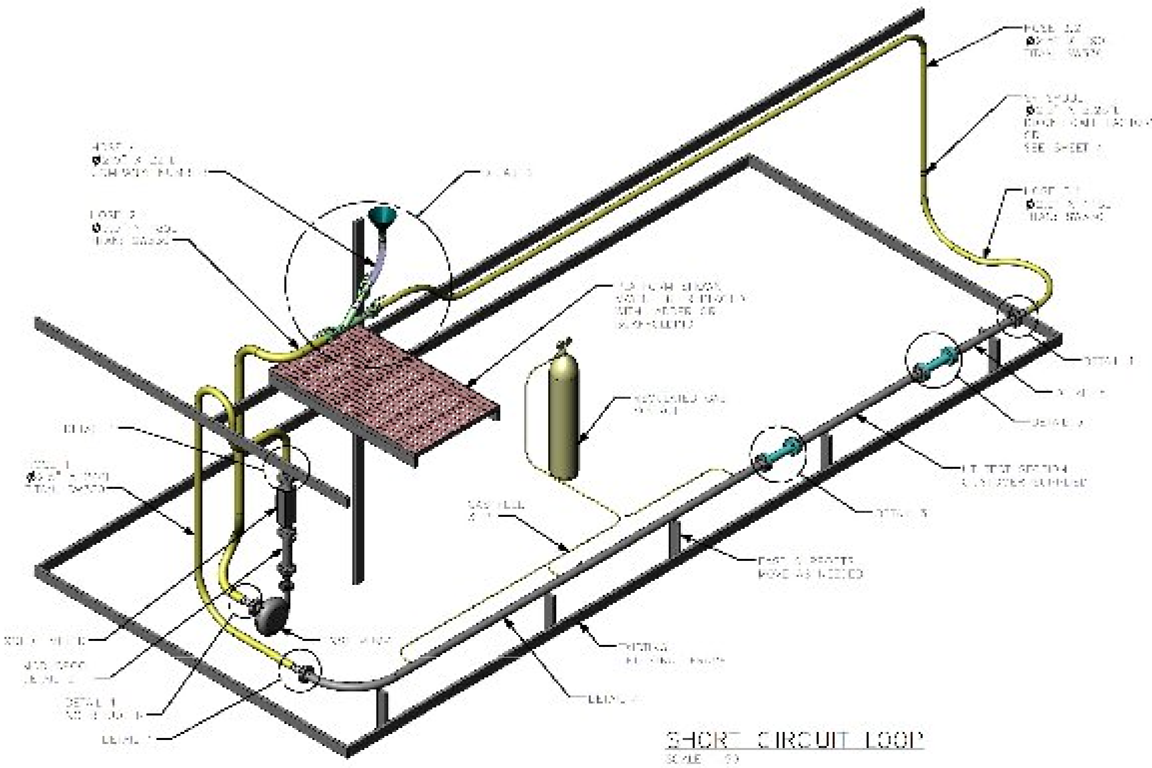

Figure 7. Flow Loop Configuration

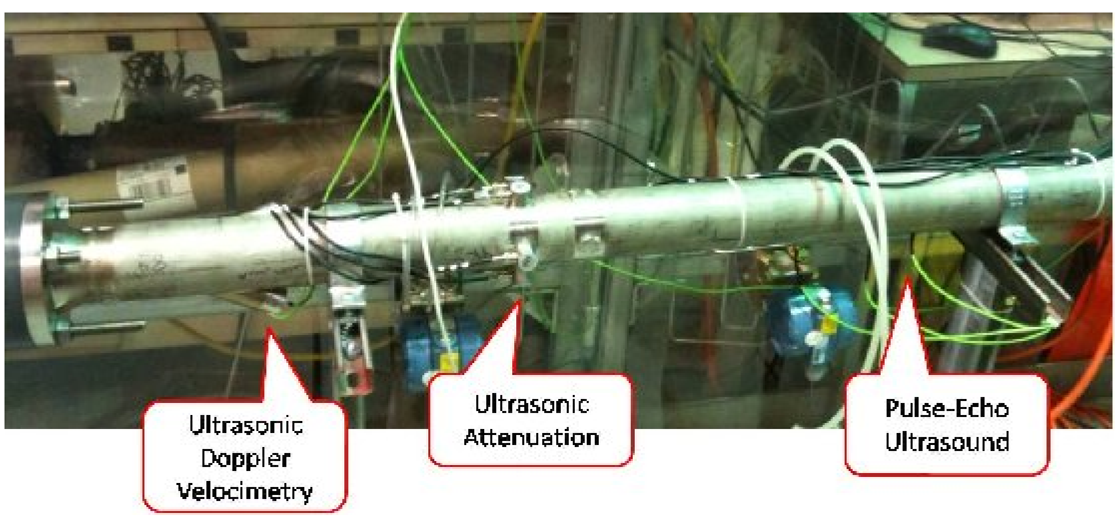

Figure 8. Instrument Test Section

LESSONS LEARNED FROM RELATED MIXING DEMONSTRATIONS

While the objectives of the work may be different there are many similarities in equipment, fluid flow theory, and operational implications between this work and the work that supported resolution of the WTP EFRT M-1 and M-3 issues.

M-3 work focused on mixing phenomena of WTP tanks using pulse jet mixer technology rather than the rotating jet pumps used in the Hanford tank farms, but there are many similarities in equipment set-up, instrumentation, and simulant use. [11]

M-1 work was focused on developing slurry flow phenomena correlations in an effort to better understand the potential for pipe plugging and pipe flushing requirements within the WTP piping. The majority of the same flow loop equipment will be used for the Hanford certification loop development. The instrumentation is different but the concepts used to detect when critical flow velocity is reached are directly tied to the principles identified in the M-1 testing. [12]

DEMONSTRATION COMPLETION AND FEED DELIVERY

The work described above represents only the first phases of the effort needed to ensure reliable and consistent feed certification and delivery of HLW slurry to the WTP. The demonstration program work described below will complete the integration of information gained from the small scale mixing demonstration into a reliable and functional Hanford tank farms feed certification and delivery system. The current baseline scheduling completes this work in time to deliver the first HLW slurry to the WTP by May of 2018.

- **Integrated Optimization Phase –** This phase is focused on evaluating the capabilities of the systems demonstrated at small scale and evaluating against WTP requirements. It is anticipated that all requirements will not be entirely met. An alternatives analysis will be performed that will evaluate modifying both Hanford tank farm feed certification systems and WTP acceptance criteria to identify an integrated solution that represents the "best value to the government". It is anticipated the results of this integrated optimization will result in some mixing system modifications and some acceptance criteria modifications.
- **Small Scale Iteration Phase** – This phase is focused on demonstrating the effectiveness of the optimized system configuration identified in the previous phase. It is anticipated that the same small scale facility will be modified to reflect the optimized system configuration and another iteration of small scale demonstrations completed. In parallel with the additional small scale mixing demonstrations, a full scale prototype of the certification test loop will be built and demonstrated to ensure an effective system can be deployed in time to support the full scale demonstration phase.
- **Full Scale Demonstration Phase** – Once the small scale configuration can be shown to meet requirements, the program will move into full scale demonstration on the WTP first feed tank AY-102. This work will be closely coordinated with the DST upgrade projects which will be responsible for procuring and installing the baseline equipment anticipated to be needed for WTP feed certification and delivery. The demonstration project will be responsible for identifying, procuring, and installing any unique instrumentation that may be necessary to verify the feed certification and delivery systems are performing up to requirements. This instrumentation, where possible, will have been identified and evaluated during the small scale demonstration

phase of work prior to performance verification at full scale. The full scale demonstration will demonstrate the effectiveness of the optimized system configuration and will ensure the tank farm systems are able to support delivery of the first waste to the WTP.

- **Mission Application Phase** – This phase is focused on evaluating results of the small scale and full scale demonstrations from the perspective of applicability to all HLW feed batches that span the entire RPP mission. It is anticipated that some feed batches will present waste and tank configurations that could challenge the effectiveness of the installed systems. This phase will identify and perform additional small scale demonstration activities to provide the confidence that all HLW feed batches can be certified and delivered to support sustained operation of the WTP through the end of the RPP mission.

CONCLUSION

Effectively mixing, sampling, certifying, and delivering Hanford HLW slurry to the WTP is a complex and formidable challenge. The Hanford tank mixing and sampling demonstration program defines a path forward that builds on a basic understanding of mixing phenomena (scouting demonstrations), develops performance and estimates based on multiple sized small scale demonstration platforms (small scale demonstrations), optimizes the integrated feed delivery and feed receipt system requirements, and demonstrates effective performance at full scale in sufficient time to support the first HLW slurry delivery to the WTP.

The lessons learned and field experience from similar test platforms used for WTP design issue resolution and the encouraging results from the early scouting demonstrations are being combined to ensure a robust and functional small scale mixing demonstration platform is completed and demonstrated later this year. The information gained will be applied to future stages of the mixing and sampling demonstration program to ensure the first HLW slurry is delivered to the WTP on time and within specification. This will begin a new era, the waste treatment activities leading to final disposition of the Hanford tank farm waste and the completion of the River Protection Project Mission.

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