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12-WTP-0161

APR 30 2012

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 5.1.3.14.

This letter provides you the deliverable responsive to Commitment 5.1.3.14 of the U.S. Department of Energy plan to address Waste Treatment and Immobilization Plant (WTP) Vessels Mixing Issues; IP for DNFSB 2010-2.

The attached report provides documentation of the basis for selection of specific test configurations for testing relative to assessing and establishing mixing capabilities and process limits across the range of WTP vessels (e.g., mixing power, contents Pulse Jet Mixer (PJM) configuration). The documentation of the basis is provided for the 4, 8, and 14-foot vessels. Documentation of the basis for the single PJM test platform will be provided in the associated Request for Technology Development (IP Commitment 5.1.3.10).

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

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

Sincerely,

Dale E. Knutson

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

WTP:WRW

Attachments

cc w/attach: (See Page 2)

cc w/attachs:

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ATTACHMENT 1
TO
12-WTP-0161

TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD (DNFSB) RECOMMENDATION 2010-2 IMPLEMENTATION PLAN (IP) DELIVERABLE 5.1.3.14

VESSEL CONFIGURATIONS FOR LARGE SCALE INTEGRATED TESTING
24590-WTP-RPT-ENG-12-017, REV. 0, DATED 04/26/12

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Issue status: Approved

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4/26/12

Date

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History Sheet

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Acronyms

ACFM	Actual Cubic Feet per Minute
CNP	Cesium Nitric Acid Recovery Process System
CRESP	Consortium for Risk Evaluation and Stakeholder Participation
CXP	Cesium Ion Exchange Process System
DBE	Design Basis Event
DC	Duty Cycle
DOD	Department of Defense
DOE	United States Department Of Energy
DNFSB	Defense Nuclear Facility Safety Board
EFRT	External Flowsheet Review Team
ERT	External Review Team
FEP	Waste Feed Evaporation Process System
FRP	Waste Feed Receipt
H/D	Ratio Of Height Of Mixed Fluid To Vessel Diameter
HLP	HLW Lag Storage And Feed Blending Process System
HOP	HLW Melter Offgas Treatment Process System
ID	Inside Diameter
JPP	Jet Pump Pair
LSIT	Large Scale Integrated Testing
MCE	Mid-Columbia Engineering
NASA	National Aeronautic and Space Administration
ORP	DOE Office of River Protection
PJM	Pulse Jet Mixer
PNNL	Pacific Northwest National Laboratory
PSDD	Particle Size and Density Distribution
PTF	Pretreatment Facility
PWD	Plant Wash And Disposal System
RDP	Spent Resin Collection
RLD	Radioactive Liquid Waste Disposal System
RPT	Report
SCFM	standard cubic feet per minute
SF	Scale Factor
SG	Specific Gravity
SRNL	Savannah River National Laboratory
TCP	Treated LAW Concentrate Storage Process System
TF	Tank Farm
UFP	Ultrafiltration Process System
VSL	Vessel
WTP	Hanford Tank Waste Treatment and Immobilization Plant

Symbols

A	Area
D	Diameter
DC	PJM Duty Cycle (Ratio Of PJM Drive Time To Total Cycle Time)
$\dot{m}$	Air Flow Rate
P	Power
N	Number of PJMs
R	Gas Constant
SG	Specific Gravity
T	Temperature
U	PJM Nozzle Velocity or PJM Jet Velocity or PJM Discharge Velocity (Peak Average)
V	Volume
W	Watt
wt%	Weight Percent
ρ	Density

Glossary

- **Scaling Factor (SF)** is the ratio of any characteristic linear dimension of the large-scale system (*as applied in this document*, the full-scale vessel diameter, $D_{Full-Scale}$) to the equivalent dimension in the reduced or scaled system (the test-scale vessel diameter, $D_{Test-Scale}$), where SF = $D_{Full-Scale}/D_{Test-Scale}$
- **Geometric Scale Ratio** is used in this document interchangeably with **Scaling Factor** and refers to the comparison of the equivalent linear dimensions in the large-scale system to the test-scale system.
- **Volumetric Scale Ratio** is the ratio of the volume of the large-scale system to the volume of the test-scale volume.

1 Introduction

The Hanford Tank Waste Treatment and Immobilization Plant (WTP) is being designed and built to treat and vitrify the waste stored in Hanford's underground waste storage tanks. Tank wastes that have been blended and retrieved at tank farms will be transferred to WTP for pretreatment and vitrification. WTP process vessels will hold the waste at various stages in the WTP treatment process. These vessels mixing systems are required to support their mixing functions.

WTP uses pulse-jet mixer (PJM) technology for slurry mixing applications that require solids movement/suspension, solids mixing, blending of process waste, and release of hydrogen gas retained in the solids. PJMs are driven by jet pump pairs (JPPs) that use compressed air as the motive force. The suction phase draws process waste into the PJM from the vessel through a nozzle located at the bottom of the PJM. The nozzle is within about 6 inches of the vessel bottom head. Suction is caused by one side of the JPP operating as an air ejector creating a partial vacuum within the PJM. The drive phase pressurizes the PJMs by injected air through a high pressure nozzle and diffuser through the drive side of the JPP. This pressurization discharges the process wastes in the PJM at high velocity (~8 to 12 m/sec) into the vessel causing solids and fluid mixing to occur. The drive phase is followed by the vent phase, which allows for depressurization of the PJM by venting through the JPP into the pulse jet vent system. These three phases (suction, drive, and vent) make up the mixing cycle.

Thirty-eight vessels within the WTP use PJM mixing technology, with each vessel fitted with a PJM array that is tailored to mixing requirements and slurry characteristics unique to the vessel. Five of the thirty-eight vessels are designed to process non-Newtonian slurries. Vessels with non-Newtonian slurry rheology use air spargers in addition to PJMs to increase the mixing power delivered to the vessel and to shear the slurry in the upper vessel volume that are outside the effective mixing zone of PJMs.

The WTP has developed an approach to complete the Large Scale Integrated Testing (LSIT) of selected WTP pulse jet mixed vessels to complete verification of the design, determine performance limits and reduce risks associated with the design of these vessel mixing systems. Testing is required to complete vessel system design verification. The WTP *Integrated Pulse Jet Mixed Vessel Design and Control Strategy*, 24590-WTP-RPT-ENG-10-001, Rev. 1 (Reference 1) provides a background on PJM vessel mixing designs and describes the testing approach to support PJM Vessel design verification and evaluation of operational controls.

This report documents the basis for selection of the 4, 8, and 14-foot test vessels* for PJM performance and scaling testing per commitment 5.1.3.14 (Vessel Configuration for Testing) in the *Department of Energy Plan to Address Waste Treatment and Immobilization Plant Vessel Mixing Issues - Implementation Plan for Defense Nuclear Safety Board Recommendation 2010-2*, Rev. 0 dated November 10, 2011, CCN 242510 (Reference 4, known as the 2010-2 Implementation Plan (IP)) to document the *"basis for selection of specific test configurations for testing relative to assessing and establishing mixing capabilities and process limits across the range of WTP vessels, (e.g., mixing power, contents, PJM configuration). The documentation shall define the technical basis and requirements for all test configurations and sizes including the 4-ft, 8-ft, 14-ft, and 6-ft single PJM test platform. ERT (External Review Team) review comments and resolution will be included with the deliverable transmittal."*

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* The 4-foot is the existing 43.2-inch acrylic vessel and the 8-foot is the existing 93.2-inch acrylic vessel.

The technical basis for the single PJM test platform is to perform prototypic testing of a single, full scale PJM to evaluate PJM control systems. Requirements for the single PJM control tests include evaluation of prototypic operation across the full drive, vent, and suction cycle. This testing will also include the use of pressure feedback control. Additional testing information will be provided in the Request for Technology Development per IP commitment 5.1.3.10.

This report is organized to address each portion of the commitment 5.1.3.14 of the 2010-2 IP (Reference 4) in the following order:

a) Technical basis for test vessel sizes - Section 2
b) Process limits considerations for vessel contents and mixing power - Section 3
c) Technical basis for test configurations - Section 4

Suction line and sparger scaling information as well as the overall scaling basis for PJM mixing phenomena is under evaluation by the LSIT program team and will be summarized in the 2010-2 IP commitment 5.1.3.13.

2 Technical Basis for Test Vessel Sizes

The WTP has selected test vessel diameters of 4-foot, 8-foot, and 14-foot to support obtaining data required for verifying the WTP PJM-mixed vessels will perform their required mixing functions. Early in the LSIT program, engineering judgment was used to choose the vessels to support testing. The 4-foot and 8-foot acrylic vessels were available from earlier test programs. A 14-foot vessel was originally chosen as it was the largest vessel size that could feasibly be built with an acrylic head for observation. The selection of a 14-foot test vessel then allowed for testing at a scale that matches a full-size non-Newtonian vessel.

Testing at multiple scales will be utilized to support verification of PJM-mixed vessel design. Further information on WTP full-scale, PJM-mixed vessels is included in Appendix A, which provides a tabulation of the vessel information, including PJM array configurations and selected operating parameters. The following discussion describes the considerations that were included in selecting the vessel sizes for testing.

2.1 Consideration 1: Test Vessel Size to Address Extrapolation

Industrial guidelines were reviewed for recommended bases for scaled testing to address external concerns with uncertainty in extrapolation. These guidelines are consistent with comments from external review groups (VCT Expert Review Team (ERT) and Consortium for Risk Evaluation and Stakeholder Participation (CRESP)).

2.1.1 Industrial Guidelines for Test Vessel Sizing

Industrial guidelines for scaling are provided in "Plant Design and Economics for Chemical Engineers", Peters and Timmerhaus (Reference 29). Scaling recommendations based upon diameter ('geometric' scale also referred to as scale factor (SF)) vary from a test-scale to full-scale ratio of 3:1 to 10:1 and for volume ('volumetric' scale) vary from a test-scale to full-scale ratio of 10:1 to 100:1 depending on the type of equipment under evaluation (Reference 29, Chapter 2,Table 6, Factors in scale-up and design). The range of scale factors in Table 6 of Reference 29 covers many types of process equipment and is not specific to mixing operations.

These guidelines, applicable to the sizing of industrial scale equipment, provide an accepted range for SF to compare the size of the largest WTP vessel containing significant solids (HLP-VSL-00022) to a test vessel size. Applying these SF ranges as a benchmark for the selection of test vessel size using HLP-VSL-00022 (internal diameter of 38 feet), the recommended range of test vessel sizes would be between 3.8 feet to 12.7 feet in diameter. The volumetric scale ratio range equates to a geometric scale ratio range of 2.15 to 4.64[†], for volumetric scale ratio values of 10 and 100, respectively.

The following scale ratios are applicable for a full-scale, 38-foot diameter vessel, HLP-VSL-00022 compared with a 14-foot diameter test vessel:

- The SF or geometric scale ratio is 2.71:1, which exceeds the Reference 29 guidance to utilize geometric scale ratios from 3:1 to 10:1.
- The volumetric scale ratio is 20:1 when the H/D is 1, which is well within the Reference 29 guidance to utilize volumetric scale ratios from 10:1 to 100:1.

Charts depicting the geometric scale ratios comparing all of the WTP PJM-mixed, full-scale vessels to the LSIT test vessels are provided in Figure 1 and the volumetric scale ratios comparing all of the WTP PJM-mixed, full-scale vessels to the 14-foot test vessel are provided in Figure 2 in Section 2.1.3.

Note that although the LAW feed receipt vessels, FRP-VSL-00002A/B/C/D, have a diameter of 47 feet and are larger than HLP-VSL-00022, the solids present in the FRP vessels are less challenging to mix than the solids expected in HLP-VSL-00022. The FRP-VSL-00002A/B/C/D can contain up to 3.8 wt% solids, but these solids are required to be slow settling. Prior to transfer from the Tank Farm (TF) to the WTP, the TF feed staging tank has a mandatory settling time to allow solids that settle faster than 0.03 feet/min to settle below the transfer location within the tank, so that tank-waste liquid with as few solids as feasible is transferred to these FRP vessels. Therefore, for the purpose of the test vessel configuration selection, the FRP vessels have been grouped with PJM-mixed vessels containing no or very low solids, where the use of a volumetric scale ratio limit of < 100:1 (or a geometric scale ratio of < 4.64:1 for an H/D of 1) would be appropriate.

[†] When the vessel fill height (H) to vessel diameter (D) are equal (i.e. when H/D is 1), the geometric scale ratio or SF by length is determined from the cube root of the volumetric scale ratio values. In other words, the geometric scale ratio of 4.64 is equivalent to a volumetric scale ratio of 100 or the cube root of 100, when H/D is 1.

The geometric scale factors described above are consistent with approaches utilized in prior PJM mixing test programs. The report, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, J. Bamberger et al., WTP-RPT-113, Rev. 0, 24590-010-TSA-W000-0004-114-00016, Rev. 00A (Reference 30) Section 3.3.2 states:

> "Typically in scaled fluid mixing test [geometric][‡] scale factors up to about 10 are considered acceptable, that is, much of the important physics can be capture at small scale. For the non-Newtonian test program, design of scale prototypic vessels were limited to conservative scale factors in the range of 4 to 5 due to the relative new nature of the tests and the importance of the outcome."

The SF for the HLP-VSL-00022 compared to the 14-foot diameter test vessel is 2.71:1, which is more conservative than the range used for previous non-Newtonian testing.

Further industrial guidelines for scaling are provided in the "Handbook of Industrial Mixing, Science and Practice, North American Mixing Forum", Wiley & Sons, Inc, 2004 (Reference 5). Chapter 12 provides recommendations for the range of volumetric scale ratio extrapolation relative to the level of uncertainty associated with the mixing system. Table 12-9 (Reference 5) indicates the acceptable range of volumetric scale ratio of 10:1 to 20:1 for mixing systems with high uncertainty and for a volumetric scale ratio of up to 100:1 for mixing systems with low uncertainty. Although the mixing phenomena is not identical for mechanically mixed and PJM-mixed systems, the higher level of uncertainty in PJM-mixed systems is more similar to that of a mechanically mixed system with a high degree of uncertainty, where the recommended range in volumetric scale ratio is 10:1 to 20:1.

2.1.2 Consortium for Risk Evaluation and Stakeholder Participation Test Vessel Size Recommendations

The report, "Evaluation of Consortium for Risk Evaluation and Stakeholder Participation (CRESP) Review Team Letter Report 7 - PJM Vessels" dated June 29, 2010, Attachment 1 to CCN 218915 (Reference 6) provides feedback on the evaluation of PJM mixing for WTP vessels. A number of issues are addressed in this report, and among them are recommendations on "Up-scaling PJM and Vessel performance from Small-scale Tests to Full-Scale Tests". Specifically, the team letter identified the following recommendation:

- Experience from the chemical process industry, which is analogous to WTP processing, indicates that each step of scale-up of novel and complex processes should not exceed a factor of 10 on a volumetric basis. The recommendation is based in part on two key issues: a) that the life cycle of the WTP exceeds that of nearly any industrial facility, and b) any industrial facility that might last as long as WTP will be updated and modified on a continuing basis whereas modifications to WTP will be extremely difficult if not impossible once radioactive waste processing begins.

Using the recommendation for scale-up not to exceed a factor of 10 on a volumetric basis, the corresponding geometric scale-up factor is 2.15 when the H/D is 1. In its summary, CRESP recommended that the test vessel size selection be "near full-scale," based on a volumetric scale ratio of 8:1, which is equivalent to geometric scale ratio of 2:1 when the H/D is 1. The volumetric scale range of at least 8:1 can be accommodated for an H/D > 1 with the test configurations selected in this evaluation, which provide the test volume capacity that meets or exceeds the CRESP guidance for volumetric scaling.

[‡] Added [geometric] for clarification.

2.1.3 Summary of Volumetric Scale-Up Recommendations

LSIT test results will be applied to assess a number of WTP mixing vessels by extrapolation of test results to full scale. A range of recommendations for scale-up for extrapolation of test data was developed in Section 2.1 above based on industrial guidelines.

Figure 1 provides the geometric scale ratios or SFs that apply between the full-scale WTP vessels and the scaled 4-foot, 8-foot, and 14-foot diameter test vessels.

Figure 1 Geometric Scale Factors for WTP Mixing Vessels Relative to 4-Foot and 8-Foot Diameter Test Vessels and a 14-Foot Diameter Industrial Test-Scale Vessel

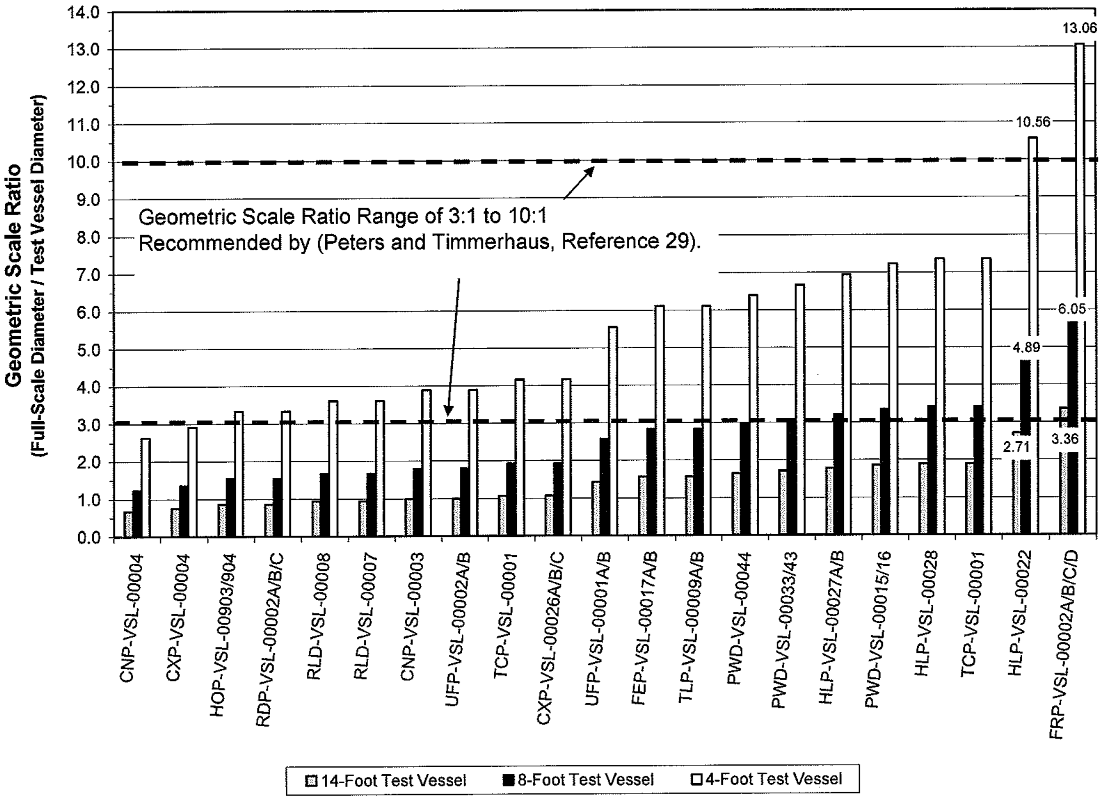
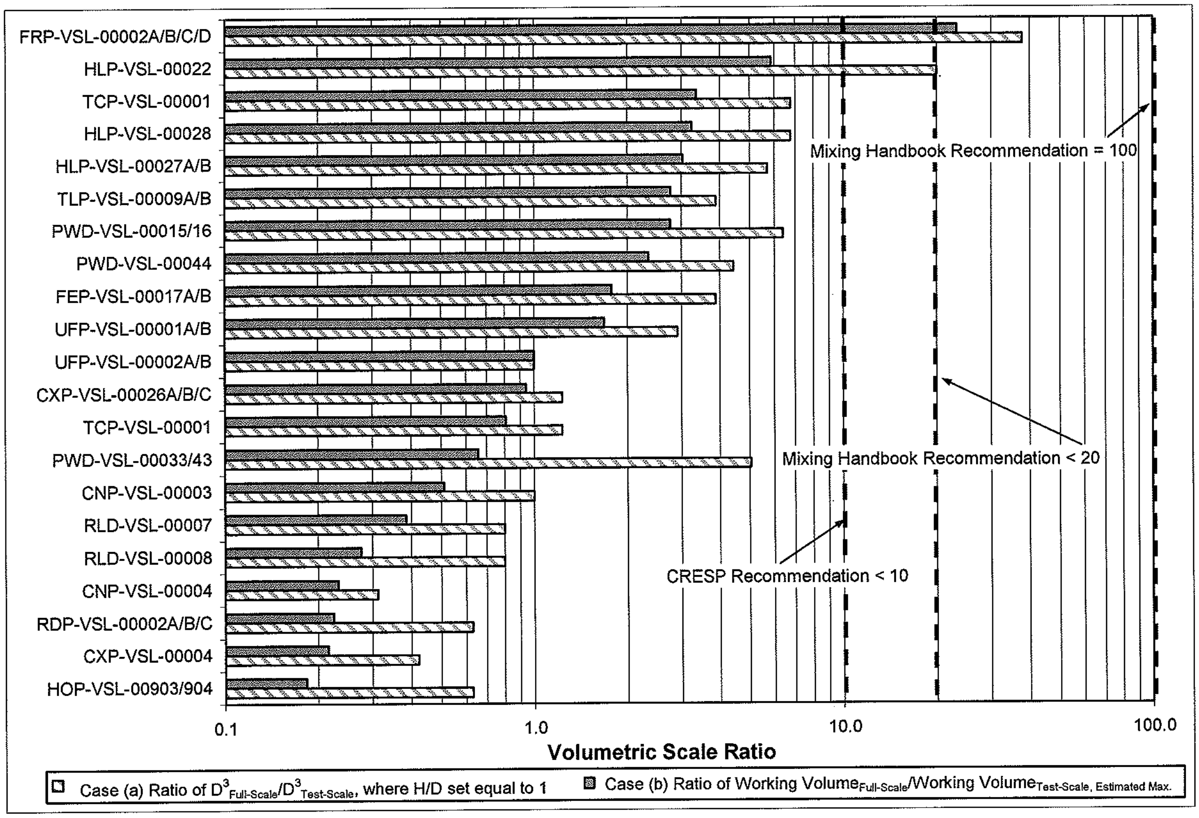


Figure 2 provides the volumetric scale ratios that apply between the full-scale WTP vessel volumes and a scaled 14-foot diameter test vessel volume for the following conditions:

Case a) Where the volumetric scale ratio is determined holding the H/D at 1 for both the full-scale WTP vessel and the 14-foot diameter test vessels (i.e. the volumetric scale ratio is the cube of the diameter of WTP vessel divided by the cube of the diameter of the test vessel (i.e. 14 feet cubed)

Case b) Where the volumetric scale ratio is the working volume of the WTP vessel divided by the estimated maximum working volume for the 14-foot diameter test vessel

Figure 2 **Volumetric Scale Ratios of WTP Mixing Vessels Relative to a 14-Foot Diameter Industrial Scale Test Vessel**



If tested in a 14-foot diameter test vessel, almost all of the WTP PJM-mixed vessels have volumetric scale ratios at or less than 10:1, the most conservative scaling recommendation in Reference 5. When the H/D is equal to 1, only vessels (HLP-VSL-00022 and FRP-VSL-0002A/B/C/D) have volumetric scale ratios greater than 10:1 (Reference 5) and only HLP-VSL-00022 exceeds the CRESP volumetric scale ratio recommendation of 8:1 (Reference 6) for a vessel containing settling solids. When scaled testing of HLP-VSL-00022 is conducted in a 14-foot diameter vessel, a volumetric scale ratio of 20:1 is achieved when the H/D equals 1, which is within the range of the industrial guidelines and at the upper end of the range for the volumetric scale ratios recommended in Reference 5 for systems with higher uncertainty.

The solids in FRP-VSL-00002A/B/C/D are defined as non-settling due to requirements for pre-settling before transfer (See Section 2.1). If a scaled test of FRP-VSL-00002A/B/C/D were conducted in a 14-

foot test vessel, it would have a volumetric scale ratio of 38:1. This is far less than the 100:1 upper limit recommended for systems with lower degree of uncertainty (depicted in Figure 2).

Based on this analysis of geometric scale ratio (See Figure 1), all WTP PJM-mixed vessels can be tested in a 14-foot vessel and be within the applicable recommended ranges for geometric scale ratios. Based on this analysis of volumetric scale ratio (See Figure 2), all WTP PJM-mixed vessels can be tested in a 14-foot diameter test vessel and be within the applicable recommended ranges for volumetric scale ratios.

Note that an upcoming decision point is included in the 2012-2 IP to assess the requirement for testing in vessels larger than 14 feet in diameter (Commitment 5.1.3.15). Technical criteria used to make the decision related to Commitment 5.1.3.15 will be developed and a technical justification will be provided that will support the decision.

2.2 Consideration 2: Select Test Vessel Sizes to Allow Extrapolation from Applicable Correlations

This second consideration is determining the number of test vessel scales and the test vessel sizes that will provide sufficient data to allow extrapolation using correlations developed for mixing phenomena. This section explains the conclusion that three test vessel sizes are needed so that the mixing system performance can be analytically described.

2.2.1 Number of Test Vessel Sizes Needed for LSIT PJM Performance Testing

Industrial guidelines from Reference 5, Chapter 10 states: “Often especially for processes involving multiple phases or fast reactions, it is necessary to perform several experiments at two or more different scales, where the vessel size based on diameter is varied by at least a factor of 2.” For HLP-VSL-00022, the vessel diameters would be less than 20 feet, less than 10 feet, and less than 5 feet. The 4-foot acrylic vessel is within this range and has been used previously in multiple mixing studies at both Pacific Northwest National Laboratory (PNNL) and Mid-Columbia Engineering (MCE). The 8-foot acrylic vessel is available and is approximately twice the diameter of the 4-foot vessel. The progression would result in an ideal large-scale test vessel with an inside diameter of approximately 16 feet, following a geometric progression of 4, 8 and 16, but such a selection would not permit an exact full-scale match up with a WTP vessel that demonstrates both Newtonian and non-Newtonian behavior, such as the14-foot UFP-VSL-00002A/B vessel. Additionally, the 14-foot vessel can use an acrylic head to allow visual observations.

Mixing performance depends on vessel size (scale) as a key geometric parameter against which effectiveness of other mixing performance parameters such as PJM nozzle velocity, drive time, spatial arrangement, pulse volume fraction (ratio of PJM discharge volume to vessel volume) can be evaluated. Using data from three sizes provides more accurate scaling methods and better enables the assessment of uncertainty of these methods and is consistent with industry guidelines. Selection of three vessel sizes provides sufficient data to establish an observable trend so that behaviors of specific mixing parameters can be extrapolated with respect to vessel scale and is consistent with industry guidelines.

Note that an upcoming decision point is included in the 2012-2 IP to assess the requirement for testing in vessels larger than 14 feet in diameter (Commitment 5.1.3.15). Technical criteria used to make the decision related to Commitment 5.1.3.15 will be developed and a technical justification will be provided that will support the decision.

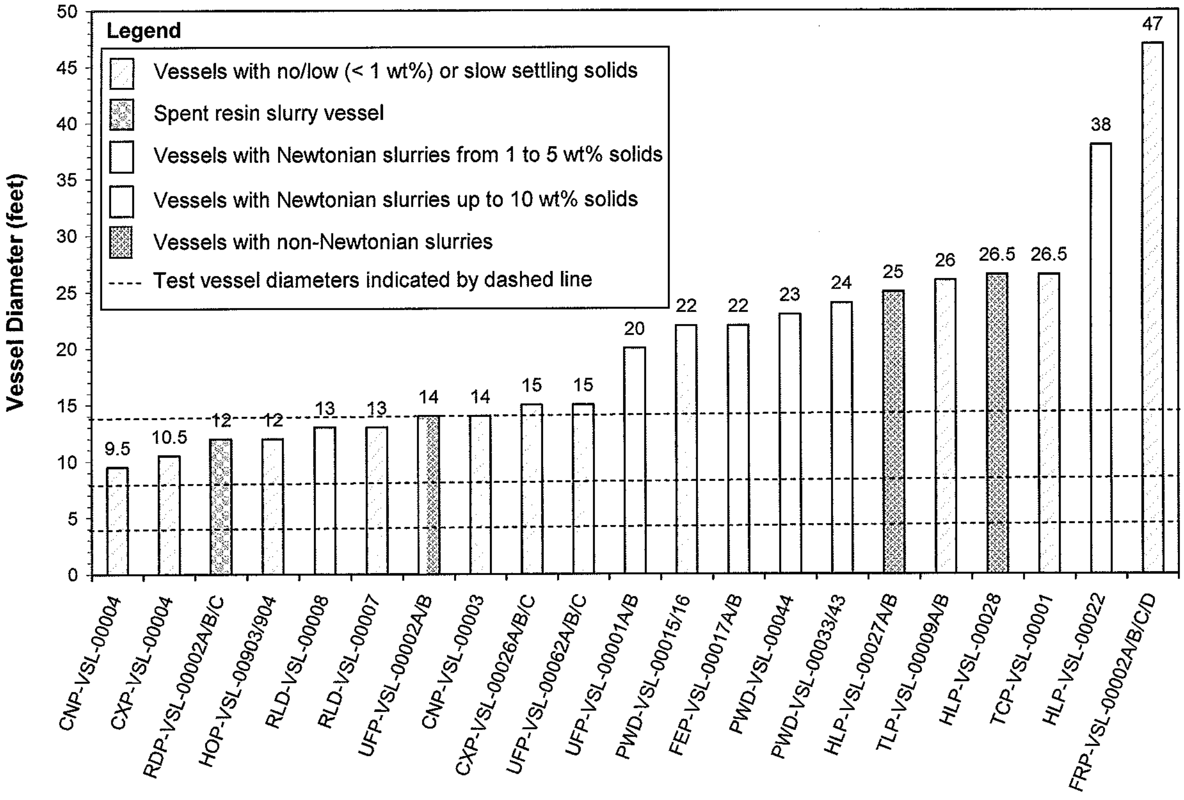
2.2.2 WTP Full-Scale Vessel Size Compared to Selected Test Vessel Sizes

The approach used for test vessel size selection was structured to address selection of three sizes while also considering cost-effective options for implementing a large scale test program. This resulted in the selection of 4-foot, 8-foot, and 14-foot diameter test vessels.

Note that vessels smaller than 4-foot were not considered for the LSIT program, since the physics and laminar versus turbulent flow regimes applicable to larger vessels would be a challenge to maintain at smaller scales.

The various vessel diameters evaluated for mixing performance relative to the three vessel sizes selected for LSIT are shown in Figure 3.

Figure 3 Relationships between Test Vessel Sizes and Full-Scale WTP Vessel Sizes



The 14-foot test vessel allows full-scale tests of the UFP-VSL-00002A/B and RLD-VSL-00008 vessels.

2.3 Consideration 3: Compliance with DOE Technology Readiness Assessment Guide

The DOE issued the *Technology Readiness Assessment Guide*, DOE G 413.3-4 dated October 12, 2009 (Reference 11) as a method of judging the maturity of technology where projects such as the WTP have ongoing technology development and deployment. Ideally, technology development follows a progression of testing where the scale factor increases incrementally to a SF of 1.0.

The guide provides methods to assess whether a technology has been developed to an extent where full-scale deployment is consistent with management of programmatic risk. The principles included in Reference 11 have been used by both NASA and the DOD for assessment of test scaling in technology development. Technology readiness is evaluated on a scale of 1 to 9 where level 9 is defined as a technology in its final form and operated under the full range of operating conditions, such as an actual system with the full range of wastes in hot operations. Level 8 is defined as an actual completed and qualified system though test and demonstration, while Level 7 is a full-scale, prototypic system demonstrated in a relevant environment. Level 6 is a pilot-scale, prototypic demonstration and is consistent with the LSIT tests to be performed on the 14-foot platform in the UFP-VSL-00002A/B configuration with a prototypical PJM drive, and testing in the RLD-VSL-00008 configuration.

Levels of technology development below Level 6 are consistent with the smaller scale tests performed in the LIST 4-foot and 8-foot platforms; these are consistent with the definitions of Engineering Scale (Level 5) and Laboratory Scale (Level 4). The definitions in Reference 11, Table 2 of SFs are as follows:

- Full Plant Scale - Matches final application
- Engineering Scale - Between 1/10-scale and full-scale
- Laboratory Scale - Less than 1/10-scale

The scaling sequence provided by using the 4, 8 and 14-foot vessel sizes, where the 14-foot test vessel represents full-scale testing, provides SF ratios of sequence of about 3.9:1.0, 1.8:1.0 and 1.0:1.0 respectively for UFP-VSL-00002A/B. The sequence for RLD-VSL-00008 is nearly the same at 3.6:1:0, 1.7:1.0, and 0.93:1.0. For the largest vessel array with significant solids loading, HLP-VSL-00022, the SF sequence is 10.6:1.0, 4.9:1.0, and 2.7:1.0. This latter sequence is consistent with the technology development concepts put forward in Reference 11. The 4-foot scale is larger than the minimum size definition of (SF = 1/10th), but selection of the 4-foot test scale is based on achieving a minimum practical test vessel size with arrays that may include up to 18 PJMs.

3 Process Limits Considerations for Vessel Contents and Mixing Power

3.1 Vessel Contents

Process waste characteristics considered in the selection of vessel configurations are listed below. More information on the process waste characteristics and associated process limits applicable to mixing will be summarized in the document, *Hanford Waste Treatment Plant Pretreatment Mixing Large Scale Integrated Testing: Properties That Matter for Design Basis Testing*, D. C. Koopman, et al, SRNL-STI-2012-00062, Draft (*under development*) (Reference 12).

- Particle size and density distribution
- Solids content in g/L or wt%
- Liquid phase density and particle-liquid density difference
- Liquid phase viscosity
- Slurry rheology and related cohesive properties, including their time dependent properties
- Shear strength of settled waste, including its time dependent properties
- Critical shear stress for settled waste erosion
- Other attributes as included in Reference 12

The primary discriminators for vessel mixing design is processing slurries and process wastes that behave as Newtonian fluids versus slurries that behave as non-Newtonian fluids, in particular, the amount of solids that settle between PJM pulses out of the total undissolved solids fraction in the vessel. Characterization of settling solids is made with respect to time depending on the mixing functions during both normal and post design basis events (DBEs). This distinction is made because under certain post-DBE postulated conditions, vessels mixers are not operated with the same frequency that is applied during normal operations.

Process vessel limiting conditions for process wastes are generally described with respect to the weight or volumetric fraction of solids and the maximum rheological properties during both normal and post-DBE operations. Mixing functions during normal process operations are focused toward support chemical mixing chemical additions such as those associated with leaching operations, and mixing to assure that solids are moved forward in the waste treatment process. In this respect, mixing vessel contents are viewed from mixing time to support waste processing rates and prevention of settling solids accumulation.

Post-DBE mixing functions for vessels with intermittent mixing include the ability of the mixing systems to adequately disturb settled particulate layers to release flammable gas inventory. Post-DBE mixing there is a potential for a settled solids layer with shear strength to form during periods when the mixers are not operating. This layer then requires sufficient particle-to-particle shearing be produced by PJM operation during post-DBE, periodic mixing to mobilize the solids and to release flammable gas.

The following sections provide an overview of process waste properties considered in test configuration selection. These subsequent sections are divided into sub-sections to distinguish WTP vessels that process Newtonian fluids from WTP vessels that process non-Newtonian fluids. Within each category, the properties of the process fluids and particulates are provided for each PJM-mixed vessel. The rationale for down selection of vessel configurations to be included in the LIST is then provided. Section 3.2 provides information on mixing power delivered to the various processing vessels, with discussion of vessels to be included in LSIT from the mixing power perspective.

3.1.1 Vessels Processing Newtonian Fluids

Table 1 provides a listing of vessels that are designed to process Newtonian fluids. They may contain settling solids that can form a settled layer with shear strength. The depth and shear strength of a settled layer that may form during periods where mixers are not operating are functions of the waste properties, primarily the undissolved solids content and the particulate settling rate. It is not the purpose of this report to define the design basis particulate size and density distribution (PSDD) for vessels, but rather to indicate the approximate design basis solids loading, and to consider vessels where the solids may be likely to form a settled bed either between PJM drives, or following DBE events where the mixing occurs intermittently. Post-DBE intermittent mixing is described in the *System Description for Pulse jet Mixer and Sparger Mixing Subsystems*, 24590-WTP-3YD-50-00003, Rev. 0 (Reference 23). Depending on the PSDD, vessel particulate is expected to form a concentration gradient over the height of the vessel. A gradient can include a higher solids loading at the bottom of the vessel by a factor of two or more relative to the bulk vessel average particulate concentration that would be applicable if the system were assumed to be homogeneous. This type of gradient increases the mixing challenge, making the solids loading an important factor in LSIT test array selection. Table 1 listing of solids represents the maximum vessel bulk average concentration.

Table 1 Newtonian Process Vessel Maximum Undissolved Solids (1)

Vessel Tag Number	Vessel Name	Normal Solids Content (wt%)	Max. Solids Content (wt%)	Fast Settling Solids	Comment
CNP-VSL-00003	Eluate Contingency Storage	0.0	0.0	No	----
CNP-VSL-00004	Cs Evaporator Recovered Nitric Acid	0.0	0.0	No	----
CXP-VSL-00004	Cesium Ion Exchange Feed	0.0	0.0	No	----
CXP-VSL-00026A/B/C	Cesium Ion Exchange Treated LAW Collection	0.0	0.0	No	----
FEP-VSL-00017A/B	Waste Feed Evaporator Feed	1.0	2.0	Yes	----
FRP-VSL-00002A/B/C/D	Waste Feed Receipt	0.0	3.8	No	LAW feeds are required to have a settling velocity less than 0.03 ft/min
HLP-VSL-00022	HLW Feed Receipt	10	10	Yes	Streams up to 200 g/L solids can be transferred. Batch size and vessel contents are controlled to keep solids at or below the equivalent of 10 wt%.(2)
HOP-VSL-00903/904	SBS Condensate Receiver	0.1	0.17	No	Solids are normally below 26 μm
PWD-VSL-0015/16	Acidic / Alkaline Effluent	0.06	0.06	Yes	----
PWD-VSL-0033/43	Ultimate Overflow Vessel / HLW Effluent Transfer	1.0	5.0	Yes	5 wt% is an off-normal from an overflow
PWD-VSL-00044	Plant Wash	0.5	2.0	Yes	2 wt% is an off-normal
RDP-VSL-00002A/B/C	Spent Resin Slurry	31	31	No	Solids are spent resin with low specific gravity
RLD-VSL-00007	Acidic Waste	0.1	0.1	No	Solids are normally below 26 μm
RLD-VSL-00008	Plant Wash and Drains	0.0	5.0	Yes	5 wt% is an off-normal from an overflow Normal solids are normally below 26 μm
TCP-VSL-00001	Treated LAW Concentrate Storage	0.1	1.0	No	Solids are normally below 26 μm
TLP-VSL-00009A/B	LAW SBS Condensate Receipt	0.1	1.0	No	Solids are normally below 26 μm
UFP-VSL-00001A/B	Ultrafiltration Feed Preparation	10	10	Yes	Feed from HLP-VSL-00022 and FEP-VSL-00017A/B
UFP-VSL-00062A/B/C	Ultrafilter Permeate Collection	0.0	0.0	No	Ultrafilter supernatant

(1) Solids content and size information are based on the vessel assessments. References provided in Appendix A.

(2) Solids content is controlled to a maximum equivalent of 10 wt% in a linear relationship between grams per liter solids and sodium molarity § 8.2.2.1 of the WTP contract (DE-AC27-01RV14136, Section C, Specification 8).

3.1.2 Vessels Processing Non-Newtonian Fluids

Table 2 provides a listing of vessels designed to process non-Newtonian fluids and equipped with PJM mixers and spargers. They may contain solids that can form a shear strength. The range of Bingham plastic consistency and dynamic yield stress of the slurry in these vessels during normal operation is from a low of 6 centipoise and 6 Pascals (this lower limit is in review with DOE-ORP personnel) to a maximum of 30 centipoise and 30 Pascals. During post-DBE operation, the shear strength can increase above 30 Pascals during periods between intermittent mixing. These ranges need to be considered in developing tests for vessel configurations that process these non-Newtonian fluids.

Table 2 Non-Newtonian Process Vessel Maximum Solids Loading

Vessel	Vessel Name	Max. Solids Content (wt%)	Comment
HLP-VSL-00027A/B	HLW Lag Storage	20	Feed from UFP-VSL-00002 batch processes.
HLP-VSL-00028	HLW Feed Blend	20	Feed from HLP-VSL-00027A/B and Cs Ion Exchange resin regeneration.
UFP-VSL-00002A/B	Ultrafiltration Feed	20	Feed to UFP-VSL-00002A/B is ~10 wt% solids, Newtonian slurry and is concentrated in the ultrafiltration process to remove supernatant, where the process waste develops into a non-Newtonian slurry.

3.2 Vessel Mixing Power

Vessel mixing power has three sources: 1) PJM operation for both Newtonian and non-Newtonian process vessels, 2) sparger operation in non-Newtonian vessels, and 3) vessel recirculation which generally has an insignificant contribution to total mixing power except in the case of vessels UFP-VSL-0002A/B which are part of the ultrafiltration loop. Recirculation mixing power is not tabulated here because batch operations require only part time operation of the loop. The UFP-VSL-00002A/B vessels are required to meet mixing functions solely with the PJMs and spargers in operation.

The following equation has been used to calculate PJM mixing power per unit volume of waste during the drive cycle of the PJM to provide a general comparison between WTP vessels. Appendix A contains a tabulation of the vessel data used to determine mixing power. Power per unit volume during the drive portion of the PJM operation is determined from Equation (1) below

$$P/V = 0.5 \cdot \rho \cdot N \cdot A \cdot U^3 / V \qquad \textbf{(Equation 1)}$$

where:
P = power (watts)
V = vessel volume (m^3)
ρ = slurry density (kg/m^3)
N = number of PJMs
A = nozzle area (m^2)
U = PJM discharge velocity (peak average) (m/s)

The following sections provide a tabulation of mixing power with vessels at their respective full batch volume level and at a minimum level where all PJM are in operation. This latter condition represents the maximum power per unit volume of process waste in the vessel. Appendix A includes all vessels PJM power during drives cycle and average PJM power over the complete duty cycle (DC). The average is obtained by multiplying the drive cycle power by the DC. The vessel power tabulation has been normalized at a constant specific gravity of 1.0 for comparison purposes.

3.2.1 Newtonian Fluid Process Vessel PJM Mixing Power

Test vessel array selection is based, in part, on mixing power provided by the combination of vessel volume, PJM array geometric variables, PJM operating parameters, and in the case of non-Newtonian process vessels, the mixing power provided by sparger arrays. A summary of vessel PJM mixing power at the vessel maximum working volume level (vessel working volume is full batch level plus heel) is provided in Table 3 for the vessels with higher solid content of settling solids. Additionally, the power per volume is provided at minimum volume where all of the PJMs are operating, which is the 'Low Mixing Volume' (Level 7 in the vessel sizing calculations) plus the volume of the PJMs.

The maximum power per unit volume of process waste occurs at the minimum volume where all of the PJMs are operational, because the volume of process waste is at its lowest point before switching to 25% PJM operational mode, and because the PJM discharge velocity is near its maximum. PJM discharge velocity increases as the vessel level decreases because the PJM nozzle backpressure exerted by the static head of process waste within the process vessel decreases. A description of PJM operating principles is provided by Reference 23. Maximum velocity, hence maximum power delivered at the lower level has a significant benefit in prevention of particulate buildup during batch-to-batch operations.

Section 4 describes the use of power per unit volume as one of the vessel configuration selection criteria.

Table 3 Newtonian Vessel Mixing Power Tabulation

Vessel Number	Working Volume (gal)	P/V at working volume during drive (W/m3)	Minimum Volume [(a)] (gal)	P/V at low level during drive (W/m3)
HLP-VSL-00022	185,265	203	60,236	889
PWD-VSL-00033/43	20,800	211	7,420	1537
RLD-VSL-00008	8,721	251	2,714	2101
UFP-VSL-00001A/B	53,332	470	14,354	2714

Note: (a) This is the 'minimum volume' where all of the PJMs are operating, which is the 'Low Mixing Volume' (Level 7 in the vessel sizing calculations) plus the volume of the PJMs.

The power per unit volume values indicated in Table 3 are provided to show a general comparison between vessels that will process wastes with relatively high levels of settling solids. Solids loading is also important and notably, of these vessels, HLP-VSL-00022 has one of the highest solids loading.

3.2.2 Non-Newtonian Fluid Process Vessel PJM and Sparger Mixing Power

A summary of vessel PJM mixing power is provided in Table 4, which is similar to the information in Table 3, which uses the same batch and minimum PJM operating levels. In addition, sparger power is included. Sparger operation is governed automatically by vessel level. When the level is above the PJM chandelier array, then all spargers are in operation. As the process waste level drops, operation of the set of sparger tubes above the chandelier is terminated. As the process waste level drops to a point near the end of the sparge tube, all sparger operation is terminated. A description of sparger operating principles is provided by Reference 23.

Power delivered by spargers increases with delivery depth and slurry specific gravity for some constant air actual volumetric flow rates (acfm). Sparger power listed in Table 4 is derived from Equation (2) as described in "Scaling of Air Spargers for the Engineering-Scale HLP-27 Test Vessel" attachment to Letter WTP/RPP-MOA-PNNL-000508, dated July 2, 2010, CCN 219734 (Reference 24):

$$P_{SPARGER} = \dot{m}RT\ln\left(\frac{V_{Surface}}{V_{AtDepth}}\right) \qquad \textbf{(Equation 2)}$$

where:
$P_{SPARGER}$ = sparger power (watts/m^3)
$\dot{m}$ = air flow rate (mol/s)
R = gas constant (Pa·m^3/mol·K)
T = temperature (K)
$V_{Surface}$ = specific volume of air as it breaks the slurry surface (m^3)
$V_{At\ Depth}$ = specific volume of air at depth as it leaves the sparge tube (m^3)

Sparger power is a function of the counteracting decrease in slurry volume and the lower expansion ratio between the surface and release depth specific volume. Even though the expansion ratio in Equation (2) is smaller with lower vessel level, the net power per unit volume (accounting for both PJMs and spargers) increases as the vessel level drops due to the correspondingly smaller volume of waste being mixed. The modeling has been conducted at a constant air delivery rate to match mixing power at a design point because the WTP will be operated in this manner, i.e., there is no automatic device / instrumentation that will throttle sparger air flow to maintain constant power delivery. There is an automatic cutoff when level drops to a point where the upper spargers are close to being uncovered.

Table 4 Non-Newtonian Process Vessel Mixing Power

Vessel Number	Working Volume (gal)	Drive Only PJM P/V (W/m^3)	Average[a] PJM P/V (W/m^3)	Sparger Mixing P/V (W/m^3)	Min. Vol.[b] Drive Only PJM P/V (W/m^3)	Min. Vol.[b] Average PJM P/V (W/m^3)	Sparger Mixing P/V[c] (W/m^3)
	Minimum Volume (gal)						
UFP-VSL-00002A/B	31,609	354	57	71	6100	455	22
	4,310						
HLP-VSL-00027A/B	95,909	150	21	77	1525	122	17
	18,405						
HLP-VSL-00028	106,058	138	19	87	888	71	17
	33,301						

Notes: (a) Time averaged power is power delivered during the PJM drive multiplied by the PJM Duty Cycle. Refer to Appendix A for equations used to determine PJM mixing power and note English units may be applied in Appendix A.
(b) This is the 'minimum volume' where all of the PJMs are operating, which is the 'Low Mixing Volume' (Level 7 in the vessel sizing calculations) plus the volume of the PJMs.
(c) Only deep sparge tubes are assumed to be in operation. Estimated deep tube submergence is 7 feet. Tubes above shroud are not in operation.

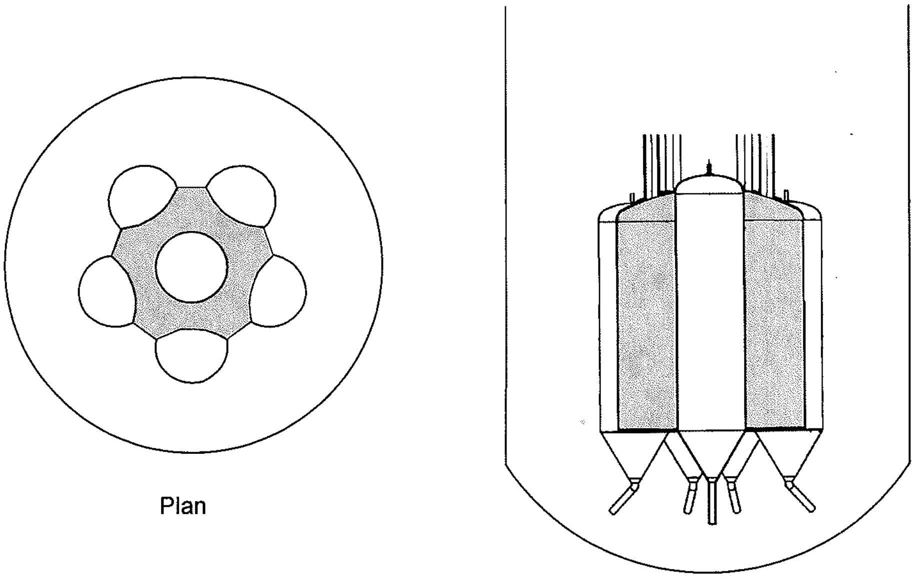
The minimum operating volumes where all PJMs are operational and the corresponding maximum PJM power per unit volume discussed in Section 3.2.1 are also applicable to the vessels processing non-Newtonian wastes.

4 Technical Basis for Test PJM Array Configurations Included in LSIT Testing

Two types of PJM arrays are used in WTP mixing vessels, the distributed arrays applicable to Newtonian process fluids, and chandelier arrays applicable to non-Newtonian process fluids. Reference 23 provides an overview of the variety of PJM arrays that are included in the WTP vessel designs for both Newtonian and non-Newtonian process vessels.

Figure 4 and Figure 5 provide general depictions of these two types of PJM arrays, while Table 5 provides information on the number of PJMs associated with each vessels' array design, which is under consideration for test vessel configuration. Chandelier arrays comprise a cluster of either 6 or 8 PJMs mounted within a shroud that prevents build up of settled solids between the closely packed PJMs. Vessels that have the chandelier array PJM configuration include air spargers that assist in mixing the annular zone within the vessel located between the shroud and vessel wall, as well as mixing the upper region of the vessel located above the shroud. Sparger scaling information will be summarized in the 2010-2 IP Commitment 5.1.3.13.

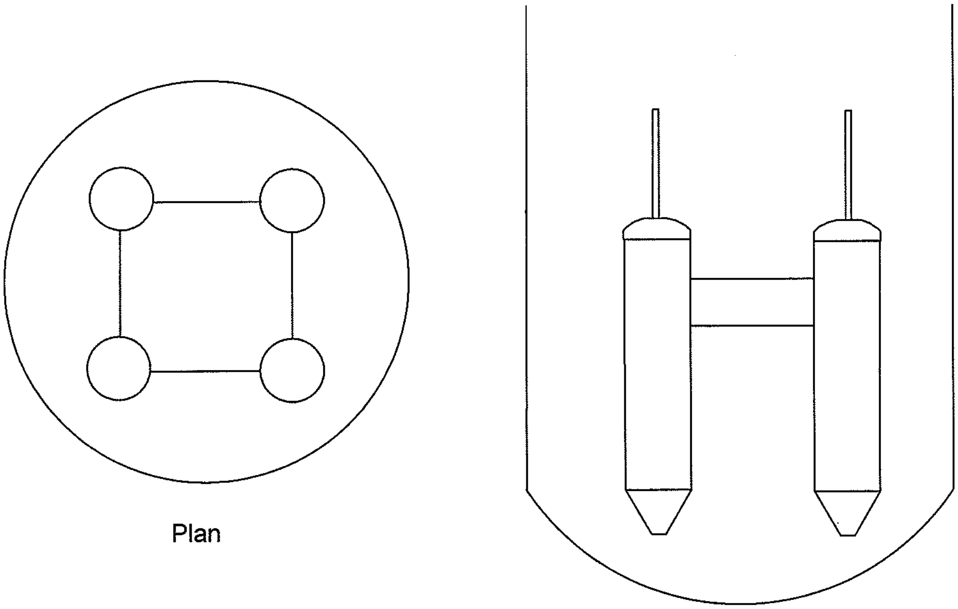
Figure 4 Plan and Section View of a Typical Chandelier PJM Array



Plan

Section

Figure 5 Plan and Section View of a Distributed PJM Array



Plan

Section

Table 5 lists the WTP PJM-mixed vessels and provides the corresponding vessel diameters, PJM array type and the number of PJMs in the vessel design. Scaling factors are provided for consideration in final selection of test vessel size and configuration, where test vessel configuration selection is summarized in Section 4.

Table 5 WTP Vessel Geometric Scaling Factors Relative to the 14-Foot Test Vessel

Group	Vessel(s)	Dia. (ft)	Number Of PJMs Per Vessel	Array Type	Interpolation or Extrapolation and Scale Factor
No / or Less than 1 wt%	CNP-VSL-00003	14	4	Distributed	Full Scale; 1.00
	CNP-VSL-00004	9.5	4	Distributed	Interpolation by 0.68
	CXP-VSL-00004	10.5	1	NA	Interpolation by 0.75
	CXP-VSL-00026A/B/C	15	6	Distributed	Extrapolation by 1.07
	FRP-VSL-00002A/B/C/D (note a)	47	12	Distributed	Extrapolation by 3.36
	HOP-VSL-00903/904	12	4	Distributed	Interpolation by 0.86
	PWD-VSL-00015/16	22	8	Distributed	Extrapolation by 1.57
	RLD-VSL-00007	13	4	Distributed	Interpolation by 0.93
	TCP-VSL-00001	26.5	8	Distributed	Extrapolation by 1.89
	TLP-VSL-00009A/B	26	8	Distributed	Extrapolation by 1.86
	UFP-VSL-00062A/B/C	15	6	Distributed	Extrapolation by 1.07
Normal Low Solids Less than 5 wt%	FEP-VSL-00017A/B	22	8	Distributed	Extrapolation by 1.57
	PWD-VSL-00033/43	24	8	Distributed	Extrapolation by 1.71
	PWD-VSL-00044	23	8	Distributed	Extrapolation by 1.64
	RLD-VSL-00008	13	4	Distributed	Interpolation by 0.93
High Solids	HLP-VSL-00022	38	18	Distributed	Extrapolation by 2.71
	UFP-VSL-00001A/B	20	12	Distributed	Extrapolation by 1.43
Non-Newtonian	HLP-VSL-00027A/B	25	8	Chandelier	Extrapolation by 1.79
	HLP-VSL-00028	26.5	8	Chandelier	Extrapolation by 1.89
	UFP-VSL-00002A/B (note b)	14	6	Chandelier	Full Scale; 1.00
Spent resin	RDP-VSL-00002A/B/C	12	4	Distributed	Interpolation by 0.86

Notes: (a) Vessels FRP-VSL-00002A/B/C/D are included in this group because solids settling rate is low.
(b) Vessels UFP-VSL-00002A/B will also contain Newtonian material.

4.1 Array Selection Criteria

The criteria for selection of PJM arrays to be used in the LSIT are as follows:

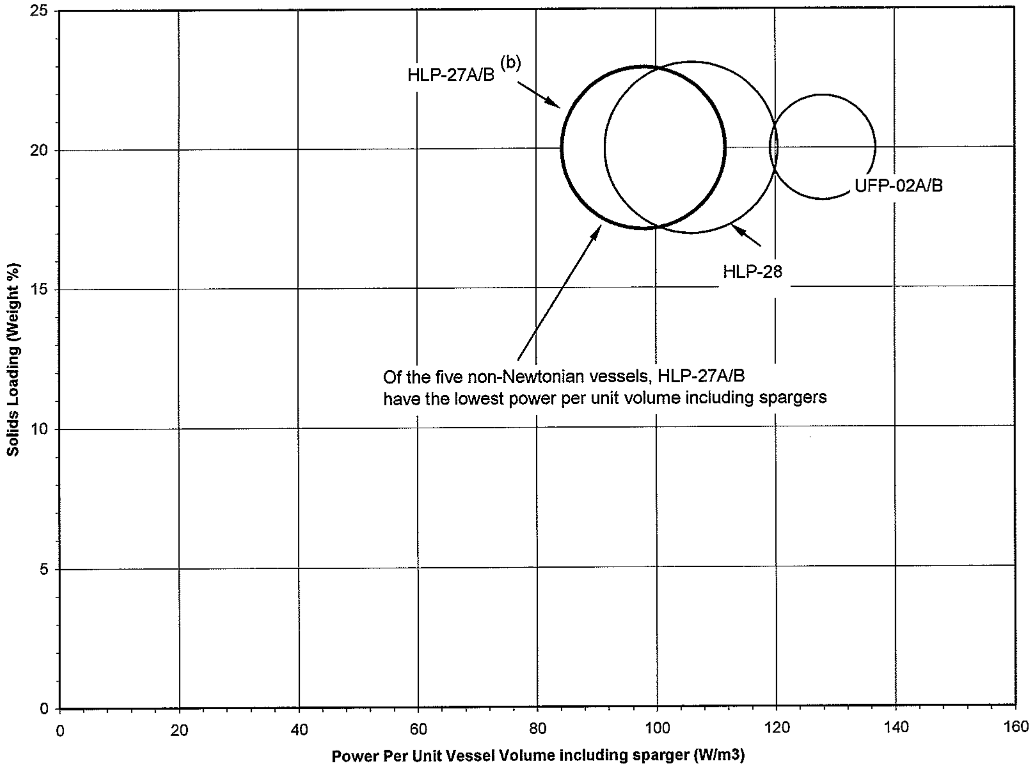
1. Arrays associated with a vessel size that matches the 14-foot test vessel in order to provide a means of full-scale, near full-scale testing. (Criterion: Full-Scale Representation)
2. Arrays associated with a vessel with high settling solids particulate loading in order to produce test results under challenging particulate suspension and mobilization conditions. (Criterion: High Solids Representation)
3. Arrays associated with vessels with relatively low mixing power per unit volume of slurry to provide a relatively conservative testing approach. (Criterion: Low Mixing Power)
4. Arrays with broad application in vessel mixing design on order to assure LSIT results with broad application to the WTP design. (Criterion: Usage Of PJM Pattern)
5. Arrays that represent the minimum and maximum number of PJMs in order to provide tests that are representative of the various process vessel array configurations. (Criterion: Diverse PJM Count)
6. A minimum of two arrays for both Newtonian and non-Newtonian vessels in order to provide necessary points of comparison, but not a number of arrays that become programmatically (cost and schedule) impractical and technically unnecessary. (Criterion: Minimum Essential Quantity)

These six criteria have been applied separately to the Newtonian and non-Newtonian process vessels. Criteria 1 and 2 have been given greater weight in the consideration of PJM arrays evaluated for testing.

4.2 Non-Newtonian Process Vessel Array Selection

There are three chandelier-type array configurations. The primary difference is that the UFP-VSL-00002A/B is configured with six PJMs and the two HLP configurations have eight PJMs. Figure 4 depicts the UFP-VSL-02A/B configuration. The UFP-VSL-00002A/B has a 14-foot diameter, while the HLP-VSL-27A/B and HLP-VSL-00028 have diameters of 25 and 26.5 respectively. The size of the circles in Figure 6 are proportional to the area coverage by each PJM with UFP-VSL-00002A/B being 2.38 m^2 per PJM while HLP-VSL-00027A/B and HLP-VSL-00028 are 5.7 m^2 and 6.4 m^2 respectively.

Figure 6 Chandelier Array Vessel Design Operating Parameters[(a)]



Note (a) Please note that the clearing region provided by a PJM in a chandelier array is not circular, but is shown as circles in this figure for the purpose of vessel-to-vessel comparison.
(b) To improve visibility in Figure 6, the coverage area per PJM for HLP-VLS-00027A/B is shaded in blue.

Although UFP-VSL-00002A/B has about twice the unit power delivery by its PJMs, building a test vessel at full scale based on one of the other two candidate vessels (HLP-VSL-00027A/B or HLP-VSL-00028) was originally considered too cost prohibitive but is under reevaluation by the project.

A second vessel with a chandelier array is required to be included in order to provide a configuration that represents the lower power, higher coverage mixing challenges of the two HLP configurations. In this regard, the two HLP vessels are close to one another in each of the two parametrics, but HLP-VSL-00027A/B is slightly lower in both parametrics. Therefore, the HLP-VSL-00027A/B configuration is selected based on unit power delivery.

The full-scale UFP-VSL-00002A/B test facility will support prototypic JPP driven PJMs.

The six criteria provided outlined in Section 4.1 are satisfied as shown by the following Table 6.

Table 6 Non-Newtonian Process Vessel Array Selection Criteria Matrix

Criterion Number	Criterion Description	Vessel Array Selection Rationale
1	Full-Scale Representation	UFP-VSL-00002A/B with a full-scale diameter of 14 feet selected to provide full-scale test data.
2	High Solids Representation	All three non-Newtonian vessels have a maximum solids loading of 20 wt%; therefore any of the three arrays are acceptable.
3	Low Mixing Power	HLP-VSL-27A/B has the lowest PJM mixing power per unit volume, and is therefore selected.
4	Usage Of PJM Pattern	Two patterns, the 6 and the 8 PJM arrays, are represented by selection of UFP-VSL-02A/B and HLP-VSL-27A/B for use in the LIST.
5	Diverse PJM Count	Same as Criterion Number 4 above.
6	Minimum Essential Quantity	Two arrays are necessary. The HLP-VSL-28 array properties are nearly identical to the HLP-VSL-27A/B configuration, and therefore not programmatically justified for inclusion.

4.3 Newtonian Process Vessel Array Selection Basis

Distributed PJM arrays range in total number of PJMs per vessel, and vessel cross-sectional area coverage per PJM depending on the mixing objectives of the vessel, and the design basis process waste solids loading.

Figure 5 depicts a four PJM array consistent with the HLW RLD-VSL-00008, Plant Wash and Drain Vessel. Vessels with low settling solids content generally require fewer PJMs, and vessels with a high solids content require more PJMs. A simple parameter defined as "coverage" is used here as a basis for comparing and selecting distributed arrays that could be used to represent the family of distributed arrays in the LSIT. Table 7 provides an overview of the number vessels that, as a group, have a particular PJM count. Included in Table 7 is mixing area coverage range for the group (vessel cross sectional area divided by the number of PJM in the vessel).

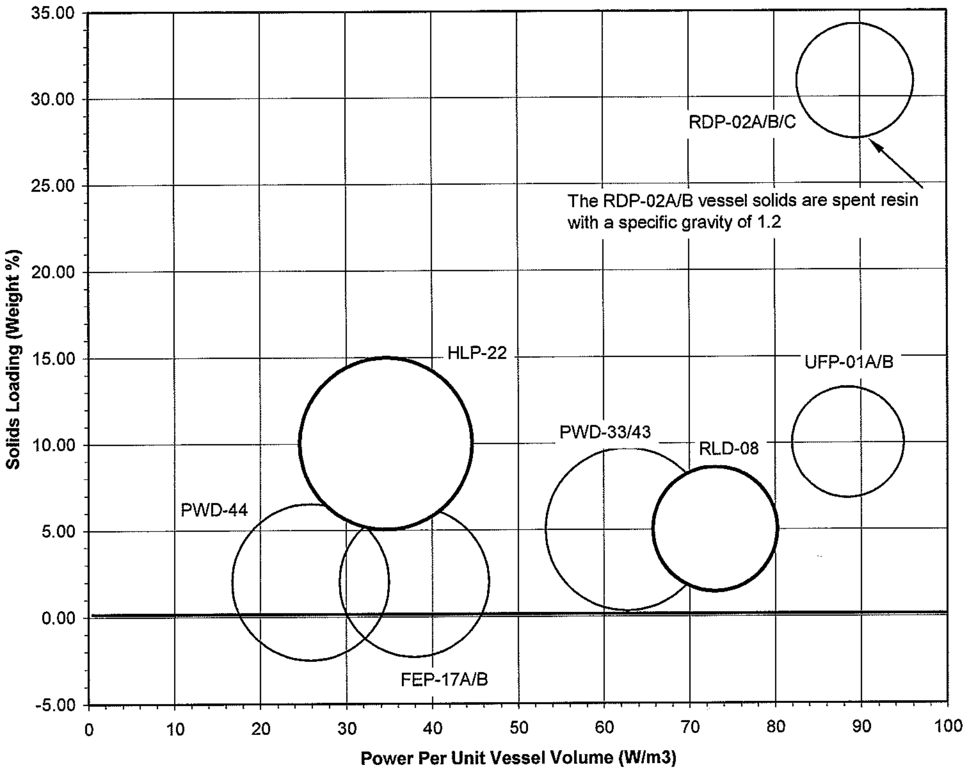
Table 7 Newtonian Process Vessel PJM Array Configurations

Group	No. Of PJMs	No. Of Vessels In Group	Area Coverage Range Per PJM (m^2)	Solids Loading Range (wt%)	Inner PJM Ring - Number Of PJMs
1	1	1	8.0	0	N/A
2 Note (a)	4	9	1.6 to 3.6	0 to 5	4
3	6	6	2.7	0	3
4	8	10	4.4 to 6.4	1 to 5	4
5	12	6	2.4 to 13.4	0 to10	4
6	18	1	5.8	10	6

Note (a) Vessels RDP-VSL-00002A/B/C do not contain HLW solids, but have a spent resin loading of 31 wt%. Spent resin, porous polymer beads do not settle at a rate that would be useful in assessing mixing performance challenges.

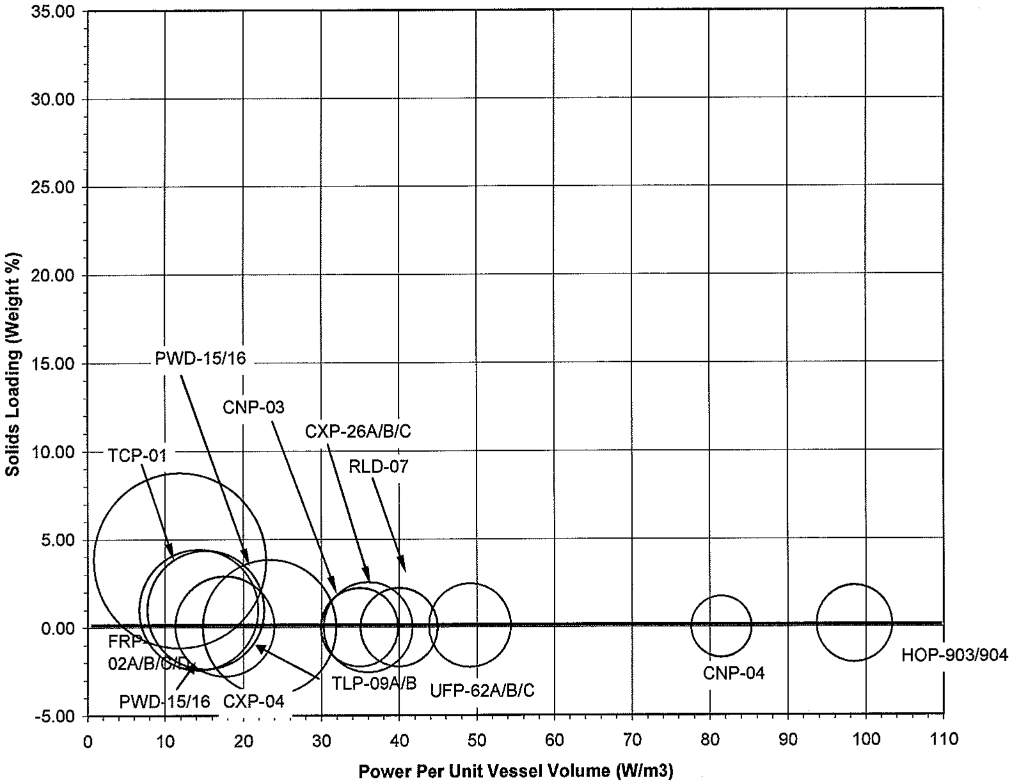
Figure 7 provides three primary distributed array vessel design operating parameters; power per unit volume of slurry, solids loading, and PJM area coverage for the higher solids vessels (vessels that process slurries with 2 wt% or greater fast settling solids). For the no solids or low solids vessels (vessels that process slurries with less than 2 wt% solids) see Figure 8. Note that FRP-VSL-00002 A/B/C/D is grouped with the low/no solids vessels in Figure 8, because the solids in this vessel are very slow settling. The size of the circle for each vessel is proportional to the area of PJM coverage. Data is tabulated in Appendix A. The number of PJMs in the center-most PJM ring is discussed later in this section.

Figure 7 High Solids Distributed Array Vessel Design Operating Parameters



To improve visibility in Figure 7, the coverage areas per PJM for HLP-VSL-00022 and for RLD-VSL-00007 are shaded in blue.

Figure 8 No Solids Distributed Array Vessel Design Operating Parameters



Note: FRP-VSL-00002 A/B/C/D is grouped with the low/no solids vessels in Figure 8, because the solids in this vessel are very slow settling.

Table 8 Newtonian Process Vessel Array Selection Criteria Matrix

Criterion Number	Criterion Description	Vessel Array Selection Rationale
1	Full-Scale Representation	Vessels that closely match the 14-foot test vessel scale are RLD-VSL-00007 and 8 at 13 feet in diameter, and CXP-VSL-00026A/B/C at 15 feet in diameter.
2	High Solids Representation	As noted in Table 7 and Figure 7, RDP-VSL-0002A/B/C has a spent resin loading of about 31 wt%. The next vessel that has the highest solids loading that matches Criterion Number 1 is RLD-VSL-00008. The vessels with the highest settling solids loading are HLP-VSL-00022 and UFP-VSL-00001 A/B.
3	Low Mixing Power	HLP-VSL-00022 has a relatively low mixing power relative to its particulate loading. Vessels PWD-VSL-00033 and PWD-VSL-00043 have the next lowest power for vessels with settling solids.
4	Usage Of PJM Pattern	The 4 and 8 PJM arrays comprise the majority of array patterns. RLD-VSL-00008 is within the majority pattern with 4 PJMs. HLP-VSL-00022 is unique with 18 PJMs.
5	Diverse PJM Count	Considering vessels with settling solids, the selection of a 4 PJM and 18 PJM array for testing provides the most diversity in PJM count.
6	Minimum Essential Quantity	Two arrays are required for LSIT due to the diversity in PJM count, coupled with consideration for mixing power range and solids loading. An 8 PJM distributed array was considered in addition to the 4 and 18 PJM arrays selected, but the WTP vessels with 8 PJM distributed arrays do not fulfill Criteria 1 and 2. Additionally, the inner ring of the 8 PJM array and the selected 4 PJM configuration are expected to have similar solids lifting performance.

Again, in the evaluation process for array selections for the LSIT, there are two criteria that are given greater weight: 1) the selection of a vessel array that closely matches the desired 14-foot test vessel diameter discussed in Section 4.2 to provide full-scale geometric similarity, and 2) vessels with the greatest mixing challenge (see Table 8). The latter consideration includes vessels with higher particulate solids loading and lower power per unit volume.

4.3.1 Newtonian Process Vessel Array Down Selection for LSIT

With a focus on selecting a vessel that meets the 14-foot geometric scaling criteria, there are 4 vessel types in the 13 to 15-foot diameter range; RLD-VSL-00007/8, CXP-VSL-00026A/B/C, CNP-VSL-00003, and UFP-VSL-00062A/B/C. Table 5 provides vessel diameters. Among this group of 4, RLD-VSL-00008 has been selected for full-scale PJM array testing based on its solids loading; the others do not process wastes containing solids. Vessels RDP-VSL-0002A/B/C are 13 feet in diameter with a solids loading of greater than 30%, but these are spent resin, porous polymer beads without the type of settling particulate that are of interest in assessing vessel mixing performance attributes.

The second vessel to be included in the LSIT distributed array testing is HLP-VSL-00022 with a geometric scaling factor of 2.71. This vessel has a high settling solids loading, and a lower power per unit volume than the other potential candidate, UFP-VSL-00001A/B. With 18 PJMs in HLP-VSL-00022, the area coverage per PJM is 5.85 m^2/PJM, whereas the area coverage for UFP-VSL-00001A/B is 2.43 m^2/PJM. The HLP vessel has about one third the power per unit volume and the same solids loading as the UFP vessel. It therefore represents a design that represents challenging parameters with respect to mixing performance attributes.

Another advantage in the selection of these two vessels is the ability to mimic both types of JPPs used by most WTP mixing vessels, i.e., the 8 m/sec and 12 m/sec design basis discharge velocities for distributed arrays. By including a full-scale RLD-VSL-00008 array in the 14-foot test vessel, full-scale JPP can be used to drive the four vessel PJMs, thereby providing prototypic drive velocity profiles. Other test arrays utilize a drive system that mimics JPP performance by closely matching the full-scale JPP drive velocity profiles applicable to each full-scale vessel JPP profile. The direct drive system can be used to drive the RLD-VSL-00008 array at higher velocities if needed to gather additional data.

The two vessels selected for scaled testing will have their PJM arrays built to three scales as summarized by Table 9 for both chandelier and distributed arrays. Test vessels are designed to accommodate scaled maximum process waste levels to vessel diameters (H/D). Scale factors are the vessel diameter ratios of the full-scale vessel to the test vessel. Actual test vessel IDs are provided as footnotes to Table 9.

Table 9 LIST Scaling Factors

Vessel	Full-Scale Vessel ID (ft)	Scale Factor 4-Foot Test Vessel (Note 2)	Scale Factor 8-Foot Test Vessel (Note 3)	Scale Factor 14-Foot Test Vessel
HLP-VSL-00022	38	10.56	4.89	2.71
HLP-VSL-00027A/B	25	6.94	3.22	1.79
RLD-VSL-00008	13 (Note 1)	3.61	1.67	0.93
UFP-VSL-00002A/B	14	3.89	1.80	1.00

Notes:
(1) PJM array to be full scale, with a larger dimension between the PJMs and vessel wall.
(2) Actual test vessel ID of 43.2-inches is used to determine scaling factor.
(3) Actual test vessel ID of 93.2-inches is used to determine scaling factor.

4.4 Array Selection Summary

The engineering approach for selection of the practicable largest scale test is to perform full-scale, prototypic testing of one WTP vessel with a PJM configuration matching the two Pretreatment Facility (PTF) Ultrafiltration Concentrate Vessels, UFP-VSL-00002A/B. This vessel configuration has a chandelier array of six PJMs designed to mix both Newtonian and non-Newtonian slurries, and has an internal diameter of 14 feet. The size of this vessel strikes a balance between the programmatic aspects of cost and schedule considerations, while providing the desired full-scale anchor point to extrapolate to larger sized vessels with the chandelier type PJM arrays that are up to 26.5 feet in diameter. The selected UFP vessel chandelier array configuration is shown by Figure 4.

Another important reason for selecting the Ultrafiltration Concentrate Vessels is their size relative to another vessel with a distributed PJM type of array, the HLW Plant Wash and Drains Vessel, RLD-VSL-00008, with a 13-foot internal diameter. In this case, because the difference in vessel diameter is small between full scale and test scale (the full scale is 93% of test scale), the PJM array will be built at full scale. This results in a somewhat larger space between the PJMs and the test vessel wall, but it serves a more important purpose; to test a full-scale, distributed array central up-well vertical flow zone that is the result of PJM discharge flow convergence at the vessel centerline. By keeping the geometry at full scale in this up-well region, the mixing performance for RLD-VSL-00008 will be confirmed without having to introduce scaling parameters. Thus, the 14-foot diameter test vessel serves as a full-scale test geometry for both chandelier and distributed PJM arrays. The selected RLD vessel distributed array is shown by Figure 5.

Using vessel UFP-VSL-00002A/B design as the full-scale vessel for LSIT, and 4-foot and 8-foot vessels to establish and confirm scaling exponents that will be applied to scaling correlations, where interpolation scaling will be applicable to six vessel designs, and extrapolation scaling will be application to 20 vessels. Table 5 provides a listing of vessels that will have mixing objectives evaluated using mixing performance profiles confirmed by LSIT, with scaling exponents applied to the geometric scale factor. The applicable scale factors are provided relative to a 14-foot test vessel. The design of the arrays follow geometric similarity, and operating parameters, such as nozzle velocity, may be adjusted as required to match a scaling rule, such as power per unit volume, power per unit area, or other scaling rule application.

5 Summary

This report was prepared to support a DOE commitment to the DNFSB commitment (Reference 4, Commitment 5.1.3.14) to document:

- Technical basis for test vessel sizes
- Process limits considerations for vessel contents and mixing power
- Technical basis for test configurations

Table 10 provides a summary of the test vessel sizes and array configurations selected for LSIT and how this selection relates to specific WTP process vessels.

Table 10 Summary of Nozzle Sizes for Selected Test Vessel Sizes and Array Configurations [(a), (b)]

Vessel Size	UFP-VSL-00002 6-PJM Chandelier Array Nozzle Size	RLD-VSL-00008 4-PJM Distributed Array Nozzle Size	HLP-VSL-00027 8-PJM Chandelier Array Nozzle Size	HLP-VSL-00022 18-PJM Distributed Array Nozzle Size
4-Foot	1.03-inch	1.11-inch	0.58-inch	0.40-inch
8-Foot	2.22-inch	2.40-inch	1.24-inch	0.87-inch
14-Foot	4-inch	4-inch	2.23-inch	1.57-inch

Note: (a) Uncertainties in the exact test nozzle size range from ±0.01 to 0.125 inches (References 28 and 29).
(b) As testing is definitized to assess PJM performance, simulants selected for testing may exceed the normal operating range for the vessels designated in this table. For example, the RDL-VSL-00008 vessel is designed to handle up to 5 wt% solids, but the testing for the 4-PJM distributed array configuration will likely include simulants with up to 10 wt% solids.

This report documents the considerations applied for selection of test vessel sizes and PJM arrays, which reviewed the wide range of process vessel designs within the WTP, and their associated process limits. The selection of three test vessels sizes for LSIT, nominally 4, 8 and 14 feet in diameter, provide a suitable range of geometric and volumetric scaling factors that are consistent with industry and DOE readiness level assessment standards and recommendations. Using three vessels in this size sequence supports the expected development of scaling correlations and provides for the data to support that provide a more accurate extrapolation of correlations to vessels beyond 14 feet in diameter to reduce uncertainty.

The selection of both distributed and chandelier arrays for testing, with each array tested at full scale and two smaller intermediate scales, provides an achievable programmatic approach for development of empirical correlations for scaling, minimizing the uncertainty associated with data interpolation and extrapolation.

6 References

1 24590-WTP-RPT-ENG-10-001, Rev. 1, Integrated Pulse Jet Mixed Vessel Design and Control Strategy

2 24590-WTP-ES-ENG-09-001, Rev. 2, titled Determination of Mixing Requirements for Pulse-Jet-Mixed Vessels in the Waste Treatment Plant

3 24590-WTP-RPT-ENG-10-001, Rev. 1, Integrated Pulse Jet Mixed Vessel Design and Control Strategy

4 Department of Energy Plan to Address Waste Treatment and Immobilization Plant Vessel Mixing Issues - Implementation Plan for Defense Nuclear Safety Board Recommendation 2010-2, Rev. 0 dated November 10, 2011, CCN 242510

5. Handbook of Industrial Mixing, Science and Practice, North American Mixing Forum, Wiley & Sons, Inc, 2004, Chapter 12, Leng, D. E. and Calabrese, R. V., Immiscible Liquid-Liquid Systems

6 Evaluation of Consortium for Risk Evaluation and Stakeholder Participation (CRESP) Review Team Letter Report 7 dated June 29, 2010, Attachment 1 to CCN 218915

7 24590-WTP-RPT-12-001, Rev. A, FLUENT Newtonian Model Verification and Validation Simulant Development Basis and Initial Simulant Approach

8 Pulse Jet Mixing Tests With Noncohesive Solids, WTP-RPT-182 dated May 2009

9 Kuhn, W. L. et al, *Technical Basis for Scaling Relationships for the Pretreatment Engineering Platform*, WTP-RPT-160, Rev. 0 dated July 2008

10. Meyer et al, Pulse Jet Mixing Tests With Noncohesive Solids, WTP-RPT-182, Rev. 0, dated May 2009

11 Technology Readiness Assessment Guide, DOE G 413.3-4 dated October 12, 2009

12. Hanford Waste Treatment Plant Pretreatment Mixing Large Scale Integrated Testing: Properties That Matter for Design Basis Testing, D. C. Koopman, et al, SRNL-STI-2012-00062, Draft (*under development*)

13. 24590-WTP-RPT-ENG-08-021-01, Rev. 1, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 1 - CXP-VSL-00026A/B/C

14 24590-WTP-RPT-ENG-08-021-02, Rev. 0, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 2 - CNP-VSL-00003/4, CXP-VSL-00004, UFP-VSL-00062A/B/C, RDP-VSL-00002A/B/C

15. 24590-WTP-RPT-ENG-08-021-03, Rev. 1, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 3 - HLP-VSL-00027 A/B, HLP-VSL-00028, UFP-VSL-00002A/B

16. 24590-WTP-RPT-ENG-08-021-04, Rev. 1, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 4 - HOP-VSL-00903/904, PWD-VSL-00015/16, TCP-VSL-00001, TLP-VLS-00009A/B, RLD-VSL-00008

17. 24590-WTP-RPT-ENG-08-021-05, Rev. 0, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 5 - PWD-VSL-00033/43/44

18 24590-WTP-RPT-ENG-08-021-06, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 6 - FRP-VSL-00002A/B/C/D

19 24590-WTP-RPT-ENG-08-021-07, Rev. 1, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 7 - UFP-01

20 24590-WTP-RPT-ENG-08-021-08, Rev. 1, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 8-HLP-22

21 24590-WTP-RPT-ENG-08-021-09, Rev. 0, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 9 - FEP-VSL-00017A/B

22 24590-WTP-RPT-ENG-08-021-10, Rev. 1, EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 10 - RLD-VSL-00007

23. 24590-WTP-3YD-50-00003, Rev. 0, System Description for Pulse jet Mixer and Sparger Mixing Subsystems

24. Scaling of Air Spargers for the Engineering-Scale HLP-27 Test Vessel, Attachment to Letter No. WTP/RPP-MOA-PNNL-00508, WTP CCN 219734 dated July 2, 2010

25. "Vessel Sizing Calculation for HLW Lag Storage Vessels (HLP-VSL-00027A/B)", Calculation Number 24590-PTF-M6C-HLP-00003, Rev. F

26. "Technical Basis for Scaling of Air Sparging Systems for Mixing in Non-Newtonian Slurries", Poloski AP, et al, PNNL-3441, WTP-RPT-129, PNNL, Richland Washington, 24590-101-TSA-W0000-0004-160-00001

27. 24590-WTP-3PS-G00Y-T0001, Rev 0, Engineering Specification for Large Scale Integrated Testing 4ft/8ft Platform Specification

28. 24590-WTP-3PS-G00Y-T0002, Rev 0, Engineering Specification for Large Scale Integrated Testing 14ft Platform Specification

29. Plant Design and Economics for Chemical Engineers, M. S. Peters and K. D. Timmerhaus, McGraw-Hill, Inc., New York, NY USA, 1980

30. *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, J. Bamberger et al., WTP-RPT-113, Rev. 0, 24590-010-TSA-W000-0004-114-00016, Rev. 00A

Appendix A - PJM-Mixed Vessel Data

This appendix provides a summary of PJM-mixed vessel information and data. The data is used in this report to provide explanations for selection of PJM arrays to be used in selection of specific test configurations for testing relative to assessing and establishing mixing capabilities and process limits. This tabulation is based on water. Power is directly proportional to slurry density. For vessels with spargers, the mixing power delivered by the spargers is not included.

Vessel Number	Vessel Name	Vsl. Working Vol. L8 $^{(a)}$ (gal)	Nomal Solids (wt%)	Max. Solids (wt%)	No. Of PJMs	Drive Time (sec)	Total PJM Cycle Time (sec)	PJM Duty Cycle $^{(b)}$	PJM Noz. Dia. (in.)	Noz. Disch. Vel. (m/sec)	Power/ Unit Volume $^{(c)}$ (W/m^3)	Min. PJM Operating Vsl. Volume (gal)	Estim. PJM Noz. Vel. (m/sec)	PJM Duty Cycle	Max. Power/ Unit Vol. $^{(d)}$ (W/m^3)	Engineering Document Data Source References $^{(f)}$
												Values Listed for Vessels with High Solids				
CNP-VSL-00003	Eluate Contingency Storage	16,127	0.0	0.0	4	9	34	0.26	4.00	8	36.0	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-02, Rev. 0 B) 24590-PTF-MVC-CNP-00003, Rev. D C) 24590-CM-POA-MPE0-00004-27-67, Rev. C
CNP-VSL-00004	Cs Evaporator Recovered Nitric Acid	7,342	0.0	0.0	4	6	22	0.27	4.00	8	81.5	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-02, Rev. 0 B) 24590-PTF-MVC-CNP-00005, Rev. B C) 24590-CM-POA-MPE0-00004-27-66, Rev. C
CXP-VSL-00004	Cs IX Caustic Rinse Collection	6,802	0.0	0.0	1	20	69	0.29	4.00	8	23.4	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-02, Rev. 0 B) 24590-PTF-MVC-CXP-00005, Rev. C C) 24590-CM-POA-MPE0-00004-27-60, Rev. C
CXP-VSL-00026A/B/C	Cs IX Treated LAW Collection	29,770	0.0	0.0	6	12	38	0.32	4.00	8	34.9	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-01, Rev. 1 B) 24590-PTF-MVC-CXP-00014, Rev. B C) 24590-CM-POA-MPE0-00004-27-73
FEP-VSL-00017A/B	Waste Feed Evaporator Feed	56,220	1.0	2.0	8	17	118	0.14	4.00	12	37.9	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-09, Rev. 0 B) 24590-PTF-MTC-FEP-00001, Rev. D C) 24590-WTP-RPT-ENG-08-021-09, Rev. 0
FRP-VSL-00002A/B/C/D	LAW Feed Receipt	379,890	0.0	3.8	12	40	197	0.20	4.00	12	11.9	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-06, Rev. 1 B) 24590-PTF-MTC-FRP-00001, Rev. E C) 24590-WTP-RPT-ENG-08-021-06, Rev. 1
HLP-VSL-00022	HLW Feed Receipt	185,265	10	10	18	35	205	0.17	4.25	12	36.6	60,236$^{(e)}$	13.5	0.10	90	A) 24590-WTP-RPT-ENG-08-021-08, Rev. 1 B) 24590-PTF-M6C-HLP-00006 Rev. F C) 24590-WTP-RPT-ENG-08-021-08, Rev. 1
HLP-VSL-00027A/B	HLW Lag Storage	95,909	20	20	8	31	228	0.14	4.00	12	21.0	18,405	15	0.08	122	A) 24590-WTP-RPT-ENG-08-021-03, Rev. 1 B) 24590-PTF-M6C-HLP-00003, Rev. G C) 24590-QL-POA-MPE0-00002-25-07, Rev. D
HLP-VSL-00028	HLW Blend	106,058	20	20	8	33	239	0.14	4.00	12	19.3	33,301	15	0.08	71	A) 24590-WTP-RPT-ENG-08-021-03, Rev. 1 B) 24590-PTF-M6C-HLP-00004, Rev. G C) 24590-QL-POA-MPE0-00002-25-06, Rev. D
HOP-VSL-00903/904	SBS Condensate Receiver	5,807	0.1	0.17	4	6	23	0.33	4.00	8	98.5	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-04, Rev.1 B) 24590-HLW-M6C-HOP-00005, Rev. D C) 24590-HLW-MPD-HOP-00033, Rev. 2
PWD-VSL-00015/16	Acidic / Alkaline Effluent	87,651	0.06	0.06	8	24	68	0.35	4.00	8	17.7	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-04, Rev. 1 B) 24590-PTF-MVC-PWD-00018, Rev. B C) 24590-CM-POA-MPE0-00004-27-62, Rev. C
PWD-VSL-00033/43	Ultimate Overflow / HLW Effluent Transfer	20,800	1.0	5.00	8	11	37	0.30	4.00	8	62.7	7,420	11	0.10	154	A) 24590-WTP-RPT-ENG-08-021-05, Rev.0 B) (33) 24590-PTF-MVC-PWD-00021, Rev. B B) (43) 24590-PTF-MVC-PWD-00022, Rev. B C) 24590-QL-POA-MPE0-00002-25-05, Rev. C
PWD-VSL-00044	Plant Wash	74,142	0.5	2.0	8	25	193	0.13	4.00	12	25.9	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-05, Rev. 0 B) 24590-PTF-MVC-PWD-00020, Rev. B C) 24590-WTP-RPT-ENG-08-021-05, Rev. 0
RDP-VSL-00002A/B/C	Spent Resin Slurry	7,085	30.9$^{(g)}$	30.9$^{(g)}$	4	13	45	0.29	4.00	8	89.4	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-02, Rev. 0 B) 24590-PTF-MVC-RDP-00003, Rev. C C) 24590-CM-POA-MPE0-00004-27-92, Rev. B
RLD-VSL-00007	HLW Acidic Waste	12,184	0.1	0.1	4	9	33	0.27	4.00	8	49.1	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-10, Rev. 1 B) 24590-HLW-M6C-RLD-00002, Rev. C C) 24590-CM-POA-MPE0-00004-27-93, Rev. C

Vessel Number	Vessel Name	Vsl. Working Vol. L8 (a) (gal)	Nomal Solids (wt%)	Max. Solids (wt%)	No. Of PJMs	Drive Time (sec)	Total PJM Cycle Time (sec)	PJM Duty Cycle (b)	PJM Noz. Dia. (in.)	Noz. Disch. Vel. (m/sec)	Power/ Unit Volume (c) (W/m³)	Min. PJM Operating Vsl. Volume (gal)	Estim. PJM Noz. Vel. (m/sec)	PJM Duty Cycle	Max. Power/ Unit Vol. (d) (W/m³)	Engineering Document Data Source References (f)
												Values Listed for Vessels with High Solids				
RLD-VSL-00008	HLW Plant Wash and Drains	8,721	0.0	5.0	4	9	31	0.29	4.00	8	73.0	2,714	11	0.10	210	A) 24590-WTP-RPT-ENG-08-021-04, Rev. 1 B) 24590-HLW-M6C-RLD-00005, Rev. C C) 24590-QL-POA-MPE0-00002-25-12, Rev. C
TCP-VSL-00001	Treated LAW Condensate Storage	102,621	0.1	1.0	8	76	227	0.33	4.00	8	14.3	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-04, Rev. 1 B) 24590-PTF-MTC-TCP-00001, Rev. C C 24590-CM-POA-MPE0-00004-27-63, Rev. C
TLP-VSL-00009A/B	LAW SBS Condensate Receipt	87,449	0.1	1.0	8	23	76	0.30	4.00	8	15.2	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-04, Rev. 1 B) 24590-PTF-MTC-TLP-00001, Rev. B C) 24590-CM-POA-MPE0-00004-27-64, Rev. C
UFP-VSL-00001A/B	Ultrafilter Feed Preparation	53,332	10	10	12	16	85	0.19	4.25	12	88.5	14,354	13.9	0.10	274	A) 24590-WTP-RPT-ENG-08-021-07, Rev. 1 B) 24590-PTF-M6C-UFP-00004, Rev. E C) 24590-WTP-RPT-ENG-08-021-07, Rev. 1
UFP-VSL-00002A/B	Ultrafiltration Feed	31,609	20	20	6	15	93	0.16	4.00	12	56.7	4,310	15.7	0.08	455	A) 24590-WTP-RPT-ENG-08-021-03, Rev. 1 B) 24590-PTF-M6C-UFP-00008, Rev. E C) /24590-QL-POA-MPE0-00002-25-02, Rev. D
UFP-VSL-00062A/B/C	Ultrafiltration Permeate Collection	25,606	0.0	0.0	6	14	45	0.31	4.00	8	40.0	-----	-----	-----	-----	A) 24590-WTP-RPT-ENG-08-021-02, Rev. 0 B) 24590-PTF-M6C-UFP-00005, Rev. 0 C) 24590-CM-POA-MPE0-00004-27-65, Rev. C

'-----' Indicates the value was not included in the table, because the vessel did not contain sufficient solids loading or sufficient settling solids.

Notes:

a) Vessel volume is the volume at Level 8 as given by various vessel sizing calculations. Level 8 is defined as the volume when the vessel is filled to the batch volume level.
b) Duty cycle is defined as drive time divided by total cycle time.
c) Power per unit volume in this column is average power based on vessel volume at the batch volume height and a SG of 1.0 and duty cycle. Power during the drive is this P/V divided by the duty cycle.
d) Bounding maximum power per unit volume in this column is based on vessel volume at the minimum operating volume height (all PJMs in operation) and the maximum SG.
e) Minimum operating level is based on 18 PJMs in operation.
f) References are identified as "A" from the EFRT Issue M3 Vessel Mixing Assessment, "B" from the vessel sizing engineering calculation, and "C" from subcontractor FLUMP analyses (note vessel with changed nozzle velocities or nozzle sizes are from the M3 Vessel Mixing Assessment.
g) Solids are spent resin

Appendix A - References:

Vessel Assessments

24590-WTP-RPT-ENG-08-021-01, Rev. 1, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 1 - CXP-VSL-00026A/B/C*

24590-WTP-RPT-ENG-08-021-02, Rev. 0, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 2 - CNP-VSL-00003/4, CXP-VSL-00004, UFP-VSL-00062A/B/C, RDP-VSL-00002A/B/C*

24590-WTP-RPT-ENG-08-021-03, Rev. 1, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 3 - HLP-VSL-00027A/B, HLP-VSL-00028, UFP-VSL-00002A/B*

24590-WTP-RPT-ENG-08-021-04, Rev. 1, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 4 - HOP-VSL-00903/904, PWD-VSL-00015/16, TCP-VSL-00001, TLP-VLS-00009A/B, RLD-VSL-00008*

24590-WTP-RPT-ENG-08-021-05, Rev. 0, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 5 - PWD-VSL-00033/43/44*

24590-WTP-RPT-ENG-08-021-06, Rev. 1, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 6 - FRP-VSL-00002A/B/C/D*

24590-WTP-RPT-ENG-08-021-07, Rev. 1, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 7 - UFP-VSL-00001A/B*

24590-WTP-RPT-ENG-08-021-08, Rev. 1, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 8 - HLP-22*

24590-WTP-RPT-ENG-08-021-09, Rev. 0, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 9 - FEP-VSL-00017A/B*

24590-WTP-RPT-ENG-08-021-10, Rev. 1, *EFRT Issue M3 PJM Vessel Mixing Assessment, Volume 10 - RLD-VSL-00007*

Vessel Sizing Calculations

24590-HLW-M6C-HOP-00005, Rev. D, *Sizing of SBS Condensate Vessel HOP-VSL-00903 & -00904*

24590-HLW-M6C-RLD-00002, Rev. C, *HLW Acidic Waste Vessel RLD-VSL-00007 Sizing Calculation*

24590-HLW-M6C-RLD-00005, Rev. C, *HLW Plant Wash and Drain Vessel RLD-VSL-00008 Sizing Calculation*

24590-PTF-MVC-CNP-00003, Rev. D, *Eluate Contingency Storage Vessel CNP-VSL-00003 Sizing*

24590-PTF-MVC-CNP-00005, Rev. B, *CNP-VSL-00004 Cs Evaporator Recovered Nitric Acid Vessel Sizing*

24590-PTF-MVC-CXP-00005, Rev. C, *Vessel Sizing for the Cesium Ion Exchange Feed Vessel (CXP-VSL-00004)*

24590-PTF-MVC-CXP-00014, Rev. B, *CXP-VSL-00026 A/B/C Cs IX Treated LAW Collection Vessel Calculation*

24590-PTF-MTC-FEP-00001, Rev. D, *Vessel Calculation for Waste Feed Evaporator Feed Vessel FEP-VSL-00017A/B*

24590-PTF-MTC-FRP-00001, Rev. E, *Vessel Sizing Calculation - FRP-VSL-00002 A/B/C/D*

24590-PTF-M6C-HLP-00003, Rev. G, *Vessel Sizing Calculation For HLW Lag Storage Vessels (HLP-VSL-00027A/B)*

24590-PTF-M6C-HLP-00004, Rev. G, *Vessel Sizing Calculation for HLW Feed Blending Vessel HLP-VSL-00028*

24590-PTF-M6C-HLP-00006, Rev. F, *Vessel Sizing Calculation for HLW Feed Receipt Vessel (HLP-VSL-00022)*

24590-PTF-MVC-PWD-00018, Rev. B, *Vessel Sizing Calculation For The Acidic/Alkaline Effluent Vessels (PWD-VSL-00015/16)*

24590-PTF-MVC-PWD-00020, Rev. B, *Vessel Sizing Calculation For The Plant Wash Vessel (PWD-VSL-00044)*

24590-PTF-MVC-PWD-00021, Rev. B, *Vessel Calculation For the Ultimate Overflow Vessel PWD-VSL-00033*

24590-PTF-MVC-PWD-00022, Rev. B, *Vessel Calculation For The High Level Waste (HLW) Effluent Transfer Vessel PWD-VSL-00043*

24590-PTF-MVC-RDP-00003, Rev. C, *Vessel Sizing Calculation - RDP-VSL-00002A/B/C*

24590-PTF-MTC-TCP-00001, Rev. C, *Treated LAW Concentrate Storage Vessel (TCP-VSL-00001) Sizing Calculation*

24590-PTF-MTC-TLP-00001, Rev. B, *Vessel Sizing Calculation-TLP-VSL-00009 A/B*

24590-PTF-M6C-UFP-00004, Rev. E, *Vessel Sizing Calculations for Ultrafiltration Feed Preparation Vessels UFP-VSL-00001A/B*

24590-PTF-M6C-UFP-00005, Rev. D, *Vessel Sizing Calculations For Ultrafiltration Permeate Vessels UFP-VSL-00062A/B/C*

24590-PTF-M6C-UFP-00008, Rev. E, *Vessel Sizing Calculation For UFP Ultrafiltration Vessels UFP-VSL-00002A/B*

JPP Datasheets

24590-CM-POA-MPE0-00004-27-60, *Rev. C, Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-62, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-63, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-64, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-65, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-66, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-67, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-73, Rev. B, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-92, Rev. B, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-CM-POA-MPE0-00004-27-93, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet Pack - PJM Mixing*

24590-HLW-MPD-HOP-00033, Rev. 2, *HOP-VSL-00903 HOP-VSL-00904 - Mechanical Data Sheet: Jet Pump Pairs for Pulse Jet Mixer Applications*

24590-QL-POA-MPE0-00002-25-02, Rev. D, *Data Sheet - JPP Mechanical Datasheet Pack, PJM Mixing Vessel UFP-VSL-00002A,B*

24590-QL-POA-MPE0-00002-25-05, Rev. C, *Data Sheet - JPP Mechanical Datasheet Pack, PJM Mixing*

24590-QL-POA-MPE0-00002-25-06, Rev. D, *Data Sheet - JPP Mechanical Datasheet Pack, PJM Mixing Vessel HLP-VSL-00028*

24590-QL-POA-MPE0-00002-25-07, Rev. D, *Data Sheet - JPP Mechanical Datasheet Pack, PJM Mixing Vessel HLP-VSL-00027A,B*

24590-QL-POA-MPE0-00002-25-12, Rev. C, *Final - Data Sheet - JPP Mechanical Datasheet Pack PJM Mixing*

ATTACHMENT 2
TO
12-WTP-0161

TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD (DNFSB) RECOMMENDATION 2010-2 IMPLEMENTATION PLAN (IP) DELIVERABLE 5.1.3.14

EXPERT REVIEW TEAM (ERT) COMMENTS & RESPONSES

Number of Pages: 24

ERT-15 Vessel Configuration

Large-Scale Integrated Mixing System Expert Review Team

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

To: Phil Keuhlen, ERT Coordinator

Subject: Concurrence on "Vessel Configurations for Large Scale Integrated Testing" (ERT-15 Vessel Configuration)

Date: April 27, 2012

Dear Mr. Keuhlen:

The Large-Scale Integrated Mixing System Expert Review Team (ERT) concurs with WTP's disposition of ERT comments documented in ERT-15 Vessel Configuration (dated April 12, 2012) as described in your response letter CCN 211787.

This letter closes review ERT-15.

Dr. Loni M. Peurrung, Ph.D.
Chair, Large-Scale Integrated Mixing System Expert Review Team
Pacific Northwest National Laboratory
902 Battelle Boulevard
Richland, WA 99352

CCN: 211787

Dear Dr. Peurrung:

VESSEL COMPLETION TEAM (VCT) RESPONSES TO EXPERT REVIEW TEAM (ERT) COMMENTS ON VESSEL CONFIGURATIONS FOR LARGE SCALE INTEGRATED TESTING (ERT-15)

References: 1) 24590-WTP-RPT-ENG-12-017, Rev A, *Vessel Configurations for Large Scale Integrated Testing*
2) CCN 237622, Memorandum, from P. J. Keuhlen, WTP, to J. Berkoe, BNI, R. F. French, WTP, W. W. Gay, WTP, "Distribution f Expert Review Team (ERT) Comments on ERT Review of Vessel Configurations for Large Scale Integrated Testing (ERT-15), dated April 16, 2012.

The VCT appreciates the ERT reviews of the subject document (Reference 1). Addressing the review comments provided in Reference 2 has made this a stronger document. The top level observations and recommendations from Reference 2 are summarized below. All of these recommendations have been accepted, and the related discussion revised as suggested by the ERT.

1. *The ERT agrees with the selection of three scales for testing, but not necessarily with the argument for three scales as presented in Section 2.2.2. As we suggested in our discussion on April 9 with WTP staff, the purpose of choosing three scales is not to capture non-linear effects, but rather to decrease uncertainty in extrapolating the results given that the physics is not fully known and to quantify uncertainty in the scaling exponents.*

   The report was updated to remove discussion on non-linear effects. The discussion of selection of three scales was revised to focus on industrial guidelines for scale up and increasing confidence in extrapolating results when there is uncertainty in the physics and scale factor exponents.

2. *The ERT observes that one aspect of the logic for the selection of the vessel scales is missing, i.e., a rationale for determining the size of the smallest vessel. One reason for selecting four feet as the diameter of the smallest vessel is that WTP already has such a vessel. However, the argument for the selection of the smallest scale could also be based on representing the right physics, e.g., keeping flow turbulent. The ERT recommends confirming that the Reynolds number and other relevant dimensionless groups will be within appropriate ranges for 4-foot testing.*

   The Reynolds numbers for the 4-foot testing were confirmed to be within the appropriate ranges considering plant scales and tabulation discussed with the ERT. Additionally, discussion was added on why 4-foot vessel was selected as the smallest test scale.

3. *The ERT recommends that the discussion of the logarithmic progression of vessel sizes in Section 2.2.3 be greatly reduced. Eight feet is between four and fourteen; it's close to the geometric mean. WTP has an 8-foot test vessel, which makes its use cost effective. In our opinion, not much more needs to be said.*

   The section on the logarithmic progression of scales was deleted.

4. *The ERT observes that there are flaws in the arguments made in Section 3 about PJM power per unit volume and sparger power and how they are affected by changes in the fluid level in the vessel. The zone of solids suspension in these systems is limited to the bottom of the vessel; hence, while the power-per-volume approach described may be applicable to blending (which is a global phenomenon in the vessel), solids mixing is more localized; and therefore, local power per unit volume prevails. Likewise, the use of the equation for power per volume on page 16 may be misleading. By including duty cycle as a factor, it reflects a time-averaged power per unit volume. Mixing depends on the power applied during the drive phase and not on the time-averaged power. While the ERT would like to see these concepts corrected in the final version of the document, they do not substantially affect the document's conclusions.*

   The table and associated discussion were updated to address power during the drive, rather than on a time-averaged basis. Comparisons of power-per-volume were added at the lowest level for operating PJMs in vessels with relatively high solids loading, and discussion was added, indicating that solid loading is an important consideration in selecting vessels for comparisons.

Attachment 1 provides the final version of the issued report, while Attachment 2 provides the responses to individual ERT member comments that have been discussed with the ERT. We believe this should allow the ERT to concur with disposition of their recommendations and closeout ERT-15.

If you have any questions concerning this matter, please contact me at 509-371-3816, or Mr. Phillip Keuhlen at 509-371-3418.

Very truly yours,

Robert F. French
Project Manager
Vessel Completion Team

PJK/dfo

Attachments: 1) 24590-WTP-RPT-ENG-12-017, Rev 0, Vessel Configurations For Large Scale Integrated Testing
2) Responses to ERT to Comments on ERT 15

cc:

Barnes, S. M. w/a	WTP	MS4-B2
Damerow, F. w/a	WTP	MS4-B2
Daniel, R. B. w/a	WTP	MS4-A2
Duncan, G. M. w/a	WTP	MSB1-55
French, R. F. w/a	WTP	MS4-A2
Gay, W. W.	WTP	MS4-A2
Hanson, R. w/a	WTP	MS4-B2
Keuhlen, P. J. w/a	WTP	MS4-A2
Olson, J. W. w/a	WTP	MS4-A2
Russo, F. w/a	WTP	MS14-3C
Underhill, W. w/a	WTP	MS4-A2
PADC w/a	WTP	MS19-A

Large-Scale Integrated Mixing System Expert Review Team

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

To: Dale Knutson, WTP Federal Project Director; Frank Russo, WTP Project Director

cc: Phil Keuhlen, ERT Coordinator; Bob French, VCT Project Manager; Russell Daniel, VCT Technical Manager; Bill Gay, VCT Project Director; ERT members

Subject: Vessel Configurations for Large Scale Integrated Testing (ERT-15)

Date: April 12, 2012

The Large Scale Integrated Mixing System Expert Review Team (ERT) was asked to review "Vessel Configurations for Large Scale Integrated Testing" (24590-WTP-RPT-ENG-12-017, Rev A). This document is intended to meet Commitment 5.1.3.14 of the Implementation Plan for Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2010-2. Per the commitment, this document provides the "basis for selection of specific test configurations for testing relative to assessing and establishing mixing capabilities and process limits across the range of WTP vessels (e.g., mixing power, contents, PJM configuration). The documentation shall define the technical basis and requirements for all test configurations and sizes including the 4-ft, 8-ft, 14-ft, and 6-ft single PJM test platform."
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 technically defensible basis for selecting the specific sizes and configurations for testing?

Note that the ERT was informed that Section 5 of the draft document on sparging would be deleted, and so no formal comments are being provided on that material at this time.

The ERT agrees with the selection of three scales for testing but not necessarily with the argument for three scales as presented in Section 2.2.2. As we suggested in our discussion on April 9 with WTP staff, the purpose of choosing three scales is not to capture non-linear effects but rather to decrease uncertainty in extrapolating the results given that the physics is not fully known and to quantify uncertainty in the scaling exponents.

The ERT observes that one aspect of the logic for the selection of the vessel scales is missing, i.e. a rationale for determining the size of the smallest vessel. One reason for selecting four feet as the diameter of the smallest vessel is that WTP already has such a vessel. However, the argument for the selection of the smallest scale could also be based on representing the right physics, e.g. keeping flow turbulent. The ERT recommends confirming that the Reynolds number and other relevant dimensionless groups will be within appropriate ranges for 4-foot testing.

The ERT recommends that the discussion of the logarithmic progression of vessel sizes in Section 2.2.3 be greatly reduced. Eight feet is between four and fourteen; it's close to the geometric mean. WTP has an 8-foot test vessel, which makes its use cost effective. In our opinion, not much more needs to be said. Figure 2 is a useful visual depiction of the test vessel scales versus the sizes of the actual vessels.

The ERT observes that there are flaws in the arguments made in Section 3 about PJM power per unit volume and sparger power and how they are affected by changes in the fluid level in the vessel. The zone of solids suspension in these systems is limited to the bottom of the vessel; hence, while the power-per-volume approach described may be applicable to blending (which is a global phenomenon in the vessel), solids mixing is more localized and therefore local power per unit volume prevails. Likewise, the use of the equation for power per volume on page 16 may be misleading. By including duty cycle as a factor, it reflects a time-averaged power per unit volume. Mixing depends on the power applied during the drive phase and not on the time-averaged power. While the ERT would like to see these concepts corrected in the final version of the document, they do not substantially affect the document's conclusions.

Beyond these specific comments, the ERT generally agrees with the document's conclusions, that is, that these vessel sizes and configurations are appropriate for large-scale integrated testing. Detailed comments from individual reviewers will be provided separately. We hope you find this input useful and look forward to your response.

ERT-15 Vessel Configuration

Review Participants:

April 9, 2012. Rich Calabrese, Richard Grenville, Ramesh Hemrajani, Loni Peurrung, Phil Keuhlen, Bob Hanson, Jennifer Meehan

April 11, 2012. Rich Calabrese, Richard Grenville, Erich Hansen, Ramesh Hemrajani, Loni Peurrung

LSIMS ERT DOCUMENT REVIEW RECORD	**REVIEW NUMBER:**	ERT-15 Vessel Configuration
	DOCUMENT NUMBER:	24590-WTP-RPT-ENG-12-017, Rev A
	DOCUMENT TITLE:	Vessel Configurations for Large Scale Integrated Testing

Comment			Comments and Recommendations:	Resolution:
Number	Reviewer	Type*		
1	LMP	O	The third paragraph indicates that LSIT will "select the mixing systems that have the least performance margin." It may be useful when the criteria are described later in the document to make the connection between the criteria and this statement.	This statement was removed in the process of resolving other reviewer comments.
2	LMP	E	The first paragraph of Section 2 and the second are somewhat redundant. The second one does a better job of setting the stage and avoiding red flag language like "well understood" and "unnecessary".	The introduction to Section 2 was reworded. One intent of that revision was to remove the redundant statements.
3	LMP	E	The last sentence is Section 2.1 seems to go out on a limb a bit relative to the degree of certainty that can be achieved with this approach.	This statement was removed in the process of resolving other reviewer comments.
4	LMP	O	There is an unrecognized implicit assumption in the size progression discussion in Section 2.2.3. You have a 4-ft test vessel. Without that vessel, you could also have chosen the progression 14-ft, 1-ft, 1/14th-ft and still be logarithmic. More generally, I would have set up the logic flow of Section 2 somewhat differently, i.e.,: • Testing should be cost-effective • Three scales better captures physics and quantifies uncertainty • The largest test vessel should be half scale • One test vessel should match a real vessel • Scales should have a logarithmic size progression • Too small becomes wrong physics, e.g., not turbulent (note: this also should be explicitly discussed) • We have a 4-ft vessel; ergo, Match UFP-02 at 14 ft; use existing 4 ft; geometric mean is about 8 ft, which we happen to have.	Section 2.2.3 is Section 2.2.2 in the updated version of the report. This section was reworded to incorporate the logic suggested.
5	LMP	E	Include the definition of TRL 6 in Section 2.3 for clarity.	The definition of Technology Readiness Level 6 was added.

***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

6	LMP	O	There seems to be something missing at the end of Section 3.1.2, a "therefore…" Perhaps it is "Hence, testing should include these ranges of solids concentration and rheology."	Added sentence to clarify, "These ranges need to be considered in developing tests for vessel configurations that process these non-Newtonian fluids."
7	LMP	O	The criteria in Section 4.1 help frame selection well. Are they weighted in any way? That is not stated when they are introduced, but later (on page 29) there is some indication that they are.	The was updated to reiterate that Criteria 1) and 2) were given greater weight in the evaluation and selection of test arrays.
8	LMP	E	It's not clear to the reader what blue denotes in Figure 5, etc.	A footnote was added to indicate that HLP-27 was shaded in blue to increase its visibility in the figure.
9	LMP	O	There seems to be a logic flow lapse in Section 4.3 in how the "Group" concept translates into Figure 6. Or maybe it's not supposed to translate, but then it's not clear why these particular vessels are in Figure 6.	The division of Figure 6 and 7 was clarified in the Section 4.3 text.
10	LMP	**M**	Once you've identified two vessel configurations in Section 4.3, you stop. Criterion 6 is "at least two", not "two". Criteria 4 and 5 aren't well satisfied by the two selected and seem to suggest the need for an 8-PJM array as a third configuration. However, it's not clear that there are any vessels with 8-PJM arrays that really warrant testing per criteria 2 and 3. But if that's the case, the document needs to say why you stopped.	This was updated (in particular in Table 9) to indicate that 8-PJM array was reviewed but not selected as the vessels where an 8-PJM array is applicable do not meet Criteria 1) and 2).
11	EKH	**M**	One of the most important aspects of scaling is that the flow regime must be the same for the various scales, if the data is to be compared. For Newtonian fluids, a Reynolds jet number of 3000 seems to be an acceptable point at which the jet leaving the nozzle is considered turbulent, but working with a buffer (at a higher RE) may be necessary. As for non-Newtonian, additional thought is required (such as using pipe analysis or if such information can be found in literature for NN jets.). Such discussions could occur in Section 2.2.2, where there is discussion about PJM velocity.	The Reynolds number for the jets were are attached for HLP-22 and RLD-8 in the **attached table**. The document now includes references to the upcoming scaling basis report (WTP-RPT-215, Draft in development) , which will provide more information on the basis for scaling as it relates to jet velocity and flow regime.

***Type:** E – Editorial, addresses word processing errors that do not adversely impact the integrity of the document.
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M – Mandatory, comment shall be resolved, reviewer identifies impact on the integrity of the document

LSIMS ERT DOCUMENT REVIEW RECORD	**REVIEW NUMBER:**	ERT-15 Vessel Configuration
	DOCUMENT NUMBER:	24590-WTP-RPT-ENG-12-017, Rev A
	DOCUMENT TITLE:	Vessel Configurations for Large Scale Integrated Testing

12	EKH	O	Since the size of the PJM nozzle is important (see above), it would be useful to see a table (could be part of an existing table, for example, Table 13.) showing the size of the PJM nozzle for the selected configurations and scales. That way no assumptions are made by the readers on what size nozzles will be used in each scale and configuration.	A table was added to the Section 5 Summary to show the selected vessel sizes and arrays with their respective nozzle sizes.
12A	EKH	E	Document needs an editorial scrub. This also includes giving equations numbers.	The document was edited as comments were resolved. Only two Equations are in the update and they have been numbered.
13	EKH	E	Page 1, second paragraph. This is picky, but use fluid rather than liquid.	This was revised as requested. Note that Section 1 was updated to incorporate other reviewer comments.
14	EKH	O	Page 4, second paragraph. What size scale would this be such that the 100:1 ratio is achieved? This was done for the other ratios in the previous paragraphs and will make this consistent.	Added corresponding geometric scale ratio to remain consistent with prior volumetric to geometric ratio discussions. This section was reworded to clarify the scale ratio relationship between test vessel scale and full scale.
15	EKH	E	Page 5, Section 2.1.3, third paragraph. "This particulate was.." should read "These particulates were.."	This was revised as requested.
16	EKH	E	Page 5, Section 2.1.3, third paragraph. Was it 70% of the total solids (note that this includes both soluble and insoluble), or 70% of the insoluble? Please verify.	Leachable solids are the solids that are insoluble until they are leached.
17	EKH	E	Page 5, Section 2.1.3. States as outlined in Section 2.0? Is there a 2.0 or just 2?	This was updated to read 'Section 2'.
18	EKH	E	Page 7, Equation (1). Provide a reference for such a form (which comes from dimensional analysis – any reference will do).	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
19	EKH	E	Page 7, Section 2.2.1. States as outlined in Section 2.0? Is there a 2.0 or just 2?	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
20	EKH	E	Page 7, Section 2.2.2. States as defined in Section 2.2; should be Section 2.2.1.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
21	EKH	O	Page 8, second paragraph, second sentence. Is potential energy required to lift solids or just kinetic energy (velocity)? Both? Agree that KE and PE can be tied together based on tank level and PJM drive pressure. Not clear.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT. Potential and kinetic energy are no longer specifically mentioned in this discussion.

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LSIMS ERT DOCUMENT REVIEW RECORD		
	REVIEW NUMBER:	ERT-15 Vessel Configuration
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22	EKH	E	Page 8, last paragraph. Should this paragraph including 1. and 2. be placed at the start of this section, stating why two scales are potential issues and a lead into why three are better?	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
22A	EKH	E	Table 1. Interesting, both solids concentration and DC have the same exponent, is that correct. Additionally, D is already defined, need to use something else.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT. The symbols used in the remainder of the text were checked to ensure they were used consistently throughout the document.
23	EKH	O	Section 2.2.2.1. This section needs to be looked at again and to drive why three vessels sizes provide a more accurate model, if that is the intent of this section.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
24	EKH	O	Equation 3 is inconsistent wrt to units. Going from Equation 3 to the next equation is wrong as well.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
25	EKH	O	Section 2.2.2.1, Page 10. Second paragraph is bit confusing, assuming one is following the argument as stated. If you want T_B to be a variable, then show it in an equation. The basis of equation 4 is that T_B is constant.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT. Potential and kinetic energy are no longer specifically mentioned in this discussion.
26	EKH	O	Section 2.2.2.1, Page 10, fourth paragraph. The first sentence does not make any sense or is incomplete in its description. I'm assuming that more energy (kinetic) is required to move/lift a larger bed of solids. As stated earlier, I don't see how potential energy is involved, other than as stated in comment 22.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
27	EKH	O	Section 2.2.3. I don't know what this section brings to the table. Is it common when doing scaling tests that this relationship exists (a=r=2 in this case) between scales (provide reference if such is true or if this is a target for scaling, even between two scales)? Also note that this relationship does not exist between the 4 and 8 foot scale, where the difference in the Ln(2) should be 0.693 rather than 0.769 {Ln(2.145)}. Also note that if you follow the a=r=2 rule and started with the 43.2 inch vessel, the next two sizes (using 0.693) would be 86.2 and 172.8 inches respectively, close to what you've got stated in Table 2. Again, not sure what this section brings to the table.	All of Section 2.2 was significantly updated to incorporate ERT recommendations. The discussion on the logarithmic scale factor was removed through the tables that had been in Section 2.2.3. Figure 2 and the corresponding text are now in Section 2.2.2.

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28	EKH	E	I do like Figure 2; don't get rid of it, since it says a lot. You could use a legend and provide a color code scheme that would show which of the tanks had undissolved solids and their maximum concentration.	Figure 2 was annotated to distinguish vessel type (by range of solids and by vessels that process Newtonian versus non-Newtonian process wastes).
29	EKH	E	Page 14, second paragraph. Yield should be stress.	This was reworded as requested.
30	EKH	E	Page 14, Section 3.1.1. How does the "particulate" settling rate affect shear strength? Settling rate (all regions of settling, free, hinder, and compaction) will affect the height of the settled bed.	This sentence was reworded to explain it applies when the mixers are not operating. The sentence now reads, "The depth and shear strength of a settled layer that may form during periods where mixers are not operating are functions of the waste properties, primarily the undissolved solids content and the particulate settling rate."
31	EKH	E	Page 16, Section 3.1.2. 1: Flocs can form when settled, creating bonds, which can effect shear strength measurements. 2: Given the rheological operating range, not sure settling is going to be an issue, once you get into this operating range. 3: Yield strength should be shear strength. 4: Would also state that the UFP vessel will be taking in the HLW Newtonian fluid and once processing is complete, will target a fluid within the targeted rheological limits.	1. The sentence was deleted from Section 3.1.2. 2. No longer applicable in the current Section 3.1.2 text. 3. Changed to dynamic yield stress. 4. UFP receipt of Newtonian slurry that is leached and concentrated, transitioning waste into non-Newtonian slurry is clarified in Table 2.
32	EKH	E	Table 5. Why is there a 20 wt% limit? Has it been shown that for all waste streams that this wt% solids yields the lower rheological limit?	The vessels are designed to process slurries up to 20 wt% solids. The ranges for rheology of the process waste have not been shown for all batches and are not expected to be entirely dependent on weight percent solids. Pre-qualification testing of actual waste feed staged for transfer to WTP will be performed to determine that rheological targets are met during tests of WTP unit operations for leaching and ultrafiltration.

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LSIMS ERT DOCUMENT REVIEW RECORD	**REVIEW NUMBER:**	ERT-15 Vessel Configuration
	DOCUMENT NUMBER:	24590-WTP-RPT-ENG-12-017, Rev A
	DOCUMENT TITLE:	Vessel Configurations for Large Scale Integrated Testing

33	EKH	O	Section 3.2. The power per unit volume is a bit misleading in the sense that power is being applied to the bottom of the vessel for the purpose of lifting the solids off the bottom or to provide mixed cavern (yield stress fluid). When the vessel is full, the power dissipated to the upper regions is negligible. Comparing available power at two different levels may be more representative in this case.	This section was updated at the request of the ERT to clarify how the information in Section 3.2 was used to identify specific vessels that should be considered for testing . The information provides a general comparison of PJM power in high-solids vessels for a general comparison of why certain vessels were considered at the minimum vessel volume where all PJMs are operating. The power per unit volume at the full working volume of the vessel is provided for information in Appendix A.
34	EKH	E	Page 16, Section 3.2, second paragraph. The statement that WTP uses equation ?? using both MKS and English units--remove it.	Units have been provided and discussion of English versus MKS was removed as requested.
35	EKH	E	Page 18, last sentence. Not clear on what you're stating. Are you stating that at the lower level the tank contents will be homogenous (you have data to show this to be the case)? Why not just state that the higher velocity, hence power at the lower level will benefit ……..	This sentence was reworded to clarify that the power available as the vessel contents are reduced to a low level helps prevent the potential for particulate build up in batch-to-batch operations.
36	EKH	E	Page 20, third paragraph, second sentence. If you're talking about sparger power, then it does go down as the level goes down, but the net power goes up due to the PJMs, given what is shown in Table 8.	This was clarified to indicate that it is referring to 'net' power.
37	EKH	E	Page 20, third paragraph, third sentence. Is it expected that the density will increase as the level decreases? Does not make sense.	This sentence was deleted in the process of resolving reviewer comments.
38	EKH	E	Table 9. Check the scale factors; I'm assuming that diameters provided are exact. Also, what type of array does UFP-VSL-00001A/B have (Distributed)? Delete Distributed on last row, repeat.	Scale factors were checked. Uncertainties for the diameters are typically between ±0.01 to ±0.125, but the specification for each vessel may indicate a slightly different uncertainty. UFP-VLS-00002A/B has a distributed array. Second 'Distributed' on last row was deleted.
39	EKH	E	Page 25, last paragraph. So it is a benefit to select 27A/B because it has a slightly lower scaling factor that 28? That is how I read it.	This is discussion was reworded to incorporate reviewer comments and is now part of 2nd paragraph of Page 21.
40	EKH	E	Figure 7. What is the first circle (vessel) in this figure? It does not have a zero solids loading. Should it be here or on Figure 6?	Note added to clarify why FRP-VSL-00002A/B/C/D is included in Figure 7.

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41	EKH	E	Page 31, last paragraph, last sentence. You can't have both a smaller space between the PJM and the wall, given that the array is 93% of the test scale. Clarify.	This was corrected to read 'larger' space between the vessel and the wall.
42	RKG		I strongly agree that a minimum of three scales must be tested.	Noted. Thank you.
43	RKG		Table 9, Section 4. I am not clear as to which arrays will be tested.	Added Table 11 to Section 5 to summarize final test vessel size and array selection.
44	RKG		This is the list of the possible number of PJMs per vessel. Are we expecting to test all of them?	Added Table 11 to Section 5 to summarize final test vessel size and array selection. This table includes test nozzle sizes also.
45	RVC	**M**	Section 2.1, General. While I am flattered that you quote my chapter, be careful in drawing the analogy between strongly coalescing liquid-liquid systems and solids suspension. What you did not say explicitly was a major point that Doug Leng was making. A well-established and quantifiable body of evidence for scaling strongly coalescing systems is lacking even for stirred tanks; forcing the conservative approach recommended by Dow practitioners. There is more experience in scaling coalescing systems than solids suspension in PJM mixed vessels. By analogy, it is prudent to be equally conservative here. The analogy is not due to similar physical mechanisms, but rather to uncertainty in mixing performance at the WTP scale.	Section 2.1 was reworded to clarify that PJM mixing has a relatively high uncertainty. So the range for volumetric scaling most applicable to that level of uncertainty was selected for consideration in LSIT vessel scale selection.
46	RVC	E	Section 2.1, General. CRESP was always happy with 1:10 scaling by volume. Since the point being made was to scale by volume rather than by length, the recommendation was given as 1:2 by length, using rounded off numbers.	The letter CCN 218967 specifically states a 1/8 volumetric scale. This section was reworded slightly and the volumetric to geometric scale values included in the text were checked.
47	RVC	O	Section 2.1, page 3, top. I understand what you are trying to say, but the phrase "Model Scaling Adjustment" implies that you are modifying the model rather than discriminating (n value) among different physical scaling mechanisms.	This item was reworded and this phrase was deleted.

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48	RVC	O	Section 2.1, page 4, top. Why is the approach conservative because some solids do not settle between pulses? I thought that you were designing for the worst case (fastest settling) PSDD fraction.	This text was reworded to clarify that FRP is expected to have very slow settling solids and it is appropriate to group with the no to low solids vessels.
49	RVC	**M**	Section 2.2, General. None of the models that you present are analytical, or are they models. They are completely empirical and cannot be derived from fundamentals. It would be more accurate to refer to them as empirical correlations.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
50	RVC	O	Section 2.2. Equations are not properly numbered. e.g., (2) rather than Equation 2.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
51	RVC	**M**	Section 2.2, General. The idea of testing at 3 scales so that you can fit non-linear empirical correlations is without basis. You need at least 3 scales to fit linear correlations. The idea of extrapolating wholly empirical correlations is equally without basis. Some of your linear correlations have a mechanistic basis (e.g., power per mass). However, all of your non-linear models are wholly empirical. Two scales work when the physics is well enough understood that it is sufficient to confirm the scale-up rule.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
52	RVC	**M**	Section 2.2.2, page 8 and Table 1. I do not fully appreciate the case being made. Is the amount of power needed to re-establish particulate potential & kinetic energy a significant fraction of the total power input? With only 3 test scales you would be fortunate to establish a constant exponent for the table entries, never mind a dependency within the exponent. Is the purpose of the proposed testing to tune the exponents in these completely empirical non-linear correlations? What would be the error or uncertainty in the constants a & b in a term like $U^{a-b\phi_s}$? There would be uncertainty associated with experimental accuracy and correctness of the function.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.

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53	RVC	O	Section 2.2.2.1, second paragraph, page 9. Reference 5 is for liquid-liquid only. You need a separate reference to Sect. 6-4 of the Mixing Handbook.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT. The scaling range is only discussed in the context of mixing systems with greater degrees of uncertainty.
54	RVC	O	Section 2.2.2.1. There is no need to provide such an elaborate and contrived example to justify 3 test scales. The equations are not dimensionally consistent. The logic does not flow well and the argument is unnecessary. If you want to establish (not confirm) unknown scaling exponents, you need at least 3 scales. If justification is needed, it would be to limit testing to just 3 scales. It might be sufficient to argue that use of 3 scales reduces uncertainty in the models / correlations and physical mechanisms.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
55	RVC	O	Section 2.2.2.1. Does blend time scale with P/V? Is this the accepted scaling approach? Again, the argument may be too elaborate.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
56	RVC	O	Page 12, sentence below Figure 2. Do you really mean UFL-VSL-00002A/B?	This sentence is referring to UFP-VSL-00002A/B and Figure 2 was annotated to show why a 14-foot test vessel is appropriate to select for a full-scale test.
57	RVC	O	Section 2.2.3, page 13. This is quite difficult to follow, somewhat obscuring the point.	The log exponent discussion from Section 2.2.3 was removed.
58	RVC	O	Section 3, General. The equations are not numbered.	The equations in Section 3 are numbered.
59	RVC	O	Section 3.1. Why are particle size & density listed separately, rather than as PSDD? Why is ϕ_s not in the list? Do you now plan to consider time dependent slurry rheology and properties of cohesive settled solids? It thought that was out for now.	The bulleted list at the beginning of the section was updated and PSDD is listed in one line. The solids volume fraction is not included in the list as it is no longer discussed in Section 2.2.
60	RVC		Section 3.1. How do you plan to scale a DBE? Are the criteria for off bottom solids clearing more or less challenging than normal operation? You say more challenging, but I thought that you did not need to lift the solids, just cause bottom motion. Are the cohesive forces in the settled layer established? Do you have a data reference to support your assertion?	The post-DBE discussion was reworded.. See Section 3.1 paragraph 4.

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61	RVC	O	Section 3.1.1. Is it well established that Newtonian behavior occurs at 10% solids, and non-Newtonian behavior begins at 20% solids?	The vessels in Table 2 are designed to process slurries up to 20 wt% solids. The ranges for rheology of the process waste have not been shown for all batches and are not expected to be entirely dependent on weight percent solids. Pre-qualification testing of actual waste feed staged for transfer to WTP will be evaluated to determine that rheological targets are met through leaching and concentration steps for process wastes with up to 20 wt% solids.
62	RVC	O	Section 3.1.1, page 14. The sentence, "*A gradient can increase the solids loading at the bottom of the vessel by a factor of two or more relative to the bulk vessel average particulate concentration, i.e., assumed homogeneity.*" makes no sense. The gradient does not cause the solids loading to be higher near the bottom. Rather, gravity, etc. cause the gradient to be steep near the bottom because of the effect on vertical solids distribution.	This was reworded to read, "A gradient can included a higher solids loading at the bottom of the vessel ..."
63	RVC	O	Section 3.1.2, page 16, first paragraph. During post DBE, how much above 30 Pa can the yield stress increase?	Shear strength can increase over time in a quiescent settled solids layer, but the specific shear strength for the layer is not quantified in this document as it varies from waste-type to waste-type. For the vessels with potentially larger quantities of settled solids post-DBE, mixing is performed to 'reset' the settled layer within every 24-hours to prevent large increases in shear strength of the settled layer.
64	RVC	O	Section 3.2, page 16 and Tables 6, 7, 8. Do you have a reference for the P/V equation? Why does DC enter? The average P/V over the entire cycle has no physical relevance. Is this the power reported in the tables? It is only the power during the discharge cycle that counts for off bottom clearing & suspension, as well as blending. Why do you use power per volume rather than power per mass?	Power per unit volume is being used to provide a basis comparison between WTP vessels. Update focus on power during drive. More clarification on the use of DC is provided in the footnotes in Appendix A.

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65	RVC	O	Tables 6, 7 & 8. Why are 2 tables needed for Newtonian vessels but only one (with more columns) needed for non-Newtonian vessels? Why is minimum volume reported for Newtonian vessels and not for non-Newtonian vessels? If the duty cycle is included in the calculation, then the significance of maximum power at minimum volume is diffused. Also, see previous and next comment.	Table 6 an 7 were combined with only the higher Newtonian solid vessel listed. Power during drive only added. Minimum volumes included for both.
66	RVC	O	Section 3 General. The energy dissipation rate (power per mass dissipated) has a strong spatial variation, being highest near the vessel bottom. It is the local power that is responsible for off bottom clearing and suspension. The local power dissipated near the bottom only depends weakly on the total vessel contents. Therefore, the power available to move solids may not vary as much as assumed as V decreases.	Noted. Added - Solids loading is also important and notably, of these vessels, HLP-VLS-00022 has one of the highest solids loading
67	RVC	O	Section 3.2.2, page 20, un-numbered equation. It would be useful to include units in the definition of variables. The gas constant is usually per mole, so is the molecular weight missing? The sparger discharge pressure is a function of liquid depth in the vessel. So how do you maintain constant discharge flow rate?	Units were added and the Equations were numbered. The air flow rate is in mol per second. The sparger discharge flow rate is not maintained at a constant discharge flow rate as vessel volume decreases.
68	RVC	O	Section 3.2.2, page 20, first full paragraph. This paragraph discusses PJM power. It should not end with a totally unrelated sentence about spargers.	This sentence is focused on closing out this entire section which is related to spargers.
69	RVC	O	Section 4, General. Which Newtonian vessel is most problematic? Which non-Newtonian vessel is most problematic? Why are these questions not integrated into the argument for PJM array/size selection?	By content UFP-VSL-00002A/B presents challenges in processing a range of material from Newtonian to non-Newtonian. HLP-22 and HLP-28 are mixing challenges being the largest vessels and are considered in the discussion.
70	RVC	E	General. In Section 3 Newtonian vessels are considered first. In Section 4, non-Newtonian vessels are considered first.	This order inconsistency is acknowledged, but the text was not changed due to concerns that is would create some inconsistencies in the existing text in the potentially affected sections.
71	RVC	O	Section 4.2, Figure 5, page 25, first	The power per unit volume at the

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			paragraph and Table 10. Figure 5 states that HLP-27 has the lowest P/V. Table 8, last column, shows HLP-28 to have a lower P/V. Be careful. Why do you select on min P/V at full volume averaged over DC rather than on some other measure of P/V?	different levels was provided for a general comparison between the vessels that may assist with array selection later in the document. This use of DC in the P/V was selected to have a uniform approach for comparing each vessel.
72	RVC	O	Section 4.3. The word Newtonian does not appear in the section title. There is no direct reference to Table 11.	It is now table 8 and is discussed in the text. The section title was updated as suggested.
73	RVC	O	Table 11. In group 2, do you mean RDP-02 or RLD-08?	RDP-2. This was corrected.
74	RVC		Page 28 to 31 and Tables 12&13. You do not discuss how PJM nozzle diameter will be scaled. For example, for HLP-22 with 18 PJMs, will the nozzle diameter be 4/2.71 inch in the 14 ft. vessel? Will it be 4/10.56 inch in the 4 ft. vessel?	The test nozzle diameters are summarized in Table 11 of Section 5.
75	RVC		Appendix A. Is the P/V value weighted by the duty cycle? Again, what is the physical significance of this number?	Equation 1 is used to determine P/V with the addition of duty cycle used in the appendix. DC defined as drive time dived by the total cycle time. This number was generated to compare general power applicable to WTP vessels, not to determine solids suspension or other characteristic of mixing performance.
76	RVC	E	Section 5. Comments withheld since we were informed that this section would not be included in the final document.	Section 5 in Revision A was removed.
77	RVC	O	General. The document does not flow well. As discussed above, some sections detract from rather than build the case for testing at the 3 selected scales. Some are not centrally relevant. It is important to clearly communicate the case for the selected test vessels.	Efforts were made to reorder the logic flow in the document to better present the rationale for vessel configuration selection.
78	RVC	O	General. It would be useful to discriminate between the mixing requirements for a DBE versus normal operation, upfront in the document.	We considered this addition to the introduction, but felt that the Post-DBE discussion was a better fit in section 3. This discussion was updated to better explain post-DBE considerations.
79	RRH	E	General. There are numerous typos in the document.	The document was edited as comments were incorporated.

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80	RRH	O	General. Sizing of test vessels should be based on maintaining flow regimes at all scales to be similar to that in full size vessel. Therefore calculations of Jet Reynolds numbers would be helpful. Also emphasis should be given for maintaining geometric similarity as much as possible.	Per an earlier ERT comment clarification was added to indicate the importance of the flow regime in vessel selection. The following sentence was added, "Vessels should be sufficiently large that they mirror the physical phenomena and turbulent flow regime as the full-scale vessel."
81	RRH	I	Page 1, first paragraph. 'Gas accumulation stays below acceptable limits' – have these limits been defined or related to acceptable thickness of layer of settled solids?	The calculation describes the time to the Lower Flammability Limit for each vessel for periods when the mixers are not operating (post-DBE) and the hydrogen generation rates applicable to ventilation requirements during normal and post-DBE operations, 24590-WTP-M4C-V11T-00011, *HGR for Seismic and Severity Level Assessments*.
82	RRH	I	Page 3, Item 3. 'Estimate of flammable gas generation rates' – I assume WTP has a model for predicting gas generation rate.	The calculation is 24590-WTP-M4C-V11T-00011, *HGR for Seismic and Severity Level Assessments*.
83	RRH	**M**	Section 2.1.1. Chapter 12 in 'Handbook of Industrial Mixing' is on Liquid-Liquid mixing. Analogy of Solid-Liquid with non-coalescing Liquid-Liquid system is incorrect. In addition to significantly different surface effects, discussions in Chapter 12 are for dispersed phase which is lighter than continuous phase, and the drops rise rather than sink like high density solids. Mixing mechanisms for the two multi-phase systems are entirely different and are driven by different physical forces.	This section was reworded to clarify that the target scaling range identified in the handbook applies to systems with relatively high uncertainty as in the case of PJM mixed systems. The definitions of coalescing systems was removed, to make the discussion solely focused on the level of uncertainty applied in selection of a scaling range.
84	RRH	I	Section 2.1.3. It is not clear how the scale factor was decided at 4.5 for PEP. Also there is no mention of Vessel number and if it is listed in Table 4.	UFP-VSL-00002A/B is the vessel of interest and discussed in Section 2.1.3 paragraph 3.
85	RRH	**M**	Section 2.2. I agree with selection of 4', 8' and 14' diameter vessels. However, I disagree with argument of non-linear analytic model for selecting sizes of test vessels. Vessel sizing should be based on providing Turbulent flow regimes or at least Transitional. Argument for using 14' vessel is correctly presented that it corresponds to 'Full Scale' for several vessels. Then the 8' diameter vessel is close to midway between	Significant portions of the text from Section 2.2 were removed as recommended by the ERT. The logic present in updated Section 2.2.2 was revised to follow the logic suggested by the ERT.

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			4' and 14'.	
86	RRH	O	Page 8, Table 1. Explanations of correlations are confusing and do not add any value to the argument. I suggest removing this table.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
87	RRH	M	Page 9, Section 2.2.2.1. Emphasis is given on "Constant Blend Time" on scale-up. In agitated tanks for most applications, blend time increases on scale-up. When systems require constant blend time on scale-up, P/V increases dramatically as demonstrated by Equation 3. In this application it would not be feasible to provide a large increase in P/V needed for constant blend time.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT.
88	RRH	O	Page 1, first paragraph. It should be recognized that when the drive phase begins, it takes some time for flow patterns to establish and provide mixing.	This comment is correct. The introduction was reworded slightly, but does not specifically discuss the time it takes for the flow pattern to be established.
89	RRH	O	Section 2.2.3. As previously described in Comment #2, I suggest removing this section, but keeping Figure 2 which provides useful information on sizes of all vessels in relation to the selected sizes of test vessels.	Significant portions of the text from Section 2.2 were removed as recommended by the ERT. Figure 2 was kept and has been annotated to reflect variation in wastes processed in each vessel.
90	RRH	E	Page 14, second paragraph, last sentence. 'Sufficient yield to be applied' should read 'sufficient shear stress to be applied'.	This was corrected.
91	RRH	O	Page 15, Table 4. This is a very useful table for surveying vessel sizes at WTP and challenges they present. It would help to add columns for vessel diameters. You may also want to consider adding columns for # of PJMs and nozzle diameters. In addition, 10 out of 18 vessels are 15ft in dia. or smaller. Mixing issues in these vessels can be addressed in the selected test vessels with maximum diameter of 14ft. Also only 3 vessels truly provide challenge of medium to high solids concentration. These differences should be highlighted so the focus of LSIT should be mainly on these three vessel types.	More detail for each vessel in provided in the comprehensive table in Appendix A. Figure 2 attempts to present the vessels in comparison to test vessel size and show what the vessel is process (i.e. high solids or low solids etc...).

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92	RRH	M	Section 3.2. Equation for P/V uses PJM Duty Cycle. This results in an Average P/V over total cycle time, which is not appropriate for assessing resultant mixing quality. Calculations of P/V during the drive phase should be added instead of or in addition to.	The use of power per unit volume in this document is meant to provide a comparison from WTP vessel to vessel. The scaling basis report (WTP-RPT-215, Draft in development) focuses on mixing performance and scaling associated discretely with power.
93	RRH	M	Page 17. It is stated that given jet velocity and nozzle diameter, P/V increases as Volume decreases. For solids suspension this is not true. While I agree that jet velocity increases somewhat due to reduced static head, solids suspension is mainly caused by jet velocity and not by P/V calculated by dividing by liquid volume in the vessel.	The vessel selection report is using P/V for general comparison between vessels. Mixing performance and scaling considerations applicable to solids suspension is included in the scaling basis report (WTP-RPT-215, Draft in development).
94	RRH	M	Page 19, Tables 6&7. It would help to have columns for # of PJMs, nozzle dia. and DC. Table 7: Values of maximum P/V should be corrected because for solids suspension it is the jet velocity that affects suspension and not P/V based on reduced liquid volume.	Table 6 & 7 were combined for only the high solids vessels with P/V reported during the drive. P/V at the lower volume includes a high jet velocity. Table provide a general comparison.
95	RRH	E	Page 21, second paragraph. Statements are already made on page 20, paragraph 3.	Prior section was reworded, which helped to reduce redundancy.
96	RRH	E	Page 21, last paragraph, second sentence. This statement is already made in the paragraph above.	The sentence was deleted.
97	RRH	O	Page 23, Table 9. I suggest adding a column for X-area coverage/PJM. You will find this number varies very widely from 2.4 m2 to 13.4 m2. These numbers are further discussed in Table 11.	Please note that we attempted consolidating this information into Table 6, but the resulting table was too crowded. So the information was not consolidated into the table as suggested.
98	RRH	M	Page 24, Figure 5. Circles imply that PJM provides a circular clearing region. This is not true with chandelier array.	A footnote was added to clarify that actual area is not circular, but is depicted as a circle for ease in comparison.
99	RRH	E	Page 26, Table 11. Some of the numbers in the column for Area coverage/PJM appear to be incorrect, e.g., Group 2 7.3 should be 3.57, Group 3 should be 2.39 to 2.74, Group 4 5.7 should be 6.4, Group 5 should be 2.4 to 13.4, Group 6 should be 5.85. Please check these numbers with your calculations.	Thank you. The table was updated. It is now Table 8 in the current document.
100	RRH	O	Page 29, second paragraph. Challenge of 30	The text was changed in footnote to

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			wt% spent resin solids has been discounted due to lower specific gravity=1.2. While this may be true, it would help to calculate Terminal Settling Velocity and Rep for this system.	Table 8 to indicate "Vessels RDP-VSL-00002A/B do not contain HLW solids, but have a spent resin loading of 31 wt%. Spent resin, porous polymer beads do not settle at a rate that would be useful in assessing mixing performance challenges."
101	RRH	O	Page 31, Table 13. Provides 4 vessels that will be mimicked for LSIT. It would be helpful to provide information on # of PJMs and nozzle diameters for each. It would be important to know if these dimensions are scaled-down using geometric similarity.	Table 11 was added to Section 5 to summarize these items.

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	Vessel	Test vessel		D_0	U_0	ρ	μ	D0	μ	ν	Re-jet	
				in	m/s	kg/m^3	cP	m	kg/ms	m2/s	-	
RLD -8	156	168		4	12	1000	1	0.1016	0.001	1.00E-06	1.22E+06	Nozzle not scaled in ths array
RLD -8	156	168		4	8	1000	1	0.1016	0.001	1.00E-06	8.13E+05	Nozzle not scaled in ths array
RLD -8	156	168		4	12	1000	15	0.1016	0.015	1.50E-05	8.13E+04	Nozzle not scaled in ths array
RLD -8	156	168		4	8	1000	15	0.1016	0.015	1.50E-05	5.42E+04	Nozzle not scaled in ths array
RLD -8	156	93.2		2.39	12	1000	1	0.060699	0.001	1.00E-06	7.28E+05	
RLD -8	156	93.2		2.39	8	1000	1	0.060699	0.001	1.00E-06	4.86E+05	
RLD -8	156	93.2		2.39	6	1000	1	0.060699	0.001	1.00E-06	3.64E+05	
RLD -8	156	93.2		2.39	12	1000	15	0.060699	0.015	1.50E-05	4.86E+04	
RLD -8	156	93.2		2.39	8	1000	15	0.060699	0.015	1.50E-05	3.24E+04	
RLD -8	156	93.2		2.39	6	1000	15	0.060699	0.015	1.50E-05	2.43E+04	
RLD -8	156	43.2		1.11	12	1000	1	0.028135	0.001	1.00E-06	3.38E+05	
RLD -8	156	43.2		1.11	8	1000	1	0.028135	0.001	1.00E-06	2.25E+05	
RLD -8	156	43.2		1.11	5	1000	1	0.028135	0.001	1.00E-06	1.41E+05	
RLD -8	156	43.2		1.11	12	1000	15	0.028135	0.015	1.50E-05	2.25E+04	
RLD -8	156	43.2		1.11	8	1000	15	0.028135	0.015	1.50E-05	1.50E+04	
RLD -8	156	43.2		1.11	5	1000	15	0.028135	0.015	1.50E-05	9.38E+03	

1.22E+06 max
9.38E+03 min

	Vessel	Test vessel		D_0	U_0	ρ	μ	D0	μ	ν	Re-jet
				in	m/s	kg/m^3	cP	m	kg/ms	m2/s	-
HLP-22	456	168		1.57	12	1000	1	0.039771	0.001	1.00E-06	4.77E+05
HLP-22	456	168		1.57	8.6	1000	1	0.039771	0.001	1.00E-06	3.42E+05
HLP-22	456	168		1.57	12	1000	15	0.039771	0.015	1.50E-05	3.18E+04
HLP-22	456	168		1.57	8.6	1000	15	0.039771	0.015	1.50E-05	2.28E+04
HLP-22	456	93.2		0.87	12	1000	1	0.022063	0.001	1.00E-06	2.65E+05
HLP-22	456	93.2		0.87	7.1	1000	1	0.022063	0.001	1.00E-06	1.57E+05
HLP-22	456	93.2		0.87	12	1000	15	0.022063	0.015	1.50E-05	1.77E+04
HLP-22	456	93.2		0.87	7.1	1000	15	0.022063	0.015	1.50E-05	1.04E+04
HLP-22	456	43.2		0.40	12	1000	1	0.010227	0.001	1.00E-06	1.23E+05
HLP-22	456	43.2		0.40	5.5	1000	1	0.010227	0.001	1.00E-06	5.62E+04
HLP-22	456	43.2		0.40	12	1000	15	0.010227	0.015	1.50E-05	8.18E+03
HLP-22	456	43.2		0.40	5.5	1000	15	0.010227	0.015	1.50E-05	3.75E+03

4.77E+05 max
3.75E+03 min