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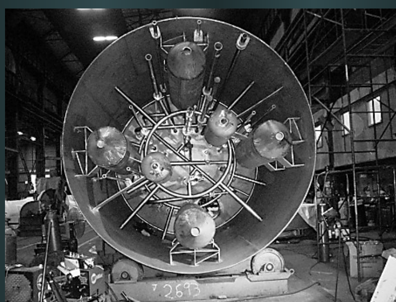

U.S. Department of Energy Approach for Resolution of Pulse-Jet-Mixed Vessel Technical Issues in the Waste Treatment and Immobilization Plant

Revision 0

U.S. Department of Energy
Office of River Protection
Richland, Washington 99352

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Revision 0

Approvals:

3-20-14	
Langdon Holton Senior Technical Authority	Date
3-20-14	
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Executive Summary

The U.S. Department of Energy (DOE) restricted engineering, procurement, and construction work on the Waste Treatment and Immobilization Plant (WTP) Project's Pretreatment (PT) and High-Level Waste (HLW) Facilities in 2012 because of unresolved technical issues and a misalignment of the safety basis and the design. One of the major unresolved technical issues was associated with the ability of the pulse-jet mixer (PJM) –mixed vessels located in these facilities to perform their required mixing functions, including the ability to control air to the PJMs. The WTP has 38 PJM vessels: 34 located in the PT Facility and 4 in the HLW Facility.[1]

DOE conducted an extensive PJM vessel testing program that was initiated in 1998. A detailed historical testing summary is provided in Appendix A. Based on the results of this program, adequate testing information exists to verify and confirm the mixing system design for 30 of the 38 vessels in the WTP. These 30 vessels contain liquid only, spent ion-exchange resin, or wastes and process recycle streams that contain a low solids concentration—typically less than 5 percent by weight.

However, technical gaps exist in the ability of DOE to verify the PJM control system design and the mixing performance of the eight vessels in the PT Facility that would contain a higher solids concentration (greater than 5 percent by weight). These gaps will be closed with additional testing and engineering analysis. These eight vessels represent five vessel designs in terms of total operating volume and number of PJMs. These eight vessels are also some of the largest in the PT Facility, having volumes of 30,000 to 160,000 gallons and up to 18 PJMs. DOE determined the costs associated with testing these five large vessel designs would be very large, and the testing schedule would span 6 to 8 years. Thus, DOE is pursuing a design solution that will replace, at a minimum, the five large vessel designs with a smaller standard design. This strategy will substantially reduce the testing cost and schedule duration.

This strategy document describes the scope of work, schedule, and estimated costs to resolve remaining issues associated with the PJM-mixed vessels. This resolution strategy relies on the use of a smaller standardized PJM-mixed vessel design, capable of mixing high solids, to replace the five vessel design concepts currently identified for the PT Facility. This strategy will:

- Add confidence that the vessel design will effectively resolve a hydrogen event by ensuring more complete mixing, thereby releasing any trapped hydrogen gas (a concern identified by the Defense Nuclear Facility Safety Board ([DNFSB])
- Add confidence that the vessel design will effectively resolve any nuclear criticality issue by ensuring solids are well mixed and do not accumulate in the vessel (a concern identified by the DNFSB)
- Provide operational contingency and plant reliability because the smaller vessel design will allow additional vessels to be placed in the design to provide redundancy

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[1] Technical issues in the HLW Facility have been substantially resolved, including those associated with PJM mixing. DOE is in the process of establishing the conditions under which they will approve the resumption of production engineering in this facility at the time this report was issued.

- Partially resolve other technical issues, including erosion, by adding material thickness (to increase design margins) and pipeline plugging (by improving vessel and pump transfer hydraulics)
- Reduce the cost of and expedite PT Facility technical issue resolution.

Two vessels will be tested using full-scale prototypes to obtain the required information to close the issues on PJM vessel mixing and control. These vessel prototypes represent vessel designs, or vessel design features, that have been previously tested and demonstrated to mix a wide variety of solids concentrations. Testing with the first vessel (a prototype of RLD-VSL-00008—an existing vessel design) will be initiated in Fiscal Year (FY) 2014. The primary purpose of this testing is to demonstrate the PJM control system design and operating concepts. The second vessel, which will be a replacement standardized design, will be tested first at a small scale in FY 2014/FY2015, and then at full scale in FY 2015/FY 2016. The purpose of this vessel testing is to demonstrate PJM mixing performance and control system testing.

The evaluation and testing program described herein currently is estimated to be completed over a 3-year period at an estimated cost of \$147–\$180 million. The budget and schedule will be refined as the scope is further defined.

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Terms

BNI	Bechtel National, Inc.
CFD	computational fluid dynamics
CRESP	Consortium for Risk Evaluation and Stakeholder Participation
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
EFRT	External Flowsheet Review Team
FSVT	full-scale vessel testing
FY	fiscal year
GAO	Government Accountability Office
HLW	High-Level Waste (Facility)
MCE	Mid-Columbia Engineering
PJM	pulse-jet mixer, pulse-jet mixing, pulse-jet mixed
PT	Pretreatment (Facility)
WSU	Washington State University
WTP	Waste Treatment and Immobilization Plant

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1.0 Introduction

1.1 Purpose

This document describes the U.S. Department of Energy's (DOE) current approach to resolve the remaining technical issues associated with pulse-jet mixer (PJM) –mixed vessels in the Waste Treatment and Immobilization Plant (WTP) Pretreatment (PT) and High-Level Waste (HLW) Vitrification Facilities. It includes a description of vessel mixing requirements, testing requirements and capabilities, the management approach, and cost and schedule. This document is intended to provide a management-level summary of the approach for completing design verification of PJM-mixed vessels in the WTP. More detailed technical documentation for completing the design verification processes will be provided in appropriate design documentation, test plans, and technical reports as this approach is implemented.

1.2 Background

A number of technical and project management reviews and summary reports have been prepared that describe issues associated with PJM-mixed vessels in the WTP.

In 2005, Bechtel National, Inc. (BNI), chartered a team of subject matter experts from the chemical processing industry, glass industry, nuclear waste treatment industry, national laboratories, and universities, known as the External Flowsheet Review Team (EFRT) to review the waste treatment and immobilization process. This team identified a number of design-related findings, including inadequate design of the mixing systems. Specifically, the EFRT said:

> Issues were identified with mixing system designs that will result in insufficient mixing and/or extended mixing times. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs. [1, 2]

The resolution of these mixing issues required an engineering analysis to assess the adequacy of PJM-mixed vessel designs. In 2010, a joint DOE/BNI Technology Steering Group concurred with the closure of these issues based on (1) direction provided by the WTP Federal Project Director and BNI Project Director, and (2) the commitment by BNI to complete the recommendations in the closure records, which included additional scaled testing and verification and validation of computational fluid dynamics (CFD) calculations. The closure records indicate the design confirmation methods[b] would be a combination of engineering calculations (calculations originated and checked by engineering), CFD calculations, and scaled testing.[3-6]

On July 1, 2010, the Consortium for Risk Evaluation and Stakeholder Participation (CRESP), an independent review team under contract to DOE, identified a number of concerns with the

[b] Design confirmation refers to a step in the WTP design process where the design is supported by inputs and verified assumptions. This should not be confused with design verification.

closure approach to the EFRT issue related to PJM performance.[7] CRESP found that uncertainty in PJM performance and the absence of full-scale or near-full-scale testing represented a large risk for the WTP Project.

On December 17, 2010, the Defense Nuclear Facilities Safety Board (DNFSB) sent a letter of concern (Recommendation 2010-2) to DOE, in which it considered that the testing and analysis performed at Hanford were insufficient to establish, with confidence, that the PJM mixing and transfer systems would perform adequately at full scale. The letter addressed the requirement for the DOE to ensure the WTP will operate safely and effectively during its 40-year operating life.[8] The DNFSB recommended developing a full-scale test plan and completing verification and validation of any computational models used by the WTP Project.

The DOE accepted the Board's recommendation on February 10, 2011, and prepared an implementation plan outlining the actions the DOE and its contractors would take to demonstrate that PJM mixing, transfer, and sampling systems would perform adequately at full scale.[9]

On November 8, 2012, Secretary of Energy Steven Chu informed the DNFSB by letter that the current design verification[c] strategy needed to be changed for several reasons, most notably because of "the relatively low confidence in the design verification and analysis methods…" for the vessels that had high solids concentrations.[10] High solids concentrations are considered to be greater than 5 weight percent (wt%).

The design verification approach was revised to eliminate sole reliance on computational models and scaled mixing performance from smaller test vessels for the vessels that contained high solids concentrations, requiring testing of full-scale vessels with simulated waste slurries.

The Government Accountability Office (GAO) issued a report in December 2012 that identified waste mixing as one of the significant technical issues that DOE and BNI were trying to solve.[11] This report said DOE had directed BNI to demonstrate the PJMs will work properly and meet the safety standards for the facility, and noted that "no timeline for completion of this testing had been set."

The GAO report also said BNI had been directed to halt construction on the Pretreatment Facility and parts of the HLW Facility because BNI was "unable to verify that several vessels would work as designed and meet safety requirements." The GAO estimated that resolution of the mixing technical issues could take at least an additional 3 years of testing and analysis.

Finally, the GAO reported concerns about the ultimate cost and final completion date for the project, "given that several critical technologies (e.g., pulse jet mixers) have not been tested and verified."

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[c] "Design verification is performed to provide reasonable assurance that the design conforms to a specific subset of design requirements (e.g., Safety, Waste Acceptance Impacting, other select requirements). Design verification is performed on the design documents used as the basis for the acceptance of work, whether procured or performed in the field, to ensure that completed work is evaluated against documents that are verified to represent project requirement." Definition of "design verification" from 24590-WTP-3DP-G04B-00027, 2014, *Design Verification*, Rev. 15, Bechtel National, Inc., Richland, Washington.

On September 11, 2013, the DOE sent a letter to the DNFSB advising them that its earlier implementation plan in response to DNFSB Recommendation 2010-2 would be revised by February 28, 2014.[12] The letter explained, “The revised technical approach addresses concerns associated with the potential accumulation of solids due to inadequate mixing, which may lead to inadvertent criticality, episodic flammable gas releases and the ability to control PJMs to mitigate overblows….” The letter continued, “Nuclear safety issues…will be resolved by analysis and testing, if needed, and PJM control issues will be addressed by testing.” These concerns were projected to be resolved during 2014 and 2015.

On January 28, 2014, the DNFSB closed Recommendation 2010-2[13] based on significant changes that DOE was making to resolve the PJM mixing issues, including: (1) establishing a capability to ensure Hanford tank waste is delivered to the WTP in compliance with the design basis, and (2) evaluating of the use of smaller and standardized PJM vessel designs in the PT Facility. The DNFSB indicated they will continue to review and monitor the design and construction of WTP and will advise as necessary to ensure the adequate protection of the public health. The underlying safety-related PJM mixing issues remain unresolved and include:

- Accumulation of fissile material at the bottom of the vessels, potentially leading to criticality
- Generation and accumulation of hydrogen resulting from the accumulation of solids, potentially leading to explosions;
- Accumulation of solids that interfere with the PJM control system, causing frequent overblows (discharge of air from the PJM) that may lead to equipment damage
- The ability to obtain representative samples as a prerequisite for meeting safety-related aspects of the waste acceptance criteria and management of criticality hazards.

A more complete list of open WTP safety issues is contained in the Board’s Periodic Report to Congress dated December 26, 2013.[14]

1.3 Approach to Resolution

This approach for resolution of PJM vessel mixing issues has two key elements:

1. Ensuring the Hanford tank waste delivered to the WTP complies with the design basis for particle size distribution and density. This will be achieved by characterizing and preconditioning the waste if required. This action will simplify the testing program for the PJM-mixed vessels and ensure that the testing program results will demonstrate expected vessel mixing capability.
2. Using a standardized high-solids PJM-mixed vessel for the vessels that normally contain greater than 5 wt% solids. This standardized vessel design will simplify the testing program and expedite that technical issue resolution for the PT Facility by testing a single vessel design using a range of simulant compositions.

The DOE is evaluating a design change for the PT Facility that potentially replaces the eight high-solids Newtonian and non-Newtonian bearing vessels having five different designs with an increased number of smaller PJM vessels having a single common design. The five existing vessel deigns being evaluated are: UFP-VSL-00001A/B, UFP-VSL-00002A/B, HLP-VSL-

00022, HLP-VSL-00027A/B, and HLP-VSL-00028. Figure 1 is a graphical depiction of the PT Facility and identifies the planned locations of these vessels.

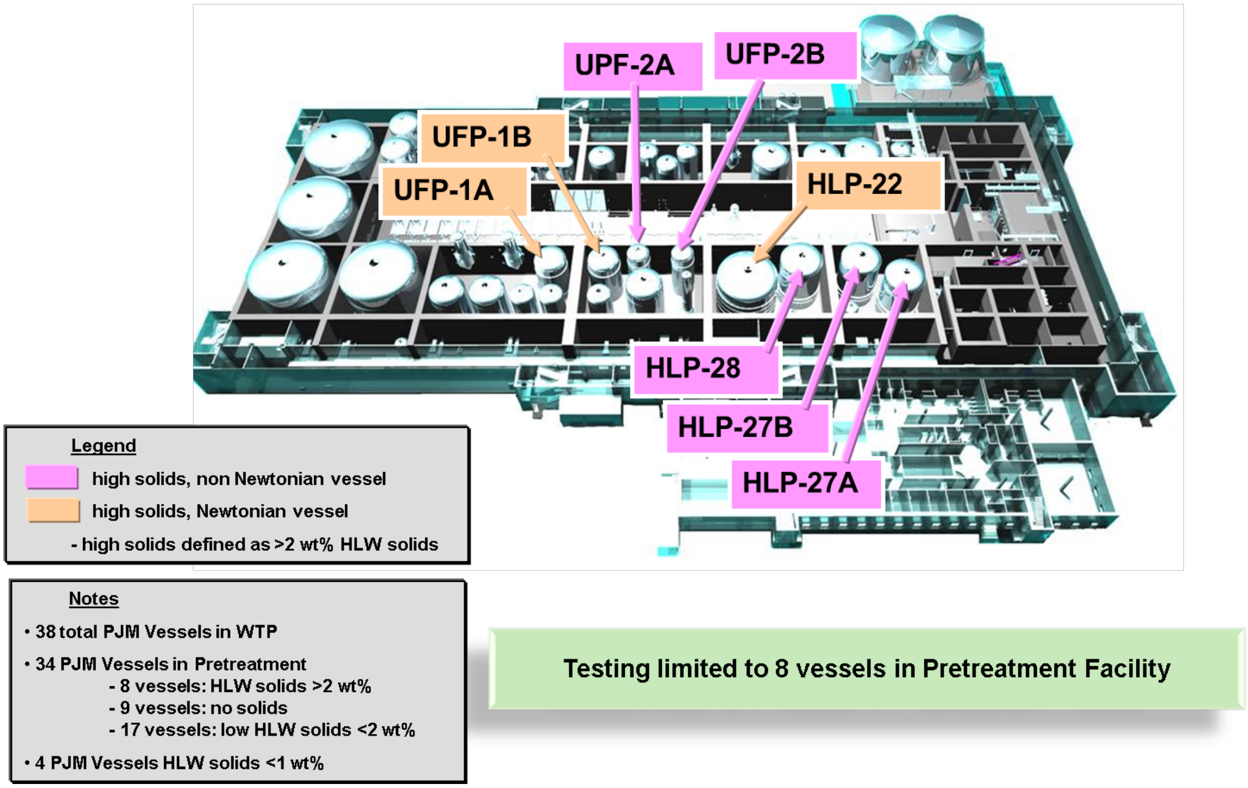

Figure 1. Pretreatment Facility Layout Showing the Location of the Eight Vessel Designs Being Reevaluated.

The currently planned vessels range in size from nominal capacities of 30,000 to 160,000 gallons, with dimensions of 14–38 ft in diameter. The proposed replacement vessel would be approximately 14–16 ft in diameter and have a nominal volume of approximately 20,000–25,000 gallons with complete specifications yet to be determined. An increased number of vessels may be required to provide adequate processing volumes using the single vessel design concept compared to the currently planned vessels.

The benefits to the standardized vessel design strategy include:

- Adding design confidence and potential simplification of the resolution of technical issues associated with hydrogen accumulation and release, criticality safety, structural integrity, and corrosion/erosion
- Establishing common bases for control, safety, operations, sampling, training, commissioning, and in-service inspection
- Providing operational contingency with a design that can mix a range of waste fluid properties
- Reducing the schedule for full-scale vessel testing by several years and reducing the associated cost of testing by several hundred million dollars.

This approach addresses PJM design verification requirements in three testing phases that will be completed by full-scale testing.

1. The first phase is completion of the current test program for the PJM control system in the RLD-VSL-00008 test vessel. Testing under this program will be based on incrementally increasing the simulant viscosities and solids loading to challenge the functional capabilities of the hardware and control algorithm. The strategy is to subject the system to process conditions that exceed those expected in the PT Facility for conservatism. Data obtained under an NQA-1 program[15] would be used to verify a control strategy; data not collected under an NQA-1 program would be used to develop efficient design verification testing for the standardized vessel design (third phase described below).
2. The second phase of the program will be small-scale testing to support design selection of a standardized vessel intended to replace the high-solids vessels in the PT Facility. This testing would identify the preferred PJM configurations to test at full scale.
3. The third phase of the program will be full-scale testing of the standardized vessel design. This portion of the program will include evaluation of the design to meet safety and process mixing requirements. This test phase will be used to generate PJM mixing and control data that will be used to verify the design.

2.0 Pulse-Jet-Mixed Vessel System Requirements

The design requirements for the PJM control system and the PJM vessel mixing requirements are summarized in this section. A brief description of the 38 PJM-mixed vessels currently installed or to be installed in the WTP is provided in Appendix B; the general description of the PJM operation is summarized in Appendix C.

2.1 Pulse-Jet-Mixed Vessel Mixing Requirements

PJM-mixed vessel mixing requirements are derived from process requirements and safety functions. Mixing requirements vary by vessel, depending on the vessel's function. Nine mixing requirements related to process functions and waste conditions in vessels must be verified, as listed in Table 1.

Table 1. Vessel Mixing Requirements. [a]

Mixing Requirement	Function	Description
1	Transfer	Mix to facilitate heat transfer for cooling
2		Mix to prevent plugging of transfer lines
3	Blend	Mix to blend liquid waste streams of different constituents
4		Mix to facilitate chemical reactions during reagent additions
5	Sample	Mix to allow for a representative sample of absorbers to evaluate potential for criticality
6		Mix to allow for a representative sample of solids that drive hydrogen generation
7		Mix to support analysis required for process control [b]
8	Store	Mix to release gas contained within the waste
9		Deleted
10		Mix to limit solids accumulation within a vessel

a. 24590-WTP-ES-ENG-09-001, *Determination of Mixing Requirements for Pulse-Jet-Mixed Vessels in the Waste Treatment Plant*, Rev. 2, Bechtel National, Inc., Richland, Washington.

b. Mixing requirement 7 will be expanded to include overall integrated sampling capabilities.

2.2 Pulse-Jet Mixer Control Requirements

The PJMs must satisfy the control requirements shown in Table 2 to perform their intended function.

Table 2. Pulse-Jet Mixer Control Functions. [a]

PJM Control Functions	Function	Description
1	Air Flow	The air supply flow rate and pressure must be adequate to achieve the necessary fluid velocity in the nozzle that supports mixing requirements.
2		The airflow to/from each PJM must be sufficient to produce the required suction phase and drive phase durations that support mixing requirements.
3	Control	The control system design must provide controlled and consistent drive and suction phase cycling of PJMs to support mixing.
4		The control system design must provide controlled and consistent drive and suction phase cycling to limit overblows.

[a] 24590-WTP-3YD-50-00003, 2012, *System Description for Pulse Jet Mixer and Sparger Mixing Subsystems*, Bechtel National, Inc., Richland, Washington.

PJM = pulse jet mixer.

3.0 Testing Requirements

A brief summary of the testing requirements to support verification of the PJM-mixed vessels is provided in this section. Testing will be performed to provide:

- Demonstration of mixing and sampling performance in vessels that have solids concentrations greater than 5 wt% using a full-scale standardized vessel design prototype
- Demonstration of the PJM control system design performance in a range of fluid conditions, including solids concentrations, solids settling rates, and fluid viscosity.

For the purposes of this strategy, a "data gap" is defined as the difference between the data that have been collected thus far from testing and/or analysis and the additional data that are required to verify the design for PJM vessel mixing and/or PJM control. A gap analysis considers both technical risks and cost/schedule considerations to reduce risk.

The following data gaps are associated with solids accumulation in PJM-mixed vessels containing more than 5 wt%:[d]

- **PJM Mixing**
  - **Inadvertent Criticality and Episodic Flammable Gas Release**. A risk evaluation is planned in Fiscal Year (FY) 2014 that will address these issues.[12] This plan anticipates that testing will not be necessary for the Newtonian[e] vessels (in accordance with the planning assumptions) because the current safety basis is very conservative; however, testing is required for non-Newtonian vessels. This testing must demonstrate the ability of the vessel design to adequately mix waste simulants having a range of fluid conditions (e.g., solids concentration, viscosity, shear strength) in normal and off-normal conditions.
  - **Ability to Pump High-Solids-Bearing Slurries**. Even if analysis and testing demonstrate that criticality, flammable gas, and PJM overblow are all mitigated and create no nuclear safety issues, the ability to pump the solids from the vessels, and to periodically flush out the solids, must be demonstrated. The main concern is the potential for enough solids accumulation to interfere with—and possibly plug—the transfer pump suction line near the bottom of the vessel.
  - **Integrated Sampling Capability**. Solids stratification from mixing will generate samples containing solids concentrations that may vary with the PJM cycle. Test data will quantify sampling capabilities using the WTP configuration, and will be used to update sample requirements to reflect actual performance.

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[d] Below 5 percent solids, the vessel is considered to contain low solids; above 5 percent, the vessel is considered to contain high solids.

[e] Newtonian fluids typically are very low in solids and are most common in nature. For the Hanford Site tank farms, most of the low-activity waste would be considered Newtonian. When mixed, these wastes have a linear response to applied shear forces. Non-Newtonian fluids typically contain suspended solids and may be a thick suspension. Most of the HLW is considered non-Newtonian, and the viscosity typically will change when mixed.

- **PJM Control**
  - **PJM Overblow (Release of Air Out of the PJM Nozzle)**. More data are needed to ensure the PJM control system will function reliably and will reduce or prevent PJM overblow during operation. Concerns include structural limitations, ventilation system limitations, and overall reliability of the PJM system to provide adequate mixing.

3.1 Existing Testing Capabilities

Existing testing capabilities and testing capabilities currently under construction will be used to close the remaining technical gaps. These capabilities and participating organizations include the following facilities.

3.1.1 Mid-Columbia Engineering Facility

The Mid-Columbia Engineering (MCE) facility in Richland, Washington, where PJM control system testing using an 8-ft-diameter vessel and a single RLD-VSL-00008 PJM can collect data for control of PJMs. This information is a required precursor to full-scale PJM controls testing in the RLD-VSL-00008 test vessel. This facility also houses a 4-ft-diameter vessel and several PJM arrays in various prototypic configurations to support a variety of test scenarios. The assembled arrays represent PJM designs that were previously tested. Figure 2 is a picture of the 4-ft-diameter test platform at the MCE facility.

Figure 2. Four-Foot-Diameter Test Vessel at the Mid-Columbia Engineering Facility.

BNI is responsible for oversight of the ongoing and future testing, as well as cost and schedule performance of the testing program at the MCE facility. BNI develops the test plans based on engineering data needs, while the operating procedures for the facility have been developed by Energy Solutions. Energy Solutions is the NQA-1-certified test organization, but MCE is responsible for facility maintenance and building operations. This facility has supported test programs since 2009.

3.1.2 Washington State University Facility

Construction is progressing on a new full-scale vessel testing facility, also located in Richland. The facility is owned by Washington State University (WSU) and operated by Energy Solutions. This facility will be used to test both the full-scale RLD-VSL-00008 test vessel and a full-scale standardized design prototype. The RLD-VSL-00008 test vessel has been installed in the facility. PJM controls testing program under prototypic conditions will be initiated in the summer of 2014. A computer-aided design drawing rendering of the WSU Full-Scale Vessel Test (FSVT) Facility is shown in Figure 3.

In addition, a full-scale (14-ft) prototype vessel is onsite. Unlike the RLD-VSL-00008 test vessel, which has a fixed configuration, this prototype vessel can accept different PJM arrays and/or different bottom head shapes. The design of the standardized array will be selected based on engineering analysis and small-scale testing at the MCE facility. A photo of the RLD-VSL-00008 test vessel at the WSU facility is shown in Figure 4 and a graphical depiction of this vessel is provided in Figure 5. A second full-scale test vessel is depicted in Figure 6, and a photograph of the vessel being transported by barge to Richland, Washington, is shown in Figure 7.

BNI is responsible for technical and project oversight of the engineering, procurement, and construction work at the WSU facility, including the scope and test plan for the PJM controls testing to be conducted following the scoping testing at MCE.

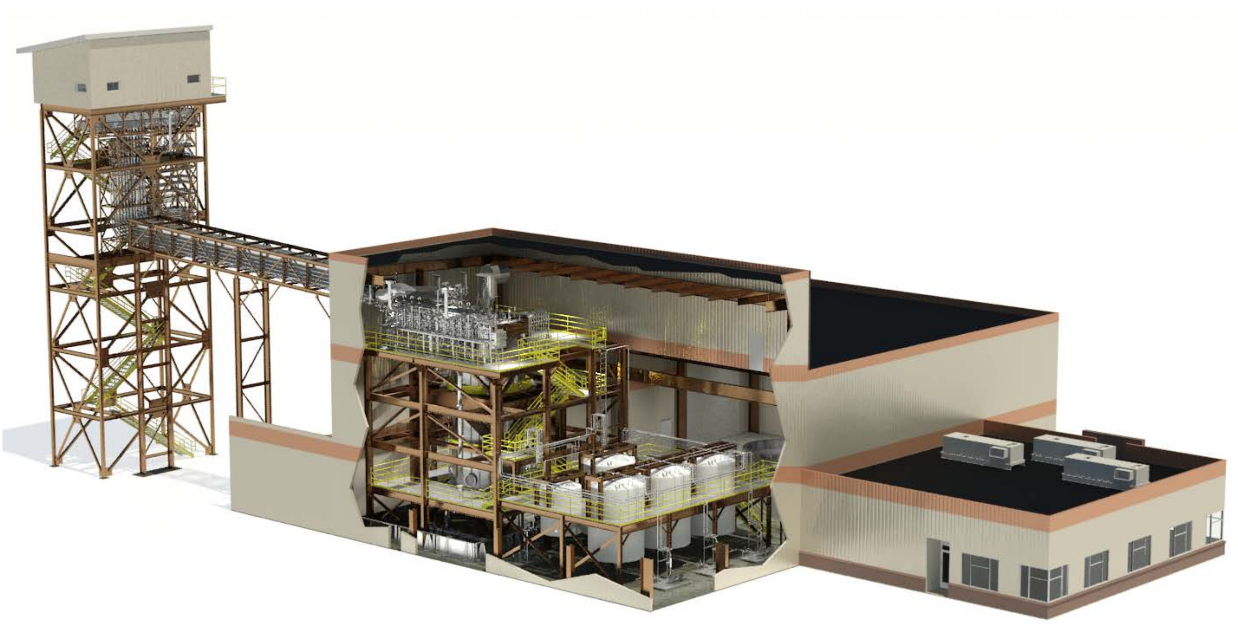

Figure 3. Washington State University Full-Scale Vessel Test Facility Rendering.

Figure 4. Photograph of the RLD-VSL-00008 Test Vessel at the Full-Scale Test Facility.

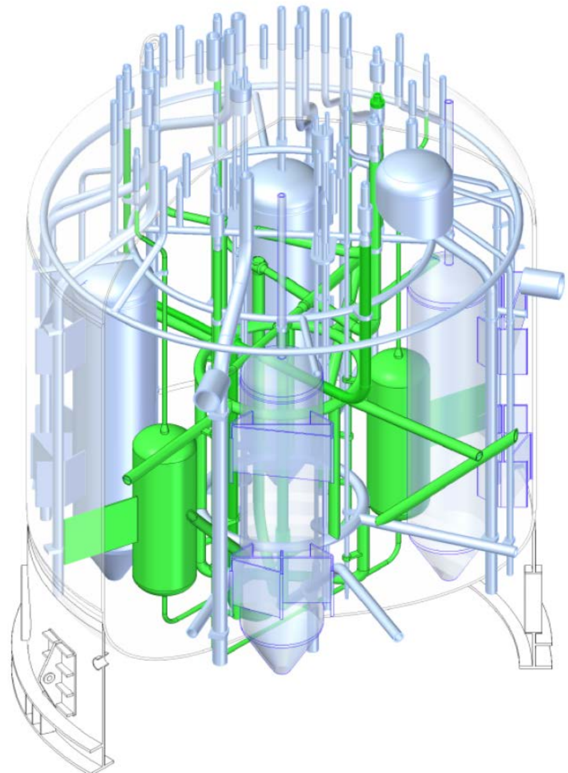

Figure 5. Graphical Depiction of the RLD-VSL-00008 Test Vessel.

Figure 6. Full-Scale Test Vessel at Washington State University Facility.

Figure 7. Full-Scale Test Vessel Being Transported by Barge to Richland, Washington.

3.2 Preparation of Test Plans and Procedures

3.2.1 Testing of Mixing Performance

BNI will use an engineering study to specify vessel functional and mixing requirements, test conditions, and detailed test objectives, which in turn will be used to develop test plans. The test plans will convert test objectives and requirements into test actions, which will then be converted into test run sheets.

Each test plan will identify acceptance criteria and provide a basis for development of the procedures required for each individual test. These plans include the test configuration and test objectives, and specify:

- Overall test scope
- Characteristics to be tested
- Test methodology, including key test activities/requirements, and specific data collection and analysis requirements
- Data to be obtained (including accuracy and precision)
- Instrumentation
- Monitoring to be performed
- Samples to be collected and analyses to be performed
- Test parameters and target values (including accuracy and precision)
- Test conditions, including environmental conditions
- Required simulant volume and characterization
- Test acceptance/success criteria
- Test matrix, including test vessel, test and operational requirements, simulant requirements, and order of testing, including selection methodology
- Statistical basis for the test matrix, including the selection of unique test combinations, replicate tests, and number of samples and analyses
- Statistical design of experiments
- Test uncertainty, including basis (inaccuracy and imprecision)
- Technical rationale supporting test program
- Data management (configuration control)
- Administrative hold points (i.e., approval, test continuation).

Based on the technical details of test plans, detailed test procedures and multiple test run sheets will be developed to provide direction for operations. Test procedures and test run sheets will include:

- Initial conditions to enter the test, including operating conditions/limits, instrumentation requirements, equipment, etc.

- Safety requirements related to simulant handling, test execution, etc.
- Specific hold or inspection points
- Step-by-step operator instructions
- Required data collection and handling needs and controls.

To support the testing at the test facility, unit operating instructions also will be developed for all major equipment to ensure equipment is safely operated in accordance with the testing needs and/or manufacturer's recommendations. The test facility contractor, Energy Solutions, will develop the test procedures and operating procedures.

3.2.2 Testing of Pulse-Jet Mixer Controls

An approach similar to testing for mixing performance (as described in Section 3.2.1) is used for PJM controls testing. BNI is responsible for identifying test objectives and developing the required test plans for verification of the PJM control system designs.

3.2.3 Vessel Testing Simulants

Simulated waste compositions will be developed to support the PJM mixing and control system testing. Selection of a simulant appropriate for the functional requirement(s) to be tested will be completed. Simulant choice will be based on existing data, previous development, and/or testing with an objective to choose a path that is not overly complicated. Clear specification of the important properties and limiting conditions with respect to the vessel functional requirements will be documented. Simulant development will consider:

- Specific functional requirement; multiple simulants may be required
- Waste chemistry impacts on fluid/slurry properties and on vessel performance
- Instrumentation and measurement capabilities
- Behavior of proposed simulants during laboratory/small-scale testing.

3.3 Establishment of the Testing Organization

DOE will direct the vessel testing and design verification program through contracting mechanisms. DOE staff members also are involved in the day-to-day execution of the program from a management, technical, and project controls perspective.

For mixing performance testing, responsibility is divided among organizations to take advantage of specific expertise. Test direction and oversight will be performed by an integrated Joint Test Group composed of personnel from DOE, BNI, Energy Solutions, and external support. Test direction and oversight will ensure the testing is conducted in a manner that provides data to support the test objectives.

Engineering design, procurement, and construction; test performance; and safety oversight of PJM testing will be conducted by BNI, with requirements flowdown to the testing subcontractor, Energy Solutions. BNI will be accountable for cost and schedule performance.

BNI may solicit technical assistance for PJM mixing testing by Federal laboratories, industry, and academia on an as-needed basis. The labs are members of the Joint Test Group to ensure that testing and data collection meet the intent of the test plan and provide real-time feedback during the test program.

3.4 Data Analysis and Development of Test Results

A data analysis plan will be prepared by BNI that specifies how test data will be analyzed to generate results that meet the test objectives, including demonstration of whether the PJM mixing systems fulfill the mixing and control requirements shown in Table 3. Data analysis will provide an estimate of uncertainty for each of the test results, using methodology provided in the American Society of Mechanical Engineers consensus standard for test uncertainty.[16]

Following completion of testing, test reports will be issued with the results of testing compared to the test objectives, data needs, and success criteria. BNI, as the design authority, will use this information either to verify or revise the design of the PJM vessels if requirements are not met.

3.5 Design Review Traceability to Requirements

Engineering design documents, historical data and information, and benchmark data and information will be reviewed by BNI to verify the design of the PJM vessels against the nine mixing requirements in Table 1 and the four control requirements in Table 2. If a mixing requirement cannot be demonstrated to be fully met by design reviews, alternate calculations will be utilized to address any data and information gaps. "Alternate calculations use alternate methods to verify correctness of the original calculations or analyses."[14]

Alternate calculations will include data and information from sources that include:

- Other engineering documents used to support design
- Technical studies, evaluations, and experiments used to support design
- Engineering experiments
- Other engineering calculations or engineering-based analyses
- Relevant engineering documents from similar facilities and projects.

Table 3 is a traceability matrix showing the principal techniques to be used to verify the design against each control and mixing requirement.

Table 3. Design Requirements Traceability Matrix.

Control Functions and Mixing Requirements		Design Review	Alternate Calculations		Comments
			Engineering Analysis	Engineering Experiments	
CF-1	Adequate Fluid Velocity	X	X	X	Note
CF-2	Sufficient Suction/Drive Phase Durations	X	X	X	Note
CF-3	Support Mixing by Controlled Cycling	X	X	X	Note
CF-4	Limit Overblows by Controlled Cycling	X	X	X	Note
MR-1	Heat Transfer for Cooling	X	X	—	—
MR-2	Transfer Line Plugging	X	X	X	Note
MR-3	Blended Waste Streams	X	X	—	—
MR-4	Facilitate Chemical Reactions	X	X	—	—
MR-5	Sample to Support Criticality Analysis	X	X	—	Note
MR-6	Sample to Support Hydrogen Generation Solids Analysis	X	X	X	Note
MR-7	Support Process Control Analysis	X	X	X	Note
MR-8	Limited Gas Release	X	X	X	Note
MR-9	Not Applicable	—	—	—	Deleted
MR-10	Limited Solids Accumulation	X	X	X	Note

Note: NQA-1 data from testing supports engineering analysis and design review activities.
CF = control function.
MR = mixing requirement.

4.0 Technical Issue Program Management

4.1 Roles and Responsibilities

The DOE is responsible for the technical, cost, and schedule performance of the WTP. The DOE executes the WTP and the PJM vessel testing program through formal contracting mechanisms. DOE staff members also are involved in the day-to-day execution of the program from a management, technical, and project controls perspective.

BNI is accountable to DOE for the adequacy of the design, technical, and safety performance of the WTP. This includes the conduct of the PJM testing program and resolution of the associated design and safety issues.

Engineering design, test performance, and safety oversight of PJM mixing testing will be conducted by BNI, with requirements flowdown to the testing subcontractor. BNI will be accountable to DOE for cost and schedule performance.

4.2 External Technical Review and Oversight

4.2.1 Consortium for Risk Evaluation with Stakeholder Participation

The DOE has retained the CRESP organization to advise and provide guidance on strategies and plans to close the remaining technical issues with the WTP. Most important of these are the issues requiring resolution before DOE can authorize a resumption of production engineering in the PT Facility. This includes the PJM vessel design and nuclear safety issues associated with hydrogen gas release and a potential inadvertent criticality.

CRESP interactions occur through formal presentations and discussions with DOE and BNI. CRESP guidance is provided informally and formally by letter. DOE has requested four reviews per year until the technical issues are resolved. The first review occurred in November 2013 and resulted in nine recommendations for DOE action.[17]

4.2.2 Defense Nuclear Facilities Safety Board

The DOE has a responsibility to resolve the technical and safety issues associated with the WTP and demonstrate how those issues are resolved to the DNFSB. These issues are described in Section 1.2. Interactions with the DNSFB occur through formal and informal interactions with the DNSFB staff.

4.2.3 Use of Subject Matter Experts

DOE has retained and will continue to retain specific subject matter experts to conduct independent reviews of the PJM vessel and control system designs and testing program. This is done to provide greater assurance in the resolution of the final design and operating solutions.

5.0 Cost and Schedule

This section summarizes the major decisions, cost, and schedule to resolve the PJM vessel mixing issues.

5.1 Milestones and Decision Points

Major milestones and decisions that outline the PJM technical issues resolution strategy are listed in Table 4 and shown in Figure 8.

Table 4. Major Milestones of the PJM Vessel Technical Issue Resolution Strategy.

Milestone	Decision or Milestone	Date
M1	Selection of Standard Vessel Design Based on Small-Scale Testing and Engineering Analysis	December 2014
M2	Engineering Study to Evaluate the Technical and Economic Benefits of the Standardized Vessel Design in Pretreatment	December 2014
M3	Completion of Control System Testing for the Low-Solids/No-Solids Vessels	December 2014
M4	Completion of Design Verification Strategy of the 30 Low-Solids/No-Solids vessels	April 2015
M5	Completion of Control System Testing for the High-Solids Vessels	August 2015
M6	Finalization of Pretreatment Cell Design Layout for High-Solids Vessel Designs	March 2016
M7	Completion of Demonstration Testing of the Standardized Vessel Design for Mixing	July 2016

5.2 Schedule

The planned PJM vessel testing program is designed to close the remaining technical gaps associated with PJM control system testing and with the PJM vessels. These gaps require the testing of two PJM vessels designs: RLD-VSL-00008 and a new standard vessel design.

Specially built platforms are being assembled in FY 2014 and FY 2015 to support this testing. In addition, smaller scale vessel testing will be initiated in early FY 2014 using existing test capabilities at the MCE facility. A schedule of the major activities is presented in Figure 8.

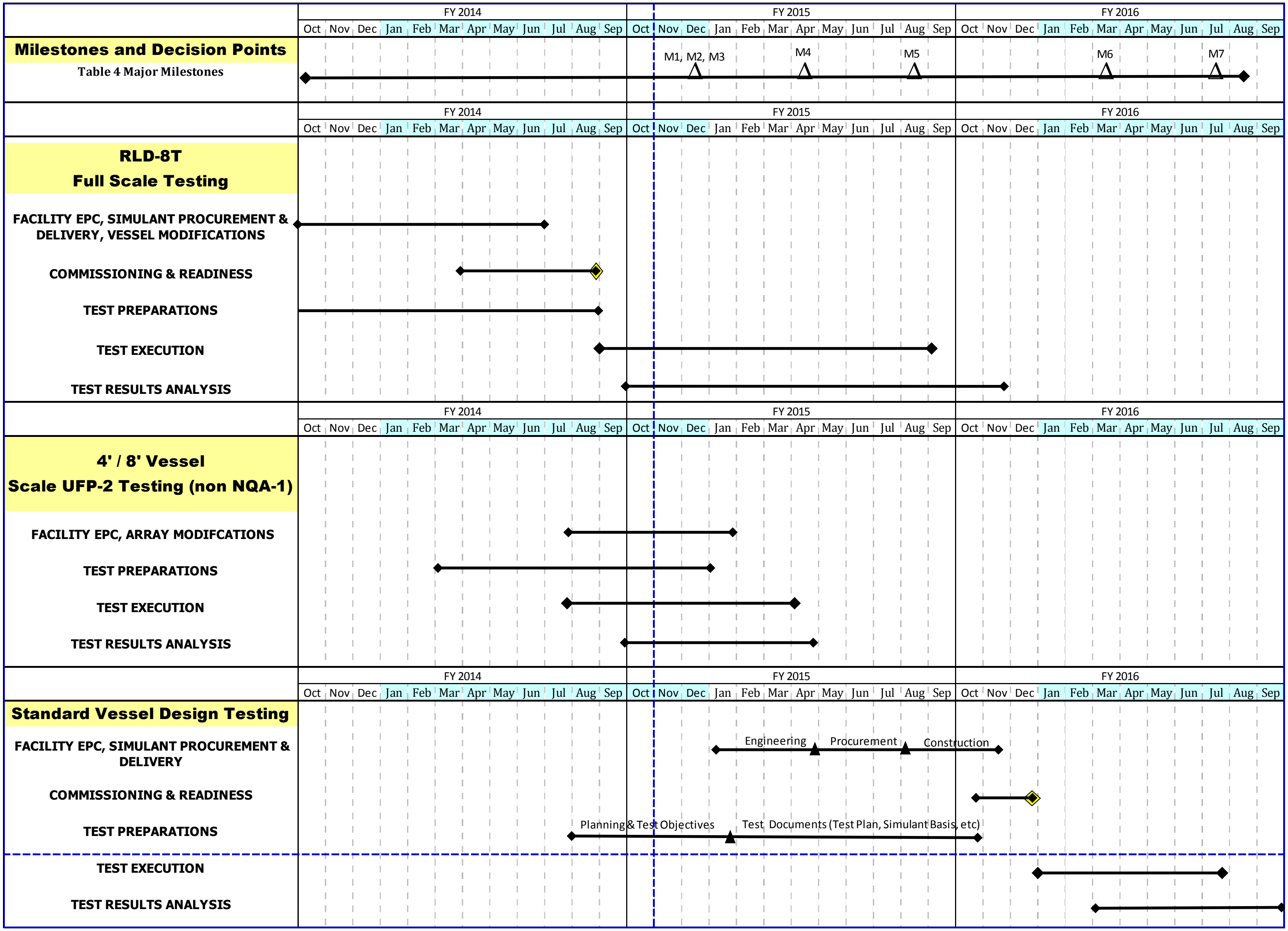

Figure 8. Pulse-Jet Mixer Vessel Testing Program Schedule to Support Completion of Design Verification.

5.3 Estimated Costs

Table 5 summarizes the estimated cost for the following vessel tests:

- RLD-VSL-00008 (full-scale test)
- Small-scale standard vessel design testing (4-ft/8-ft scale non-NQA-1 test, includes three array configurations)
- Full-scale standard vessel design.

These cost estimates are budget quality rough order of magnitude estimates, as detailed plans and cost estimates have not been fully developed. DOE anticipates that the actual costs could be substantially lower. In addition, based on budget guidance, the DOE may need to adjust the testing and completion schedule.

These cost estimates include costs for engineering and operating labor to prepare for and conduct the tests; procure and make up simulants; modify the existing test facility; design the vessel platform, including supporting test equipment and PJM arrays; and analyze test data to support vessel design verification. Also included are indirect costs, contingency, and program management.

Table 5. Annual Budget Estimate to Complete Pulse-Jet Mixer Vessel Testing Program.

Cost Element	FY 2014 Budget ROM Estimate ($M)	FY 2015 Budget ROM Estimate ($M)	FY 2016 Budget ROM Estimate ($M)	Total
RLD-VSL-00008T Testing	$25-$30	$20-$25	$0	$45-$55
Standard vessel testing (includes small-scale testing in the UFP-VSL-00002 and 8-ft-diameter vessels)	$2-$5	$20-$30	$30-$40	$52-$75
Support from government labs, industry, and academia	$15	$15	$20	$50
Total	**$42-$50**	**$55-$70**	**$50-$60**	**$180**

FY = fiscal year.
ROM= rough order of magnitude.

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Appendix A

Summary of Pulse-Jet Mixer Testing at the Waste Treatment and Immobilization Plant

From 2007 to 2012, reduced-scale tests evaluated pulse-jet mixer (PJM) configurations and mixing performance. These tests also examined a range of process parameters in an attempt to verify the PJM design.

During the testing period, the Waste Treatment and Immobilization Plant (WTP) Project also performed several engineering evaluations that utilized tools, such as computational fluid dynamics (CFD) and low-order accumulation models (LOAM), to predict mixing performance. These efforts resolved the External Flowsheet Review Team (EFRT) PJM issue (known as M3), and identified PJM vessel design changes to improve the mixing performance of several vessels.

In 2012, it was determined that some evaluation methods were not appropriate for all waste types (not all rheological conditions [i.e., non-Newtonian/Newtonian] are evaluated using the same methods). Some waste characteristics lend themselves well to computational methods; others do not. Additional data on mixing performance of waste simulants with rapidly settling solids is required to fill knowledge gaps in vessel design performance.

Testing for WTP PJM vessels began in 1999 under the British Nuclear Fuels Limited (BNFL) WTP contract. Since then, multiple testing programs have been completed, supporting PJM vessel design for many of the PJM vessels and allowing the current testing program to focus on two vessel designs. Figure A-1 is a timeline of PJM vessel testing.

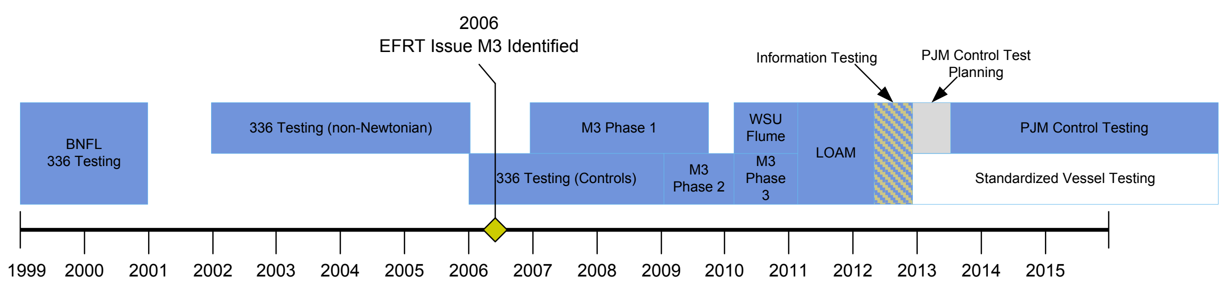

Figure A-1. Testing Timeline.

- **BNFL Testing**. Pacific Northwest National Laboratory (PNNL) began testing for BNFL in 1999. Testing was conducted in a 156-inch-diameter vessel similar to the RLD-VSL-00008 test vessel design. This testing resulted in high confidence in PJM mixing for high-solids slurries, representing wastes that were then evaluated as the most challenging (Newtonian slurry up to 36 percent solids by weight). Testing was not performed under an NQA-1 program.
- **Building 336 Testing**. Both Newtonian and non-Newtonian slurry testing was performed in the Building 336 test facility. Development testing of leaching and ultrafiltration processes during 2003 and 2004 led to a conclusion that some Pretreatment (PT) Facility vessels would contain non-Newtonian slurries; therefore, non-Newtonian testing was conducted. Testing resulted in PJM cluster array design modifications, the

addition of air spargers in five vessels (UFP-2A/B, HLP-27A/B, and HLP-28), and removal of the High-Level Waste (HLW) Facility feed-preparation vessel. Newtonian vessel testing focused on PJM controls. Testing was not performed under an NQA-1 program.

- **Major Issue 3 (M3) Newtonian Testing**. M3 testing partially addressed issues identified by the EFRT in 2006 related to fast-settling solids in Newtonian slurries. Three testing phases addressed (1) scaled correlation development, (2) initial small-scale prototypic testing, and (3) determination of design changes. Phase 2 testing was conducted with a 43-inch prototypic vessel based on literature and Phase 1 results; however, the 43-inch vessel testing did not confirm data from Phase 1 because the simulants used in Phase 1 were simple water/glass bead simulants. Phase 3 testing supported closure of M3 and resulted in design changes to increase mixing power, including a larger nozzle diameter, an increase in PJM drive velocity, and additional PJMs. Testing was performed under an NQA-1 program with some additional informational testing.
- **Washington State University Box Flume Test**. This test evaluated bottom clearing using a vertical continuous full-scale jet on a flat bottom. Data showed that radial clearing can be predicted from published equations for jet development and sediment transport. Testing was not performed under an NQA-1 program.
- **LOAM Testing**. LOAM testing was focused on solids accumulation for the distributed array designs. Some test results varied from LOAM predictions and LOAM use was stopped in lieu of verified and validated CFD. Tests to evaluate design features to examine the pumpout performance of vessels with cluster arrays resulted in high uncertainty in projected performance with non-Newtonian fluids. The post-LOAM testing showed good results for Newtonian fluid pumpouts, but more experiments are required. Testing was performed under an NQA-1 program with some additional informational testing.
- **Post-M3 Vessel Verification**. CFD initially was chosen as the primary method to support design verification; however, the use of CFD was stopped. A scaling test was chosen as an alternate methodology. This methodology was developed by PNNL, but it proved to be too complex to achieve a strong basis for scaling test results. In addition, the number of tests to generate correlations was even greater than what had been needed for CFD verification and validation. This led to the need to conduct full-scale testing to provide added confidence in results from CFD or scaling tests. Testing was all informational and not performed under an NQA-1 program.

Table A-1 provides a chronology of previous PJM vessel testing activities.

Table A-1. Pulse-Jet Mixer Vessel Testing Summary.

Test Program	Testing Performed	Budget ($M)	Similar WTP Vessels	Test Vessel Diameter (inches)	Number of PJMs	Simulant Type N	Simulant Type NN	Report Number	Purpose/Scope	Outcome	Notes
BNFL Testing	2000	Unknown	RLD-08	156	4	X		BNFL-RPT-048	High-solids slurries representing wastes then evaluated as most challenging (this was the understanding at project transition).	Proved PJM and RFD technology up to 36 wt% solids. Found that at 28wt% and above, mixing was nearly homogenous (for solids suspension) and that settled solids can be fully homogenized within 1-2 hours. These test results support analysis of HLW Group 5 vessels.	
336 Testing	2002-2006	30	Non-Newtonian: UFP-02, HLP-27, CRV Vessel	17.25, 34, 40.5, 70, 153	0, 1, 4, 6, 8, 9, 12	X	X	WTP-RPT-061, 077, 078, 081, 110, 113, 114, 128, 129, 132, 156, 179	Test arrays realized some PT Facility and HLW vessels would contain non-Newtonian slurries that could retain hydrogen (due to leaching/ ultrafiltration).	NNV: Added PJM cluster array design and air spargers. UFP-2A/B, HLP-28A/B, HLP-28 modified. HLW feed preparation (CRV) vessels were removed. Newtonian: PJM controls testing.	
	2006-2009		Newtonian: RLD-08					WSRC-TR-2004-00398, 00399, 00430			
M3 Phase I (PNNL Testing)	2007-2008	15	NA	15, 34, 70	4, 8, 12	X		WTP-RPT-182	Testing was used to develop scaling correlations. Uncertainty on particle size/density to be used in correlation.	Developed correlation for each phenomena (suspension and clearing). Decision made to conduct prototypic (vessel specific) testing. Single particle size correlation developed, but selection of single particle size and 0.2 scale factor not fully accepted by all stakeholders. Evaluations conducted using correlation indicated that vessel bottoms would not clear.	
M3 Phase II (MCE Testing)	2009	24	FEP-17, HLP-22	43.2	8, 12	X		24590-WTP-ES-PET-09-001	Small-scale prototypic PJM configuration (43-in. scale vessel based on literature and Phase 1 results). Key test focus was solids accumulation on the vessel bottom.	Identified areas of concern in the PJM intersections. 43-in. prototypic vessel testing did not confirm correlations from Phase 1.	Did not include pumpout. Use multiple simulants, including complex (six-part) simulants. PJM drive and suction (prototypic)
WSU Box Flume	2009		HLP-22	223 x 268 w/ 152 between nozzles	2	X		24590-WTP-ES-PET-10-001	Use flume test to evaluate scaling of ZOI with vertical jet on full-scale vessel bottom.	Analysis of the data shows that the radial clearing can be predicted from existed published equations for jet development and sediment transport. Clearing radius results were consistent with CFD predictions.	

Table A-1. Pulse-Jet Mixer Vessel Testing Summary.

Test Program	Testing Performed	Budget ($M)	Similar WTP Vessels	Test Vessel Diameter (inches)	Number of PJMs	Simulant Type		Report Number	Purpose/Scope	Outcome	Notes
						N	NN				
M3 Phase III (MCE Testing)	2009-2010	16	FEP-17, HLP-22, UFP-01, FRP-02	43.2	8, 12, 18	X		24590-QL-HC1-M00Z-00001 CCN 220458 (M3 closure document)	Determination of design changes (by increasing PJM nozzle size, drive velocity, angled nozzles, and number of PJMs).	Data supported TSG closure of M3 (Newtonian and non-Newtonian vessels). Design changes: • Identified low/under-powered vessels and changed PJM features to increase mixing power • Increased nozzle size (HLP-22, UFP-1A/B) • Increased PJM drive velocity (FRP-2, FEP-17, HLP-22, PWD-44, UFP-1A/B) • Added more PJMs (HLP-22, UFP-1A/B).	Included vessel pumpouts.
LOAM and Information Only Testing	2011-2012	2.7	HLP-27	43.2, 97	4, 8	X	X	24590-WTP-RPT-ENG-11-013 (LOAM testing) CCN 238152 (Info only testing)	Focused on solids accumulation for the cluster array. Info only testing was to examine improvements in the pumpout of cluster arrays and prepare for CFD V&V testing.	Some test results varied from LOAM predictions and use of LOAM stopped in lieu of V&V'd CFD. Post LOAM information only testing found less accumulation in Newtonian fluids vs LOAM tests. Non-Newtonian fluid pump-outs had good results but more experiments were needed to confirm.	Included vessel pumpouts.

BNFL = British Nuclear Fuels, Limited.
CFD = computational fluid dynamics.
CRV = concentrate receipt vessel.
HLW = High-Level Waste (Facility).
LOAM = low-order accumulation model.
MCE = Mid-Columbia Engineering.
N = Newtonian.
NN = non-Newtonian.
NNV = non-Newtonian vessel.
PJM = pulse-jet mixer.
PNNL = Pacific Northwest National Laboratory.
PT = Pretreatment (Facility).
RFD = radar fluid detector.
TSG = Technical Steering Group.
V&V = verification and validation.
WSU = Washington State University.
ZOI = zone of influence.

Appendix B
Pulse-Jet-Mixed Vessel Summary Descriptions

Vessel Selection

The Waste Treatment and Immobilization Plant (WTP) currently has 22 different vessel design configurations representing the 38 pulse-jet-mixed (PJM) vessels (34 in the Pretreatment [PT] Facility, 4 in the High-Level Waste [HLW] Facility).

Twenty-seven PJM vessels currently are installed in the WTP: 2 in the HLW Facility and 25 in the PT Facility. Two additional low-solids vessels are to be installed in the HLW Facility, and one low-solids vessel is to be installed in the PT Facility. The designs of these 30 vessel designs to adequately perform the mixing function will be verified using a combination of existing and new test data. Additional testing will confirm their control system design.

Low Suspended or Slow-Settling Solids Vessels

Table B-1 lists 30 low-solids vessels and identifies the nature of the waste and solids each will receive. Sufficient information and data exist on mixing performance to state, with confidence, that mixing is not an issue for these 30 vessels. Design can be verified through engineering design documents, historical data and information, and applicable benchmark data and information (see references listed at the end of this Appendix). No engineering experiments are required.

Table B-1. Low-Solids Pulse-Jet-Mixed Vessels.

Vessel Information	PJMs	Waste	Expected Solids
CXP-VSL-00004, Cs IX Feed Vessel	1	Cs IX caustic supply	• 0 wt% • Low suspended solids
CNP-VSL-00003, Eluate Contingency Storage Vessel	4	Cs IX concentrate	• 0 wt% • Low suspended solids • Acidic vessels
CXP-VSL-00026A/B/C, C Cs IX Treated LAW Collection Vessels	6	Ultrafilter permeate	• 0 wt% • Low suspended solids
UFP-VSL-00062A/B/C, Ultrafilter Permeate Collection Vessels	6	Ultrafilter permeate	• 0 wt% • Low suspended solids
CNP-VSL-00004, Cs Evaporator Recovered Nitric Acid Vessel	4	Cs IX acid supply	• 0 wt% • Low suspended solids • Acidic vessels
FRP-VSL-00002A/B/C/D, Waste Feed Receipt Vessels	12	As-received LAW waste	• < 3.8 wt% • Suspended solids • Slow-settling solids
FEP-VSL-00017A/B, Waste Feed Evaporator Feed Vessels	8	As-received LAW waste and recycles	• < 5 wt% • Low suspended solids
PWD-VSL-00033, HLW Effluent Overflow Vessel	8	PT Facility effluent (includes overflows)	• < 5 wt% • Low suspended solids
PWD-VSL-00043, HLW Effluent Transfer Vessel	8	PT Facility effluent (includes overflows)	• < 5 wt% • Low suspended solids
PWD-VSL-00044, Plant Wash Vessel	8	PT Facility effluent (includes overflows)	• < 5 wt% • Low suspended solids
PWD-VSL-00015/16, Acidic/Alkaline Effluent Vessels	8	Acidic/alkaline cleaning effluent	• < 5 wt% • Low suspended solids
TCP-VSL-00001, Treated LAW Concentrate Storage Vessel	8	LAW melter feed concentrate	• < 5 wt% • Low suspended solids
TLP-VSL-00009A/B, LAW SBS Condensate Receipt Vessels	8	Ultrafilter permeate and recycles	• < 5 wt% • Low suspended solids
RLD-VSL-00008, Plant Wash and Drains Vessel	4	HLW effluent (includes overflow)	• < 5 wt% • Low suspended solids
RLD-VSL-00007, Acidic Waste Vessel	4	HLW melter offgas condensate	• < 5 wt% • Low suspended solids
HOP-VSL-00903, Melter 1 SBS Condensate Receiver Vesse1	4	HLW melter offgas condensate	• < 5 wt% • Low suspended solids
HOP-VSL-00904, Melter 2 SBS Condensate Receiver Vessel	4	HLW melter offgas condensate	• < 5 wt% • Low suspended solids
RDP-VSL-00002A/B/C, Spent Resin Slurry Vessels	4	Spent IX resin	• NA, spent resin • Slow-settling solids • Potential high solids

Cs = cesium.
HLW = High-Level Waste (Facility).
IX = ion exchange.
LAW = Low-Activity Waste (Facility).
NA = not applicable.
PJM = pulse-jet mixer.
PT = Pretreatment (Facility).
SBS = submerged bed scrubber.

High-Solids Vessels

Table B-2 identifies the PJM vessels for which mixing performance has not been verified during previous assessments. These vessels contain solids greater than 5 percent by weight with Newtonian and/or non-Newtonian slurries. These vessels provide the greatest amount and level of uncertainty. As such, verifying the design of the vessels in Table B-2 requires engineering experiments to demonstrate performance against the mixing requirements.

Table B-2. High-Solids Pulse-Jet-Mixed Vessels.

Vessel Information	PJMs	Waste	Expected Solids
HLP-VSL-00022, HLW Feed Receipt Vessel	18	As-received HLW from the tank farms	• > 5 wt% • Newtonian slurry • Fast-settling solids
UFP-VSL-00001A/B, Ultrafiltration Feed Preparation Vessels	12	Blended HLW prepared as feed to the ultrafiltration system	• > 5 wt% • Newtonian slurry • Fast-settling solids
HLP-VSL-00027A/B, HLW Lag-Storage Vessels	8	Washed and leached solid slurries from the ultrafiltration system, including cesium ion-exchange effluent in HLP-27 B	• > 5 wt% • Non-Newtonian slurry • High-suspended solids
HLP-VSL-00028, HLW Feed Blend Vessel	8	Washed and leached solid slurries from the ultrafiltration system, including cesium ion-exchange effluent	• > 5 wt% • Non-Newtonian slurry • High-suspended solids
UFP-VSL-00002A/B, Ultrafiltration Feed Vessels	6	Washed and leached sludge solids	• > 5 wt% • Newtonian and non-Newtonian slurry • High-suspended solids

HLW = High-Level Waste (Facility).
PJM = pulse-jet mixer.

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Appendix C
Description of Pulse-Jet Mixer Operation

Description of the Pulse-Jet Mixing System

Pulse-jet mixers (PJM) are used in nuclear applications for mixing radioactive liquids, slurries, and sludge. The PJM systems have no moving parts and do not require maintenance. Many of these PJM systems are operating worldwide. For example, they are used at the nuclear fuel reprocessing plant at Sellafield in Cumbria, England, where more than 150 PJM systems are installed, with the longest serving system operating for more than 40 years. The original Waste Treatment and Immobilization Plant (WTP) engineering, procurement, and construction contractor, British Nuclear Fuels, Limited, incorporated PJM technology into the WTP design. The U.S. Department of Energy provided this design to Bechtel National, Inc. (BNI), in the WTP conceptual design. The WTP application of the PJM technology involves use of much larger vessels with more diverse fluid characteristics than had previously been tested or used in operations internationally. Thus, a testing program is required to verify the designs.

In the WTP, liquids/slurries will be mixed using PJMs in 38 vessels. PJMs are cylindrical tanks internal to the vessels that mix fluids by drawing them into the vessels by a vacuum and then pressurizing the vessel to eject the fluid via discharge nozzles. The designs of the mixing systems are based on each vessel's characteristics, size, and geometry.

The PJM cycle has three phases, as shown in Figure C-1:

1. **Suction Phase**. A jet pump is used to create a vacuum on the PJM and draw process fluid into the PJM from the process vessel.
2. **Drive Phase**. When the PJM is full, air pressure forces fluid out of the PJM and into the process vessel, thereby mixing the vessel contents.
3. **Vent Phase**. The system is vented to depressurize the PJM. The compressed air in the PJM passes back through the jet pumps and into the vent system, thus allowing the PJM vessel to repeat the cycle.

Note: Although this reflects the current design at WTP, use of PJM gravity refill (no suction phase) when the vessel is full and/or use of a gravity drop (no drive phase) when the vessel is at low level, potentially could reduce risk of overblow and may be considered to resolve PJM control concerns.

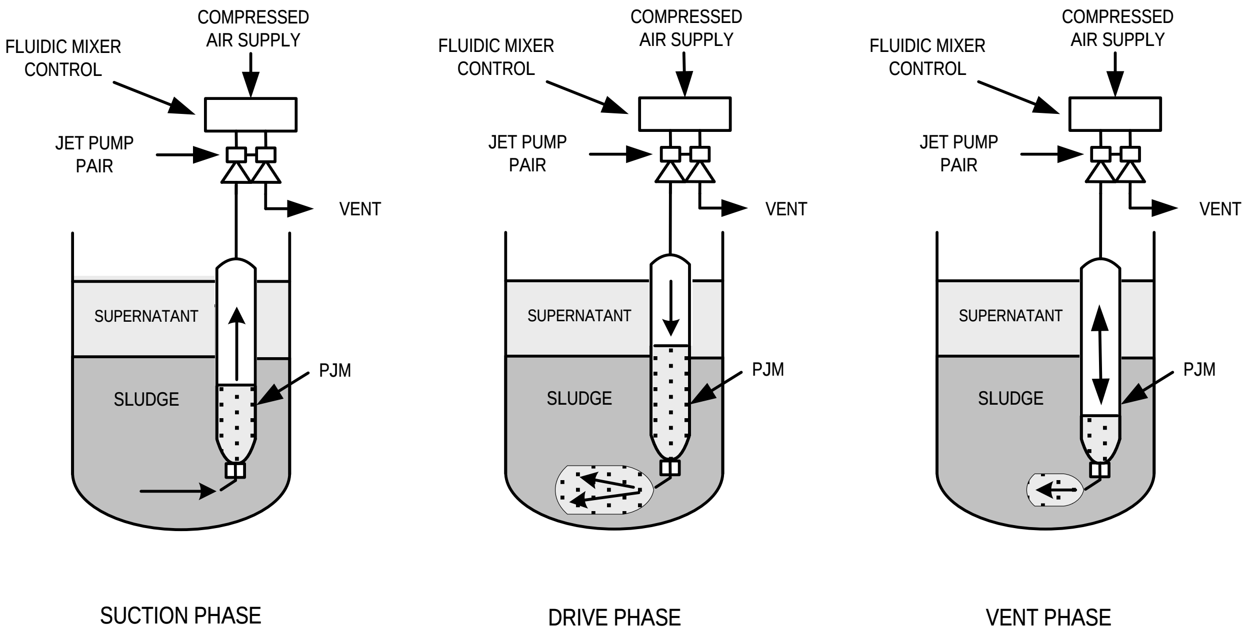

Figure C-1. Operation of a Pulse-Jet Mixer.

Pulse-Jet Mixer Control Testing Uncertainties

As previously described, the WTP PJMs are designed to force the fluid/slurry in the vessel through a jet that induces agitation and mixing. The PJMs work on pressurized air to drive the fluid/slurry out of the PJM and into the vessel. The drive phase is controlled so the PJM does not empty completely, in order to avoid introducing air into the vessel. After the drive phase, the PJM is refilled with the vessel fluid/slurry via suction applied to the PJM.

Analysis completed by BNI that examines the flow of air from the regulator, through the jet pump pair, and terminating at the PJM nozzle fluid discharge is required to confirm the PJM control design. There is some concern over the adequacy of analysis completed to date. Therefore, BNI will use an alternate analysis that utilizes test data to confirm the PJM control design.

During the cyclic operation, overpressurization of the parent vessel could occur if a PJM overblows. Two types of overblows are possible:

- A **drive** overblow occurs when a PJM is in the drive phase, and the fluid and slurry are completely expelled from the pulse tube. As a result, a volume of pressurized air is blown out of the PJM, creating a significant pressure pulse inside the vessel. These pressure pulses place hydrodynamic loads on the components inside the vessel and, if overblows occur over the life of the vessel, could cause damage due to fatigue of components and piping in the vessel. These loads are evaluated within the vessel structural design analysis. Drive overblows can be detected by the PJM control system, as demonstrated in previous testing.
- A **vent** overblow occurs when a PJM is in the vent phase, and the fluid and slurry are completely expelled from the pulse tube. During the first few seconds of the vent, the PJM continues to empty because of residual pressure and the downward momentum of

the PJM's contents. As a result, pressurized air is blown out of the PJM, creating a pressure pulse inside the vessel at a reduced pressure relative to a drive overblow. Vent overblows have not been detected by the PJM control system in previous testing.

A change to the PJM design to reduce the magnitude of overblows may be evaluated by BNI. An orifice placed in the side of the PJM would effectively cause a small overblow (insignificant load to the vessel components) that would be detectable by the control system. This feedback signal would close the air supply to the PJM and stop the drive. The use of such a relief orifice is not proven and must be operationally tested to verify the benefits of this approach to the design.

BNI's baseline vessel design analysis utilized a conservative estimate that bounded overblow loads and assumed a number of overblows. The design limits on number of overblows was not evaluated. Work is progressing utilizing less conservative bounding loads and evaluating the design limit on quantity of overblows. These results may modify the current requirements on PJM control to prevent overblows and meet vessel structural limits.

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