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19-WTP-0041

MAY 15 2019

The Honorable Bruce Hamilton, Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, D.C. 20004

Dear Chairman Hamilton:

RESOLUTION OF DEFENSE NUCLEAR FACILITY SAFETY BOARD CONCERNS RELATED TO CONTROL OF PULSE-JET MIXERS OVERBLOW AND IMPACT TO VESSELS AT THE WASTE TREATMENT AND IMMOBILIZATION PLANT

References:

1. *27th Annual Report to Congress,* Defense Nuclear Facilities Safety Board, Washington, D.C., dated April 27, 2017.
2. DNFSB letter from J.E. Mansfield to I.R. Triay, DOE-HQ, "DNFSB Staff Review of the Pulse Jet Mixing Technology in the Pretreatment Facility of the Waste Treatment and Immobilization Plant (WTP) at the Hanford Site," dated January 6, 2010.
3. DNFSB letter from P.S. Winokur to S. Chu, Secretary of Energy, "Recommendation 2010-2, Pulse Jet Mixing at the Waste Treatment and Immobilization Plant," dated December 17, 2010.
4. HQ Memorandum from I.R. Triay to P.S. Winokur, DNFSB, "Response to DNFSB January 6, 2010 Letter Concerning the Design and Testing of PJM Technology," dated May 17, 2010.
5. HQ Memorandum from D.B. Poneman to P.S. Winokur, DNFSB, "Revised Technical Approach to Resolve DNFSB Concerns Associated with Control and Operation of WTP PJM Vessels Containing Solids," dated September 11, 2013.
6. DNFSB letter from P.S. Winiokur to E. Moniz, Secretary of Energy, "DNFSB Closure of Recommendation 2010-2," dated January 28, 2014.

The Defense Nuclear Facilities Safety Board (DNFSB) concerns related to the design of the pulse-jet mixing systems in the Waste Treatment and Immobilization Plant (WTP) associated with the ability to control pulse-jet mixers (PJM) and prevent frequent overblows is listed in the *27th Annual Report to Congress* (Reference 1). The U.S. Department of Energy (DOE), Office of River Protection (ORP) requests that the Attachment to this letter be provided to the DNFSB to support DOE's determination that the technical issue on the control of PJMs in WTP process vessels has been resolved.

In coordination with, and participation from the DOE Office of Environmental Management staff, ORP is submitting this record documenting the technical basis for the resolution of the DNFSB safety concern with the ability to control PJM and prevent overblows in WTP PJM process vessels.

Background:

Over the last six years, ORP and DNFSB have jointly identified a number of technical issues on the WTP, specifically on the Pretreatment (PT) Facility and to a lesser extent with the High-Level Waste Facility. In 2012, ORP directed the WTP contractor to stop design-related activities on both facilities, except in areas of the High-Level Waste Facility not impacted by these issues. Also in 2012, the Secretary of Energy established a team to better understand fundamental technical weaknesses with the design of the WTP, particularly issues that could result in adverse consequences within the WTP black cells. A number of those issues overlapped with those identified by ORP and DNFSB. To provide a focus on resolution of all these technical issues, ORP and the WTP contractor assembled teams to address each of the issues.

As one condition of authorizing the WTP contractor to begin design activities on the PT Facility, ORP determined resolution of the technical issues was required. Documentation demonstrating a sound technical basis for closure of the first several of these were submitted to the DNFSB.

This letter documents Bechtel National, Inc.'s (BNI) position that concerns raised by the DNFSB regarding utilizing bubbler instrumentation in control of PJMs to prevent overblow in WTP (Reference 2) have been resolved.

Statement of Issue:

The DNFSB's specific concern related to control of PJMs and resulting impact on components within vessels was stated in Reference 2 as follows:

> The presence of a deep sediment layer may also have a detrimental effect on the performance of bubbler systems used to measure the tank level and average density in the vessels. The tank level and average density are inputs to the calculation of the drive time of the pulse jet mixers, which is relied upon to prevent overblows. The cumulative effect of many overblows could result in the material failure of components internal to process vessels located in black cells.

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This concern was also captured in Board Recommendation 2010-2, *Pulse Jet Mixing at the Waste Treatment and Immobilization Plant* (Reference 3), stated as follows:

> …the presence of a large solids inventory could have a detrimental effect on the vessel level instrumentation, which is required to control the PJMs.

This concern was addressed in Reference 4, providing a description to the DNFSB of the planned resolution, including full scale testing of PJM technology for use at WTP. Work activities completed after this letter led to a change in strategy provided in Reference 5, including testing planned to address PJM control issues. Acceptance of the proposed strategy was provided in Reference 6, noting that closure of the issue with control of PJMs remained unresolved:

> Accumulation of solids that interfere with the pulse jet mixer control system, causing frequent overblows (discharge of air from the pulse jet mixer) that may lead to equipment damage…

The DNFSB has worked closely with the DOE to oversee testing of prototypic PJMs, as discussed in the *27th Annual Report to Congress* (Reference 1).

BNI has now completed the testing of prototypic PJMs in vessels settling solids, confirming the control system can adequately perform its function by operating PJMs in support of mixing functions while preventing overblows and impact to the vessel structure and ventilation system. In addition, results of structural analysis of PJM overblow events in high-solids vessels show that overblow is not a concern and will not cause equipment damage, even if PJM overblows were a normal occurrence (millions of cycles). The Attachment was prepared to address the concerns raised by the DNFSB staff in further detail.

Based on this information and on DOE acceptance of the prototypic testing of PJM control and operation of two WTP vessels and structural analysis of PJM vessels with high solids discussed in the Attachment to this memorandum, BNI considers DNFSB and DOE concerns, as stated above, are resolved and no longer present an impediment to the resumption of design and engineering in the PT Facility.

If you have any questions, please contact me, or you may contact Langdon Holton, Technical Authority, Waste Treatment and Immobilization Plant Project, (509) 373-9202.

B. T. V

Brian T. Vance
Manager

WTP:LKH

Attachment

19-WTP-0041

RESOLUTION OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD CONCERNS RELATED TO CONTROL OF PULSE-JET MIXER OVERBLOW AND IMPACT TO VESSELS AT THE WASTE TREATMENT AND IMMOBILIZATION PLANT

(20 pages including cover page)

Attachment
19-WTP-0041

Resolution of Defense Nuclear Facilities Safety Board Concerns Related to Control of Pulse-Jet Mixer Overblow and Impact to Vessels at the Waste Treatment and Immobilization Plant

Statement of Issue

The Defense Nuclear Facilities Safety Board (DNFSB) identified several concerns related to the design of the pulse-jet mixing systems in the Waste Treatment and Immobilization Plant (WTP) (DNFSB, 2010). One concern was associated with the ability to control pulse-jet mixers (PJM) and prevent frequent overblows. The concern was stated as follows:

> ...The presence of a deep sediment layer may also have a detrimental effect on the performance of bubbler systems used to measure the tank level and average density in the vessels. The tank level and average density are inputs to the calculation of the drive time of the pulse jet mixers, which is relied upon to prevent overblows. The cumulative effect of many overblows could result in the material failure of components internal to process vessels located in black cells.
>
> ...the presence of a large solids inventory could have a detrimental effect on the vessel level instrumentation, which is required to control the PJMs.

The U.S. Department of Energy (DOE) responded to the mixing concerns in a letter dated May 17, 2010, from I.R. Triay to P.S. Winokur (DOE, 2010). This letter outlined a strategy for resolving questions associated with the use of PJM technology at WTP, especially in vessels containing high solids concentration wastes. With regard to the PJM control concern, the response committed to:

> Develop design methods that demonstrate that system performance can meet functional requirements with bounding design basis inputs.

This resolution strategy was changed to an approach based on full-scale testing of PJM control and operation (DOE, 2013). This strategy was recognized as an acceptable approach by the DNFSB through closure of Recommendation 2010-2 (DNFSB, 2014). However, Recommendation 2010-2 also noted that the underlying safety-related pulse-jet mixing issues remained unresolved, including:

> Accumulation of solids that interfere with the pulse jet mixer control system, causing frequent overblows (discharge of air from the pulse jet mixer) that may lead to equipment damage...

In April 2017, the DNFSB issued the *27th Annual Report to Congress* (DNFSB, 2017), which stated that the DNFSB continues to work closely with the DOE to oversee resolution of the issue associated with PJM control, which includes full-scale prototypic testing.

Summary

The strategy to resolve the DNFSB concern regarding PJM control and overblow used the following:

- Full-scale vessel testing of the PJM control system using two vessel designs tested using relevant waste simulants to demonstrate PJM control system adequacy
- Evaluation of the potential impact on the vessel internal structure by completing structural analysis on two vessel designs; the conceptual design of a new proposed standard high-solids vessel (SHSV) design and a vessel design being fabricated for installation in the High-Level Waste Facility (RLD-VSL-00007/8).

The full-scale vessel testing used two vessel designs: a prototype of a HLW Facility vessel (e.g., RLD-VSL-00008T) and the SHSV prototype. This testing demonstrated that the as-designed level and density measurement controls can be effectively used to control the PJM drive time and prevent PJM overblows[1] in a broad range of fluids. The testing information has been summarized in technical reports providing a basis to prepare guides to be used to finalize the plant designs for the HLW and Pretreatment (PT) facilities.

Detailed structural analysis on the SHSV and RLD-VSL-00007/8 design showed that repeated overblows, over millions of cycles, will not result in material failure of components internal to SHSV's proposed for implementation in the PT Facility black cells and placement of RLD- VSL-00007/8 in the HLW Facility's wet process cell.

Based on this summary, DOE considers that the DNFSB concerns, are resolved and the work completed will support the resumption of PJM vessel design and engineering in the HLW and PT facilities.

Background and Actions Taken

The strategy to resolve DNFSB concerns related to control PJM overblow and potential structural impact from overblows involved full-scale prototypic PJM vessel testing to develop and demonstrate PJM control and structural analysis of PJM vessel designs (SHSV and RLD-VSL-00007/8) to demonstrate that PJM overblows do not result in structural damage.

Description of the Pulse-Jet Mixer Control System

PJM is the mixing technology selected for vessels located in non-maintainable areas of the HLW and PT facilities. A schematic of the PJM and instrumentation and control system design is depicted in Figure 1.

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[1] A overblow is the uncontrolled release of pulse-jet mixer drive air from the pulse-jet mixer discharge nozzle. An overblow is not desired because of aerosols generated at the liquid surface due to gas release and the hydrodynamic load on the vessel structure.

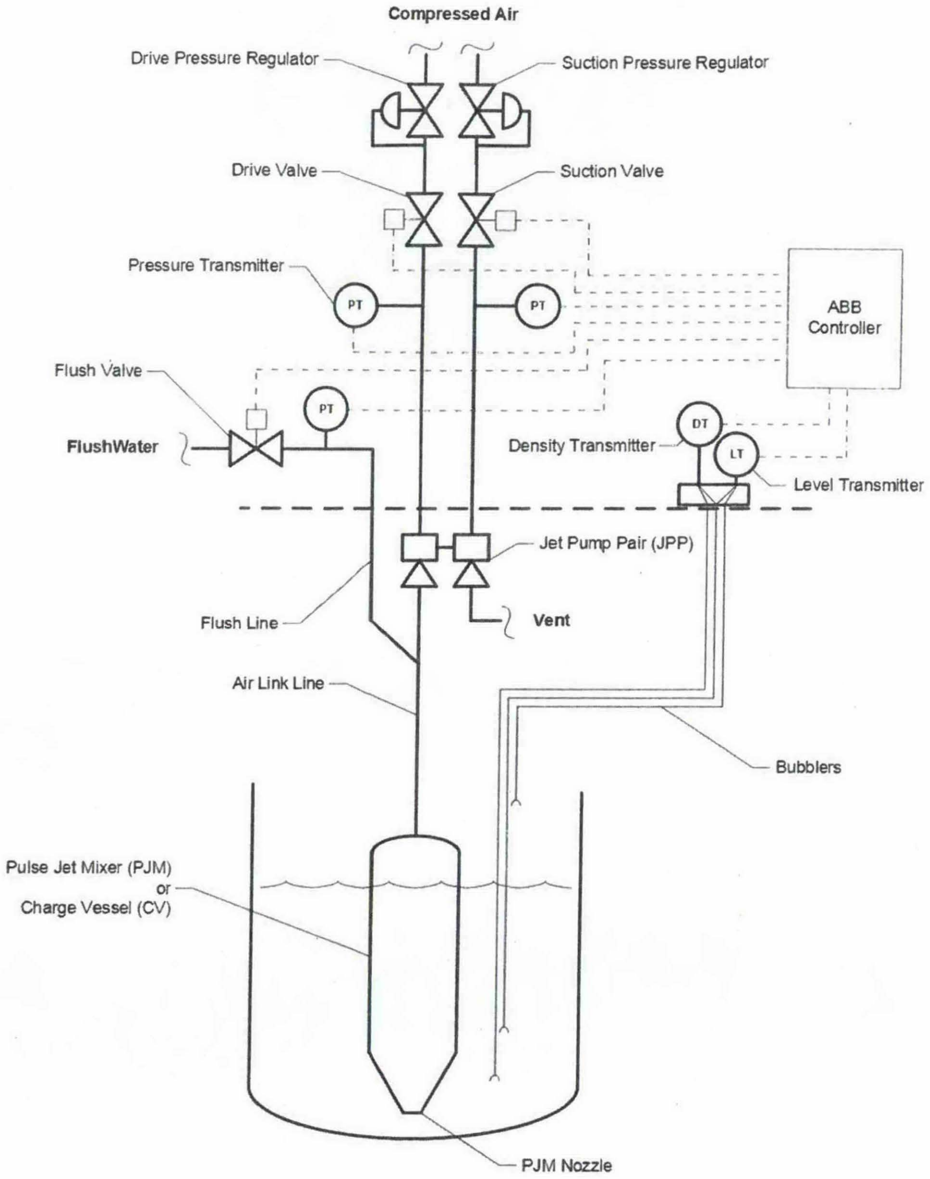

Figure 1. Schematic of the Pulse-Jet Mixer Control System.

The PJM system is comprised of a jet mixer tube, jet pump pair (JPP), and control instrumentation[2]. The PJM tube is submerged in the waste solution. The lower end of the PJM tube converges to a PJM jet nozzle. The upper end of the PJM is connected to a JPP by means of an air link line. The JPP provides motive air used to impart suction, discharge, and vent phases resulting in waste solution movement out from the PJM tube (see Figure 2), which constitute an operating cycle of the pulse tube. Multiple, successive operating cycles are necessary to adequately mix the vessel contents.

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[2] The dashed line in Figure 1 represents where PJM system control components are typically located. Below the dash line the process vessel, JPP, air link line and bubblers are located in an inaccessible space such as a black cell. Above the dashed line, detectors, transmitter, control instrumentation, and air system valves are located in an accessible/limited occupancy space.

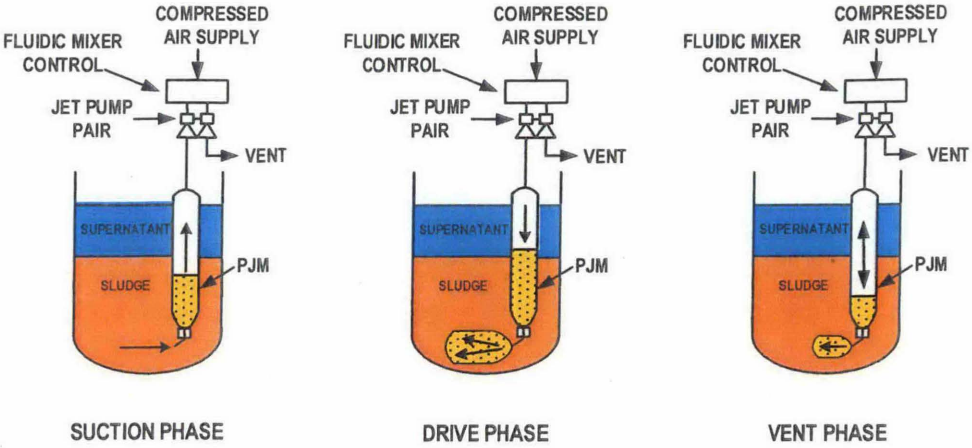

Figure 2. Operating Phases of Pulse-Jet Mixer.

There have been numerous studies investigating mixing performance since PJM incorporation into the WTP design. PJM mixing performance and the reverse flow diverter sampling system in a test vessel having a diameter of 3.96 m were investigated (PNWD-3054/BNFL-RPT-048, *Demonstration and Optimization of BNFL's Pulsed Jet Mixing and RFD Sampling Systems Performance Using NCAW Simulant*). Using simulant containing up to 36 wt percent insoluble solids, they studied the effects of varying the number of PJMs operating and the operating frequency in the solids suspension. The 3.96 m diameter test vessel was used to evaluate the ability of the ABB[3] and Triconex[4] control systems to detect when the pulse tube becomes full (charge vessel full [CVF]) and detect drive overblows (PNNL-18267/WTP-RPT-179, *PJM Controller Testing with Prototypic PJM Nozzle Configuration*). They found that both controllers were not capable of detecting drive overblows for conditions in which CVF detection is not possible (i.e., low vessel levels and high-density fluid conditions). There has been testing of the PJM performance conducted at relatively small scales with the objective of applying the mixing behavior obtained at small scale to large scale. Experimental and analytical studies were conducted identifying the dimensionless parameters critical for scaling the PJM system and models were developed for predicting mixing behavior at full scale (PNWD-3551/WTP-RPT-113, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries* and PNNL-18098, *Pulse Jet Mixing Tests with Noncohesive Solids*). Although there are several studies on PJM mixing performance, research addressing some of the challenges in controlling PJM operations, to support adequate mixing, is scarce. PJM controls rely on the ability of the control algorithm to accurately detect when the pulse tube becomes full by monitoring the pressure change in the PJM tube. However, for relatively tall PJMs expected to operate at low vessel levels and high-density fluid conditions, the pressure change associated with the state of PJM full or CVF cannot be detected. Not being able to detect CVF could prevent accurate determination of the PJM drive time (i.e., the time air is added to the PJM during the drive phase). Additional control strategies were required to continue PJM operation when CVF was no longer detectable.

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[3] ABB Ltd, Zurich, Switzerland.

[4] Schneider Electric brand.

Pulse-Jet Mixer Operation

Figure 2 depicts the PJM operating phases. There are three phases during the PJM operation:

- *Suction phase*: A vacuum is applied to refill the PJM with liquid-solids waste.
- *Drive phase*: Liquid-solids waste filled PJM is forced to discharge a predetermined portion of the tube content at a high velocity through the nozzle.
- *Vent phase*: Pressure supplied to the PJM is vented to the pulse-jet ventilation system.

The end of the vent phase marks the end of an operating cycle. When the fluid level and density conditions allow for the suction set pressure to fill the PJM, the CVF control mode is typically used.

In CVF mode, the control algorithm monitors the decreasing pressure in the air link line as the JPP draws the fluid up the PJM. As the fluid fills the PJM and enters the air link line, a sudden pressure drop occurs at which point CVF is detected and the suction phase is ended. However, as the vessel fluid level becomes relatively low during a vessel transfer scenario, the refill time in the suction phase increases and the rate of change in the pressure signal, which is necessary to terminate the suction phase, is no longer detectable.

Prototypic Testing of Pulse-Jet Mixer Control and Operation

The following three test phases of full-scale prototypic PJM control systems were designed and completed to resolve remaining issues associated with the PJM control system design:

- *Phase 1*: PJM control system testing focused on evaluating performance by mixing low solids fluids (less than 5 w percent) using a vessel prototypic of the HLW Facility and PT Facility. The vessel prototype was of an HLW vessel (e.g., RLD-VSL-00008T/ RLD-8T). This vessel is a four-PJM mixed vessel with a nominal diameter of 12.5 feet and a batch volume of approximately 16,000 gallons.
- *Phase 2*: PJM control system testing focused on the impact of fast settling solids in low viscosity fluids (e.g., 1 to 10 centipoise) and higher viscosity fluids (up to approximately 30 centipoise and 30 pascal) on control system performance using the HLW Facility vessel prototype (RLD-8T).
- *Phase 3*: PJM control system testing used a new proposed larger capacity PJM mixed vessel design proposed for potential use in the PT Facility, termed the SHSV. This vessel is equipped with 6 PJMs and 13 air-spargers used to promote mixing. SHSV internal diameter is 16 feet, vessel height of 23 feet and batch volume of 22,000 gallons.

The key conditions for the RLD-8T and SHSV designs are shown in Table 1.

Table 1. Radioactive Liquid Waste Disposal vessel and Standard High-Solids Vessel and Design Differences.

Key Physical Property	Radioactive Liquid Waste Disposal (RLD-8T)	Standard High-Solids Vessel (SHSV)
PJM Height	10'	16'
Max Slurry Density	1.2 g/mL	1.5 g/mL
Vacuum Required for each PJM	~ 12 ft H_2O	~ 24 ft H_2O
Heel Volume	Sufficient to fill all PJMs	Insufficient to fill all PJMs

H_2O = water.
PJM = pulse-jet mixer.
SHSV = standard high-solids vessel.

A wide range of design and operational issues associated with the control of PJMs were evaluated and reported on after each test phase. The topic focusing on "Drive Time Determination and Coordination" documents the successful results of using bubbler indicated level and density as inputs to the PJM control approach to prevent overblow. Topics addressed are identified below:

- Drive time determination and coordination (design issue that addresses the DNFSB concern on PJM control on overblow and potential structural damage)
- Confirm jet pump pair selection, air link sizing, and development of operating data (design issue)
- Interfacing systems requirements and operating data gap resolution (design issue)
- PJM nozzle velocity accuracy and precision (commissioning issue)
- PJM system maintenance (operations issue).

Control System Design Development and Testing

The PJM control system is designed to adjust the PJM drive time (e.g., the time air is added to the PJM during the drive phase, see Figure 2) to provide a total PJM stroke length measured as height of fluid that both supports mixing and prevents overblow. This is accomplished by adjusting the drive time based on the vessel level and fluid density indicated by the bubbler instrumentation. PJM drive time is variable: it tends to be longer (i.e in seconds) until CVF is detected, and will be shorter when vessel level is lower and CVF is difficult to detect. Each PJM has its own control system (see Figure 1), but their controllers are connected to a master control system that coordinates multiple PJMs to synchronize the PJM drive phases.

Prototypic software was developed prior to testing based on guides provided by NuVision Engineering, Inc., WTP experience in implementing NuVision Engineering, Inc.'s concepts, and an evaluation of the physical limits of the vessel configuration as it relates to PJM operation. The considerations of physical limitations included heel volume available to fill PJMs at low levels, fluid densities, vacuum achievable with a JPP, etc.

Testing of the Radioactive Liquid Disposal 8T vessel in Phase 1 and Phase 2 was not impacted by physical limits of that configuration. The increase in vessel size, PJM size, range of operating levels, and liquid densities introduced additional considerations for control of the SHSV.

The controls developed for the SHSV required three modes of operation to address both the vacuum required to fill a PJM and the heel volume available to fill PJMs. The three modes are depicted on Figure 3 which relates the vessel fill level and density of the fluid. The software is designed to transition between each mode based on the level and density indicated by the bubblers. The transition points can be estimated prior to commissioning, but are verified and adjusted as necessary during commissioning.

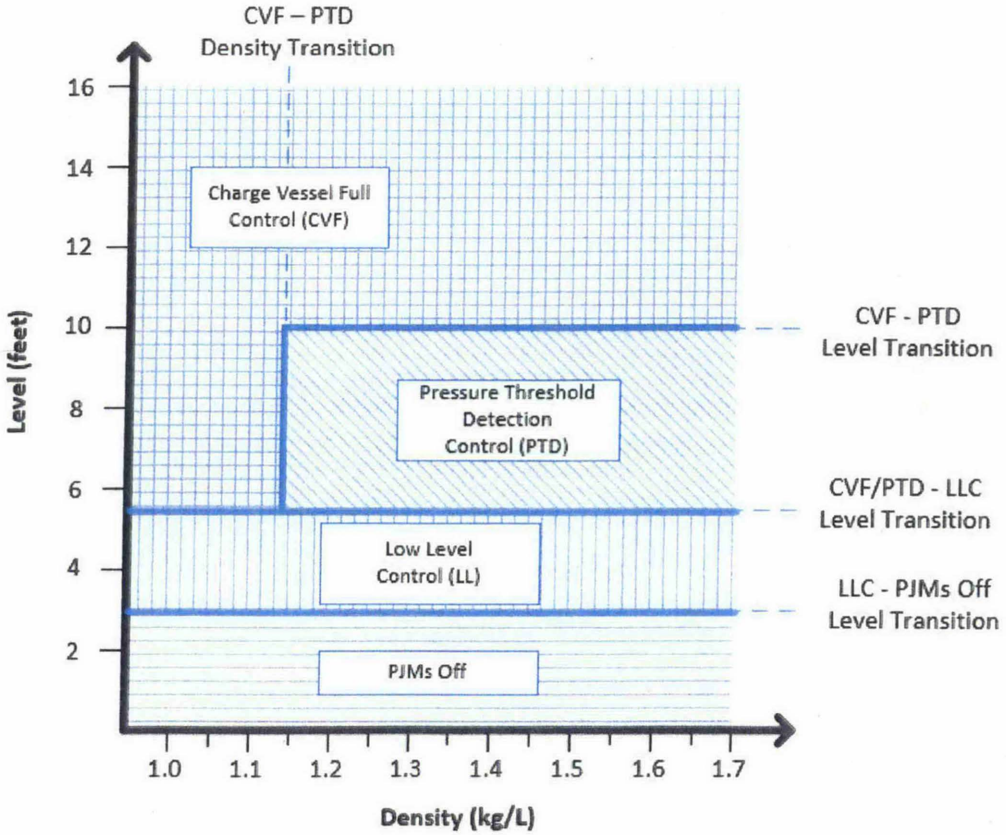

Figure 3. Standard High-Solids Vessel Control Modes.

Charge Vessel Full Mode

The typical CVF signal indicating the PJM is full is used as a trigger to the end the suction phase. Synchronization is achieved with a 'Drive Pause,' by venting each PJM after the PJM is filled and initiating (i.e., synchronizing) the drive phase after the last PJM has filled. The drive time is adjusted each cycle based on the indicated level and density in the vessel and ranged from approximately 15 to 20 seconds for the SHSV. All six PJMs are operated if the indicated level is high enough to allow six PJMs to fill. Otherwise, three PJMs are operated alternately cycle to cycle.

Note: CVF was the only mode required to operate the radioactive liquid disposal vessel (RLD- 8T) in Phase 1 and Phase 2 tests.

Pressure Threshold Detection Mode

The pressure in PJM reaching a commissioned threshold (indicating enough vacuum has been developed to fill the PJM) is used as the trigger to initiate the drive phase. Synchronization is achieved by holding all PJMs in the suction phase until all PJMs have reached the target threshold vacuum pressure. The drive time is constant and commissioned to 15 seconds for the SHSV. All six PJMs are operated if the indicated level is high enough to allow six PJMs to fill; otherwise, three PJMs are operated alternately cycle to cycle.

Low Level Mode

The PJMs are partially filled during the suction phase and PJM aspiration is prevented by initiating the drive phase after low-level set point is reached based on the bubbler indicated level. All PJMs are driven together once the vessel level reaches the set point. The drive time is constant and commissioned to be five seconds for the SHSV.

Bubbler Layout

A multi-level bubbler layout is incorporated into the SHSV design, as shown on Figure 4. This layout mitigates the impact of settling solids on the bubblers low in the vessel by including bubblers higher in the vessel for conditions of high solids loading in a full vessel. The lower bubbler is used as the vessel is emptied. This arrangement allows for effective indication of vessel level and density over a wide range of operating conditions. The control modes and number of PJMs operating described above in the three modes: CVF, Pressure Threshold Detection, and Low Level in relation to the bubbler level are summarized in Figure 4.

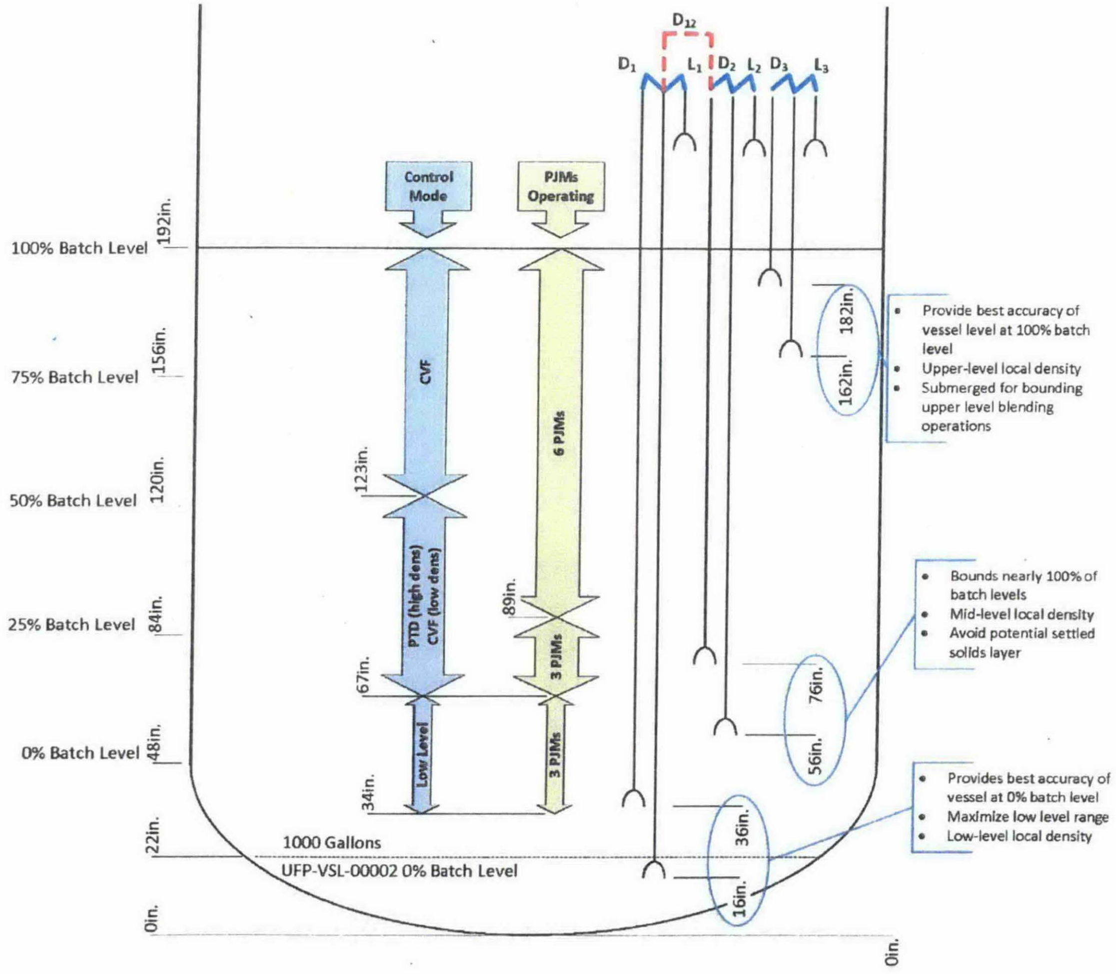

Figure 4. Bubbler Layout.

Summary of Pulse-Jet Mixer Control System Testing Results

Testing completed in Phase 1 and Phase 2 using the RLD-8T vessel demonstrated success in using level and density indicated bubbler instruments to control PJM operation in CVF mode over a wide range of slurry properties using six simulants, including water, 1.2 g/ml density simulant swith no solids, non-Newtonian simulants up to 30 Pa and 30 cP, and undissolved solids in water between 6 wt percent and 30 wt percent settling solids.

Phase 3 testing is directly applicable to WTP design as it tested the prototypic SHSV design, including high solids operation over a wider range of vessel levels than tested in Phase 1 and Phase 2. Phase 3 testing included four simulants including water, 1.5 g/ml density simulants with no solids, non-Newtonian simulants up to 30 Pa and 30 cP, and undissolved solids in water between 15 wt percent and 30 wt percent settling solids.

The results from Phase 3 testing indicate that the PJM stroke can be controlled to support mixing and prevent overblow using the bubbler instrumentation to indicate level and density in high-solids vessels at WTP in order to adjust PJM drive time. The testing included over 2,500 individual PJM cycles with no overblows using the prototypically developed control system.

This is a conservative estimate, as it does not include commissioning runs, dry runs, operator training runs, etc. One unplanned overblow was observed during the course of Phase 3 testing. However, it was due to a solenoid valve failure caused by water in the test facility instrument air lines and not the prototypic control system or prototypic valves and instrumentation.

The multi-level bubbler system was shown to effectively measure vessel level and vessel density in order to determine the control modes of operation for adjusting PJM drive time. This allowed for effective control of the PJM stroke, as well as providing density gradient information in the SHSV that can be used to inform plant operations staff on the state of the process fluid in the vessel.

The following studies were issued to document the results of testing for use in developing the PJM control design (key reports associated with issue identified by the DNFSB are shown in **bold**):

- Phase 1 test reports:
  - **24590-WTP-ES-ENG-15-025, *Informal Study of Drive Time Determination for Pulse Jet Mixers with Phase 1 Test Data from 13' FSTF***
  - 24590-WTP-ES-ENG-15-009, *Phase 1 PJM Controls Testing –Confirming JPP Selection, Air link Sizing and Routing*
  - 24590-WTP-ES-ENG-15-031, *Study for Pulse Jet Mixer Controls Interface Gaps Phase 1 Test Summary*
  - 24590-WTP-ES-ENG-15-012, *Nozzle Velocity Accuracy and Precision (Commissioning)*
- Phase 2 test reports:
  - **24590-WTP-ES-ENG-16-015, *Phase 2 Drive Time Determination for Pulse Jet Mixers at the Full Scale Test Facility***
  - 24590-WTP-ES-ENG-16-016, *Phase 2 PJM Controls Testing – Confirming JPP Selection, Air link Sizing and Operating Data*
  - 24590-WTP-ES-ENG-16-013, *Informal Study of Pulse Jet Mixer Controls Interface Gaps Phase 2 Test Summary*
  - 24590-WTP-ES-ENG-16-014, *Informal Study of Phase 2 Pulse Jet Mixer Controls Nozzle Velocity and Precision (Commissioning)*
  - 24590-WTP-ES-ENG-16-019, *Informal Study for Phase 2 Pulse Jet Mixer Controls System Maintenance (Flushing Systems)*
- Phase 3 test reports:
  - **24590-WTP-ES-ENG-17-010, *Drive Time Determination for Pulse Jet Mixers at the Full Scale Test Facility***
  - 24590-WTP-ES-ENG-17-002, *Phase 3 PJM Controls Testing –Confirming JPP Selection, Air link Sizing and Operating Data*

- 24590-WTP-ES-ENG-17-007, *Pulse Jet Mixer Interface Gaps Phase 3 Test Summary*
- 24590-WTP-ES-ENG-17-005, *Pulse Jet Mixer Controls Nozzle Velocity Accuracy and Precision (Commissioning)*
- 24590-WTP-ES-ENG-17-013, *Phase 3 Pulse Jet Mixer Controls System Maintenance (Flushing Systems).*

DOE provided briefings to DNFSB staff on the results of the Phase 1, Phase 2, and Phase 3 testing results on October 27, 2015; May 3, 2017; and October 5, 2017, respectively.

Application of Pulse-Jet Mixer Vessel Testing Results

The successful demonstration of the prototypic control system in operating PJMs in a high-solids vessel was used to support development of design guides for use in developing PJM designs across WTP. Smaller vessels will likely require only one control mode, while larger capacity vessels will require the three control modes developed to support the SHSV design, as depicted conceptually on figure 5.

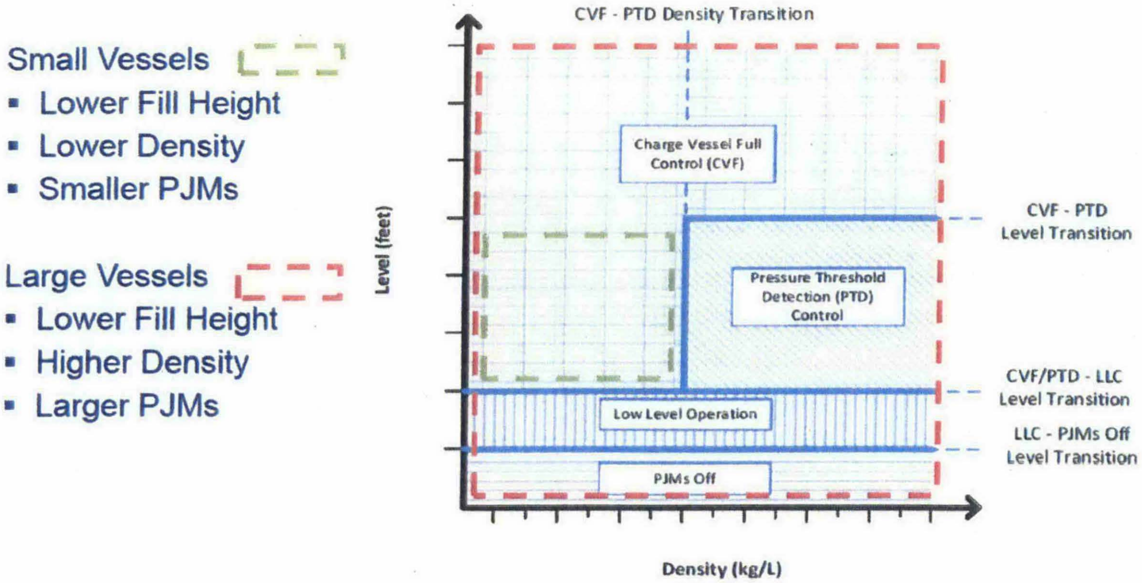

Figure 5. Waste Treatment and Immobilization Plant Application of Pulse-Jet Mixer Control Modes.

Preparation of Design Guides

Based on testing information, three design guides have been prepared to complete the design of the PJM systems for the WTP.

24590-WTP-3DG-J42W-00001, Pulse Jet Mixer Controls and Instrumentation, dated December 21, 2017

Design guide 24590-WTP-3DG-J42W-00001, *Pulse Jet Mixer Controls and Instrumentation*, describes the facility design, component selection, and control strategy in sufficient detail to aid in the final control strategy selection of each vessel's PJM system. Guidance within this document includes requirements and recommendations for selection of the following system components:

- Pressure transmitters
- Bubblers
- Pressure regulators
- On/off control valves.

Additionally, this guidance for the design of software requirements related to the control of the PJMs is provided. The guide discusses design considerations related to the suction, drive, ventilation, and flushing of the systems to aid in the development of those requirements. This includes guidance on the physics of PJM operation to help determine the appropriate methods of control for each vessel.

24590-WTP-3DG-M67W-00001, Pulse Jet Mixer Mechanical Design Guide, dated December 21, 2017

Guide 24590-WTP-3DG-M67W-00001, *Pulse Jet Mixer Mechanical Design Guide*, provides guidance to engineering regarding the following major topics:

- Mechanical considerations
- Design requirements and recommendations or considerations for air link piping, valves, and mechanical equipment for the PJM mixing system
- Performance characterizations of the PJM mixing system that affect the interfacing system engineer's or affected engineering discipline's design efforts
- Air link line flush maintenance
- JPP selection and managing subcontractor NuVision Engineering, Inc. work scope and deliverables
- Future development for in-house PJM cycle analysis for JPP mechanical datasheet system data.

24590-WTP-3DG-G01W-00001, Pulse Jet Mixer Controls Commissioning, dated January 17, 2018

Design guide 24590-WTP-3DG-G01W-00001, *Pulse Jet Mixer Controls Commissioning*, is to assist controls and instrumentation and mechanical systems engineers in determining the initial PJM control tunable parameters and system constants for commissioning a pulse-jet mixed vessel within the WTP facilities. Additional information on selecting control logic can also be found in this guide. Determining and verifying the PJM control tunable parameters and system constants is an integral part of commissioning a PJM mixed vessel and, therefore, the commissioning process is also outlined within this guide.

Structural Analysis of Pulse-Jet Mixer Vessels with High Solids

Structural Load Cases and Over Blow

The structural analysis of vessels is required to consider multiple load cases and combinations of load cases to evaluate the structural integrity of the vessel, which include:

- Normal design loads
  - Deadweight, external loads
  - Buoyancy
  - Internal and external design pressures
  - Hydrodynamics, PJM thrust
  - Single over blow and multiple over blow
- Occasional loads (not routine and are identified as unique design conditions)
  - Seismic earthquake, design basis earthquake
  - Sloshing loads
  - Hydrogen in piping and ancillary vessels
- Operational loads (fatigue)
  - Thermal expansion loads
    - Steady state average wall temperatures
    - Steady state thru-wall temperature gradients
    - Transient temperature profiles
  - Cyclical operating loads
    - Fill/Empty
    - Operating pressures
    - Operational hydrodynamic loads
    - Single over blow and multiple over blow.

The over blow loads are one of many loads evaluated as both a "normal design load" and in fatigue analysis. The over blow load is divided into three unique phenomena impacting the vessel structure (24590-WTP-MVC-50-00011, *Engineering Calculation, Pulse Jet Mixer Overblow Vessel Loads*):

- *Acoustic Pressure and Frequency*: Attributed to the transition of the air-fluid surface across the PJM nozzle plane. The load consists of an acoustic pressure (2 Hz to 200 Hz) developed within the first 200 milliseconds (ms) of the event. These acoustic loads act in both a lateral/horizontal direction and vertical direction and the magnitude is based on approximately 1,350 over blow tests.

- *Bubble Rise*: Occurs after the bubble has fully formed at the PJM nozzle and rises to the surface hitting any pipe or supports along the way, impacting the structure with 1.7 psig in the vertical direction, directly over the over blowing PJM, within the PJM diameter zone of influence, and projected areas of components in the zone.

- *Bubble Expansion*: Rapid expansion of the bubble from the PJM nozzle. This fluid acceleration generates hydrodynamic loads acting on the vessel internals. The loading applied to structural analysis represents the peak loading from this event with an associated dynamic load factor based on the Independent Expert Review Team recommendation (CCN: 278573, "Independent Expert Review Team Assessment of the Hanford Tank Waste Treatment and Immobilization Plant Design Analysis of Selected Black Cell Vessels with Pulse Jet Mixing, CH2M Hill and Bechtel Engineering, April 2015").

Both cases of a single overblow, overblow from a single PJM, and multiple overblow, overblow from multiple PJMs at the same time are considered for each overblow phenomena (24590-WTP-MVC-50-00011 and 24590-QL-HC9-WA49-00001-05-00002, *Subcontractor Submittal, Pulse Jet Mixer Overblow Testing for Assessment of Loadings During Multiple Overblows*):

- *Acoustic Pressure and Frequency*: The acoustic loads are determined based on the most conservative test results considering both single and multiple overblows. Therefore, there is no need to superpose the loads to model a scenario where multiple PJMs overblow simultaneously (multiple overblow event), since it has been considered in determining the applied load.
- *Bubble Rise*: The bubble rise load is applied per PJM independently and combined for the multiple over blow event.
- *Bubble Expansion*: The bubble expansion loading accounts for the single and multiple over blow events separately. For the bubble expansion loading, the multiple over blow event occurs when the over-blow loading from five of the PJMs strike the sixth at the same time. This does not necessarily mean five PJMs had an over blow condition at the same time, but that the bubbles reach the remaining PJM simultaneously.

Standard High-Solids Vessel Results

The conceptual design for the SHSV was evaluated in accordance with WTP design guides for design, seismic, and fatigue loads, including single overblow and multiple overblow, using Finite Element Analysis (ANSYS Version 13). The fatigue analysis was completed using the ASME VIII Division 2, *Design & Fabrication of Pressure Vessels*, structural stress method, as recommended by the Independent Expert Review Team in CCN: 278573.

Results of the analysis show that multiple simultaneous PJM overblows are not a concern for the SHSV and will not cause equipment damage. This analysis is documented in 24590-WTP-ES-ENG-15-003, *Engineering Study, Standard High Solids Vessel Design (SHSVD) Structural Evaluation Study*. Over blow loads were considered a normal loading condition, occurring with each PJM cycle, estimated to be 10 million cycles. Each of the three over blow phenomena created stresses less than 10 percent of the allowable stress for the material, while other loads result in stresses that are 44 percent of the allowable stress.

Radioactive Liquid Waste Disposal Vessel Results

The original internal PJM support design for the RLD-VSL-00007 and RLD-VSL-00008 vessels are a close representation of vessel designs found onsite. As directed by CCN: 283113, a reanalysis of these vessels was performed to incorporate the Independent Expert Review Team recommendations per CCN: 278573, more specifically the implementation of ASME VIII Division 2, structural stress method within the fatigue analysis. The following physical modifications were required to meet the criteria of a PJM over blow every PJM operational cycle:

- A thicker integral reinforcing pad was required for the pump suction nozzle
- Internal pipe supports were added to support the dipped piping
- Wall thickness of the PJM was increased
- Internal support welds were contoured to reduce fatigue stress concentrations.

With these modifications and aligning PJM operational cycles to mixing requirements the final results show that over-blow is not a concern for the RLD-VSL-00007 and RLD-VSL-00008 vessels. This analysis is documented in 24590-HLW-MVC-RLD-00014, *RLD-VSL-00007 & RLD-VSL-00008 Vessel Stress Analysis with ANSYS.*

Summary and Conclusions

The strategy to resolve the issues on PJM control as identified by the DNFSB involved:

- Full-scale prototypic testing of PJM control and operations
- Structural analysis of PJM vessels.

The basis to complete PJM control system design for the HLW and PT facilities has been established based on full-scale prototypic testing and analysis of the two vessel designs. Test results demonstrate the control system is capable of preventing over blows over a range of conditions, including settling solids and using level and density indicated by bubbler instrumentation.

Structural analysis of the SHSV and RLD-VSL-00007/8 has shown that the structural integrity of these PJM vessels are not impacted by over blow loads at or above 10-million cycles.

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