Report to Defense Nuclear Facilities Safety Board (DNFSB) on Critical Information Requested in DNFSB Letter dated March 24, 2004

The following information identifies each of the DNFSB critical information requests and provides a U.S. Department of Energy (DOE) response.

DNFSB Information Request No. 1:

Identify the critical information needed to design mixing systems for non-Newtonian high-level wastes.

DOE Response:

The critical information for mixing design are the design basis rheology which establishes limits on waste receipt and revised hydrogen generation rate calculations. These are used in equipment sizing and for defining the operational modes of the mixing systems which establish normal and standby equipment sizes and controls system, and control logic requirements, and time required to generate flammable gas within these vessels. Also needed are limitations on equipment such as maximum vessel levels, which establish instrumentation and protective features, and mixing requirements that are needed to support adequate vessel heat transfer.

Other critical information needed to design mixing systems for non-Newtonian high-level wastes includes the mixing equipment specifics: the number of PJMs per tank, the PJM nozzle diameter, the PJM body diameter, the PJM nozzle velocity, PJM air demand, the number of sparge tubes, the air flow per sparge tube, the spacing and location of the sparge tubes, and the recirculation pumps used in the design. This information is developed from testing programs and analysis based on design basis rheology. The equipment information defines the support system requirements including the controls systems, instrumentation, air flow rates, line and tubing sizes, compressed air systems (including important to safety backup power and compressed air systems), anti-foaming capabilities, electrical power demands, and ventilation system capacities. The definition of these design features are discussed in the physical modeling report provided as Attachment 1 of this package. The report documents the data and scale-up methodology used to select the mixing systems for the non-Newtonian vessels in the Pretreatment (PT) facility. These designs are considered bounding in that they include the set of PJMs, recirculation pumps, and spargers. Although refinement of the operating strategies is likely, no further equipment will need to be added to these tanks to achieve the mixing and gas release requirements. These designs, also termed the March 2004 designs, are based on data developed in a testing program managed by the WTP Research and Technology (R&T) organization using resources at Battelle's Pacific Northwest Laboratory and the Savannah River Technology Center (SRTC).

Several mixing systems have been identified which will accomplish the needed mixing and hydrogen control. These include combinations of pulse jet mixers (PJMs), recirculation systems, and spargers. The current conceptual design for planning purposes is described in Attachment 4. Spargers are tubes that provide for a low volume of air to be bubbled through the liquid, thereby providing mixing via an air lift as the bubbles rise. From these considerations, designs have been defined that meet the mixing and gas removal requirements.

DNFSB Information Request No. 2:

Identify the quality and adequacy of test data being used to provide the information required by comment/issue number one.

DOE Response:

The test data developed by the two laboratories that underpin the selected designs have been reviewed by BNI in accordance with the approved Quality Assurance Program as well as undergone a quality review within the respective testing organizations. DOE considers the test data to be of high quality. A report of that test data is contained in Attachment 1. This report provides additional information on mixing system design, the quality of the test data, relevant mixing properties of the non-Newtonian high-level waste, and the use of surrogate test materials to bound actual waste behavior. The quality review of Attachment 1 for the PT facility confirmed that the design and operating strategies specified in Attachment 2 remain consistent with the test data. This report demonstrates that the tanks will be mixed and release gas generated by the wastes under normal and upset conditions.

DNFSB Information Request No. 3:

Discuss the relevant mixing properties of non-Newtonian high-level waste.

DOE Response:

The waste slurries delivered to the WTP are expected to be essentially Newtonian. The washing and leaching operations conducted within the Pretreatment Facility convert the waste to non-Newtonian slurries. Samples from waste tanks C-104, AZ-101, and AZ-102 have been pretreated in the laboratory and their flow properties measured. Based on these measurements, a design slurry rheology bases of 30 Pa Bingham yield stress and 30 cP consistency upper bound were established. The waste data, along with the behavior of the clay simulant are shown in Figure 3.2 of Attachment 1.

DNFSB Information Request No. 4:

Discuss the acceptability of using surrogate materials to bound in-situ waste behavior.

DOE Response:

The acceptability of using surrogate materials to bound in-situ waste behavior was established through the analysis of actual wastes, tests of simulant materials, and consultant input. For initial testing, Laponite, a synthetic clay, was used. Laponite is transparent and the yield stress can be adjusted via the composition. These properties were highly advantageous to evaluate mixing systems and mixing effectiveness. Laponite yield stress however is significantly reduced after mixing (shear thinning behavior) therefore a kaolinite/bentonite clay mixture was used to simulate high level waste in the actual tests which determined and demonstrated mixing system effectiveness. Clay mixtures are well known simulants for non-Newtonian materials. A clay mixture was selected for testing which had a 25-30 cP. This clay mixture had a weight percent solids of 25-30%. The expected weight percent solids in the high level waste material is expected to be in the 15-20% weight percent range. The yield stress of 30 Pascals has been estimated to bound 70-80% of the material that will be fed to the WTP if these wastes are concentrated to 20 weight % solids in the Pretreatment facility. By measuring pretreated waste samples prior to processing, the Pretreatment operating parameters will be established for each waste tank to ensure that the waste remains less than or equal to 30 Pa. Rheology values will be included within the WTP Technical Safety Requirements document to ensure the extent of concentration within the PT facility is below the rheological design basis. It should also be noted that testing was done at broad range of yield stress levels (5 to 40 Pa clay simulants) to ensure adequate system performance. The mixed clay simulant was recommended by an international panel of mixing experts:

- Dr. Edward J. Lahoda – Westinghouse (Chair)
- Dr. Arthur W. Etchells – DuPont Consulting (retired DuPont)
- Dr. Alvin Nienow – University of Birmingham, England
- Dr. David Dickey – MixTech Consultants (retired Chemineer, Inc.)
- Dr. Richard Calabrese – University of Maryland
- Dr. Michael R. Poirier – Savannah River Technology Center

The mixing panel was convened in October, 2003 to review the PJM program and concluded that the clay simulant provides the best representation of waste slurry rheology. This simulant bounds the waste behavior for the following reasons:

- The mixed clay simulant used for the final mixing tests exhibits Bingham plastic behavior, or a constant consistency (viscosity) at increasing shear rates (better mixing). The properties of the actual pretreated wastes examined, however, are Herschel-Bulkley in nature. Herschel-Bulkley materials are shear thinning, i.e. the consistency is reduced at higher shear rates. Therefore, the clay simulant exhibits significantly higher viscous effects under representative mixing conditions than the actual waste.
- The design basis consistency for pretreated wastes is 30 cP. The consistency of the simulant should have been reduced to 5 to 8 cP to maintain similitude in the scaled models but was not lowered to provide additional conservatism. The clay simulant consistency was 20 to 30 cP. This means the viscous effects are much more pronounced in the models than at full scale. For example, jet velocities decay faster in the model than at full-scale.
- The yield stress of the simulant used for the scaled model mixing demonstrations generally exceeded the 30 Pa upper bound. Most of the PJM hybrid mixing tests were conducted with 33 to 37 Pa yield stress clay which would have created conservatively smaller mixed caverns than the 30 Pa waste will create.
- The waste density is expected to be in the 1.3 to 1.35 g/ml range at its high yield stress conditions. The clay density was 1.2 g/ml, which meant that the model PJM's were only developing ~90% of the momentum that the plant WTP design jets will deliver, again producing a conservatively smaller mixing cavern than the WTP design.

DNFSB Information Request No. 5:

Discuss the amount of excess capacity in the design to address experimental uncertainty.

DOE Response:

In order to put the conservatism of the design into perspective, scaling of test results to date indicates that normal operation gas hold-up in the full scale vessels will be less than 1% by volume. Instantaneous gas releases were not observed during testing until more than 20% gas by volume had accumulated in the tank. Even then, in the test of 7 Pascal simulant where this was observed, the release occurred over a 20 second period. Because the retained gas volume is so low, an instantaneous, uncontrolled release does not appear to be credible.

Although experimental uncertainty assessments are being performed where specific measurements are made, the PJM mixing program was planned and executed to provide greater assurance of significant design margin, using the measures described further below. Conservative approaches taken at each stage of the PJM testing program are outlined below. The PJM safety margin results from the conservative simulant selected (see response to #4 above), the scaled testing approach, the methodology used to develop the sparging correlation, and the techniques employed to evaluate gas retention and release behavior of the models.

Approach to Scaling Test Stands

- Two of the three key non-dimensional parameters, the Strouhal number and the simulant yield stress, were preserved through the scaled designs. The third, the Reynolds number, was smaller in the model due to the high apparent slurry viscosity. This implies that the mixing behavior will be better at full scale.
- The highly turbulent mixing caverns developed by the PJM's appear to scale-up conservatively, i.e. the preliminary test data indicates larger mixing caverns at larger scale (data still undergoing quality review).

Sparging Correlation Development

- Spargers are effective in mixing the tank above the injection point due to the recirculation flow established by the air bubbles. Injection point is ~6 inches from the vessel floor. Therefore, any experimental uncertainties associated with the size of the PJM mixing cavern size does not reduce the overall mixing in the portion of the vessels mixed by spargers.
- The sparging tests were conducted in tanks that were approximately of half-WTP vessel depth. The test data indicates that the sparged volume is a weak function of submergence depth. When these tests were conducted, at half the immersed sparger depth, the sparged volume was fully developed. Sparger behavior will be scaled based on these observations, not the model-scaling factor.
- The full-scale WTP process vessels utilize only 67% of the measured sparger zone-of-influence (ZOI) diameter to conservatively apply the test data. Further, these conservative ZOI's are overlapped in the design so that the full surface of the mixing caverns are covered by a ZOI to carry the mixing to the entire tank.

- The layout of the spargers in the plant vessel designs does not credit synergism between adjacent spargers. Based on discussions with Dr. A. W. Eschels (of the expert mixing panel) the down-flow in the full-scale tanks is expected to be faster than the single sparger test data would suggest. To confirm this expectation, a multisparger test is planned to be conducted by the end of July.
- The sparger ZOI correlation was developed using data measured with 36 Pa simulant. This simulant rheology is 20% higher than the bounding 30 Pa waste. Thus, the ZOI's in the WTP will be larger than the ZOI predictions used to assure full mixing cavern coverage in the plant designs.

Gas Retention and Release Measurements

- The technique developed to rapidly generate in-situ bubbles in the simulated waste created conservatively small bubbles, which are more difficult to release. Therefore, the measured gas hold-up and release rates are lower and slower than the WTP will experience. This phenomenon occurs because the simulant gas generation rate was much more rapid than normal waste, preventing normal bubble "ripening" due to the physics of bubble formation.
- The WTP is evaluating anti-foaming agents to assure that gas release will not be impeded due to slow coalescence at the slurry surface. This will also assure that the gas bubbles will not be 'armored' by slurry particles, which could inhibit the gas release as has been observed in the Hanford waste tanks. This anti-foam technology is mature, and its specific application at WTP will be based on tests currently in progress at the Savannah River National Laboratory for WTP.
- The gas hold-up and release measurements conservatively do not include the effects of mass transfer by other means (e.g. stripping by the sparge air or from the slurry surface).
- Gas removal from both clay and a chemical waste simulant has been measured to enable estimation of the actual waste slurry gas hold-up behavior.

Work is continuing to optimize the design and it may be determined that equipment may be operated differently and/or that not all features are required. The need for applying active single failure criteria to PJMs for mixing the lower portions of the vessels during post-DBE conditions is being analyzed based on recommendations from the March 31 to April 1, 2004 external review panel. In no case however, is it envisioned that PJMs would not be a part of the mixing systems. DOE will keep the Board staff apprised of any developments in these areas.

DNFSB Information Request No. 6:

Discuss the impact of mixing designs on interfacing safety structures, systems, and components.

DOE Response:

The mixing system PJMs supplemented by spargers or recirculation pumps to achieve required mixing during normal operations and after a design basis event. These systems are designed to prevent hydrogen hazards based on conservative assumptions about hydrogen generation and release rates and recovery actions. The requirements are to maintain vessel head space flammable gas concentrations below the lower flammability limit (LFL) so there is appreciable margin against deflagration during normal operations, and not to exceed the lower flammability limit following a DBE. These requirements impact the interfacing pulse jet ventilation, process vessel ventilation and compressed air systems. The hydrodynamic loads from pulse jet mixer operation and malfunctions are included in the vessel design criteria. A PJM System Description is in preparation that describes the functional criteria and safety design bases, how the test data is translated into the design, applicable standards, and detailed design requirements including interfaces with other facility systems, structures, and components.

Table 1 lists the primary interfacing systems and functions for the Pretreatment Facility and the related impacts and design actions associated with implementing the March 2004 base design.

DNFSB Information Request No. 7:

Discuss the ability to meet established design requirements and standards.

DOE Response:

Mixing system design requirements include achieving:

- off-bottom suspension to move solids through the system,
- blending of wastes and reagents,
- and release of evolved hydrogen gas.

As noted above, the hydrogen mitigation design requirement is to maintain vessel headspace levels at less than 25% of the LFL in the headspace for normal operation, and 100% of the LFL after a DBE.

The requirements above will be considered to have been achieved when the following conditions are met:

- no stagnant regions in the vessels
- low gas hold-up in the tanks
- predictable gas release during normal operation and following a DBE (to justify the operation cycles selected in the final design)

The results of the experimental tests, performed and anticipated, are intended to provide evidence that adequate mixing is achieved for a given configuration (Attachment 1). The tests include mixing tests and gas release tests. The March 2004 base mixing designs are derived from a successful testing configuration - number of PJMs, spargers, and recirculation pumps, their arrangement, and flow rates. This March 2004 base mixing design configuration is described in the design requirements outlined in Attachment 3. Additional design requirements will also be identified in the system description for support systems necessary for the mixing systems to accomplish their functions. These include the ability to keep spargers from blocking and capability to clear spargers and PJMs that might become blocked (even assuming continuous PJM and sparger operation), and addition of anti-foaming agents.

Table 1 - Summary of Principal Impacts of March 2004 Base Design In Pretreatment

Item	Impact/Status
Compressed air supply	Higher velocity PJMs and added spargers require more compressed air than previous design. • Analysis has shown that the existing plant service air compressor capacity is adequate • Higher peak demands of the redesigned PJMs will require larger air receiver vessels in PT • Supply headers in PT are not affected
Jet pump pair (JPP) design	Higher velocity PJMs require a larger capacity JPP • AEA has been released to develop 'hybrid" JPP that boosts capacity • Design complete, confirmatory testing initiated • No impact to existing layouts
Added spargers	Air supply piping, sparger tubing, and valve racks are necessary • Layout studies have identified routing of piping and location of racks
Vessels	Vessel internals will change • Vessel sizing calculations updated to reflect more displacement by internals • Revision of vessel internals drawings for relocated PJMs , added spargers, and erosion wear plates are complete for all PT non-Newtonian vessels. • Vendors are released to start work and provide schedules and pricing for design changes
Vessel heat removal	Non-Newtonian fluid and changed mixing requires recalculation of heat-exchanger sizing • Complete for all PT vessels • Larger cooling jackets needed for Lag Storage and Blend vessels, added external heat exchangers necessary for ultrafiltration feed preparation (UFP) vessels • Added process cooling water demand identified and confirmed to be within existing capacity.
Erosion resistance	Higher velocity, relocated PJMs require more erosion allowance and at a different location • New allowance determined for PJM nozzles and impingement areas, calculation revision in progress • High velocity impingement zones identified using CFD analyses and included on revised vessel drawings
Pulse jet ventilation (PJV) system	Current capacity has been evaluated as adequate for increased PJM air flow. (Newtonian PJMs are assumed to operate no more than 25% of the time.) PJM operation frequency is still being finalized.
Process vessel vent system (PVV)	Has been redesigned to accommodate added flow from intermittent spargers. Higher potential liquid carryover being evaluated. Intermittent sparger frequency is still under development.
Added recirculation pumps	Evaluation confirmed adequate space exists and practical layout possible before decision to use pumps was made. Addition requires: • Revised hot cell layout and additional jumpers • New vessel nozzle connections and internal piping • Connection to power supply (adequate distribution capacity confirmed to supply 3 ~100 hp pumps) • Evaluation of adequate NPSH, preliminary calculation completed. • Additional process equipment platforms required
PJM controls	Controller logic not yet coded – no impacts; instrument and control racks under evaluation
C5 Ventilation system	In post-DBE operation, some purge may exhaust to black cells rather than be processed through PVV. Added load on C5 has been evaluated and can be accommodated.

A preliminary analysis suggests that the "idling" sparge flow rate that is specified to keep spargers from blocking may also be adequate for purging the headspace of any hydrogen (to be confirmed through the design process). Consequently, the normal vessel purge system will be disconnected from the non-Newtonian vessels and the purge function assigned to the spargers. Completion of the design process will include confirmation that measures to address indications of sparger plugging are included in the design and operating strategies.

The operation of the mixing equipment must be such that the hydrogen limits are maintained. Attachment 2 indicates the required operations. For normal operations, the mixing systems are operated continuously so that evolved hydrogen is continuously released to the headspace and purged, keeping headspace hydrogen levels well below the limits.

For post-DBE operation it is expected that intermittent operation of the mixing equipment can be shown to adequately manage hydrogen concentrations based on gas release testing performed to date. Intermittent operation will allow a much-reduced equipment requirement for ITS diesel-generators and compressors necessary to operate spargers and PJMs; ideally no more than one of the seven non-Newtonian vessels would need to be mixed at a time. As noted in Attachment 2, the mixing intervals are to be determined. Demonstration that these design requirements are satisfied post-DBE requires calculation of limiting hydrogen generation rates for each vessel (completed), calculation of the time to LFL (in progress), and demonstration by testing of the amount of time necessary to re-establish the sparging zones of influence that are needed to provided adequate mixing defined above (scheduled for May). It should be noted that in the limiting case, continuous operation of the spargers and PJMs provided by the March 2004 base design will satisfy post-DBE hydrogen management design requirements. Another potential post-DBE mixing alternative is continuous sparging with intermittent PJM operation. This is discussed in response to question 8 below.

Additional design requirements are set in the Integrated Safety Management System process and include accomplishment of the required mixing assuming a single failure of an active component, withstanding natural phenomena hazards such as earthquakes, and with required fire separation of redundant components.

The WTP Safety Requirements Document contains the standards applicable to the important-to-safety mixing design components and equipment include ASME Section VIII for vessels and ASME B31.3 for piping and tubing. These standards are implemented in design calculations, design documents, and procurement documents. Design specifications and design guides detail the analyses and features necessary to achieve compliance with the standards.

DNFSB Information Request No. 8:

Discuss any other options being pursued to supplement or replace pulse jet mixing.

DOE Response:

There are no options being pursued to replace pulse jet mixing, and no options being examined that involve other than PJMs, spargers or recirculation pumps to accomplish mixing. However, the project continues to evaluate means to simplify and improve the March, 2004 design (Attachment 2).

Two initiatives proceeded in parallel with the design work with the expectation that some of the design components could be deleted within the mixing systems, maintenance could be simplified, and improvements could be made to the control logic. These initiatives are: 1) employing an intermittent sparging of the Lag Storage and Blend process vessels to replace the recirculation pumps and 2) utilizing continuous sparging and intermittent PJM operation post-DBE. These initiatives proceeded on the basis of a Peer Review comprised of experienced safety personnel from Savannah River, Oak Ridge, and other locations, held on March 31, 2004 and April 1, 2004. This panel also observed that an intermittent mixing strategy appeared feasible.

The path forward to examine these initiatives is outlined below:

- Demonstration of intermittent sparging for normal operations requires showing that the time required for a sparger to establish the recirculation mixing pattern is much less than operational durations and that the gas retained in the vessels remains at low concentrations. The tests to determine the time to achieve steady state recirculation are in progress. The gas retention tests will be completed in June, 2004.
- Adoption of a post-DBE continuous sparging and intermittent PJM operating strategy is contingent on demonstrating that the WTP diesel generator capacity can supply the power needed for the sparger air supply, the rate that gas accumulates near the vessel floor where the spargers are least effective, and the ability of PJMs to release this retained gas when they are activated. The assessments are in progress and the tests are being scheduled.

The engineering details for implementation of these initiatives are under review.