Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput

Assessment Conducted by an Independent Team of External Experts

March 2006

Chartered by
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at the Direction of the US Department of Energy
Office of Environmental Management
Washington, DC 20585

Executive Summary

The purpose of the Waste Treatment and Immobilization Plant (WTP) is to treat and vitrify radioactive wastes stored in the Hanford High-Level Waste Tanks. This review by an independent team of external experts was conducted to determine how well the WTP will meet its throughput capacities based on the current design. The external flowsheet review team (EFRT) comprised technical experts with experience from industry, academia, and scientific laboratories.

The EFRT conducted a comprehensive review of the entire WTP process flowsheet and throughput. These experts reviewed thousands of pages of documents and held numerous sessions with Project personnel as well as with personnel at supporting sites. The review entailed asking hundreds of probing questions about technical and engineering details. Most of those questions were satisfactorily resolved in those reviews and discussions.

The review answered three principal questions:

- Are there any major issues that will prevent the Plant from operating?
- Are there any major issues that will prevent meeting contract rates with commissioning and future feeds?
- Are there any potential issues that could prevent meeting contract rates with commissioning and future feeds?

From this assessment, the EFRT concludes:

- Line plugging will result in unplanned outages that prevent the WTP from operating consistently. If this major issue is corrected, there are no other issues that will keep the Plant from operating.
- Including line plugging, there are 17 major issues that will prevent the WTP from meeting contract rates with commissioning and future feeds. The major issues must be fixed to ensure the Plant will meet design throughput for all presently identified feeds.
- There are 11 potential issues that could also prevent meeting contract rates with commissioning and future feeds. Fixing potential issues is necessary to provide additional assurance of meeting design throughput.

The EFRT developed several insights about culture and organization that affect the WTP. These insights start with the impression that the WTP lacks a clear definition of mission throughput, including required throughput. This clear definition must come from the owner—in this case, the US Department of Energy.

The WTP has an essential role in the clean-up of the Hanford Site. The EFRT believes that all of the issues have solutions and do not require development of new technologies. Some of these fixes are already underway. Resolution of all the issues will require commitment of additional operations, engineering, and research and technology resources. Failure to address the issues and implement fixes will result in a protracted start-up and arduous operations.

Summary of Issues

This section provides an overview of the issues identified by the EFRT. More specific details are given in the main body of the report. Categorization of the issues was based on a review of documents and information from Project personnel and subject-matter experts as well as the EFRT's judgments of probabilities and consequences. These judgments are based on more than one-thousand man-years of relevant experience of the team.

During the EFRT's review, hundreds of possible concerns were assessed. After evaluation, 28 remained as issues. The remaining issues were determined to be either "systemic" or "process area specific," and further categorized as "major" and "potential." Systemic issues apply to multiple areas or across the entire Plant. A major issue will prevent meeting contract rates with commissioning and future feeds. A potential issue could prevent meeting contract rates with commissioning and future feeds. The EFRT believes all of these issues have solutions, and example fixes are provided for some issues. The major issues must be fixed to ensure the Plant will meet design throughput for all presently identified feeds. Fixing potential issues is necessary to provide additional assurance of meeting design throughput.

Systemic Issues – Must Be Fixed

The systemic issues, all major, are listed below:

Plugging in process piping

Piping that transports slurries will plug unless it is properly designed to minimize this risk. This design approach has not been followed consistently, which will lead to frequent shutdowns due to line plugging.

Mixing vessel erosion

Large, dense particles will accelerate erosive wear in mixing vessels. The effects of such particles on vessel life must be re-evaluated.

Inadequate design of mixing systems

Issues were identified related to 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.

Design for commissioning waste vs. mission

The WTP has not demonstrated that its design is sufficiently flexible to reliably process all of the Hanford tank farm wastes at design throughputs.

Must have feed pre-qualification capability

Without waste feed pre-qualification, each new batch of waste will require additional time for WTP to evaluate unit process responses and adjust operating parameters to define efficient processing. Bench-scale testing of unit operations with actual wastes would identify unexpected results and prevent potential Plant problems.

Process operating limits not completely defined

Many of the process operating limits have not been defined. Further testing is needed to define process limits for WTP unit operations. Without this more complete understanding of each process, it will be difficult or impossible to define a practical operating range for each unit operation.

Inconsistent long-term mission focus

The US Department of Energy and the WTP Project have made design choices without consistently taking into account life-cycle costs. These decisions appear to be more focused on capital cost than on long-term operating cost and throughput.

Limited remotability demonstration

The current commissioning plans for the WTP appear to be "minimum essential" and do not demonstrate long-term mission capabilities. This pertains to equipment repair/ remotability, especially involving large and unique pieces of equipment and piping. If these issues are not addressed, the risk of lengthy repairs during radioactive operations is significantly increased.

Lack of comprehensive feed testing during commissioning

The current plans for commissioning, which do not include leaching, do not adequately support the Plant's future processing requirements.

Critical equipment purchases

The Project must carefully evaluate critical material and equipment purchases (e.g., the ion exchange columns and ultrafilters) to ensure the best equipment is purchased.

Loss of the WTP expertise base

Loss of the WTP expertise base is already evident and likely to lead to a lengthy start-up and arduous operation. Because of the length of the WTP Project and the history of its funding, the continuity of the technical resources is being impacted.

Major Issues by Process Area – Must Be Fixed

The major issues identified for specific process areas are shown below.

Pretreatment Facility

- ***Inadequate ultrafilter area and flux***

  For wastes requiring leaching, a combination of inadequate filter flux and area will likely limit throughput to the high-level waste (HLW) or low-activity waste (LAW) vitrification facilities.

- ***Undemonstrated leaching processes***

  Neither the caustic leaching nor oxidative leaching process has been demonstrated at greater than bench scale.

- ***Instability of baseline ion exchange resin***

  The baseline ion exchange resin will not provide acceptable performance because of rapid degradation of its mechanical stability.

- ***Availability, operability, and maintainability***

  The Pretreatment Facility will be difficult to reliably operate and maintain and may have less than the required availability.

LAW Vitrification Facility

- ***Mis-batching of melter feed***

  Mis-batching of melter feed will likely occur, leading to premature melter failure.

HLW Vitrification Facility

- ***Plugging of film cooler and transition line***

  Plugs will likely form in the melter film cooler or the transition line to the off-gas system. These plugs will be difficult to remove and could constrain glass production.

Potential Issues – Should Be Fixed

The potential issues identified for specific process areas are:

Pretreatment Facility

Evaporators

- Undemonstrated decontamination factor
- Effect of recycle on capacity
- Adequacy of control scheme

Ultrafiltration/Leaching

- Potential gelation/precipitation

Ion Exchange

- Inadequate process development
- Questionable column design[1] (see major systemic issue "Critical Equipment Purchases")
- Questionable cross-contamination control
- Complexity of valving
- Effectiveness of cesium-137 breakthrough monitoring system

LAW Vitrification Facility

- Lack of spare melter[1] (see major systemic issue "Inconsistent Long-Term Mission Focus")

HLW Vitrification Facility

- Lack of spare melter[1] (see major systemic issue "Inconsistent Long-Term Mission Focus")

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(1) This item is not included in the count of 11 Potential Issues. It is included as an example within a major systemic issue. It is noted here because of its individual importance.

Analytical Laboratory and Sampling

- Undemonstrated sampling system

Balance of Facilities

- Lack of analysis before unloading glass-forming chemicals into silos

Design of Control Systems

- Incomplete process control system design

Conclusions

In summary, the EFRT concludes the review with three words:

Essential – The WTP has an essential role in the clean-up of the Hanford Site.

Flawed – The EFRT has identified 17 major issues that must be addressed and fixed to ensure the Plant will meet design throughput for all presently identified feeds. In addition, 11 potential issues have been identified that should be addressed and fixed to provide additional assurance of meeting the design throughput.

Fixable – The EFRT believes that all of the issues have solutions and do not require development of new technologies. Some of these fixes are already underway.

The EFRT developed several insights about culture and organization that affect the WTP. These insights start with the impression that the WTP lacks a clear mission and shared vision. For example, there is a lack of agreement about required throughput and how this translates into length of mission.

The Construction Industry Institute (CII) is a research consortium at the University of Texas. A major part of its mission is to improve the effectiveness of the construction industry. One of the important findings of CII is that projects have a much higher probability of success if the owner and contractor are aligned on mission and objectives. The clear mission statement must come from the owner—in this case, the US Department of Energy. In a very large project with widely varied feed streams and first-of-a-kind technology applications, such alignment is particularly critical.

Unless there is such a clear mission statement, the owner and contractor cannot develop an effective shared project strategy. A key aspect in implementing a shared project strategy is agreement on throughput, the adequacy of basic data, and the adequacy of preliminary flowsheets and piping and instrumentation diagrams. This process must be owner-driven.

Addressing the above insights and fixing the major and potential issues identified in this report are essential for the WTP to be successful.

Acronyms and Abbreviations

AL	Analytical Laboratory
ALARA	As Low as Reasonably Achievable
ASME	American Society of Mechanical Engineers
BNI	Bechtel National, Inc.
BOF	Balance of Facilities
CII	Construction Industry Institute
CMA	crane maintenance area
CNP	cesium nitric acid and recovery process system
DF	decontamination factor
DOE	US Department of Energy
DWPF	Defense Waste Processing Facility
EAC	estimate at completion
EFRT	external flowsheet review team
FEP	waste feed evaporation process system
GFC	glass-forming chemical
HEPA	high-efficiency particulate air
HLW	high-level waste
IGRIP	Interactive Graphics Robotic Instruction Program
IHLW	immobilized high-level waste
ILAW	immobilized low-activity waste
ISARD	Integrated Sampling and Analysis Requirements Document
LAW	low-activity waste
MT	metric ton
MTG	metric tons of glass
MTTR	mean-time-to-repair
OR	Operations Research (Model)
ORP	DOE Office of River Protection
P&ID	piping and instrumentation diagram
PJM	pulse jet mixer
PSD	particle size distribution
PTF	Pretreatment Facility
TLP	treated LAW evaporator process system
TU	Tank Utilization (Model)
UF	ultrafiltration
UFP	ultrafiltration process
WPA	waste packaging area
WTP	Hanford Waste Treatment and Immobilization Plant
WVDP	West Valley Demonstration Project
ZOI	zone of influence

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Introduction

The mission of the US Department of Energy's (DOE's) Office of River Protection (ORP) is to retrieve and treat Hanford's tank waste and close the tank farms to protect the Columbia River. As part of that mission, DOE has contracted with Bechtel National, Inc. (BNI) to design, construct, and commission the Hanford Waste Treatment and Immobilization Plant (WTP) to treat the radioactive waste, separate it into high- and low-activity fractions, and produce canisters of high-level waste (HLW) glass and containers of low-activity waste (LAW) glass. Currently, the Plant is at approximately 70% design and 30% construction completion.

During the annual review of the estimate at completion (EAC) for the WTP Project, DOE determined the proposed changes to the cost estimate and the Project throughput must be verified before completing the annual Congressional budgetary process [Letter 05-WTP-75, Contract DE-AC27-01RV14136 – Direction for Resubmission of the Estimate at Completion]. DOE directed the Project to convene an external flowsheet review team (EFRT) to conduct a comprehensive review of the entire WTP flowsheet, focusing on throughput.

This report provides the comprehensive results of the EFRT review. A separate document, "Background Information and Interim Reports for the Comprehensive Review of the Hanford Waste Treatment Flowsheet and Throughput," contains an overview of the Hanford Site and the WTP; technical write-ups prepared by ERFT participants or sub-teams; and summaries of the participants' expertise and experience.

Scope of Review

The scope of the review involved an assessment of whether the WTP, as currently designed, would meet the throughput capacity specified in the contract and required for the long-term mission:

- Pretreatment LAW product, 2200 sodium units/yr
- Pretreatment HLW product, 480 canisters/yr
- LAW vitrification product, 733 sodium units/yr
- HLW vitrification product, 480 canisters/yr (nominally 6 MT of HLW glass/day)
- Peak rate of limiting pretreatment unit operation is 2950 sodium units/yr.

Three fundamental capacity aspects were considered: the basic sizing of the Plant and equipment (intrinsic capability), the process capacity based on the process design, and the actual capacity. Actual capacity is the ability to sustain product output at the desired rates after including Plant availability (the percentage of actual operating time).

Specifically, the following questions were addressed:

- Are there any major issues that will prevent the Plant from operating?
- Are there any major issues that will prevent meeting contract rates with commissioning and future feeds?
- Are there any potential issues that could prevent meeting contract rates with commissioning and future feeds?

The scope of the review did not include evaluation of solution alternatives or optimization. The example remedies provided in this report are intended as guidance on possible methods to address the issues. Determining the future actions is the responsibility of DOE and WTP Project staff.

The scope also did not include:

- Ability to meet a 17-year mission life
- Ability to meet Year 2028 objectives
- Authorization (safety) basis
- Building designs and shielding
- Cost and schedule evaluation
- Hydrogen in piping and ancillary vessels
- Process alternatives
- Seismic criteria
- Supplemental LAW treatment capability
- Support systems not interacting directly with the process, such as electrical and non-process water
- Tank farm operation
- Waste disposal
- Waste form and qualification.

Approach

The EFRT began the review process with a Project-wide kickoff meeting, October 16-20, 2005. By the end of that week, the team had outlined the strategy and approach for three functional teams: technology, engineering, and operability/maintainability.

Each functional team developed operating strategies to accomplish a full review of the WTP processes and to assess the Plant's capability to meet design throughput:

- The technology team divided responsibilities along key process operations, e.g., ion exchange, ultrafiltration, and glass melting. Team members examined the fundamental chemistry and process scope for each step of the process. This team also examined specific technologies broadly applicable to WTP such as slurry handling, mixing, and off-gas.

- The engineering team divided the review by Plant operating areas: Pretreatment Facility (PTF), Low-Activity Waste (LAW) Vitrification Facility, High-Level Waste (HLW) Vitrification Facility, Analytical Laboratory (AL), and Balance of Facilities (BOF).

- The operability/maintainability team worked across the entire WTP, relying on the experience of its members in international and domestic nuclear facilities. The team started with a "tabletop" review of process flow diagrams, piping and instrumentation diagrams (P&IDs), general arrangement drawings, and other selected Project documents.

- Integrated working sub-teams were established to ensure the individual teams did not become too narrowly focused and isolated from the overall review. Sub-teams for specific topics or unit operations frequently included interactions among members from the three functional teams.

- As a final approach to make sure no major areas were overlooked, the engineering and technology functional teams developed a matrix of chemical plant risks, based on discoveries during the review and individual engineering experiences. This matrix of potential issues was used to assess risk areas of the WTP process that merited particular attention. An overview of how the issues were categorized is shown in Figure 1, and the matrix is presented in Tables 1 through 3.

To facilitate effective functioning between the EFRT and the WTP Project, a liaison team under the flowsheet review project manager helped to coordinate communications. This team included a liaison for each of the EFRT functional teams. This liaison team was essential to the smooth operation and the effectiveness of the EFRT and played an important role in coordinating and clarifying information. The liaisons supported communication by establishing links that included hardcopy deliveries, electronic delivery of information, and a dedicated computer server for common access to needed information. The liaisons in conjunction with Project personnel determined the appropriate subject contact points within the Project and facilitated meetings. The liaisons also ensured an integrated approach was

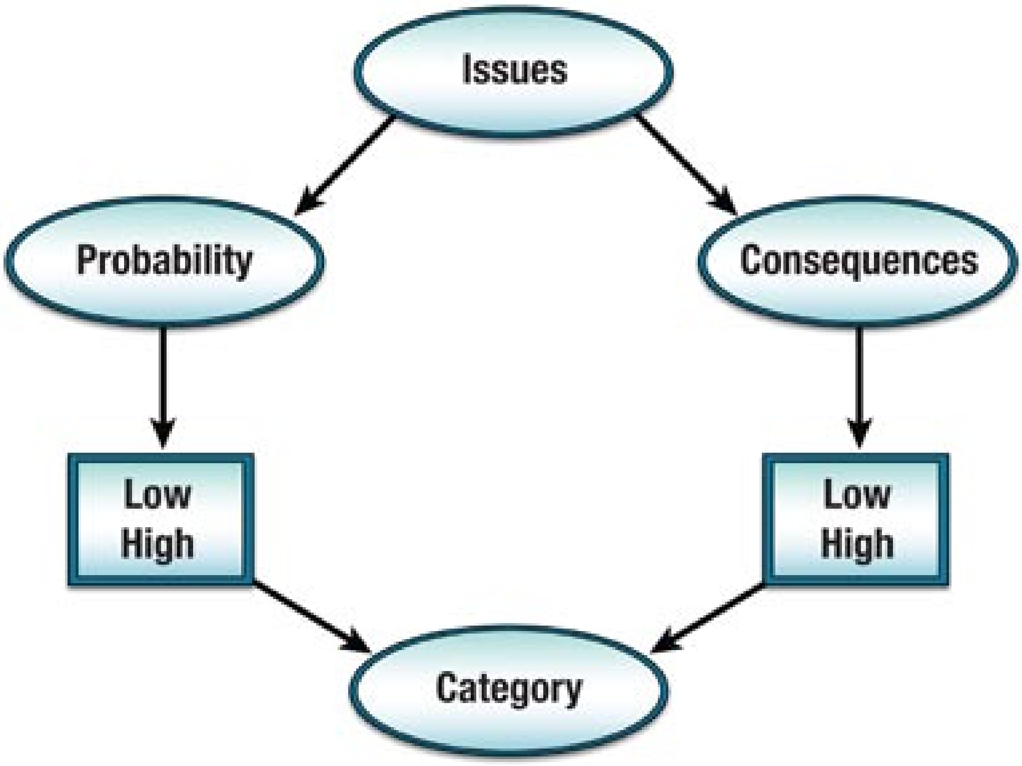

Figure 1. Categorization of Issues

taken and information was shared across the EFRT groups. The liaison team maintained communications with Project personnel and the EFRT off-site. Through this interaction, the risk of miscommunications and false starts was reduced.

Technical report writers, involved from the beginning of this assessment, assisted with document production. The technical writers maintained direct contact with the EFRT throughout the review process.

The most effective information-gathering technique was for small cross-functional groups of the EFRT to meet with small groups from WTP Engineering, WTP Commissioning and Training (Operations), WTP Research and Technology, and Project subcontractors. These meetings were conducted informally, and questions were often provided in advance so that the appropriate explanatory material could be prepared.

To ensure good communications, drafts and presentations were periodically provided to Project and US Department of Energy staff. Feedback from these interactions was considered in developing this report.

Table 1. Risk Areas in Chemical Plant Design—WTP Risk Areas

Risks in Process Characteristics:	**Risks in WTP**
Variable feed stream characteristics	X
Narrow operating windows	X
Feeds, process steps with slurries/solids	X
Multiple recycle streams	X
Unexpected or untested chemicals in feed	X
New, first time process chemistry	
Risks in Design:	
New and unproven technology	X
Misapplied technology	
Unfamiliar technology	
Extending design basis beyond basic data range	X
Highly complex, large number of process steps	
Very large scale-up	X
Heavy reliance on models	X
Misapplied models	
Heavy dependence on vendor designs	X
Complex control strategy	
Inappropriate control strategy	
Risks in Project Execution:	
Contract limitations and specificity	X
Critical equipment bought at lowest bid	X
Multiple organization involvement	X
Lack of clarity in project objectives	X
Stove-piped organizations	X
Inaccessible equipment	X
Long time cycle, concept to operation	X
Inadequate feedback between design and vendor organizations	X

Table 2. Ways to Mitigate Risks

Risks in Process Characteristics:	**Dealing with Risk**
Variable feed stream characteristics	Test full range of conditions; design for worst case to ensure adequate capacity; add specialized equipment as needed for some variants
Narrow operating windows	Develop thorough process understanding
Feeds, process steps with slurries/solids	Minimize plugging points—eliminate sharp pipe bends
Multiple recycle streams	Test effects of recycle streams thoroughly
Unexpected or untested chemicals in feed	Simulate feeds, test thoroughly
New, first time process chemistry	Develop thorough process understanding; test
Risks in Design:	
New and unproven technology	Test, test, test; evaluate alternatives; add capacity to cover uncertainty
Misapplied technology	Understand technology limitations
Unfamiliar technology	Test thoroughly under process conditions
Extending design basis beyond basic data range	Extend basic data by further testing
Highly complex, large number of process steps	Isolate steps by additional storage
Very large scale-up	Clearly understand scale-up factors; test with simulants; make appropriate use of models
Heavy reliance on models	Understand model limitations and work around
Misapplied models	Understand model limitations and work around
Heavy dependence on vendor designs	Close liaison with technology, design, and vendor
Complex control strategy	Design with "Keep as simple as practical for operation" concept
Incomplete control strategy	Couple control strategy with process design
Risks in Project Execution:	
Contract limitations and specificity	Contract and desired results should match
Critical equipment bought at lowest bid	Critical equipment procured from most qualified source
Multiple organization involvement	Communicate, communicate, communicate
Lack of clarity in project objectives	Make objectives very specific
Stove-piped organizations	Provide broader perspective and responsibility in key people
Inaccessible equipment	Test aggressively
Long time cycle, concept to operation	Maintain knowledge continuity
Inadequate feedback between design and vendor organizations	Provide frequent and effective feedback

Table 3. Risk Areas in WTP Beyond Usual Chemical Plant Risks

Risks in Process Characteristics:
Extremely demanding emission requirements
Radioactive chemical processing
Risks in Design:
Multiple complex nuclear design requirements
Lack of unified basic data report
Lack of rigorous scale-up methods, combining lab/pilot testing and appropriate models
Risks in Project Execution:
Time and expense of corrections after radioactive feeds introduced

Systemic Issues

During the EFRT's review, hundreds of possible concerns were assessed. After evaluation, 28 remained as issues. The remaining issues were determined to be either "systemic" or "process area specific," and further categorized as "major" and "potential." Systemic issues, discussed below, apply to multiple areas or across the entire Plant. Issues identified for specific process areas are discussed in the next section. All the systemic issues were classified as major issues and will prevent meeting contract rates with commissioning and future feeds. The EFRT believes all of these issues have solutions, and example fixes are provided for some issues.

Inadequate Design for Solids-Containing Fluids

Inadequate consideration of solids-containing fluids will lead to problems with mixing, erosion, and line plugging. The WTP has a variety of mixing vessel designs, such as pulse jet mixers (PJMs), air spargers, and conventional mechanically agitated tank designs. Issues were identified relating to mixing system designs that could result in insufficient mixing and/or extended mixing times, and reduced vessel life. These issues are a result of a design basis that discounts the effects of large particles in rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs.

Plugging in Process Piping

The EFRT, based on its experience and expertise, concludes that any line containing both solids and liquids can be expected to plug and should be designed to prevent plugging for both rapidly settling and hindered-settling slurries. This design approach has not been followed consistently, which will lead to frequent shutdowns due to line plugging.

Because of the high variability of the wastes, the WTP process piping needs to handle a wide range of materials from Newtonian to non-Newtonian fluids to settling slurries. For the upper-bound non-Newtonian fluids, the Project has addressed potential plugging issues in an acceptable manner. However, that is not the case for Newtonian (or non-Newtonian fluids with low yield stress and apparent viscosity) fluids with low solids contents, i.e., the lower rheological bounds.

For slurries with solids that can settle, a minimum line flow is required to avoid plugging. This minimum flow depends mainly on particle density and line sizes but includes other factors such as rheology, particle size and morphology, pipe rise and runs, constrictions, and elbows. Minimum pipe flow is not simply a minimum transport velocity issue and must factor in worst-case fluid properties expected over the life of the Plant and for reasonably expected upset conditions. At this time, the EFRT cannot quantify how severely process line plugging would affect Plant throughput, since the time to plug a process line is highly variable. However, based on the EFRT's industrial experience, it is anticipated that some piping could plug within days to a few weeks. Also, it should be noted the Hanford tank farms have experienced plugging by high-phosphate wastes. This further points out the need to address potential line plugging via mechanical or chemical mechanisms.

Some ways to reduce the risk of line plugging include:

- Maintaining a nominal velocity of 6-10 ft/s
- Using "sweeping"-type elbows for 90-degree turns
- Minimizing the number of closed-end pipe stubs, line constrictions, and expansions where solids can be trapped or settle
- Designing for the entire range of particle sizes and densities instead of just the average
- Flushing slurry-containing lines at an adequate transport velocity after each transfer.

In summary, the EFRT recommends a thorough review of all slurry-containing process lines to ensure the line-plugging potential is minimized. This review should consider both mechanical and chemical plugging mechanisms.

Mixing Vessel Erosion

The mixing vessels in the WTP's "black cells" have been designed for a 40-year life. The material allowance for erosive wear for vessels mixed with pulse jets has been determined based on a suite of calculations. The bases for these calculations include:

- Measured particle size distributions (PSDs) and particle hardnesses for the waste types to be processed during radioactive commissioning (1 to 310 µm, with an 11-µm median particle size; a density of 2.9 g/cm^3; and a hardness of 4.3 Mohs)
- Expected fluid velocities (typically 8 m/s exiting the pulse jet's nozzle)
- Expected solids concentrations in the vessels (40%)
- Equations for erosive wear taken from the literature for similar particles and velocities (e.g., gypsum)
- Conservative duty cycles (e.g., 100% usage of the PJMs assumed for some calculations)
- Erosion varies no more than a factor of two from parallel to perpendicular impingement.

However, none of these estimates have been verified by direct measurement. The assumed PSD, particle hardness, and density are based on measurements of samples taken from the initial tanks to be processed. Since not all of the waste types produced at the Hanford Site are represented in these samples, the relationship between the properties of the solids-bearing fluids used for design and those that will be encountered during operations is not known. For example, it is expected that some of the waste types to be processed will contain much denser particles of PuO_2, CeO_2, ZrO_2, and ThO_2. Recycle streams will contribute particles of unreacted glass-forming chemicals (GFCs) and of glass that may also greatly exceed the design-basis particle size.

[For reference, see R.F. Schumacher, *Characterization of HLW and LAW Glass Formers – Final Report*, WSRC-TR-2002-00282, Rev. 1, October 3, 2003; J.R. Jewett et al., *Selection of the Particle Size Distribution to Use in the Waste Feed Delivery Slurry Transport Model*, RPP-11694, Rev. 0, 2002; J.R. Jewett et al., *Values of Particle Size, Particle Density, and Slurry Viscosity to Use in the Waste Feed Delivery Slurry Transport Model*, RPP-11694, Rev. 0, July 2002, RPP-9805, Rev. 1, 2002; E.C. Buck et al., *Identification of Washed Solids from Hanford Tanks 241-AN-102 and 241-AZ-101 with X-ray Diffraction, Scanning Electron Microscopy and Light-Scattering Particle Analysis*, 24590-101-TSA-W000-0004-134-01, Rev. C, June 2003; A.P. Poloski et al., *Final Report: Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*, WTP-RPT-112, Rev. 0, 24590-101-TSA-W000-0004-172-0001, January 2006; W.S. Callaway et al., *Distribution of Plutonium-Rich Particles in Tank 241-SY-102 Sludge*, CH2M-0400872, CCN 090263, May 2004.]

The only certainty about the solids-containing fluids in the PJM vessels is that they will contain particles having a wide range of sizes, variable densities, and hardness factors, at both low and high concentrations. Vessel erosion will be caused by discharge from the PJMs, the characteristics of which have not been adequately evaluated. The erosion analysis has been based on fluids with a single set of waste properties and compared to literature reports of tests with fluids with a limited range of particle characteristics. These studies were focused on erosion caused by pipe flow (i.e., flow parallel to the metal surface) rather than particle impingement.

There are references in the literature that indicate erosive wear may increase with the square of the particle size. Based on the set of equations and parameters used, erosive wear rates caused by a small amount of large particles may be as much as 150 times those calculated for the median particle size used for vessel design. As a result, it is not possible to preclude premature failure of vessels with PJMs due to erosion based on these unverified calculations.

DOE-ORP has extensively reviewed the design basis for erosive wear allowances in these vessels. In recognition of the uncertainties in the PSD and hardness of the waste particles, ORP recommended several in-process monitoring methods to ensure erosive wear is not excessive (e.g., inspection of pipes and pumps for erosive wear, when taken out of service). ORP further mandated, as a part of acceptance of feed from the Hanford waste tank farms by the WTP, the PSD and hardness of the waste particles must be evaluated to ensure they are within the design basis.

While the EFRT agrees that such determinations are good practice, they are not sufficient to address all of the concerns above. It is not clear that the operator of the WTP can provide reliable warning of erosive wear during radioactive operations. Even if a problem is discovered before it compromises vessel integrity, it is not clear how the facility operator could respond without a lengthy interruption of waste processing. It is also not clear what the tank farm operator will do with a batch of feed staged for delivery to the WTP if its properties do not fall within the design basis, especially if this occurs relatively early in the Plant's operation when tank farm space will be limited. As a result, the EFRT concludes that calculated erosive wear rates should be experimentally verified under conditions representative for WTP applications (e.g., appropriate PSDs, angles of impingement, concentrations, hardness, and velocities, in both dilute and concentrated suspensions) before radioactive operations commence.

Inadequate Design of Mixing Systems

The uncertainties in particle and fluid characteristics also impact mixing. The EFRT identified three mixing issues:

- Resuspension of solids in Newtonian fluids
- Design of baffles in mechanically agitated tanks
- Resuspension of solids and mixing times in non-Newtonian fluids.

In general, the design of vessels with PJMs has concentrated on non-Newtonian hindered-settling slurries; less attention appears to have been paid to Newtonian fluids with low solids concentrations that settle rapidly. The assumed worst case for mixing applications in the Pretreatment Facility has been a 20 wt% solids, non-Newtonian fluid with 30 Pa yield stress and 30 cP consistency. While this fluid is difficult to blend and may cause unrecognized problems of long blend times or incomplete blending, the fluid properties are not the worst case for solids suspension. Newtonian mixing problems have been evaluated with 2.9 gm/cm^3, 22-μm median-size particles. These particle properties are not the worst case for solids suspension. Denser, larger particles may be more difficult to suspend than those considered in current designs, resulting in the possible accumulation of settled particles. As noted above, it is not clear how well these fluid properties represent process streams that will actually be encountered in the WTP.

In addition, the mechanically agitated LAW and HLW melter feed preparation tanks have questionable baffle designs, which may not be adequate for complete suspension of glass-former solids. All of these could result in segregation of larger particle material in process vessels. While the impacts to throughput cannot be quantified, segregation should be avoided for processes controlled on the basis of fluid composition. This may be resolved by testing already planned.

A critical parameter in the design of PJMs for solids suspension and resuspension is the zone of influence (ZOI), which establishes the number of pulsed jets needed for different size vessels. According to the PJM guidelines, the ZOI should decrease for large, dense, rapidly settling particles; this has not been reflected in the vessel designs. Without experimental data or experience to support these ZOI areas, solids suspension is questionable. Other vessels with PJMs should be reviewed with respect to experience supporting successful operation for the design conditions and limiting waste properties. The computational fluid dynamics model of the system, which has been based on continuous jet flow of two-phase systems, may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.

An accumulation of large particles in the bottom of the tanks may further reduce the efficiency of the PJMs. Accumulation may also cause plugging of the measurement bubblers. Removal of those particles will require specific tank clean-up operations that are not planned in the design.

Another issue relates to either insufficient testing of the selected mixing system designs or application of the test information to the design. For non-Newtonian slurries that behave as a Bingham plastic, mix times in the process vessels agitated by PJMs are long (up to 2 days for waste feed receipt vessels; up to 3 hours for some smaller vessels). These mixing times have not been incorporated in the Tank Utilization (TU) Model. Incorporation of adequate mixing times into the TU Model could show a reduction in throughput. In addition, inadequate mixing times may result in variable feed delivery to process vessels downstream.

A thorough review of the design of all of the mixing vessels is needed that specifically considers the expected PSD in each vessel (including recycle streams) and the effects of the unhindered settling of larger particles in Newtonian fluids. Testing of key process steps involving mixing (e.g., leaching processes) with simulated waste at an engineering scale appears essential. These tests could include the use of subsurface fluid addition or introduction of fluids into recirculating flow streams.

Inadequate Design for Highly Variable Feeds

The current WTP design will likely have difficulty in meeting throughput requirements because of the wide compositional range of the waste. Without prior knowledge of the relationship between the waste properties and WTP unit operations, the WTP operators will likely have a difficult time dealing with unforeseen chemical, physical, or rheological changes. In addition, many of the process operating limits of WTP unit operations have not yet been determined, especially those relating to compositional variation in the Pretreatment Facility.

Design for Commissioning Waste vs. Mission

The WTP has not demonstrated that its design is sufficiently flexible (in this case, "flexible" means the ability to process each batch in a consistent manner at an assured throughput) to reliably process all of the Hanford tank farm wastes at design throughputs. The Hanford tank farm wastes span a wider compositional range than the wastes at the West Valley Demonstration Project (WVDP) or the Savannah River Site.

The range of waste compositions (expressed as oxides) currently anticipated to be received by the WTP is shown in Figure 2. Species important to glass performance or processing vary greatly. For example, the aluminum content varies by a factor of 7; the sodium content by a factor of 16. This variability affects equipment design; Plant operations; glass formulations; and, if not designed for, subsequently Plant throughput.

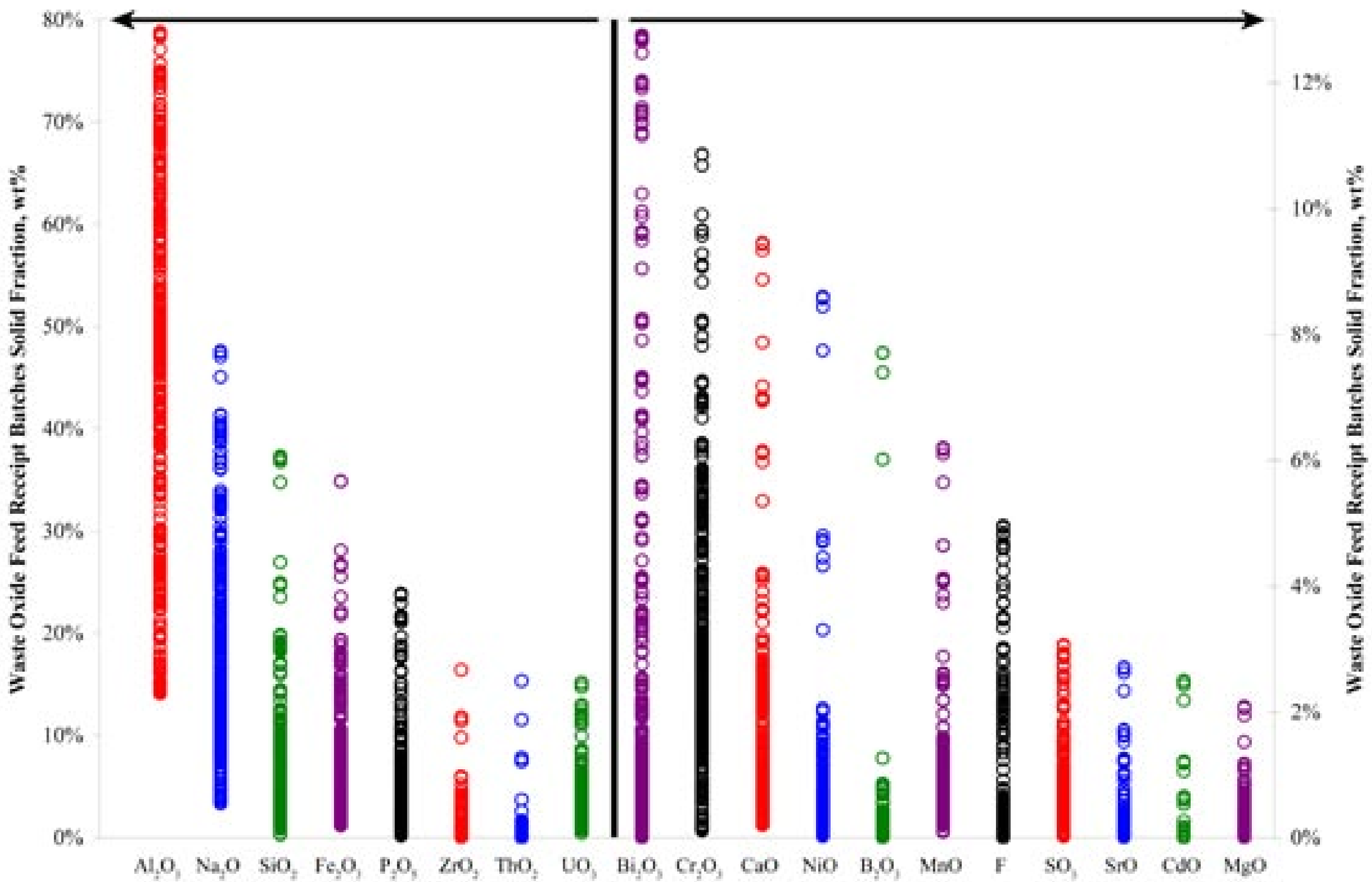

Figure 2. Expected WTP Feed Variability [data taken from V. Vora, *Dynamic (G2) Model Version 3.1 Verification and Validation Report*. 24590-WTP-VV-PO-04-0004, Rev. 0., September 2, 2004]. Circles represent the predicted composition for each WTP feed batch.

The process flowsheet and Plant design should take the wide range of feed compositions into account. The insoluble waste feed to the WTP will have large fluctuations in the concentrations of iron, aluminum, strontium, sodium, zirconium, and other waste constituents. While the fluctuations for the soluble wastes will be less pronounced, they will also be significant. As a result, the HLW material delivered to the WTP from the tank farms will vary considerably from batch to batch, where "batch" in this context means an approximate 1-million-gallon quantity of waste staged at the tank farms ready to transfer to the WTP.

As an example of the lack of flexibility, the WTP's glass product control models currently do not consider wastes from the Hanford tank farms that comprise some 40% of the total waste (e.g., waste from the bismuth phosphate process). In order to incorporate these wastes in the product control models, an extensive experimentation and modeling effort will be required. The results of this experimentation/modeling may have an impact on facility design and operation.

Similarly, the current design does not consider the marked tendency of soluble Hanford wastes containing phosphates to gel and plug process lines [J. S. Lindner et al., "An Experimental Study of Particle Growth, Aggregation, and Plug Formation During Saltwell Supernatant Transfers," Twelfth Symposium on Separation Science and Technology for Energy Applications, Gatlinburg, TN, 2001]. In the tank farms, phosphate gels caused several transfer lines to plug. This phenomenon could severely impact the operability of ultrafiltration and ion exchange.

As another example, the current design intends to control sodium concentration to the ion exchange process by density control. There does not appear to be sufficient data available to conclude that a consistent relationship exists between sodium concentration and solution density. In particular, any solids in the stream or significant variation in the soluble constituents in the stream could introduce significant error in the estimated sodium content.

The WTP must be flexible enough to tolerate this variability. In the case of the ultrafiltration system, between 20 and 30% of the insoluble wastes from the Hanford HLW tanks are unlikely to meet design throughput, because the rheological properties of the material are poorer (reach the rheological design limit for pumping at lower solids concentration) than those used for design [see *Final Report: Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*, Appendix C, 24590-101-TSA-W000-0004-172-0001, January 2006]. For these feeds, the HLW melters will have to be fed at a rate below their design capacity of 3 metric tons of glass (MTG) per day because the melters cannot tolerate the extra water load. In part, the mixing problems discussed above also are manifestations of the lack of design flexibility.

The WTP must consider the impacts of the feed variability on the Plant's ability to support the removal of waste from the Hanford tank farms. Even with the feed pre-qualification step recommended by the EFRT, adaptation of glass product control models to include new waste compositions could significantly delay processing. Plugging due to phosphates in soluble wastes has caused serious consequences in the Hanford tank farms and must be addressed before radioactive operations are initiated. An experimental program to resolve these issues is strongly indicated. Such a program would also partially address the issue relating to loss of expertise (discussed below).

Must Have Feed Pre-Qualification Capability

Feed pre-qualification is the assessment of chemical, physical, and rheological properties of actual feed streams as they move through bench-scale representations of the WTP unit operations. It also includes measuring the performance of these unit operations and bracketing and targeting process conditions. The testing through unit operations would identify any unexpected results and prevent potential Plant problems. Without waste feed pre-qualification, each new batch of waste will require additional time for WTP to evaluate unit process responses and adjust operating parameters to define an efficient processing window to meet throughput.

Batches of approximately 1 million gallons will be prepared in the Hanford tank farms about a year before transfer to the WTP. These feeds consist of 1) a salt solution, mainly sodium nitrate, nitrite, and hydroxide, which contains most of the cesium-137; and 2) a sludge slurry consisting of compounds that are insoluble in a caustic solution. Some of the major elements in the sludge are aluminum, iron, and bismuth. Most of the strontium-90 and transuranic elements are in the sludge phase. Most of the elements in the periodic chart are in one of these wastes. Although there will be some blending of these wastes to reduce the variability seen by the WTP, there will likely still be wide swings in the feed stream composition and properties. Because of this waste variability it will be extremely difficult to predict Plant performance.

There are two shielded hot cells in the Analytical Laboratory designated for process technology work. However, the equipment list currently specified for these hot cells is insufficient to perform this waste pre-qualification. Also, there is no analysis specified in the *Integrated Sampling and Analysis Requirements Document* (ISARD) [24590-WTP-PL-PR-04-0001, Rev. 0, December 8, 2004] to perform complete waste pre-qualification. In addition to the Analytical Laboratory, there are other locations where this work can be performed.
To conduct this work, appropriate equipment must be purchased and a plan formulated.

Some of the recommended components of waste pre-qualification are listed below:

- Composition analyses of both soluble and insoluble fractions of the waste (note: this is currently required by the ISARD)

- Characterization of the waste to determine physical properties, e.g., rheology versus wt% solids

- Small-scale testing of
  - Cross-flow filtration to determine filter flux and maximum solids concentration potential
  - Sludge washing to determine residual salt content

- Aluminum and chromium leaching to determine expected process efficiencies
- Ion exchange performance to determine cesium-137 removal efficiency
- HLW and LAW melting to confirm glass formulation adequacy.

With the above information, the WTP can more efficiently process the wastes.

Process Operating Limits Not Completely Defined

Many of the process operating limits of WTP unit operations have not yet been determined.

Much of the research and technology work for the WTP has been to validate the process equipment design. This type of work is required, but is certainly not adequate to completely develop a process. The key variables that affect the efficiency of each process must be known. Then, the upper and lower bounds of each process variable must be understood. Finally, possible and unexpected interactions of these variables must be understood. Without this more complete understanding of each process, it will be difficult or impossible to define a practical operating range.

The EFRT recommends additional testing be performed to expand the understanding of WTP process capability and to define practical process operating limits for each unit operation.

Inconsistent Long-Term Mission Focus

Positive measures have been taken to improve WTP operations, such as the pursuit of a bead ion exchange resin, laser ablation analytical techniques, and an additional HLW melter. However, there appears to be an inconsistent long-term mission focus. The EFRT identified several design decisions that reduced Project capital cost but have the potential to increase life-cycle costs. Other improvements that would increase Project cost but decrease life-cycle cost are not being pursued.

Examples of decisions that appear to increase life-cycle costs:

- Elimination of one of the PTF hot cell cranes
  - Impact: Meeting throughput requirements depends on a PTF availability of at least 80%. Availability is directly affected by the PTF hot cell crane. It is uncertain whether the current design throughput requirements can be met long term with only a single hot cell crane.

- Elimination of steam ejectors from some vessels
  - Impact: Leaves only one path for emptying some vessels. If the single outlet valve fails closed, such that the manual override is ineffective, its repair will require draining the vessel contents onto the cell floor as the jumper is removed. In turn, significant delays to restart will be caused by the need to recover this liquid and clean up the resulting contamination.

- Elimination of the standby diesel generators capable of supplying backup power to the melters.
  - Impact: An 8- to 10-hour power outage could result in the freeze-up of all four melters. The consequence could require a major outage to replace the melters.

Examples of improvements that could reduce life-cycle costs:

- Deoxygenate the feed to the ion exchange columns
  - Impact: Increased resin life would quickly pay for this design change.

- Define the replacement/maintainability logic for the PTF and evaluate the repair of, instead of replacing, very large assemblies such as the ultrafilters.
  - Impact: Spare part inventory will be optimized and/or mean-time-to-repair (MTTR) will be reduced by avoiding increased procurement time.

- Provide a manipulator with flexibility or tactile feedback on the PTF hot cell crane
  - Impact: Decreased possibility of damage to electrical jumpers. Although the electrical connectors have been shown by testing and calculation to withstand the maximum force that can be applied by power manipulators, this does not account for out-of-line loads.

- Provide a jumper mock-up facility
  - Impact: Increased likelihood that replacement jumpers will fit and provide a leak-tight seal.

- Track and mitigate operational (post-contract) risks
  - Impact: Implementing a risk-handling strategy will reduce operational problems.

- Provide spare LAW and HLW melters
  - Impact: Would prevent reduced facility throughput while a new melter is procured.

Life-cycle costs should receive appropriate consideration in decisions to provide a balance between incentives to complete construction and commissioning, with a longer-term view motivated to ensure the WTP facility can be efficiently operated to complete its vital mission.

Limited Commissioning Plan Scope

The current commissioning plans for the facility appear to be “minimum essential” and do not demonstrate long-term mission capabilities. If these issues are not addressed, the risk of problems during radioactive operations is significantly increased.

Limited Remotability Demonstration

The EFRT is concerned the planned remotability demonstration will not provide confidence that subcomponents in hot cells can be remotely changed out many years after commissioning. Because a subcomponent can be installed does not mean it can be remotely changed out once the process has been running. Running the process may induce displacements and change clearances on the pipes and subcomponents due to vibrations, pressure, and temperature. Demonstrating subcomponent remotability using the permanently installed crane and viewing system after thermal cycling would be much more beneficial and would increase confidence in its feasibility when required in the future during radioactive operations. It also verifies procedures and enhances operator proficiency. If the problems are identified before radioactive operations begin, they could still be fixed (much more easily) with hands-on repair.

The Project plans to demonstrate remotability of process or mechanical subcomponents in a piecemeal fashion. To verify different attributes, the construction crane may be used. For instance, the construction crane may be used to remove and reinstall jumpers with contact viewing instead of using the permanently installed remote crane and TV viewing system. The permanently installed crane and viewing system will be used for key attributes such as the ability to place the impact wrench socket on the jumper loosening nut. Additionally, the IGRIP (Interactive Graphics Robotic Instruction Program) three-dimensional computer simulation will be used to identify sequences of work, such as jumper removal sequences.

The current WTP plan of remotability testing was successfully used at the Defense Waste Processing Facility (DWPF) and the WVDP, although some jumpers at WTP exceed the size of the jumpers tested at these facilities. Another approach, as practiced by other companies represented on the EFRT, is essentially a complete disassembly of the plant and reassembly before hot commissioning. However, the facilities where this approach was used have significantly fewer jumpers. This disassembly/reassembly approach, while comprehensive, may not be justified for WTP. The EFRT recommends that, at a minimum, selective equipment unique to WTP, such as 24-inch jumpers, be tested remotely with actual Plant equipment after heat-up/cool-down cycles.

The risk introduced, without a more extensive remotability demonstration, is that problems could occur in later years after the facility has been operating. The Project should re-evaluate the long-term benefits of a more comprehensive remotability demonstration, especially where unique or different designs are incorporated, or where heat-up/cool-down cycles could affect remotability.

Lack of Comprehensive Feed Testing During Commissioning

The current plans for commissioning are based on contract requirements (see section above, Inconsistent Long-Term Mission Focus) and are not adequate to support the longer-term mission. In this light, the goal of commissioning should be to provide the WTP staff with the opportunity to determine how the facility will respond to expected variations in feed composition. Given the variability of feed (and of control) inherent in the WTP's current path, the "minimum essential" approach (commissioning with a single initial feed composition that does not require leaching) cannot provide the understanding necessary to cope with variations in waste composition [*WTP Commissioning Plan Part A*, 24590-WTP-PL-G-01-002, Rev. 0, July 1, 2002; *WTP Commissioning Plan Part B*, 24590-WTP-PL-OP-05-0002, Rev. A, September 14, 2005].

Most importantly, because there are no plans for any large-scale testing of the leaching processes, the first time these processes will be used in the facility will be during radioactive operations. As a result, for each new batch of feed received, the WTP operators will most likely be in a "catch-up" mode, that is, trying to determine how to operate with what they have, instead of being able to accelerate based on an understanding of how the facility responds to changes in composition. At a minimum, there should be fairly extended operations with three sludge simulants (a simulant of the initial feed, a simulant of a feed requiring aluminum removal, and a simulant of a sludge requiring chromium removal). One salt simulant is probably sufficient.

During commissioning, all operations must be performed as they would be during radioactive operations. Integrated operations are absolutely essential. Recycle streams also need to be included to provide the ultimate value of commissioning. A suggested scheme would be to start with the initial feed simulant, proceed to a caustic leaching simulant, then an oxidative leaching simulant, and finally prepare the facility for hot commissioning by operating with the initial feed simulant.

Critical Equipment Purchases

The Project must carefully evaluate critical material and equipment purchases (e.g., the ion exchange columns and ultrafilters) to ensure the best equipment is purchased.

It is recognized in the commercial nuclear power industry that many materials and components should be of a higher quality than the standard commercial product. For certain nuclear facility components, requirements MUST be specified in detail and vendors prequalified on the basis of a commercial-grade dedication process. An example is the design of the current ion exchange column. In the preliminary drawings submitted by the vendor, the process fluid distribution/collection piping for removing fluids from the column does not permit complete displacement of one process fluid by another. This may result in undesirable contamination/mixing of the process fluids. It is important that vendor designs meet Project requirements. In some cases, the range of industry failure experience would justify sole source procurement for specialized items. The EFRT recommends WTP re-evaluate procurement processes, especially for equipment located in a black cell. This evaluation should include development of a rigorous supplier qualification-certification program for all critical components, from procurement to receipt to installation.

One such example of critical equipment purchases involves the sintered metal filters for the ultrafiltration unit. Premature filter tube failure would require replacing the entire ultrafiltration unit. While the units can be changed out during operation, the change-out is a lengthy and costly operation and will impact Plant throughput. Filter manufacture is a demanding craft, requiring a vendor with a sustained record of success. A procurement approach tailored to provide critical products with a minimal failure rate should be undertaken.

Loss of the WTP Expertise Base

Loss of the WTP expertise base is likely to lead to a difficult start-up and a lengthy learning curve before any increase in process capability can be considered. In most chemical industry projects and in many previous nuclear projects, the length of the project was such that the technical capabilities represented by the research, development, and design personnel were available to support commissioning and start-up. In addition, the designers were often available to help write procedures and provide information on design intent, and then provide system descriptions with that information. Because of the length of the WTP Project and the history of its funding, these technical resources may not be available for either. Many of the technical experts have left the Project, which appears to have created gaps in the expertise base, lack of consistency in technical documents, and out-of-date system descriptions. Every effort should be made to retain a core capability of the technical expertise within the Project and key suppliers through Plant start-up. With vendors, there may be little that can be done except to insist on complete documentation, including basis of design.

Issues by Area

Major and potential issues are discussed here by area: Pretreatment Facility, Low-Activity Waste Vitrification Facility, High-Level Waste Vitrification Facility, Analytical Laboratory, and Balance of Facilities. As noted, major issues are defined as those that will prevent meeting contract rates with commissioning and future feeds. Potential issues are defined as those that could prevent meeting contract rates with commissioning and future feeds.

Pretreatment Facility

The Pretreatment Facility is designed to treat and separate the waste streams delivered from the Hanford tanks into a low-activity waste stream by removing most of the solids and radioisotopes from the stream and diverting the solids and radioisotopes to a high-level waste stream. The two independent waste streams will then be sent, respectively, to the LAW and HLW vitrification facilities to produce immobilized (vitrified) low-activity waste (ILAW) and immobilized high-level waste (IHLW) forms. The PTF will contain "black" cells and a "canyon"-type process cell (hot cell). The hot cell will house the majority of the special processing equipment, including ultrafilters, ion exchange columns, and transfer pumps. The equipment in the hot cell is connected by "jumpers" that are remotely removable by an overhead crane for repair or replacement.

Evaporators

In the PTF, following waste feed receipt from the tank farms, two feed evaporators (FEP; waste feed evaporation process system) concentrate a blend of feed and recycle streams to approximately 5 molar sodium salts. The FEP evaporators provide feed to ultrafiltration. These evaporators routinely process waste that contains undissolved solids. The treated LAW evaporator (TLP; treated LAW evaporator process system) concentrates the LAW submerged bed scrubber recycle and effluent from the ion exchange process for feed to the LAW Vitrification Facility. This evaporator also processes waste that contains undissolved solids. The cesium ion exchange evaporator (CNP; cesium nitric acid recovery process system) concentrates the cesium-137 stream, after elution from ion exchange, for blending with feed streams to the HLW Vitrification Facility. The overhead contains 0.5M nitric acid for recycle back to ion exchange.

The large feed recirculation lines in the feed evaporator system include jumpers so that piping and associated equipment can be removed and replaced remotely. The newly designed, 24-inch jumper and connector are unique in size to DOE operations. A demonstration has shown that a graphite gasket and a rubber gasket can provide an adequate seal; however, the graphite gasket requires a high torque on the connectors, and the rubber gasket is not suitable for this highly radioactive application. For this reason, the Project is pursuing a metallic gasket as an alternative. The remotability of this large unique equipment should be demonstrated with actual Plant equipment after temperature cycling and before radioactive operations (see Limited Remotability Demonstration section, Systemic Issues).

Line plugging and jumper replacement are major issues that affect the evaporators, but these issues are addressed under Systemic Issues.

Potential Evaporator Issues

Decontamination Factor. The specified decontamination factor (DF) of 6×10^7 has not been demonstrated. Typical experience of evaporators in nuclear service is one to two orders of magnitude lower. The DF requirement is driven by limits on radiological exposure from the downstream storage vessel.

Example solution: Change the area radiation zone classification.

Capacity. There are perhaps hundreds of individual purges, washes, and PJM wash water streams that end up in either the FEP or TLP evaporators. The amount of water and the composition of wash products are not known. While it is probable that the evaporators will be capable of handling this additional source of feed, the amount and impacts on recycle streams and the effluent treatment facility have not been determined.

Example solution: Characterize these streams and determine the impact on the flowsheet.

Control. The feed to ion exchange should be 5 molar sodium. The current evaporator design relies on density measurements to control the sodium molarity. It is questionable whether the density measurement control will guarantee the desired control of sodium concentration over the range of feeds. Failure to maintain sodium concentration within the required range will result in either reduced throughput or reduced ion exchange performance. A Coriolis meter used on the Hanford 242A HLW evaporator was found to be acceptable. However, the Coriolis meter requires maintenance and cannot be located in the black cells. The Project has indicated there is no space to locate the meter outside of the black cells.

Should the Project determine the density measurements provide the required adequacy, then it is important that the bubbler probes remain unobstructed. Level and density, which control the feed and discharge, are determined by pressure variation between probes. To accurately measure density, the bubbler lines must be kept free of solids. To accomplish this, the plan is to use humidified air and periodically flush with water.

Example solutions:

- Re-evaluate density as an effective method of measuring sodium molarity or investigate other methods of determining sodium concentration.

- Space considerations for Coriolis meters should be revisited.

Ultrafiltration/Leaching

The key unit operation of the pretreatment process is the combined ultrafiltration (UF) and leaching process step. The production rate and quality of the downstream operations of both the LAW Vitrification Facility and the HLW Vitrification Facility are directly related to the performance of this step.

The parameters that impact the performance of the ultrafiltration/leaching processes, as well as the rest of the WTP, are as follows:

- The ultrafilter area/flux
- The duration of the leaching processes
- The effectiveness (amount of solids dissolved) of the leaching processes
- The solids content of the slurry transferred to the HLW system
- The ratio of HLW glass to the solids transferred from UF
- The amount of undissolved solids delivered to the UF/leaching system.

Each of these parameters is directly impacted by the chemical and physical properties of the material contained in the tanks to be processed. The proper characterization of the material in the tanks will be a key factor in controlling the performance of ultrafiltration and leaching steps (see Must Have Feed Pre-Qualification Capability, Systemic Issues).

Major Ultrafiltration/Leaching Issues

Ultrafilter Area and Flux. An inadequate combination of flux and surface area will likely limit throughput to the LAW or HLW vitrification facilities. The design of the ultrafilter is based on a flux of 0.0277 gpm/ft^2. Using this flux to calculate the desired permeate rate of 15 gpm gives a required ultrafilter area of 541 ft^2. The current design has 726 ft^2 for each of the two ultrafilter trains. This would appear to be more than adequate except for two factors:

- Limited experimental data with both Hanford actual wastes and simulated feeds have shown lower fluxes. The EFRT analysis of the data indicates a flux of 0.015 gpm/ft^2 is much more likely.
- Leaching is included in the current design but has an impact equivalent to reducing the ultrafilter area available to support solids concentration by 50%.

Based on this analysis when leaching is included, the expected permeate flow is 7-10 gpm compared to a design basis of 15 gpm. In addition, this results in a reduction in the production rate of HLW slurry.

Example solutions:

- The ultrafilter area should be increased to cover the equivalent loss of area associated with leaching time.
- Filtration experts recommend that the ultrafilter membrane should be asymmetrical in nature—improvements of 10-20% in flux might be realized.

- More frequent back-pulsing of the ultrafilter membrane should be evaluated to obtain higher average fluxes. Additional ultrafilter testing prior to start-up can reduce optimization time spent during operations with actual waste.

Mechanical stability of the ultrafilter tubes is very important. Premature tube failure would require replacement of the entire ultrafiltration unit. While the units can be changed out during operation, this is lengthy and costly, and will impact Plant throughput. Discussions with solid/liquid separations experts indicated use of lower-quality tubes has resulted in premature failures.

Example solution: Procure ultrafilter tubes that have displayed reliable service in industry. Equipment procurement is a major issue and is addressed under Systemic Issues.

The EFRT concluded that the use of ultrafiltration in the WTP is a challenging application of this technology because of the high solids concentration target, which is beyond the typical application of this technology. This does not imply that the technology is misapplied, but that its effective implementation will require skilled operation and real-time Plant optimization.

Example solutions:

- Conduct additional testing to refine the optimum processing window.

- If a higher ultrafilter flux is required, due to a desired shorter mission life requested by DOE, alternative solids separation technologies, e.g., rotary filters, centrifuge, evaporators, should be considered.

Undemonstrated Leaching Processes. The purpose of the caustic and oxidative leaching processes is to wash and dissolve materials (aluminum, chromium, and other salts) that would affect the performance of the HLW system. Without a scale-up study, the ability to predict the effectiveness of these processes is limited. The current design calls for the leaching processes to be conducted in the ultrafiltration feed vessel. The working volume of this tank is designated at 22,100 gal. After the initial charge and subsequent feed, the contents of the tank are concentrated to 20 wt% solids, then washed, caustic treated, washed again, and re-concentrated before transferring to the HLW vitrification system.

When actual radioactive waste is used in testing, small sample sizes are used because of cost, radiation dose to personnel, and disposal issues. As a result, the experiments to define the leaching steps have been carried out using only 50-250 ml samples. Scale-up of the processes using these data has not been demonstrated. These small-scale experiments are capable of defining the leaching chemistry, but they will not indicate the performance of the leaching processes at full scale.

A number of factors make scale-up of this system very challenging:

- The system is non-Newtonian in nature.
- There are many additions of fluids with viscosities much different than the bulk fluid.
- There are materials that could gel or precipitate.
- There could be a considerable amount of foam.
- There are variable fluid regimes in the tank—a mixture of laminar, transition, and turbulent.
- A non-conventional mixing system is used.
- The calculated blend time of the PJM/air sparger system is quite long.

Without scale-up data, any statements about the productivity of the leaching processes are assumptions based on the premise that the ultrafiltration tank will perform in a similar manner as the small-scale tests.

Example solution: Conduct ultrafiltration/leaching system scale-up testing of all leaching (caustic and oxidative), washing processes, and filtration scenarios.

High solids slurry feed to the melter is desired to reduce volatiles and increase throughput. Experimental data indicate that some slurries will have borderline rheological properties, which would require operation of the ultrafilter system at a less than 20 wt% solids. While testing has shown it is possible to maintain HLW vitrification melt rates with lower concentration feeds, this mode of operation could lead to off-gas system plugging, especially in the film cooler. Design of the ultrafiltration calls for it to ultimately produce a slurry with a solids content up to 20 wt%. However, consistent delivery of a high solids feed from ultrafiltration to HLW vitrification may not be possible.

Example solutions:

- Consider options to concentrate solids at a different part of the process.
- Reduce water to melter by further concentration before the melter.
- Design an effective film cooler cleaning system.

Optimum leaching conditions are not known without testing. The IHLW canister production can be minimized by increasing the effectiveness of the leaching processes. If the HLW sludge is not effectively leached, too many IHLW canisters will be produced; or, if extra caustic has to be added to provide the required degree of leaching, an excessive number of ILAW containers could be produced. The ability to meet Plant throughput will be enhanced by understanding the leaching processes.

Example solutions:

- Pre-qualify material and establish the properly balanced leaching parameters for the waste.

- Balance between ILAW and IHLW waste packages needs to be defined by DOE for the mission life.

Potential Ultrafiltration/Leaching Issue

Gelation/Precipitation. Some of the feeds to the leaching operation will contain significant amounts of aluminum and other materials that could precipitate. There is the possibility aluminum gel will form in the leach tank itself or in other streams from the leaching operation if unfavorable leaching conditions occur.

Example solution: Conduct scale-up testing of the leaching processes to ensure problematic gels/precipitates do not form and post-filtration precipitation does not occur.

Ion Exchange

The purpose of the ion exchange unit operation in the Pretreatment Facility is to remove cesium-137 from the LAW salt solution so that this stream can be vitrified in the LAW melter. Filtrate from the ultrafiltration process in pretreatment is the feed for the ion exchange process. This stream has a nominal sodium concentration of 5 molar. The nominal column processing rate is 15 gpm. The cesium-137 limit in the LAW glass is 0.3 Ci/m^3, which requires that greater than 99.9% of the cesium-137 be removed from the LAW stream. Gamma monitors, combined with sampling, are used to detect cesium breakthrough.

Four columns filled with a specific ion exchange resin are used. Three of the columns are used in series for cesium removal, while the fourth is in its elution/regeneration cycle. The first column is run to predetermined cesium breakthrough, while the other two columns function to ensure the required level of cesium removal is achieved. Then, one of the other columns becomes the main column. Ten cycles of loading and elution/regeneration is the design basis. Extreme care must be taken to ensure the feed to the ion exchange columns is free of solids, or the resin bed could plug.

The baseline shard ion exchange resin has excellent specificity for cesium removal. The resin is made by bulk polymerization and then crushed and sieved for use, which leaves craze lines in the resin particle. This resin has a propensity to fragment during normal operations and causes a high pressure drop across the resin bed. The resin loses approximately 30% of its capacity from radiation damage during the 10-cycle design life.

An alternative resin in bead form is a backup resin. This bead resin has excellent physical stability in operation. The bead resin specificity for cesium is somewhat lower than the baseline ion exchange resin, but exceeds process requirements. In addition, the bead resin only loses approximately 1% of its capacity from radiation damage during the 10-cycle design life.

The bead resin will meet the design basis of 10 cycles. This could be extended by a factor of 5-10, if dissolved oxygen is removed from the ion exchange feed. Oxygen in the feed to the ion exchange unit reduces the cesium capacity of bead resin about 1% per cycle. While some oxygen will continue to be produced in situ by radiolysis, approximately three-quarters of the resin degradation is due to dissolved oxygen in the feed to the ion exchange unit. Additional tests should be performed to demonstrate a process to remove oxygen from the ion exchange feed, so that a capital versus operating cost reduction decision can be made. Standard technologies for deoxygenation of the ion exchange feed are available.

Major Ion Exchange Issue

Baseline Ion Exchange Resin Stability. Based on test results, the EFRT does not believe that baseline shard resin will achieve the required 10-cycle design life. Both the shard and the bead resin forms have been tested extensively at laboratory- and pilot-plant scale. When shard resins shrink and swell during elution, regeneration, and loading cycles, craze lines that formed during the crushing process develop into cracks, and small fragments of the polymeric shards break off as fines. In a packed ion exchange resin bed, fines fill the interstitial spaces between the larger shards. This results in increasing pressure drop and a reduction in the size of the shards with each ion exchange cycle. The shard resin thus cannot be run for 10 cycles without considerable intervention to frequently re-orient the bed and remove fines. The bead resin is not subject to these fragmentation problems and service life may well exceed the 10-cycle design basis. This type of experience with shard ion exchange resins is the primary reason that, by 1960, the commercial ion exchange industry generally discontinued using bulk polymerization processes and moved to suspension polymerization where the particle geometry and form are established at the monomer stage.

The degradation described above with shard-form resin was observed in testing in almost all runs carried out using varying column diameters and bed aspect ratios. In the 24-inch-diameter column test series, the pressure drop through the resin bed increased with each cycle. During cycle 6, fissures began to form through the resin bed and there was evidence of channeling. Turbidity in the water effluent stream also occurred in cycle 6, which indicated the presence of fine particles from resin degradation in the rinse stream.

Despite efforts to adapt by adding an upflow step during testing, fissures and channeling continued for the remaining six cycles. It is possible that incorporating an upflow step from the first cycle may have reduced the extent of the problem, but based on commercial experience with shard resin, the problems would not have been eliminated.

The bead resin has performed well at all stages of assessment and showed normal hydraulic performance. Bead resins are uncracked and made using a bead expansion process. This type of ion exchange resin is very stable and should not develop significant quantities of fines during the volume changes of the elution/regeneration cycle. In the 24-inch column test run, the pressure drop through the bead resin bed during simulant loading remained constant for 16 cycles.

Example solution: The shard-form ion exchange resin should be replaced with the bead resin. The EFRT understands that plans to do so are in progress.

Potential Ion Exchange Issues

Inadequate Process Development. The effects of process variables, such as concentrations of hydroxide, potassium, aluminum, and recycles along with flow rates and temperature, have not been determined experimentally. These effects have been predicted by computer modeling and need to be confirmed with experimental testing. This information is necessary to predict the performance of the ion exchange process with feeds that vary in composition.

Example solution: Complete work in progress on bead resin to better understand the ion exchange process.

Solids in the Ion Exchange Feed. Since there is no pre-filtration of the ion exchange feed just before it enters the column, care must be taken to avoid solids formation. Modifications in the ultrafiltration process could cause post-precipitation of aluminum hydroxide, strontium carbonate, or other precipitates, which could plug the ion exchange resin bed and cause premature elution and back-flushing. This would adversely affect the productivity of the ion exchange unit operation. This issue is a subset of the Gelation/Precipitation potential issue in the Ultrafiltration/Leaching section above.

Example solutions:

- Add a pre-filter ahead of the ion exchange columns.
- Perform additional testing to increase the understanding of the steps required, especially in ultrafiltration, to ensure a solids-free feed.

Column Design. As noted in the Critical Equipment Purchases section (Systemic Issues), the ion exchange columns are being purchased on a design/build basis from a vendor having little experience in designing ion exchange columns. The preliminary design has some unconventional and unacceptable column features that led to rejection of the design by the Project. The effectiveness and efficiency of the ion exchange unit operation could be seriously compromised with a poorly designed column.

One example of poor design is the process fluid distribution/collection piping. The column internals for removing process fluids from the top of the column (upflow operations) and the bottom of the column (downflow operations) do not permit complete displacement of one process fluid by another. This may result in undesirable contamination/mixing of one process fluid with another.

Example solution: A vendor with proven expertise in ion exchange column design should be used for this critical piece of equipment.

Cross-Contamination Control. The current flowsheet calls for loading and eluting the ion exchange columns in a downflow mode. This passes the concentrated cesium-137 solution and the decontaminated salt solution through the same piping. A small quantity of nitric acid eluate, containing the concentrated cesium-137, trapped in a tee or other section of pipe can easily cause a batch of treated ILAW glass to be out of specification for cesium-137 loading. Large quantities of treated LAW would have to be reprocessed through ion exchange if a serious cross-contamination occurred.

Example solutions:

- Piping/valving design should be re-evaluated to minimize cross-contamination.
- Upflow elution should be evaluated.

Complexity of Valving. The design of the ion exchange system has >80 valves, many of which are interlocked to prevent processing in the event of incorrect valve line-up. This complex system increases the risks of processing outages and decreases expected availability because of valving or limit switch errors. If a valving error occurs, it could lead to cross-contamination, which would require reprocessing of materials.

Example solution: Re-evaluate the valving system to determine if it can be simplified.

Effectiveness of Cesium-137 Breakthrough Monitoring System. The design basis for determining cesium-137 breakthrough is questionable. The design basis uses gamma monitors to detect for cesium-137 breakthrough. Gamma radiation does not come directly from cesium-137, but from its short-lived barium-137m daughter, which has a 2.6-minute half-life. A LAW stream exiting the ion exchange columns with no cesium-137 will still show a high gamma measurement from the barium-137m. This barium-137m concentration will be higher than that in the inlet stream since the cesium-137 bound to the resin will be decaying to barium-137m. The WVDP found that it was very difficult to calibrate their in-line system for cesium-137 breakthrough without periodically physically sampling the streams, which will lengthen the ion exchange processing cycle.

Example solution: Re-evaluate the way that cesium-137 breakthrough will be determined.

Availability, Operability, and Maintainability

Major Pretreatment Issue

The Pretreatment Facility will be difficult to reliably operate and maintain and may have less than the required availability.

Facility Availability. Accurate modeling and good input data are necessary to determine the actual availability of the Pretreatment Facility. The current PTF availability is reported as

83%, which is above the basis of design requirement of 80%. However, this reflects many assumptions that need to be reviewed. Examples of some non-conservative assumptions and apparent omissions include:

- Hot cell valve life (at an assumed 10 years in lower radiation areas) appears to be very optimistic, and based solely on tests of elastomer seal efficiency for 2-inch valves. There has not yet been a successful seal test with larger valves, and other modes of failure (for example, actuator and proximity switch failure, seat breakage and seizure) have not been assessed. Assuming a more realistic 3.3-year valve life, the availability is reduced by 11%.

- The MTTR data does not include flushing of lines/elution of ion exchange resin before the resin is removed from the columns.

- Instrument loops are not modeled.

- The ion exchange hydrogen mitigation system is not modeled.

- Predictive and corrective maintenance is not modeled for the hot cell shield doors.

- Corrective maintenance for the hot cell crane is not modeled.

- One-hundred percent availability of spare parts and labor is assumed.

- Due to the status of design, not all vendor-provided equipment is modeled.

Equipment that was not modeled was assumed to have an availability of 100%.

Furthermore, the Operations Research (OR) Model predicts a continuing buildup of failed equipment because the hot cell crane cannot keep up with size reduction requirements and a specific outage may be required to size reduce and dispose of this failed equipment.

It is noted that one overly conservative assumption was found. The OR Model assumes that the hot cell crane is fully utilized for the entire MTTR and not available for other purposes. This is clearly not the case, as MTTR includes work not involving the crane, such as preparing the work package.

Example solutions:

- Update and complete assumptions and modeling.

- Enhance performance of equipment as necessary.

Operability and Maintainability. There will be difficulty in operating and maintaining the PTF.

Single outlet line and valve - There are 14 vessels that have only a single outlet line and outlet valve. If one of these valves failed shut such that the manual override was ineffective, the only way to repair it would be to empty the tank contents by loosening/removing the valve jumper and allowing the tank to drain to the hot cell floor. This would result in a significant impact to Plant operations for the recovery and clean-up of the hot cell. The EFRT considers this an unacceptable approach.

Example solutions:

- Reinstate the tank heel emptying steam ejectors into the design.
- Install a freeze seal jacket upstream of the valve with the coolant piping routed to an accessible area.

Leak detection - Current design relies on sump alarms in one of three hot cell sumps for detection of small to medium leaks. [Large leaks could be detected by vessel level changes.] There is no planned or required routine visual inspection using the crane TV cameras to inspect for leaks, and there are no other cameras in the PTF hot cell. A small leak or a leak of non-Newtonian fluid could remain undetected for long periods as it may not flow to the sump.

Example solutions:

- Perform a periodic crane inspection of the hot cell (and include in the OR Model).
- Install remotable cameras and lights in the hot cell to perform this inspection.

Valve jumper repair/replacement policy - There are reportedly 252 actuator-operated valve jumpers of various sizes in the hot cell. The actuators are integral with the valves and are not designed to be removed remotely. This means that every time there is a failure of a valve, whether it is a valve failure, actuator failure, or even a proximity switch failure, the whole jumper has to be removed. This approach requires flushing lines and breaking jumpers, and may require tank draining followed by removing and replacing the complete assembly. Since actuators are more prone to failures than the valves, the Project should consider designing the actuator to be removed separately from the jumper. It is also not clear what the spare parts inventory will require because the maintenance policy has not been completely defined.

Example solution: Design the actuator such that it can be removed remotely without removing the jumper.

Contamination control - There is capability for decontaminating failed equipment and the crane in the hot cell size reduction area. However, the EFRT received varying accounts on plans for decontaminating the crane before it was transferred to the crane maintenance area (CMA). The CMA is an elevated platform within the waste packaging area (WPA) and contamination from the crane will affect the WPA. Technicians working in these areas will always be required to wear respirators during crane maintenance and waste packaging activities. The philosophy of some of the companies represented on the EFRT is to use much stricter control over the spread of contamination. These companies design their facilities with decontamination and swabbing capabilities to the point that the worker generally does not need a respirator to perform routine work (although in some cases respirators are required regardless). Consideration should be given to adopting this practice. These other companies also have a dedicated path for the waste, which is independent of the CMA (similar to the design of HLW).

Example solution: The decontamination philosophies and contamination control strategies should be assessed to see which approach better matches the ALARA requirements.

Cross-contamination of utilities and reagent distribution lines - The *Operations Requirements Document*, 24590-WTP-RPT-OP-01-001, Rev. 2, May 5, 2003, and sections of the *Basis of Design*, 24590-WTP-DB-ENG-01-001, Rev. 1C, January 7, 2005, call for provisions in the design of process and utility piping for preventing unplanned siphoning or backflow and, more generally, for preventing or mitigating cross-contamination. Preventing back-diffusion of radioactivity in WTP appears to rely mostly on vertical distance, which mitigates the siphoning risk only. There are no physical provisions located in C5 areas (like hydraulic guards) that will prevent back-diffusion of contaminated aerosols or even physical movement of radioactive liquids from process vessels to reach valves and instrument systems located in galleries and areas accessible to operators.

Project personnel explained that hydraulic guards would require periodic refilling and level detection to verify the presence of sufficient water to provide a seal. They considered it better to dispense with these complications and, instead, always assume that valves and instrument systems are contaminated. However, the EFRT believes this approach overlooks the considerable disruption to routine operation and maintenance that can be caused by even minor contamination, because of the need for tenting, temporary shielding, and operator protection when maintaining or replacing these valves. Experience shows that, when hydraulic guards are not present, there is ultimately significant contamination of out-cell areas, causing severe disruptions to operations. In the EFRT's experience, level detection is not required when periodic refilling is employed. Note that this issue applies to the LAW and HLW vitrification facilities as well.

Example solution: Reconsider the introduction of hydraulic guards to prevent diffusion and migration of radioactivity into out-cell valves and instruments.

Low-Activity Waste Vitrification Facility

Feed to the LAW Vitrification Facility from the Pretreatment Facility consists of soluble salts, from which > 99.9% of the cesium-137 has been removed, and recycle streams from the LAW. This feed has a high sodium, aluminum, chromium and sulfate content compared to HLW feed and is much less variable in composition. The feed is sampled and analyzed in the Analytical Laboratory. These analyses are input to a model that develops a recipe for the GFCs to be added to the LAW feed. This heuristic model contains statistically derived submodels to ensure glass acceptability for disposal and processability. Thus, if the LAW feed from pretreatment is adequately mixed with the GFCs in accordance with the recipe, an acceptable glass product will consistently be produced.

Using the recipe, GFCs are blended at the GFC storage area and then transferred to the LAW Vitrification Facility for mixing with the LAW feed. After the LAW and the GFCs are mixed, the resulting material is fed to one of two melters designed to operate at a process capacity of 15 MTG/day each. This design rate is achieved by using 18 bubblers in each melter with an air rate of about 0.75 scfm. The air rate can be varied, depending on conditions, between 0.1 and 3.0 scfm per bubbler. The glass is poured out of the melter into a specially designed container. This container is allowed to cool, then capped and decontaminated by blasting with CO_2 pellets. The filled containers are disposed on the Hanford Site.

Off-gas from the melters is cleaned by passing through an extensive gas-handling train. Coarse particulate material exiting the melter (primarily GFCs and glass) is removed by a submerged bed scrubber, similar to that used at WVDP. The submerged bed scrubber also cools the off-gas to ambient temperatures. The off-gas is then passed through a wet electrostatic scrubber/precipitator to remove finer particulate material. Removal of ultrafine particles is by HEPA filtration.

The resulting gaseous stream is passed through carbon beds for mercury removal, a selective catalytic reducer system for destruction of NO_x and volatile organic material, and then a caustic scrubber to remove SO_x and CO_2. The cleaned gas stream then leaves the facility through a stack. Solids and scrubber bottoms are returned to the Pretreatment Facility.

Major LAW Vitrification Issue

Mis-batching of melter feed. There is a significant risk of mis-batching the LAW melter feed, leading to premature melter failure. This risk can best be eliminated through analysis of the melter feed.

The GFCs are added to storage silos. Although the chemical compositions are specified, there is no guarantee the GFCs will be put into the correct silo. If, for example, zircon ($ZrSiO_4$) or silica is put into the bins for boric acid or borax, the resulting melter feed will produce a glass much more viscous than that called for by the recipe. Since there is no feedback from analysis, the same mis-batching error will be made repeatedly, sending mis-batched feed to the melter potentially until glass can no longer be poured.

Example solution: Perform sampling and analysis of melter feed after addition of GFCs.

Potential LAW Vitrification Issue

Lack of a spare melter may lead to significant downtime in the LAW Vitrification Facility.

As noted in the Inconsistent Long-Term Mission Focus section (Systemic Issues), current plans do not call for spare melters. If replacement melters are not available, the downtime for a melter change-out will be at least 2 years. This will result in a decreased overall Plant availability.

Example solution: Purchase a spare LAW melter or at least the refractory and melter shell necessary for melter assembly.

High-Level Waste Vitrification Facility

The HLW feed from the Pretreatment Facility consists of insoluble HLW solids from the Hanford waste tanks, radioactive cesium from the ion exchange process, and insoluble solids contained in WTP recycle streams. This feed, which is highly variable in composition, is also sampled and analyzed in the Analytical Laboratory. The analytical results are input to a model that develops a recipe for the GFCs to be added to the HLW feed. This heuristic model contains statistically derived submodels to ensure glass acceptability for disposal and processability. Thus, if the HLW feed is adequately mixed with the GFCs in accordance with the recipe, an acceptable glass product will consistently be produced.

Using the recipe, GFCs are blended at the GFC storage area, and then transferred to the HLW Vitrification Facility for mixing with the HLW feed. After the HLW and the GFCs are mixed, the resulting material is analyzed to confirm the correct composition and then fed to one of two melters processing HLW feeds that can produce up to 3 MTG/day each. This design rate is based on using five bubblers in each melter, each with an air rate of 1.4 scfm of air (0.70 scfm/nozzle). The air rate can be varied, depending on conditions, between 0.1 and 3.0 scfm per bubbler.

The molten glass is poured by an airlift mechanism (similar to that used at WVDP) into a specially designed canister (the design is similar to the thin-walled WVDP canister, except 50% taller). This canister is allowed to cool, then welded closed. The sealed canister is decontaminated by etching the surface with a ceric nitrate solution. The canister is then water-rinsed and transferred via shielded cask to an on-site storage facility for eventual shipment to and disposal in a Federal repository.

Off-gas from the melters is cleaned by passing through an extensive gas-handling train. Coarse particulate material exiting the melter (primarily GFCs and glass) is removed by a submerged bed scrubber, similar to that used at WVDP. The submerged bed scrubber also cools the off-gas to ambient temperature. The off-gas is then passed through a wet electrostatic scrubber/precipitator to remove finer particulate material. Removal of ultrafine particles is by HEPA filtration.

The resulting gaseous stream is passed through an activated carbon absorber for mercury removal, a silver mordenite column for removal of radioactive iodine (other halides will also be removed), and a selective catalytic reduction system for destruction of NO_x and volatile organic material. The cleaned gas stream then leaves the facility through a stack. Solids and scrubber bottoms are returned to the front end of the Pretreatment Facility.

The EFRT performed a comprehensive review of the entire HLW process area. With the exception of the plugging issue noted below, the EFRT found no major issues with the melter or off-gas systems nor with the glass composition control approach. However, as noted in the section on Inadequate Design for Highly Variable Feeds (Systemic Issues), the current approach does not consider Hanford's bismuth phosphate process wastes.

Major HLW Vitrification Issue

Film Cooler and Transition Line Plugging. There is a significant risk that plugs will form in the film cooler that connects the melter to the off-gas system or in the transition line between the film cooler and the first off-gas treatment vessel, the submerged bed scrubber. These plugs will be very difficult to remove, which may lead to frequent replacement of the film cooler and/or the transition line or even replacement of the melter itself if the film cooler cannot be removed.

During testing of a pilot-scale melter system, plugs often formed in the film cooler and/or the transition line between the melter and the submerged bed scrubber. The plugs contained melted material, entrained melter feed material, and condensed semi-volatile solids (e.g., borates). Plugs occurred rather unpredictably but were more frequent when high bubbler flow rates were used or when the solids content in the melter feed was lower than assumed for the facility design. [This is a major issue for ultrafiltration.] Plug formation could not be discerned (e.g., by differential pressure measurements) until solids buildup in the film cooler or transition line was well along, i.e., until the line was already partially occluded. These plugs were rather refractory in nature and could not easily be removed. The methods employed during testing (for example, banging on the transition line) to remove plugs are not suitable for remote operations.

This is a major issue because the condition cannot be detected with the present process instrumentation until the lines are already at least partially occluded. Thus, it would require frequent replacement of the film cooler and/or the transition line, and, if the plug prevents removal of the film cooler, replacement of the melter. Since the WTP does not plan to have spare melters on hand, a severe loss of production would result until a new melter could be procured, assembled, and installed.

Example solution: The best solution is to determine an envelope of melter operating conditions so that plugs will not form. The WTP is designing a reamer for the film cooler. In light of the ineffectiveness of the DWPF and WVDP film cooler cleaners, the EFRT recommends the design and associated cleaning procedures be tested at process temperatures on a prototypic scale with simulated waste. A review of the test data by the EFRT indicates that increasing the plenum size, i.e., increasing the distance from the melt surface to the film cooler, might reduce or eliminate the potential for plugging. The EFRT suggests this example solution be further investigated.

Potential HLW Vitrification Issue

Lack of a spare melter may lead to significant downtime in the HLW Vitrification Facility.

As noted in the Inconsistent Long-Term Mission Focus section (Systemic Issues), current plans do not call for spare melters. If replacement melters are not available, the downtime for a melter change-out will be at least 2 years. This will result in a decreased overall Plant availability.

Example solution: Purchase a spare HLW melter or at least the refractory and melter shell necessary for melter assembly.

Vitrification Off-Gas Systems

The EFRT evaluation of the HLW and LAW off-gas systems identified one issue. The potential for plugging of the HLW film cooler and transition line to the submerged bed scrubber is discussed above in the HLW Vitrification Facility section.

Analytical Laboratory

In the WTP Analytical Laboratory, analytical functions are performed to support process control, waste form qualification testing, and limited technology testing and receipt/analysis of tank farm samples. The Analytical Laboratory will receive, prepare, analyze, and record data for samples having moderate to high levels of radioactivity. It includes hot cells and fume hoods for radioactive sample receipt and analysis; radiological laboratories; support areas (change rooms and miscellaneous support areas); mechanical rooms (ventilation and electrical equipment); maintenance shops, including manipulator repair; sample receipt area; and waste management areas.

The EFRT found no major issues and one potential issue.

Potential Analytical Laboratory Issue

The sampling system may not prove adequate for handling slurries. This system is critical to the success of WTP operation. The completion of the planned testing is necessary to ensure sampling system adequacy. The capability of the current baseline sampling equipment needs to be confirmed.

The WTP will rely on chemical analyses of slurries to provide information needed for effective process control. Samples will be taken from solids-containing fluids using the sampling devices, and then analyzed in the Analytical Laboratory. Based on experience at both WVDP and DWPF, sampling and analysis of solids-containing fluids is challenging. The DWPF required rework of its sampling system to be successful. If the sampling system does not provide a sample that adequately represents the fluid, then even with perfect analytical results, subsequent control actions may be incorrect and can possibly lead to process upsets. While the potential impact on throughput cannot be quantified, any additional samples and reanalysis will slow the process.

There is great confidence that the analytical methods selected will provide precise and accurate analyses of the samples provided. However, a previous test of the sampling system was partially compromised (due to tank mixing) and did not fully demonstrate the overall system's effectiveness. The ability of the sampling system to provide representative samples is absolutely essential for process control.

Example solution: A test of the system's overall effectiveness is required and should be scheduled so that, if necessary, any changes to the system may be made in a timely manner. The Project has the test scheduled and the EFRT recommends it be performed.

Balance of Facilities

"Balance of Facilities" (BOF) refers to all of the other facilities and systems required to support the three main waste processing facilities. For example, the glass-former reagent system will receive and process bulk GFCs from off-site suppliers and supply the GFCs to the melter feed preparation vessels within both the LAW and HLW vitrification facilities. Other facilities and systems within the BOF envelope include those to supply solutions of chemical reagents, chilled water, Plant steam, Plant air, demineralized and raw water, electrical services, and diesel fuel oil.

The EFRT identified two issues that have been discussed in previous sections. The first issue is lack of backup diesel generators for the melters, which was discussed in the Inconsistent Long-Term Mission Focus section under Systemic Issues. The second issue concerns the lack of a process to analyze GFCs before they are introduced into the storage silos. The impact on LAW vitrification was discussed above in the LAW Vitrification Facility section. The impact on HLW vitrification is not as great a concern as LAW vitrification, since the HLW melter feed has confirmatory samples analyzed before being vitrified. An upfront analysis of each GFC would benefit HLW vitrification, because it would eliminate the possibility of making melter feeds with incorrect GFCs and the consequent need to rework them.

Potential BOF Issue

Lack of analysis before loading GFCs into the storage silos.

Example solution: Analyze GFCs with hand-held instruments. The EFRT understands that development is already in progress.

Design of Control Systems

The WTP process control system (including computer hardware/software and instrumentation) may not provide adequate control of the WTP process.

While design and implementation of the control system are still in the early stages (the entire system will not be completely implemented until 2009), the EFRT has found indications that the system may not perform adequately due to differences among documents defining the design basis, lack of evidence of an agreed-upon control strategy, and a loss of experienced personnel needed to review system specifications.

There are inconsistencies among upper-tier requirements documents such as the *Operations Requirements Document*, 24590-WTP-RPT-OP-01-001, Rev. 2, May 5, 2003; *Basis of Design*, 24590-WTP-DB-ENG-01-001, Rev. 1C, January 7, 2005; and *Flowsheet Basis and Assumptions Requirements Document*, 24590-WTP-RPT-PT-02-005, Rev. 3, June 30, 2005. The control system design basis is defined by three types of documents: P&IDs, system description documents, and software functional specifications. A review of a group of these documents for internal consistency showed that the P&IDs did not always match the system descriptions or the software functional specifications. System descriptions were often out of date, and

P&IDs did not have a consistent level of detail. These differences indicate a need for qualified resources from the process, operational, engineering, and control system disciplines to ensure consistency among documents.

The extended schedule and this lack of consistency also imply there will be a need for the involvement of "process experts" throughout the process control design and implementation phases to ensure an adequate reflection of the control strategy. Since important process steps are not yet demonstrated (e.g., caustic and oxidative leaching), the WTP has reassigned resources away from control system design-basis definition and development. The EFRT is concerned that these resources may not be available when needed to complete design and implementation of the system. In this case, there is a risk that the process control system will be incompatible with the operational and control strategies and thus unable to provide adequate control.

WTP Throughput/Performance

Once the issues were categorized and assessed, their impact on expected throughput and performance of the Plant was addressed. This section discusses the methods and results of the EFRT's analysis of capability, capacity, and availability upon resolution of the issues.

The performance of the WTP is measured by throughput of the pretreatment processes and the glass quality and productivity of the LAW and HLW vitrification processes. The throughput of the WTP is contingent on the following factors:

- Basic design and size of the equipment
- Design of the process
- Availability parameters
- Composition and properties of the feed to the Pretreatment Facility.

The feed for the pretreatment process comes from tank farms that contain a myriad of waste materials. The composition of these materials will have a direct impact on the effectiveness of the WTP.

The feed for both LAW and HLW comes from the Pretreatment Facility. This facility consists of feedstock blending, three different evaporators, a combined ultrafiltration and leaching operation, and an ion exchange process. The evaporators and ion exchange are continuous processes with batch feed, whereas the ultrafiltration/leaching operation is essentially a batch process. The vitrification processes are semi-continuous flow processes with batch feed makeup.

The productivity of a continuous process is typically measured in volume or weight per unit of time. The productivity of a batch process is typically measured in batch size per batch per unit of time. The quality of a product is measured by analysis and comparison to specifications.

Three factors that make definitive statements about the capacity/availability of the WTP process challenging are listed below:

- The WTP is a combination of batch and continuous processes with buffer storage capacity between each process. The use of a conventional flowsheet approach is limited in developing process analysis and strategy. This deficiency is mainly the result of average flows being used to describe process steps that have discontinuous and varying flows.
- There are a number of issues that if not corrected will have significant impact on both the equipment and the process performance of the WTP.
- Over time, the availability of the equipment in the WTP will vary and have an effect on capacity.

Throughput Analysis

The analysis performed by the EFRT attempted to determine the suitability of the basic equipment, process design, and availability to determine throughput. This analysis was performed by examining equipment design, process design, and mechanical design, and formed the basis for conclusions discussed here.

As the analysis progressed, a number of issues were identified that raised questions as to the ability of the WTP to meet its goals. An example issue is the ultrafiltration/leaching step. This step may be described as a very long batch process whose first step is a continuous feed, which is then followed by a series of washings and chemical treatments. The cycle time of the leaching processes has a significant effect on the capacity of the Pretreatment Facility. The effectiveness of the leaching steps will also have an impact on the quantity of glass being produced in the two vitrification processes.

However, the leaching processes with their various feeds have not been demonstrated at a large enough scale for meaningful projections of their performance in the WTP. Statements made on the performance of these processes at this time are based on the assumption that the leaching processes will scale up as indicated on the current flowsheet and ignore the complexity of the operations and limited understanding of the leaching requirements.

It should be noted that some feeds that do not require leaching can be handled in a simplified process in which there is sufficient filtering capacity. In that case, the ultrafiltration portion of the Pretreatment Facility has the adequate equipment and process design to meet the desired throughput.

The LAW and HLW vitrification systems appear to be on a much firmer basis than the ultrafiltration/leaching system, and the calculations representing their capability are more reliable.

The use of a simplified model to evaluate scenarios under different assumptions would allow a better understanding of the impact that key parameters would have on the operation of the WTP. It would also show the effect that resolving key issues would have on the future performance of the WTP.

Analysis Results and Discussion

The throughput of the WTP may be described as an outcome of an interrelated system composed of:

- Equipment design – Intrinsic capability
- Process design – Process capacity
- Mechanical design – Availability

The system is illustrated by the "map" in Figure 3, which shows the interrelatedness of the key components of the WTP technology implementation. The figure indicates that systemic issues will also have an influence on the WTP throughput. The different elements of the figure are discussed below.

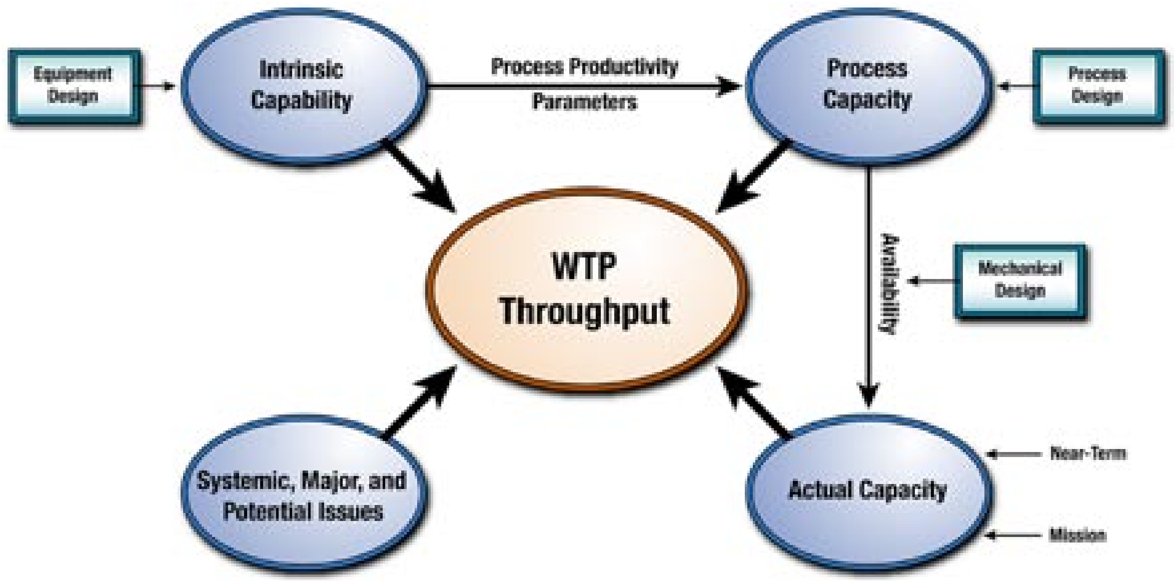

Figure 3. Relationship of Key Components of WTP Technology Implementation

Intrinsic Capability (Equipment Design)

Process equipment has an ***Intrinsic Capability***, based on its design to perform certain tasks, e.g., transfer heat, remove vapor, mix materials, and related unit operations. This capability would be defined by heat transfer area, vapor area, and mixing ability, as well as related auxiliaries such as cooling water and steam availability. It is standard practice in designing equipment to add a design margin.

The ***Intrinsic Capability*** of a piece of equipment is highly dependent on the properties of the materials being processed. For example, viscous materials will give a lower rate of heat transfer than low-viscosity materials under identical process conditions in the same equipment.

Process Capacity (Process Design)

How well a piece of equipment performs these functions depends on the process conditions that the operator desires and specifies. These are identified as ***Process Productivity Parameters***.

How well the individual items of equipment produce the desired process results and are integrated with one another has a direct bearing on the productivity of the process. The function of process design is to identify the important process parameters and match the desired process results with the intrinsic capability of the equipment. The outcome of this is the ***Process Capacity***.

Availability (Facility Design)

The facility design and equipment layout have a direct impact on the ability of the process and equipment to maintain a high level of on-stream performance. These factors are of particular significance in the WTP. The ***Availability*** of the WTP is the last factor to be considered in assessing its throughput.

Actual Capacity

Applying the availability factor to the ***Process Capacity*** gives the ***Actual Capacity*** of the WTP.

Figure 3 Insights

Figure 3 shows that the factors influencing the throughput of the WTP are equipment design, process design (process productivity parameters), and mechanical design (availability). The enhancement or degradation of these factors will lead to changes in the WTP throughput. Establishment, specification, and control of the key variables that impact these parameters will ensure predictable throughput.

Throughput

To make a definitive statement about the ability of the WTP to process material, a specific time frame must be set and a framework established. One factor that complicates the analysis of the capacity of the WTP is the interconnected arrangement of batch and continuous process steps buffered with intermediate storage capacity.

Scenarios of Interest

1. Hot commissioning (Contract period)
   Pretreatment 20-27 days
   LAW vitrification 47-63 days
   HLW vitrification 43-56 days

2. Design life of Plant – 40 years

Table 4 summarizes the EFRT's analysis of WTP's throughput and process capacity. The table shows the actual throughput required from each section of the Plant to produce the indicated quantity of glass. The table also indicates the projected maximum process capacity for each of the sections. These values were derived from the analysis of individual sections and their interaction with the overall process. These projections are based on the EFRT's assessment of the intrinsic capability of the equipment coupled with the process design.

Table 4. EFRT's Analysis of WTP's Throughput and Process Capacity (at 100% Availability)

Glass Production MT/Day		Process Stream, gpm												Glass MT/Day	
		FEP		UF (w/o leaching)		UF (w/leaching)		IX		CNP		TLP		LAW	HLW
		Req'd	Capacity @ 100% Availability	Req'd	Capacity @ 100% Availability	Req'd	Capacity @ 100% Availability	Req'd	Capacity @ 100% Availability	Req'd	Capacity @ 100% Availability	Req'd	Capacity @ 100% Availability	Capacity @ 100% Availability	Capacity @ 100% Availability
LAW	80	19.6	30-82	19.0	21.9 → IX	19.0	10.9 → IX	19.0	22 → TLP 3.3 → CNP	4.4	8	9.7	8-15	35	
LAW	60	14.7	30-82	14.2	21.9 → IX	14.2	10.9 → IX	14.2	22 → TLP 3.3 → CNP	3.3	8	7.3	8-15	35	
LAW	30	7.6	30-82	7.1	21.9 → IX	7.1	10.9 → IX	7.1	22 → TLP 3.3 → CNP	1.6	8	3.6	8-15	35	
HLW	6			0.55	4.6	0.55	0.9			0.55	0.02				6.0

Basis of calculations

UF/Filter:

- Flux = 0.015 gpm/ft^2
- Area = 1452 ft^2
- Feed Solids = 4%
- Slurry Solids to HLW = 20%
- Leaching Efficiency = 50%
- UF/Leach Cycle = 12 Days

IX:

Bead Resin

LAW:

80 MT/day LAW Equivalent to 2900 Sodium units

60 MT/day LAW Equivalent to 2200 Sodium units

30 MT/day LAW Equivalent to 1100 Sodium units

Note: "→" refers to "flow to next unit operation."

The above projections assume 100% availability. It should be noted that the Pretreatment Facility has considerable intermediate storage capacity, which can serve as a flywheel when a particular part of the Plant is out of service. A simplified throughput model, which includes estimates of the availability, should be effective in obtaining a reasonable time-based estimate of the WTP capacity.

Table 4 can be used to gain key process insights:

No Leaching (at 100% availability)

- There is ample process capacity to support 60 MT LAW glass per day
- If the process is run at maximum capacity and the feed solids are 4%, the production of slurry for the HLW system will far exceed the capacity of the HLW melter system.

Leaching (at 100% availability)

If the leaching process runs under the conditions indicated in the table, the following would be expected:

- UF/leaching is the constraint in the process.
- The UF/leaching system would limit the WTP capacity to 46 MT/day of LAW glass.
- The output of HLW slurry would be balanced with the capacity of the HLW melter.

Note that these are maximum capacities based on the assumptions listed in the table. Actual capacity will be lower when availability factors are considered. Achieving Project design requirements (60 MT/day of LAW glass) will also require fixing the major issues.

It should be noted that the capacity of the WTP will be influenced by the following factors:

- The amount and nature of the feed solids; this analysis is based on 4% solids (half of which are assumed to be removed in the leaching process).
- The actual flux achieved by the ultrafilter; this analysis is based on 0.015 gpm/ft^2.
- The active filter area; this analysis is based on the design area of 1452 ft^2.
- The efficiency of the leaching process; this analysis is based on a 6-day leaching cycle (12-day overall batch cycle) and a 50% solids dissolution.
- The solids content of slurry; this analysis is based on 20 wt% solids for the HLW system.

Table 5 shows how variation in the key parameters of filter area and flux will influence the calculated capacities.

These calculations show that either increasing the filter area by a factor of two or achieving the design flux raises the 100% process capacity to levels that would support the production of 80 MT/day of LAW glass. The actual flux will be known only after the process is operating. It is the EFRT's expectation, based on the data shown in the curve in Figure 4, that the flux will be 0.015 gpm/ft^2.

Table 5. The Effect of Filter Flux and Area on Maximum Process Capacity of UF/Leaching (at 100% Availability)

	Design Flux 0.028 gpm/ft^2		**Estimated Flux** 0.015 gpm/ft^2	
	Current Area	*2× Current Area*	*Current Area*	*2× Current Area*
Filter Area	1452 ft^2	2904 ft^2	1452 ft^2	2904 ft^2
Expected Permeate Rate, gpm	20.3	40.6	10.9	21.8
LAW	**Required Permeate Rate, gpm**			
80 MT/Day	← 18.9 →			
60 MT/Day	← 14.2 →			
30 MT/Day	← 7.1 →			
Analysis Based on a 12-Day UF/Leach Batch Cycle				

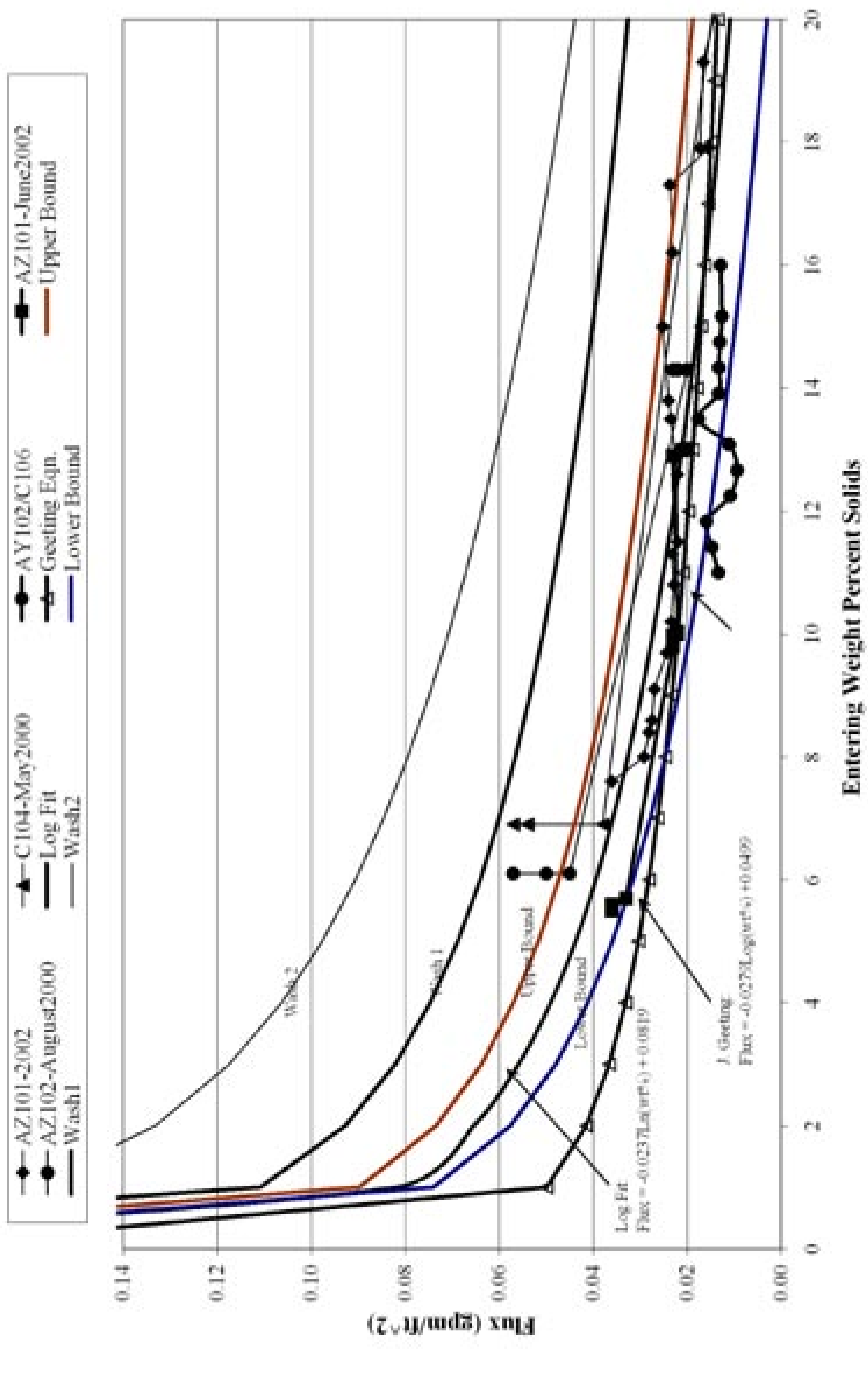

Figure 4. Correlations of UFP Filter Solids Concentration and Permeate Flux Data for WTP (taken from D. Alexander et al., *Design Oversight Report, HLW Feed Preparation System; Ultra-Filtration Process System*, Figure A.1, D-03-DESIGN-005, DOE ORP, April 2004; BNI CCN 094035, June 6, 2004)

Conclusions

In summary, the EFRT concludes the review with three words:

> **Essential** – The WTP has an essential role in the clean-up of the Hanford Site.
>
> **Flawed** – The EFRT has identified 17 major issues that must be addressed and fixed to ensure the Plant will meet design throughput for all presently identified feeds. In addition, 11 potential issues have been identified that should be addressed and fixed to provide additional assurance of meeting the design throughput.
>
> **Fixable** – The EFRT believes that all of the issues have solutions and do not require development of new technologies. Some of these fixes are already underway.

The EFRT developed several insights about culture and organization that affect the WTP. These insights start with the impression that the WTP lacks a clear mission and shared vision. For example, there is a lack of agreement about required throughput and how this translates into length of mission.

The Construction Industry Institute (CII) is a research consortium at the University of Texas. A major part of its mission is to improve the effectiveness of the construction industry. One of the important findings of CII is that projects have a much higher probability of success if the owner and contractor are aligned on mission and objectives. The clear mission statement must come from the owner—in this case, the US Department of Energy. In a very large project with widely varied feed streams and first-of-a-kind technology applications, such alignment is particularly critical.

Unless there is such a clear mission statement, the owner and contractor cannot develop an effective shared project strategy. A key aspect in implementing a shared project strategy is agreement on throughput, the adequacy of basic data, and the adequacy of preliminary flowsheets and piping and instrumentation diagrams. This process must be owner-driven.

Addressing the above insights and fixing the major and potential issues identified in this report are essential for the WTP to be successful.

Acknowledgments

The EFRT acknowledges the high level of cooperation between the WTP Project staff and the EFRT during the review. Open discussions were an important aspect of making the review process work.

The EFRT also thanks the Project liaisons. They provided timely information to our requests, both in written reports posted on the server and in lining up people, frequently on short notice, for face-to-face discussions.

Study Participants

The participants and functioning structure for the review (Figure 5) are shown here. Summary descriptions of the participants' expertise and experience are included in a separate document, "Background Information and Interim Reports for the Comprehensive Review of the Hanford Waste Treatment Flowsheet and Throughput."

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Kenneth Cooper, Ph.D. – Consultant; retired, Washington Savannah River Company

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Grenville Harrop – General Manager, Idaho Office, BNG America

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Frederick W. Damerow, Washington Group International (Technology)

Lawrence L. Lucas, Bechtel National, Inc. (Engineering)

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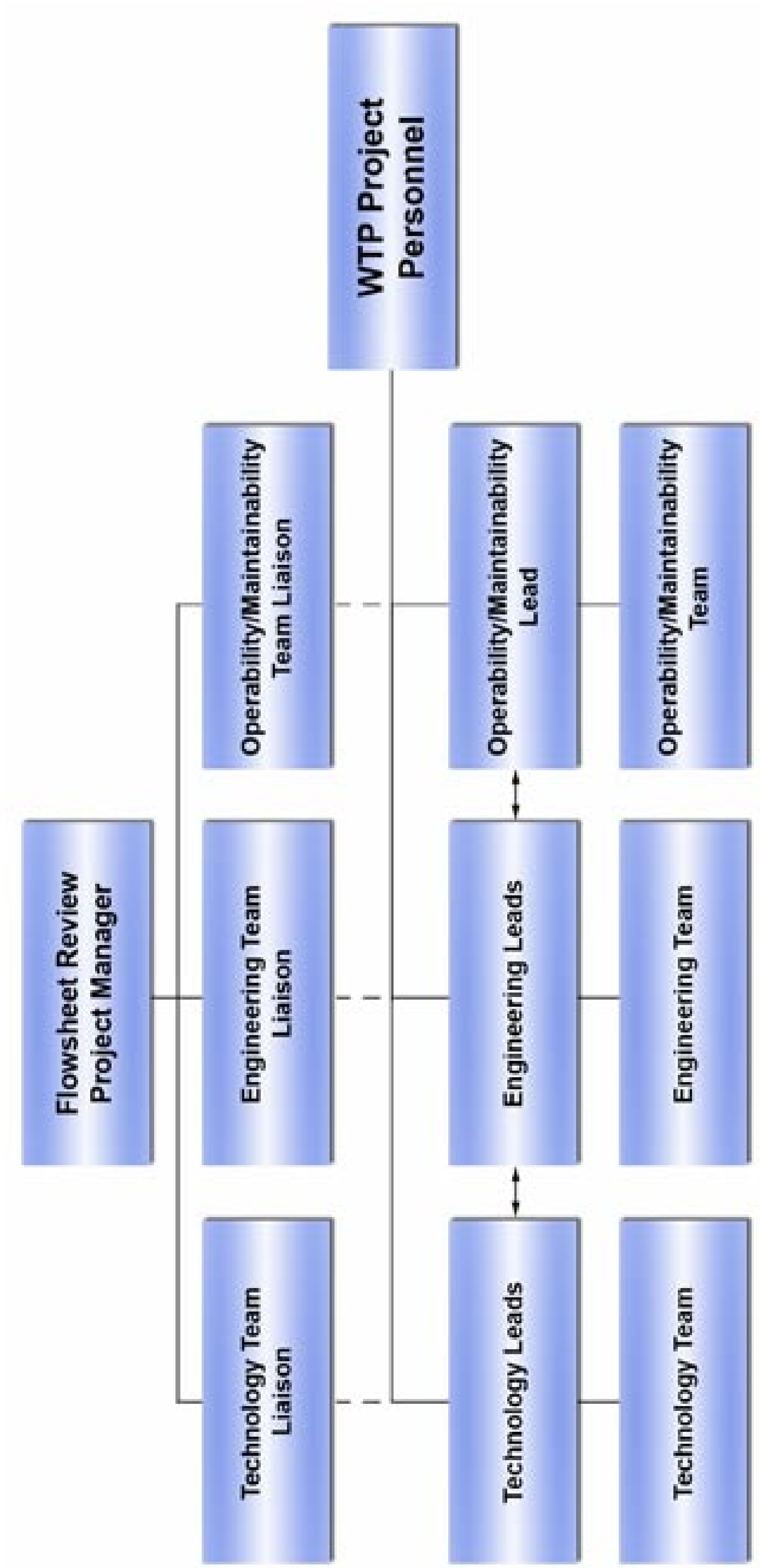

Figure 5. Functioning Structure for the WTP Flowsheet Review

Concurrence Signatures

The following individuals have participated in this review and concur with the report's observations and findings.

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