Full Focus Needed on Finishing Hanford's Waste Treatment Plant - 12196

Suzanne Dahl, Rabindra Biyani, and Erika Holmes
Washington State Department of Ecology, Richland, WA 99354

ABSTRACT

The United States Department of Energy's (USDOE's) Hanford Nuclear Site has 177 underground waste storage tanks located 19 to 24 km (12 to 15 miles) from the Columbia River in south-central Washington State. Hanford's tanks now hold about 212,000 cu m (56 million gallons) of highly radioactive and chemically hazardous waste. Sixty-seven tanks have leaked an estimated 3,785 cu m (1 million gallons) of this waste into the surrounding soil. Further releases to soil, groundwater, and the Columbia River are the inevitable result of the tanks continuing to age. The risk from this waste is recognized as a threat to the Northwest by both State and Federal governments.

USDOE and Bechtel National, Inc., are building the Waste Treatment and Immobilization Plant (WTP) to treat and vitrify (immobilize in glass) the waste from Hanford's tanks. As is usual for any groundbreaking project, problems have arisen that must be resolved as they occur if treatment is to take place as specified in the court-enforceable *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) and the *Consent Decree*, entered into by USDOE, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology (Ecology). At times, USDOE's approach to solving these critical issues seems to have caused undue wastes of time, energy, and, ultimately, public funds.

Upon reviewing the history of Hanford's tank waste treatment project, Ecology hopes that constructive criticism of past failures and praise of successes will inspire USDOE to consider changing practices, be more transparent with regulatory agencies and the public, and take a "lean production" approach to successfully completing this project. All three Tri-Party Agreement agencies share the goal of completing WTP on time, ensuring it is operational and in compliance with safety standards. To do this, Ecology believes USDOE should:

- Maintain focus on the primary goal of completing the five major facilities of WTP.
- Construct a supplemental low-activity waste (LAW) vitrification facility for the two-thirds balance of LAW that will not be treated by the vitrification facility under construction.
- Prepare infrastructure for waste feed from the tanks and facilities to handle the WTP waste streams.

To support this project track, Ecology expedites dangerous waste permitting by using a design-build approach to integrate WTP into the *Resource Conservation and Recovery Act* permit for Hanford.

INTRODUCTION

The U.S. Department of Energy's (USDOE's) Hanford Nuclear Site stores about 212,000 cubic meters (cu m) (56 million gallons) and 6.29 x 10^{18} Bq (170 million curies) of mixed radioactive and chemical wastes in 177 huge underground tanks. Sixty-seven of these tanks and their related systems have leaked or have been overfilled, releasing at least 3,785 cu m (1 million gallons) of waste to the surrounding soil, which has contaminated groundwater significantly. Hanford's tanks are only 19 to 24 km (12 to 15 miles) from the Columbia River, an irreplaceable resource for people and wildlife in the Pacific Northwest. USDOE is required to remove the waste from these tanks before it further harms the environment and the tanks are so old that removal becomes impossible.

USDOE and Bechtel National, Inc., (BNI) are constructing the Waste Treatment and Immobilization Plant (WTP) to treat and vitrify (immobilize in glass) waste from the tanks for permanent underground disposal. WTP has three major treatment facilities:

- A Pretreatment Facility (PTF) to divide tank waste into low-activity waste (LAW) and high-level waste (HLW) streams.
- An HLW Facility to vitrify the HLW stream for deep geologic disposal offsite.
- A LAW Facility to vitrify a portion of the LAW stream for near-surface disposal at Hanford.

WTP is 62 percent complete, with 86 percent of the design and 59 percent of the construction finished. The Washington State Department of Ecology (Ecology) regulates WTP through its dangerous waste permit and is involved in identifying and remedying technical and environmental issues.

As is usual for any groundbreaking project, problems have arisen. They require quick resolution to treat waste as specified in the court-enforceable *Hanford Federal Facility Agreement and Consent Order* [1] (Tri-Party Agreement) and *Consent Decree* [2], entered into by USDOE, the U.S. Environmental Protection Agency, and Washington State. At times, USDOE's approach to solving these critical issues seems to have caused undue wastes of time, energy, and ultimately public funds.

Upon reviewing the history of Hanford's tank waste treatment project, Ecology hopes that constructive criticism of past failures and praise of successes will inspire USDOE to consider changing practices, be more transparent with regulatory agencies and the public, and take a "lean production" approach to successfully completing this project. All three Tri-Party agencies share the goal of completing WTP on time, ensuring it is operational and in compliance with safety standards. To do this, Ecology believes USDOE should:

- Maintain focus on the primary goal of completing the five major facilities of WTP.
- Construct a supplemental LAW vitrification facility for the two-thirds balance of LAW that will not be treated by the vitrification facility under construction.
- Prepare infrastructure for waste feed from the tank farms and facilities to handle the WTP waste streams.

HANFORD NUCLEAR SITE OVERVIEW

Hanford is located in south-central Washington State along a roughly 80 km (50 mile) stretch of the Columbia River. The Federal government selected the 1,518 sq. km (586 sq. mile) site in

the early 1940s to produce Pu-239 for nuclear weapons as part of the Manhattan Project. The Pu-239 was produced by a series of steps that began with specially designed uranium metal (fuel) being exposed to neutrons (irradiation) in reactors along the Columbia River. The government built and operated nine plutonium-production reactors between the 1940s and 1980s.

The irradiated fuel was then shipped to the center of the site where it was reprocessed in one of five chemical facilities. This process produced a tremendous amount of liquid waste, much of which had low levels of radioactivity and was directly disposed of to the ground through trenches, ponds, and cribs. The higher activity waste from these reprocessing facilities — the waste that contained most of the radioactive elements — went into underground carbon-steel storage tanks. Carbon steel was chosen due to cost and the shortage of stainless steel during World War II.

The underground storage tanks were built on an as-needed basis as more and more waste was created. By 1964, Hanford had 149 single-shell tanks. These tanks ranged in size from 208 cu m to 3,785 cu m (55,000 to 1 million gallons). By the 1950s, Hanford officials knew that some of the single-shell tanks had leaked. Starting in 1968, they built only double-shell tanks. Hanford now has 28 double-shell tanks ranging in capacity from 3,785 to 4,164 cu m (1 million to 1.1 million gallons).

The tanks are arranged into groups called tank farms. Hanford has 12 single-shell tanks farms and six double-shell tank farms [3]. Sixty-seven of the single-shell tanks are known or suspected leakers, and the amount of waste released to soil and groundwater is conservatively estimated at 3,785 cu m (1 million gallons). How those releases occurred is currently being evaluated as well as the condition of the tanks. Hanford discharged an estimated 461,800 cu m (122 million gallons) from the tanks to cribs as well. In 1997, it was determined that releases from several single-shell tank farms had contaminated the groundwater 61 m (200 feet) below with waste [4].

Today, Hanford's 177 underground tanks hold approximately 212,000 cu m (56 million gallons). The radioactive and chemical composition, volume, and consistency of the waste vary widely from one tank to another. The tank waste can be described as a mix of chemicals and radioactive elements. Generally, the waste is divided into three types: liquids, saltcake, and sludge. The specific content of each tank has not been fully characterized.

For the calendar year 2010, the single-shell tanks held 113,550 cu m (30 million gallons), and the double-shell tanks held 98,410 cu m (26 million gallons) [5]. Hanford tank waste accounts for 60 percent of the volume and 30 percent of the radionuclides found in USDOE's defense-related HLW inventory. The waste is composed of 2.22×10^8 kg (245,000 tons) of chemicals and 6.29×10^{18} Bq (170 million curies) of radioactivity. More specifically, 58 percent of the curies contained in the double-shell tanks is from Cs-137, while 40 percent comes from Sr-90. The remaining radionuclides, such as Tc-99 and Am-243, contribute two percent of the total radionuclide inventory in double-shell tanks. Of the curies contained in single-shell tanks, 27 percent is from Cs-137, while 69 percent is from Sr-90. Four percent is from other radionuclides.

Over the decades, USDOE (and its predecessors) used various fuel-processing approaches. This added a wide range of chemicals to the waste. Before pumping the acidic, high-activity radioactive, and chemical mixed waste into the carbon-steel tanks, workers added sodium hydroxide to neutralize the waste (pH 9–14). As a result, Hanford tank waste contains large

quantities of sodium nitrate and other salts, organic chemicals, solvents, and fission products [3]. This caused the waste to separate into different radioactive and chemical layers. Workers ran evaporation campaigns, which condensed the waste and reduced its volume. They ran additional reprocessing campaigns to recover uranium, Cs-137, and Sr-90 from the waste.

Sr-90 and Cs-137 are the major contributors of short-term risks to the environment. The U-238, I-129, and Tc-99 are the major contributors to long-term risks to groundwater and the Columbia River [3].

HISTORY OF TANK WASTE TREATMENT AT HANFORD

The history of attempts to treat tank waste at Hanford has been characterized by 20 years of delay and four distinct attempts to develop treatment capacity, starting in 1989.

- *1989 – 1993*, *First Treatment Acquisition Attempt, Hanford Waste Vitrification Plant:* The plan was to retrieve and treat only the double-shell tank waste. Pretreatment was to occur in the existing B Plant. HLW would be vitrified, and LAW would be grouted. Construction was to begin in July 1991, with hot operations in December 1999. This plan failed in part due to USDOE's budget and the need to treat waste from the single-shell tanks. B Plant's inability to meet environmental standards also made its use impossible.

- *1993, Second Treatment Acquisition Attempt, Larger Hanford Waste Vitrification Plant:* Both HLW and LAW were to be vitrified, and a new pretreatment facility was needed. The resulting LAW facility would process 1.8×10^5 kg/day (200 tons/day). HLW facility construction was to be started by June 2002, and operational in 2009. LAW facility construction was to be started by December 1997, and operational by June 2005. USDOE ended this plan within months in favor of a new contracting approach: privatization.

- *1993 – April 2000, Third Treatment Acquisition Attempt, Privatization*: Originally, this attempt started as a competition between two small pilot plants. The idea of pilot plants was quickly dropped due to the stringent safety and shielding requirements of building even a test facility to handle HLW. When all the safety requirements are built in, a facility's design-life is 30 years. Hot start for LAW treatment was scheduled to be in 2002. Initially, two companies were awarded a contract, then USDOE down-selected to one contractor, British Nuclear Fuels Limited (BNFL).

  In July 1998, estimated cost of the facility was $6.9 billion, and hot operations would begin in 2007. The point of privatization was to transfer risk from USDOE to the contractor and to delay paying for facility construction by having the contractor borrow money. In February 2000, the Congressional Budget Office ruled that it would not "score" all the budget obligation now and budget authority later. The Congressional Budget Office then scored more budget obligation up front, which prompted Congress to ask, "Why pay for all this interest on borrowed money if we will need the budget obligation up front?" At this point, if not earlier, USDOE could have considered alternative financing and contract methods. In April 2000, BNFL cost estimates escalated to $15.2 billion. By May 2000, USDOE announced it was terminating BNFL and would develop a request for new proposal for the tank waste treatment contract.

- *May 2000 – Present, Fourth Treatment Acquisition Attempt*, *Government-owned, Contractor-operated Hanford Waste Vitrification Plant:*
  USDOE dropped the privatization concept and returned to a government-owned, contractor-operated request for proposal (RFP). This RFP delayed the start of construction one year to mid-2002, pushing back hot start to 2007, and full operations from 2009 to 2011. In October 2000, USDOE and Ecology agreed to modify the *Hanford Federal Facility Agreement and Consent Order* [1] to require USDOE to award a contract for the treatment complex by January 2001. In December 2000, USDOE awarded a construction contract to BNI. In December 2001, USDOE submitted a certified dangerous waste permit application to Ecology. Construction began in July 2002.

However, since the inception of the fourth plan, three major schedule slips have delayed the hot start date from 2007 to 2019, a loss of 12 years.

- In 2003, hot start moved from 2007 to 2009 (2-year delay) due to changing to new contractors in 2000 (BNI) and adopting a new funding approach.
- In 2005, full-scale operation moved to 2016 due to increasing construction schedule estimates and delays related to seismic re-evaluation.
- In 2007, hot start moved to 2019 due to new validated estimates for design and construction completion.

The early lack of commitment from the Federal level, competing USDOE projects vying for funding, and misjudgments about the types and sizes of facilities needed to treat Hanford waste have led to 20 years of delays, a series of false starts and delays in legal commitments, and increased risk from the waste stored in the tanks. Although BNI has completed over half the construction, questions remain about the successful completion of the project. USDOE recently expressed concerns about meeting the 2019 deadline.

Ecology believes that the course must be improved with a clear focus on top priorities. Through a critical review of the history of tank waste treatment, one can find answers to many questions USDOE continues to research. As Winston Churchill so eloquently stated, “The longer you look back, the further you can look forward.”

BUDGET SHORTFALLS AND SHIFTING PRIORITIES

One big challenge to staying on schedule is the Federal budget. In addition to developing treatment capacity, Hanford’s issues related to tank waste retrieval, transfer, and treatment are problems that require continuous, adequate funding to keep the project on track. Any delays escalate the risk of further environmental damage. Although Ecology is involved in budget allocation discussions at a local level, outsiders, including State employees, are not involved in crucial budget allocation discussions that go on in in Washington, D.C. USDOE is under a lot of pressure when divvying scarce resources for which many sites, contractors, and projects compete.

USDOE continues to face budget shortfalls for WTP. For the current year, their allocation is $100 million less than project cost projections [6]. The reduced funding may require USDOE to reshuffle priorities, which is time consuming and removes the focus from building WTP. Past history on funding shortfalls at WTP shows that when work slows down on a major facility, like PTF, for a year, it results in at least a two-year delay to the schedule. This is due to staff being

reassigned to new positions and subcontractor work being interrupted. Subsequent delays are caused by the time it takes to ramp up work when the funding is reauthorized.

USDOE is evaluating a number of options at this time to restructure the planned completion of WTP. Currently, USDOE is looking into starting the HLW vitrification facility before PTF is completed. This task would require USDOE to install additional underground pipelines to provide waste feed directly to the HLW facility. This is not a trivial task and could disrupt ongoing construction nearby. Then an alternative path has to be established for the recycle streams from the HLW facility back to the double-shell tanks.

USDOE is considering similar plans to start the LAW vitrification facility without PTF completed. This would require new funding for a temporary pretreatment infrastructure. In 2006, delays in building WTP prompted USDOE to find ways to show success sooner. They researched pretreating the waste using filtration and ion exchange equipment either inside or near the tanks. This plan would also require that an alternative path be established for the recycle streams from the LAW facility back to the double-shell tanks.

Although there may be benefits in starting either the HLW or LAW facility before PTF, USDOE should critically evaluate these benefits versus the costs in time and resources spent on a temporary solution. Ecology is not opposed to early treatment of tank waste; however:

- It must not slow down the overall WTP progress; it must start on time, according to legal obligations.
- It should be completed with additional funding that is beyond what is needed to meet all the legal obligations for tank waste.

PTF is a vital component in the WTP complex. Its ability to separate high-activity components from the lower activity components and a majority of the chemicals is essential to running the subsequent vitrification processes. With its varying waste feeds, PTF is undoubtedly one of the world's most complex chemical separations plants. Its design offers utmost challenges due to its remote-handled operations, requiring a conservative approach and high safety standards. Through independent oversight, detailed reviews, and testing, USDOE is on track to ensure that PTF's unique design will work. Ecology encourages USDOE to continue this focus on PTF.

To run WTP in the 2019 timeframe, systems must be available in the tank farms and for after the waste is treated to:

- Adequately blend, characterize, and deliver waste in accordance with WTP's waste acceptance criteria. Some of this infrastructure is not currently in place, which will require appropriate funding.
- Store the immobilized HLW. Hanford's vitrified HLW canisters were destined to go to the geologic repository at Yucca Mountain. But since this project has been cancelled, it is necessary to temporarily store a larger quantity of HLW canisters at Hanford for a much longer period of time than was originally planned. USDOE is planning a new, essential interim HLW canister storage facility to support WTP, also requiring steady funding.

The current budget crunch is not likely to let up in the near future, making it essential to focus on the highest priorities that result in a sustained tank waste treatment system. It is necessary to complete all the WTP facilities to meet our agreed-upon legal requirements of protecting the Columbia River from tank wastes. While it is absolutely important that the infrastructure is available to feed WTP and to manage the immobilized waste coming out of WTP by 2019, these

activities rely on known engineering processes. Completing WTP is where the significant challenges and risks lie.

WASHINGTON STATE'S UNIQUE CONTRIBUTION

To speed up overall construction of the massive WTP, Ecology decided over a decade ago to follow a design-permit-construct approach to parallel USDOE's design-build approach. This method is a common practice for large construction projects. What was not commonplace in 1999 was integrating a design-build approach into the State's *Resource Conservation and Recovery Act* (RCRA) permit for WTP.

In most RCRA-permitting approaches, the permitting agency requires the facility to be designed before the permittee can apply for a permit. Then, permit development usually takes 3 to 5 years, or more. Only after a final permit is issued can construction begin. If Ecology had followed the typical approach for WTP, permitting would only be starting now, and nothing would have been constructed yet.

Instead, Ecology implemented a phased, design-permit-construct approach. Permitting started with just 15 to 30 percent of the design. When component design and permitting is finished, construction of that component begins. While this may sound like a streamlined, simple approach to permitting, in actuality it involves a significant amount of design and regulatory review on a weekly basis. This involves as many as 40 small permit modifications per quarter and up to four major permit modifications per year.

CHALLENGES IN WTP DESIGN AND USDOE'S RESPONSE

As the buildings rise higher at the WTP construction site, new challenges crop up each day. In 2006, USDOE convened a panel of world-class experts to critically review WTP's design and operation logic. This External Flowsheet Review Team (EFRT) uncovered 28 issues. The EFRT had several important findings on the inadequacy of technical data for the leaching, ultrafiltration, and mixing of waste in vessels. Although the EFRT issue list is now considered officially closed, in some cases, the closure resulted in future required actions, including continued testing for mixing adequacy in vessels.

To resolve these issues, USDOE built a roughly one-fourth scale pretreatment engineering platform in 2008. The large-scale tests proved useful and resulted in design revisions of pretreatment processes. The technical data generated will improve WTP reliability. It points to the importance of continuing outside, expert evaluations. Moreover, periodically, there are other independent reviews, by the Defense Nuclear Facilities Safety Board (DNFSB), for example.

Recently, in response to DNFSB's Recommendation 2010-2, *Pulse Jet Mixing at the Waste Treatment and Immobilization Plant* [7], USDOE issued an Implementation Plan [8]. Through even larger-scale testing with representative simulants, mixing performance will be measured, and mixing models will be verified and validated. USDOE's commitment to action builds confidence. Ecology is pleased with USDOE's dedication to addressing the issue of adequate waste mixing in WTP vessels. But it could be confusing to an outside audience to officially close issues when legitimate research is still being conducted.

As an example of the complexity and ongoing design development, USDOE's in-house surveillance resulted in a recent report that questioned certain vessel material selections [9]. In

addition to evaluating corrosion in these vessels, USDOE's surveillance plan [10] will review vessel erosion issues, a topic of continuing concern to Ecology.

The fast-track, concurrent design-build option chosen for this huge plant necessitates field changes, especially when the process parameters are still evolving. In one recent case, an installed waste-holding vessel is being removed due to the lack of internal mixing components. The new design proposes an improved flow path with one less vessel in the Cs-137 ion-exchange system.

These types of ongoing design changes require Ecology to quickly review and process Permit Change Notices, including holding required public comment periods and expediting approval. Regulatory paperwork has never delayed the project, and that is Ecology's goal.

Too Much LAW, Too Little Time

WTP's current LAW vitrification facility may only be capable of treating one-third of the LAW feed that PTF will generate. For the past 10 years, USDOE has been evaluating other treatment methods (supplemental treatment) for the two-thirds balance of LAW. Some of these alternative technologies are steam reforming, bulk vitrification, and cement-based waste forms. The development of bulk vitrification [11] cost taxpayers about $100 million before it was abandoned.

Between 2003 and 2006, USDOE tested a variety of other waste forms for supplemental LAW treatment. Ultimately, nothing proved to be as durable and protective as glass, and none of the technologies were cheaper or faster. All of the options considered would cost as much and have similar implementation schedules as vitrification. After all that time and effort, it's clear that no other waste form performs as well as the baseline borosilicate glass.

Secondary waste associated with LAW treatment is planned for disposal at Hanford. Because it presents a significant risk to groundwater, it is important to consider this impact when choosing other methods of treating LAW. The submerged bed scrubber in the LAW vitrification facility traps and recycles the Tc-99, I-129, and other volatile components in the melter off-gas. But a small portion of these contaminants eventually ends up in the secondary waste stream that is sent to Hanford's Effluent Treatment Facility for further treatment. These contaminants also exit WTP in solid waste forms, such as carbon beds and silver mordenite columns. If time and resources are going to be spent on technology development, it would be best to do a rapid evaluation of established technologies that have worked elsewhere.

Research on other treatment methods for the two-thirds balance of LAW could enhance waste treatment, but they are difficult, time-consuming tasks. They detract from the main focus of completing WTP by the legal mandate of 2019. During the settlement agreement that resulted in the *Consent Decree* [2], all parties agreed that supplemental treatment will be some form of vitrification. Ecology is unclear whether the cost of a LAW vitrification facility twice the size of the current one has even been budgeted and is unsure how much emphasis and money USDOE is currently placing on evaluating supplemental treatment. This subject needs more attention from USDOE's top management despite other hot issues in WTP. Until there is supplemental treatment available for the remaining LAW, WTP will be constrained to run at only one-third of its capacity. If USDOE's goal is to complete tank waste treatment faster and cheaper, then proceeding with a second LAW vitrification facility, as defined in USDOE's baseline, is the best approach.

REPORTING THE STATUS: PERCEPTIONS OF PROGRESS

Reports provide opportunities to communicate WTP progress with the public and Congress. Sometimes these reports miss opportunities to fully explain, in plain language, that questions still remain for WTP. These missed opportunities lead to confusion on how complete the project is and could decrease chances to secure adequate funding.

To meet the Tri-Party Agreement Milestone M-062-49 [1], USDOE recently submitted a report [12] outlining how WTP will meet the requirement of treating the entire inventory of tank waste. No one reading that report will doubt that the plant is on schedule. Yet embedded in several places of the report are assumptions, any one of which could easily derail the timeline.

For example, one assumption is, "A Supplemental [LAW] Facility is modeled as a black box with no constraints on WTP and is available upon WTP start-up." This begs the question of how it will be possible to have a supplemental facility ready by 2022. It ignores the amount of time it takes to navigate the critical decision process, secure funding, and complete construction. Such assumptions mask the real problem of inadequate LAW capacity to run PTF at 100 percent of its design capacity.

However, the report [12] rightly points out successes in lab and pilot testing. A 2009 memorandum [13] ties together past laboratory data from many test reports on leaching and filtration characteristics of actual tank waste samples. Such efforts give confidence that WTP's design utilizes the best information.

The River Protection Project System Plan [14] analyzes several key issues and uncertainties. The plan recognizes that additional LAW treatment capacity and possibly "supplemental pretreatment capacity is required." Table 7.8, "Inaccurate Mission Decision" (p. 7-12), draws "particular attention" to this [14]. In this case, USDOE has done a better job of conveying the gaps in treatment.

GET ON WITH IT

Hanford's history over the past three decades unfortunately points to many incomplete waste treatment projects, while the tanks' age and the risk of environmental harm increase. There is wisdom in staying with the original plan: persevere and finish the WTP first.

Ecology believes that no time remains to prove out the necessary technology readiness level of another treatment process for the two-thirds balance of LAW that will not be treated by the vitrification facility under construction. Although the deadline is 2015 to decide on the details of the supplemental treatment for LAW, Ecology urges USDOE to consider a supplemental LAW vitrification facility, as their baseline indicates, and begin the critical decision process now to secure funding for it. Vitrification processes have operated at full scale successfully in other locations for decades.

Ecology is doing and will continue to do its part by expediting permitting. We strongly encourage USDOE to maintain focus on the primary goal of completing the five major WTP facilities, constructing a supplemental LAW vitrification facility, and preparing infrastructure for waste feed from the tank farms and facilities to handle the WTP waste streams. Any distraction from this focus dilutes urgency and could erode confidence and credibility in the project.

In World War II, workers built and started operating the world's first full-scale nuclear reactor at Hanford in 13 months. While it always takes longer to clean up a mess than it took to make the mess, the State and Federal governments have an obligation to the citizens of the Northwest:

- Safely build and operate WTP on schedule.
- Immobilize Hanford's worst waste that is currently sitting in old underground tanks.

REFERENCES

1. Washington State Department of Ecology, United States Environmental Protection Agency, United States Department of Energy. (2007). *Hanford Federal Facility Agreement and Consent Order*. Document 89-10, Rev. 7. Richland, WA.

2. *Consent Decree*, State of Washington v. Steven Chu, Secretary of the United States of Energy, and the United States Department of Energy. (2010). Docket no. 08-5085-FVS. United States District Court, Eastern District of Washington.

3. Gephart, R. E., and Lundgren, R. E. (1998). *Hanford Tank Cleanup: A Guide to Understanding the Technical Issues*. Technical report PNL-10773, Pacific Northwest National Laboratory, Richland, WA.

4. Office of River Protection. (1998). *Report to Congress: Treatment and Immobilization of Hanford Radioactive Tank Waste*. United States Department of Energy, Richland, WA.

5. Wollam, C. D., and Peck, B. D. (2011). *Waste Treatability Studies Report for the Hanford Site, Calendar Year 2010*. United States Department of Energy, Richland, WA.

6. Cary, A. (January 11, 2012). "154 construction workers laid off at Hanford vit plant." *Tri-City Herald*, Kennewick, WA.

7. Defense Nuclear Facilities Safety Board. (2010). *Recommendation 2010-2 to the Secretary of Energy, Pulse Jet Mixing at the Waste Treatment and Immobilization Plant*. Washington, D.C.

8. Secretary of Energy. (2011). *Department of Energy Plan to Address Waste Treatment and Immobilization Plant Vessel Mixing Issues, Implementation Plan for Defense Nuclear Safety Board Recommendation 2010-2*, Rev. 0. United States Department of Energy, Washington, D.C.

9. Fish, R., and Mandelenakis, N. (2011). *WTP Vessels Material Selection: WED Surveillance Report*. Report S-11-WED-RPPWTP-026. United States Department of Energy, Richland, WA.

10. Knutson, D. E. (November 22, 2011). "Notification of Results from the U.S. Department of Energy (DOE) Surveillance of the Vessel Material Selection for Ten Vessels at the Waste Treatment and Immobilization Plant (WTP)." Office of River Protection Letter 11-WTP-430. United States Department of Energy, Richland, WA.

11. Biyani, R. K. *Lessons Learned In Technology Development for Supplemental Treatment of Low-Activity Waste at Hanford*. Washington State Department of Ecology, Richland, WA. Presented at WM2008 Conference, Phoenix, AZ.

12. Gebhardt, M., et.al. (2011). *WTP Design Capability Study*. Technical Report 24590-WTP-RPT-PE-11-008, Rev. 1. United States Department of Energy, Richland, WA.

13. Jain, A. (2009). *Reconciliation of M-12 Ultrafiltration Bench-Scale Tests on the Actual Tank Wastes Using Cell Unit Filter (CUF) System*. United States Department of Energy, Richland, WA.

14. Office of River Protection. (2011). *River Protection Project System Plan*. Technical Report ORP-11242, Rev. 6. United States Department of Energy, Richland, WA.