DOE/ORP-2007-03
Revision 0

Hanford River Protection Project Low Activity Waste Treatment: A Business Case Evaluation

November 2007

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Executive Summary

Purpose – The U.S. Department of Energy (DOE or the Department) prepared this study to compare low-activity waste (LAW) treatment technologies and approaches that could support its integrated strategy for treating (i.e., pretreating and immobilizing) radioactive waste stored in underground tanks at the Hanford Site. The Hanford Waste Treatment and Immobilization Plant (WTP) is at the heart of DOE's strategy for treating the Hanford tank waste. The WTP Pretreatment (PT) Facility is designed to separate chemical and radioactive constituents in the tank wastes into a LAW feed stream and a high-level radioactive waste (HLW) feed stream. The LAW stream will be vitrified and disposed of on site. The HLW stream will be vitrified and disposed of in the proposed national geologic repository at Yucca Mountain in Nevada.

The LAW mass to be immobilized is approximately 10 times greater than the HLW mass to be immobilized. The WTP is designed to immobilize 100% of the HLW over a 23- to 35-year period; DOE assumed a nominal 27-year HLW immobilization period in this report. The WTP is estimated to only be capable of immobilizing approximately half of the LAW in the same time period as the HLW can be pretreated and immobilized. The Department would need to provide supplemental LAW immobilization capacity to complete the LAW and HLW immobilization missions in the same time frame. Without supplemental LAW immobilization, DOE estimates that the LAW immobilization mission will continue for approximately 60 years following the start of WTP operations (hereinafter "hot operations") in 2019; i.e., LAW immobilization would not be completed until 2079. This report evaluates various options available to DOE to reduce the duration of the LAW immobilization mission.

The Department maintains that the reduction of the LAW mission duration will reduce the overall cost to complete the cleanup of the Hanford tank waste and also reduce environmental risks associated with continued storage of wastes in the Hanford tanks. For the past several years, DOE has been evaluating technical approaches to enable it to supplement the WTP LAW immobilization and thereby reduce the LAW immobilization mission duration. Four primary supplemental LAW immobilization approaches are considered in the seven business cases presented in this report. These are:

- *2^{nd} WTP LAW Vitrification Facility (2^{nd} LAW).* The WTP LAW Vitrification Facility currently under construction could be replicated, with or without enhancements.
- *Bulk Vitrification (BV)*, a process used for hazardous and low-level wastes that vitrifies the waste in conjunction with glass-forming chemicals in single-use melters to produce massive glass waste forms. The Department has tested BV extensively at Hanford using laboratory-, engineering-, and full-scale systems.
- *Cast Stone* (CS), a grout process similar to processes in use by DOE and commercial industry for low-level radioactive waste to create monolithic grout waste forms.
- *Steam Reforming (SR),* a commercial process used for certain commercial low-level waste, and that will be used to immobilize sodium-bearing wastes at Idaho. A mineralized waste form would be required at Hanford.

The U.S. Government Accountability Office (GAO) recognized this study, which was ongoing at the time of its report, *NUCLEAR WASTE: DOE Should Reassess Whether the Bulk Vitrification Demonstration Project At Its Hanford Site Is Still Needed to Treat Radioactive Waste* (GAO-07-762, June 2007, p.16). The GAO report recommended that DOE (1) reassess the need for supplemental technology, (2) reassess the relative costs and benefits of demonstrating and deploying BV compared to other strategies, and

(3) report to Congress on the reassessment before requesting additional funding for the bulk vitrification demonstration project. The U.S. House of Representatives Energy and Water Development Appropriations Bill for Fiscal Year (FY) 2008 requests DOE to "reassess the need for the bulk vitrification project, as well as present a defined integrated strategy for low-level waste, and present this strategy to the House and Senate Committees on Appropriations."

The Department developed this report, including the seven business cases, to evaluate four key questions that encompass the House Committee direction and GAO recommendations:

1. Should DOE develop a means to supplement the WTP LAW Vitrification Facility?
2. How do the costs and benefits of BV compare with other potential supplemental LAW immobilization strategies?
3. What are the key elements in DOE's integrated Hanford LAW pretreatment and immobilization strategy?
4. Should that strategy include provisions for early LAW immobilization and/or immobilization of a portion of the LAW in the Hanford 200 West Area (both rely on tank farm-based LAW pretreatment)?

Background – The DOE Hanford Site near Richland, Washington, stores approximately 53 million gallons of chemically hazardous and radioactive wastes in 177 underground tanks, 149 single-shell tanks (SST) and 28 double-shell tanks (DST). The storage of waste in the SSTs poses greater environmental risks than storage of wastes in DSTs, which are newer and have a second shell to mitigate leakage. Sixty-seven of the SSTs previously leaked as much as one million gallons of tank waste into the soil surrounding the Hanford tanks; this leakage has increased risk to the Hanford area groundwater and the Columbia River. As a result, DOE has removed pumpable liquids from the SSTs to mitigate the threat of additional leakage during waste storage. Leakage risks increase and are carefully managed when DOE adds liquids to SSTs to retrieve wastes from those tanks.

The 28 DSTs have inadequate capacity to receive all of the SST wastes. Additional DST space will be created, which will enable additional SST wastes to be retrieved, as waste is withdrawn from the DSTs for treatment in the WTP. The Department estimates that it can achieve, on average, one SST retrieval each year (primarily sludge tanks from C-Farm) between now and the time that the WTP is scheduled to commence hot operations. The Department plans for the WTP to commence hot operations in 2019. Until that time, the rate of SST retrievals will continue to be constrained by the availability of DST space. This is illustrated in Figure ES-1.

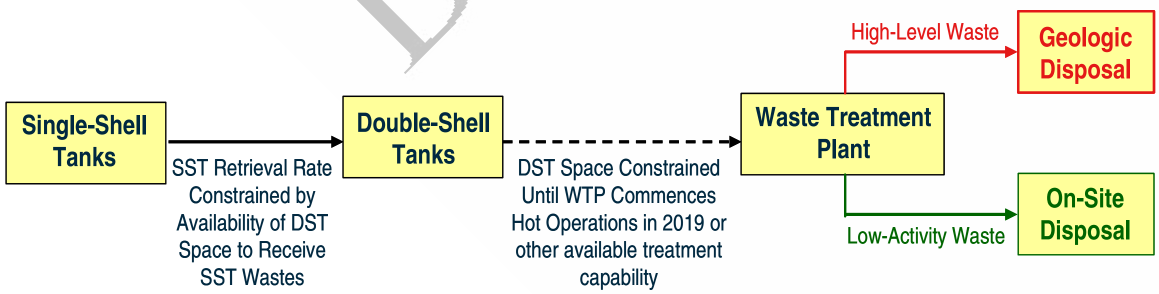

Figure ES-1. Until WTP Startup, DST Space Will Constrain SST Retrieval Rate

Most of the Hanford tank wastes resulted from spent nuclear fuel reprocessing (i.e., recovery of plutonium for defense purposes from spent nuclear fuel). The radioactive material content in the Hanford tanks, approximately 195 million curies including fission product daughter radionuclides, only makes up a few percent of the tank waste dry mass. Most of the dry tank waste mass consists of chemicals added to the wastes during reprocessing, during other Hanford operations, as well as for corrosion control. As a result, DOE has long planned to separate the chemical materials from the radioactive materials to the extent practical in order to minimize the mass of waste it disposes of in the Yucca Mountain HLW repository. The WTP PT Facility is designed to produce a HLW feed stream that contains over 95% of the radioactivity and a LAW feed stream that contains over 90% of the chemical waste mass. This is illustrated in Figure ES-2.

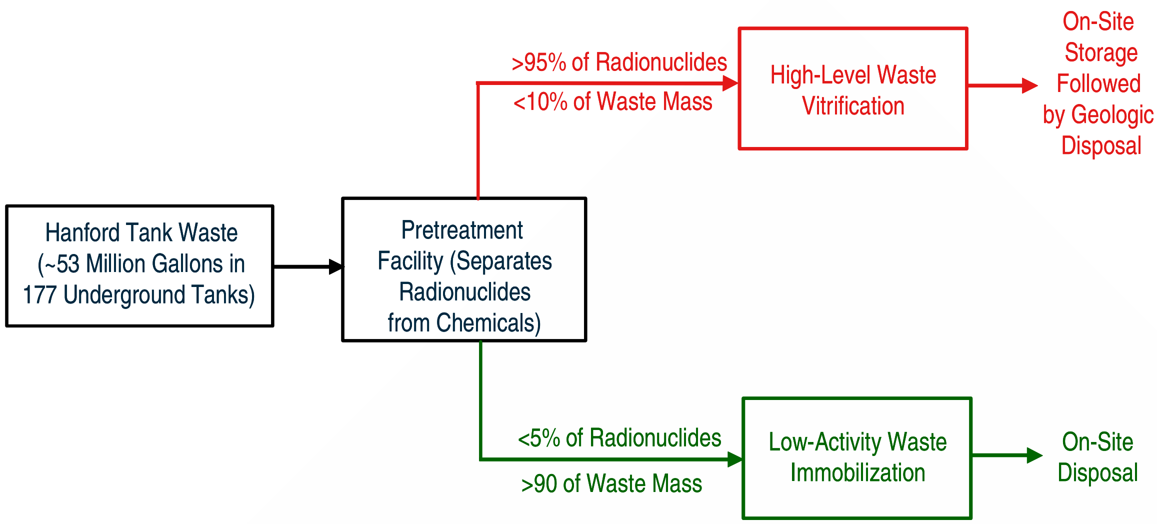

Figure ES-2. Simplified Hanford Tank Waste Treatment and Immobilization Flow Diagram

The pretreated HLW feed will be vitrified (transformed into glass) and stored on site until it can be disposed of in the proposed spent nuclear fuel and HLW repository at Yucca Mountain, Nevada. The pretreated LAW feed will also be immobilized but it will be disposed of on site. The LAW fraction that is immobilized by the WTP LAW Facility will be vitrified. The LAW fraction that is immobilized by a supplemental LAW immobilization technology, if any, could be vitrified or immobilized using another process as discussed in this report.

The WTP HLW Facility is designed to vitrify all of the pretreated HLW feed over a 23- to 35-year period. Based on the WTP commencing hot (radioactive) operations in 2019 and the 27-year HLW pretreatment and immobilization mission duration in this study, HLW immobilization could be complete in 2046. The Department currently estimates that it will produce between 10,000 and 14,000 HLW canisters depending upon the effectiveness of its initiatives to increase waste loading in the glass. At approximately 3.2 metric tons (MT) of glass per canister, that translates into approximately 32,000 to 44,800 MT of HLW glass. For comparison, if DOE vitrified all Hanford LAW in the WTP LAW Vitrification Facility (as assumed in Business Case 1), DOE would produce approximately 400,000 MT of LAW glass; i.e., there would be approximately 10 times as much LAW glass as HLW glass.

The Department has planned since the inception of the WTP Project in the mid 1990s to add additional LAW immobilization capacity. For that reason, in 2002 DOE, the Washington State Department of Ecology, and the U.S. Environmental Projection Agency undertook the evaluation of a wide range of potential LAW immobilization technologies as potential options to building a second WTP LAW facility.

The agencies ultimately identified a second LAW facility, BV, CS, and SR facilities as the most viable options for supplementing the WTP LAW Vitrification Facility. The Hanford Tank Farm Contractor issued contracts to the BV, CS, and SR facility technology vendors to develop waste forms for DOE's consideration and to develop pre-conceptual designs to implement the supplemental immobilization technologies. Based on its evaluations of the vendors' submissions, DOE elected to proceed with BV testing at the Hanford Site, SR testing at its Idaho site, and CS (grout) testing at its Savannah River Site.

The Department has not yet selected an immobilization process to supplement its Hanford LAW Facility. The Department will make that decision in accordance with its project management orders and the *National Environmental Policy Act of 1969* (NEPA), pursuant to the *Tank Closure and Waste Management Environmental Impact Statement* (TC & WM EIS)[1].

Business Cases Evaluated – The Department developed seven business cases for evaluation in this report. The evaluation of these business cases provides insights into the need for supplemental LAW immobilization and the costs, technical readiness, advantages, and disadvantages of each of the four immobilization approaches. The seven business cases are summarized below in Table ES-1.

Table ES-1. Summary Overview of the LAW Business Cases

<table>
<tr><th colspan="2" rowspan="2">Business Case*</th><th rowspan="2">Supplemental LAW Immobilization</th><th colspan="2">Year Waste Immobilization Complete</th><th rowspan="2">Comments</th></tr>
<tr><th>HLW</th><th>LAW</th></tr>
<tr><td rowspan="3">1</td><td>A</td><td>None</td><td>2079</td><td>2079</td><td>All LAW immobilized in WTP LAW facility.</td></tr>
<tr><td>B</td><td>None.</td><td>2046</td><td>2079</td><td>Same as 1A but build 31 new DSTs to store pretreated LAW and complete PT and HLW immobilization by 2046.</td></tr>
<tr><td>C</td><td>None</td><td>2046</td><td>2059</td><td>Third melter installed in LAW and all three melters upgraded to provide 1,500 MT per year.</td></tr>
<tr><td colspan="2">2</td><td>2nd LAW in 200 East</td><td>2046</td><td>2046</td><td rowspan="5">Same assumptions for Cases 2 through 5. Only the LAW immobilization technology changes.</td></tr>
<tr><td rowspan="2">3</td><td>A</td><td>BV in 200 East</td><td>2046</td><td>2046</td></tr>
<tr><td>B</td><td>3rd Melter in LAW and BV</td><td>2046</td><td>2046</td></tr>
<tr><td colspan="2">4</td><td>CS in 200 East</td><td>2046</td><td>2046</td></tr>
<tr><td colspan="2">5</td><td>SR in 200 East</td><td>2046</td><td>2046</td></tr>
<tr><td colspan="2">6</td><td>BV in 200 East and 200 West</td><td>2046</td><td>2046</td><td>BV in 200 West starts in 2014. BV in 200 East and WTP LAW start in 2019.</td></tr>
<tr><td colspan="2">7</td><td>BV</td><td>2046</td><td>2046</td><td>BV in 200 E and WTP LAW both start in 2014.</td></tr>
<tr><td colspan="6">*The WTP is located in the 200 East Area.</td></tr>
</table>

Business Case 1 (which includes Cases 1A, 1B, and 1C) considers using the WTP as currently designed to complete the entire Hanford Site tank waste treatment mission (i.e., no supplemental LAW immobilization). Processing interties between the LAW pretreatment and immobilization systems and the HLW pretreatment and immobilization systems generally require those systems to operate in parallel and have similar mission durations (Cases 1A and 1C). The Department mitigated the impact of those interties in Case 1B by building additional DSTs to store pretreated LAW until that waste can be immobilized in the WTP LAW Vitrification Facility. The objective in Case 1B is to enable the WTP PT and HLW Vitrification Facilities to complete their pretreatment and immobilization missions approximately 27 years following the start of WTP hot operations and then be closed and

[1] 71 FR 5655, "Notice of Intent To Prepare the Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, WA," *Federal Register*, February 2, 2006.

decommissioned. Low-activity waste immobilization would continue approximately 33 more years (until 2079), at which point all waste immobilization would be complete.

The WTP LAW Facility includes a third melter bay; however, in this study only two LAW melters are assumed with an immobilization capacity of 1,000 MT sodium per year. The WTP design requires that the LAW Vitrification Facility have the capability to install the third LAW melter. A third melter could potentially increase the WTP LAW capacity by one-third to 1,500 MT sodium per year. With such changes, the WTP facility could process approximately 40,000 MT of sodium over the assumed 27-year operating period, reducing the supplemental LAW immobilization system throughput requirements by approximately 40%. Supplemental immobilization would still be required for the remaining 20,000 MT of sodium. Modification of the LAW Vitrification Facility and WTP site services to accommodate the third melter would delay the early start up of the WTP LAW Facility. This is Business Case 1C.

Business Cases 2 through 5 evaluate immobilizing 100% of the HLW and the LAW in a 27-year period following the start of WTP hot operations using a second LAW facility, BV, CS, or SR facilities. Business Case 3A considers BV to provide the entire supplemental immobilization capacity. Business Case 3B considers a supplemental immobilization capacity trade-off provided by a combination of installing a third melter in the WTP LAW Facility and reducing the BV Facility size. .

Business Cases 6 and 7 also evaluate immobilizing all HLW and LAW in a 27-year period following the start of WTP hot operations; however, those cases also consider starting LAW immobilization prior to 2019. An early start to LAW immobilization also provides the potential for creating DST space (by removing LAW for pretreatment and immobilization), which may enable the retrieval of up to 19 additional SSTs prior to 2019. These two business cases evaluate starting LAW immobilization prior to full WTP startup; starting BV operations in 2014 (Case 6); and starting the WTP LAW Vitrification Facility in 2014 (LAW First) (Case 7). Although LAW First is combined with BV in Business Case 7, it could be used in combination with other LAW immobilization approaches; the difference being that other supplemental immobilization approaches would not start in 2014 in parallel with LAW First.

Observations and Conclusions – The seven business cases evaluated provide insights into approaches DOE could use to complete the Hanford Site tank farm cleanup mission. While there are many more combinations of technologies and assumptions that DOE could develop into business cases, there is adequate information presented through the evaluation of the seven business cases in this report to identify and evaluate possibilities other than those discussed. The Department's observations and conclusions are unlikely to change for any reasonable assumption sets used. The Department makes the following observations and conclusions based upon its analysis of the seven business cases presented in this report:

1. ***As illustrated in Figure ES-3, supplemental LAW immobilization can dramatically accelerate the Hanford Site tank farms cleanup mission***. The WTP LAW Vitrification Facility operating alone requires 40 years (until 2059) or up to 60 years (until 2079) to complete the immobilization of Hanford LAW compared to the 27-year mission duration in Business Cases 2 through 7. The Department does not perceive a reasonable rationale for extending the Hanford cleanup mission duration to that degree. Accordingly, DOE will continue to evaluate supplemental LAW immobilization to complete the Hanford tank waste cleanup mission.

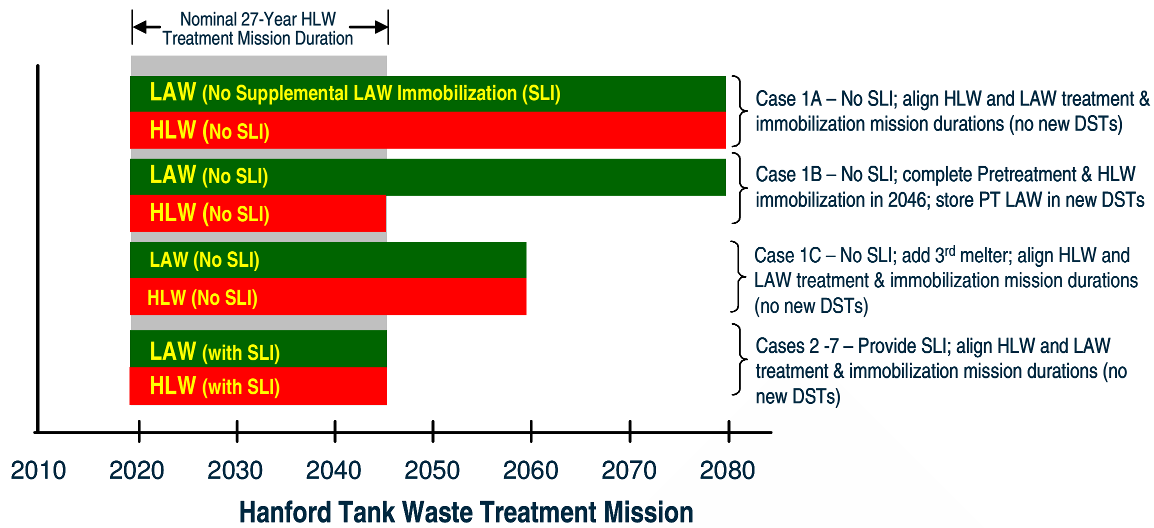

Figure ES-3. Supplemental LAW Treatment Enables Shorter Mission Duration

2. ***Supplemental LAW Immobilization Enables More Rapid SST Retrievals.*** The WTP PT Facility is designed to supply pretreated LAW at approximately twice the rate that the WTP LAW Facility is able to immobilize LAW; i.e., if only the WTP LAW Facility is used to immobilize LAW, the WTP PT throughput rate could be constrained[2] to half of its design capacity. Adding supplemental LAW immobilization would enable the WTP PT Facility to operate at its design rate. This, in turn, would create additional space in existing Hanford DSTs twice as rapidly as would occur with the WTP LAW Facility operating alone. The additional DST space created by supplemental LAW immobilization would lead to SST retrievals being completed approximately 20 years following full WTP startup (e.g., 2039).

3. ***Supplemental LAW Immobilization Reduces Costs.*** The Estimate to Complete (ETC) cost to include supplemental LAW immobilization (Business Cases 2 through 7), regardless of approach, is significantly less than immobilizing all LAW in the WTP (Business Cases 1A and 1B). The ETC costs (Table ES-2) for Cases 1A and 1B are primarily driven by the long mission duration. The small cost difference between Cases 1A and 1B indicates that building additional DSTs to store pretreated LAW (thereby enabling completion of the pretreatment and HLW immobilization missions prior to LAW immobilization mission completion) does not result in a significant cost decrease. The cost difference between Business Case 1 (A and B) and Cases 2 through 7 is statistically significant; i.e., Cases 2 through 7 cost less than Case 1 ($1 to 3 billion less in present value dollars and $8 to 19 billion less in constant dollars). The ETC costs do not include past (sunk) costs. However, based on the best available information, ETC costs do include significant uncertainties due to the conceptual nature of the business cases evaluated. The Department used Monte Carlo stochastic techniques to help establish cost uncertainties and it used statistical methods to establish the mean costs.

[2] In Case 1B, new DSTs are assumed to be constructed to overcome this constraint.

Table ES-2. Business Case ETC Cost Summary

<table>
<tr><th>Business Cases</th><th colspan="2">Near-Term Development Costs (2008 Constant $ B)</th><th>ETC Mean Costs (Present Value $ B)</th><th>ETC Mean Cost (2008 Constant $ B)</th></tr>
<tr><td>1A – WTP LAW Only (HLW and LAW Vitrification end 2079)</td><td colspan="2">0</td><td>27</td><td>56</td></tr>
<tr><td>1B – WTP LAW Only (New DSTs to enable 2046 HLW and PT completion)</td><td colspan="2">0</td><td>27</td><td>49</td></tr>
<tr><td>1C – WTP LAW Only with third melter and upgrades to all three melters</td><td colspan="2">0</td><td>26</td><td>45</td></tr>
<tr><td>2 – WTP LAW with 2nd LAW Vit Facility in 200 East Area</td><td colspan="2">0</td><td>25</td><td>40</td></tr>
<tr><td>3A – WTP with BV in 200 East Area</td><td colspan="2">0.13</td><td>25</td><td>39</td></tr>
<tr><td>3B – WTP with three LAW melters and BV in 200 East Area</td><td colspan="2">0.13</td><td>25</td><td>39</td></tr>
<tr><td>4 – WTP with CS in 200 East Area</td><td colspan="2">0.30</td><td>24</td><td>37</td></tr>
<tr><td>5 – WTP with SR in 200 East Area</td><td colspan="2">0.36</td><td>26</td><td>41</td></tr>
<tr><td rowspan="2">6 – WTP LAW and BV in the 200 West and 200 East</td><td>TF* PT</td><td>0.027</td><td rowspan="2">25</td><td rowspan="2">40</td></tr>
<tr><td>BV</td><td>0.13</td></tr>
<tr><td rowspan="2">7 – WTP LAW First and BV in 200 East Area</td><td>TF PT</td><td>0.027</td><td rowspan="2">25</td><td rowspan="2">40</td></tr>
<tr><td>BV</td><td>0.13</td></tr>
</table>

*Tank Farm

4. ***ETC Costs Do Not Adequately Differentiate Between Supplemental LAW Technologies.*** Cost differences between Business Cases 2 through 7 are unlikely to be the major factor in selecting a supplemental LAW technology**.** The differences between the mean present value ETC costs in Business Cases 2 through 7 are relatively small considering the uncertainty in those costs. The supplemental LAW immobilization cost contribution is small compared to the overall mission ETC costs for each business case. The fraction of the ETC cost attributed to including supplemental LAW immobilization ranges from 5 to 13% of the total ETC cost depending upon the technology. This is illustrated in Figure ES-4. The cost differences depicted should not be interpreted to favor one technology over another.

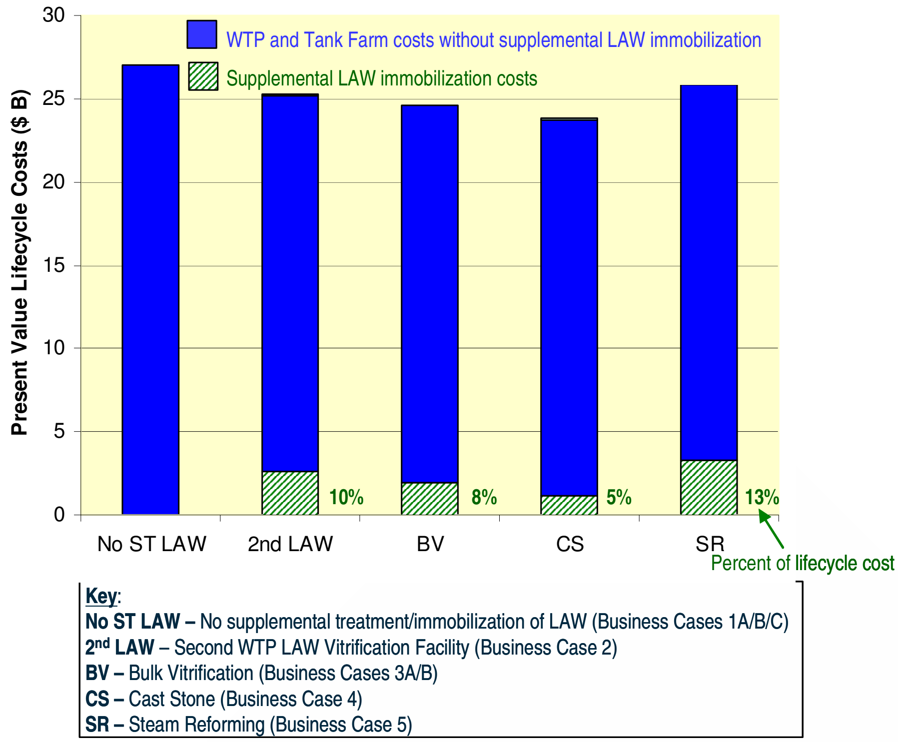

Figure ES-4. Supplemental LAW Immobilization Costs are a Very Small Fraction of the Hanford Tank Waste Cleanup Estimated to Complete Cost

5. ***Technical Readiness Discriminates Between LAW Immobilization Approaches.*** The supplemental LAW technologies are at different levels of technical readiness relative to possible deployment to immobilize Hanford LAW. Table ES-3 summarizes technology readiness levels (TRL)[3] determined by DOE for the LAW technologies considered in this report. While all technologies identified are potentially viable for Hanford LAW immobilization, the near-term development cost and time required to bring CS and SR to readiness levels on par with either building a second WTP LAW facility or BV are substantial. Cast Stone development costs are dominated by potential additional pretreatment requirements (e.g., technetium-99 removal and *Resource Conservation and Recovery Act of 1976* [RCRA] constituent pretreatment), not the cost of the CS technology itself. The Department does not anticipate that either CS or SR could be available for full-scale implementation in the same time frame as building a second WTP LAW facility or BV.

[3] Technology Readiness Levels (TRL) provide a means to determine technology readiness for implementation. Guidance for assessing technology readiness is set forth in the *Defense Acquisition Guidebook* (DoD 2004), which has been adapted by DOE and used in this report. The goal is to achieve a TRL 6 prior to incorporation of the technology into the final design. In order to attain a TRL 6, testing must be completed at an engineering- or pilot-scale with a range of simulated waste and/or limited range of actual waste, if applicable. The purpose of the assessments conducted in support of this report was to determine the readiness level of the technologies for the treatment and immobilization of Hanford LAW.

Table ES-3. Business Case Technology Readiness Level Summary

Business Case and SI* Approach	**Critical Technology Elements**(Systems)	**TRLs**
1 - WTP LAW Only	Container Sealing	5
	Decontamination	4
	LAW Melter Feed	6
	LAW Melter	6
	Melter Offgas and Vessel Vent Process	6
2 – 2nd WTP LAW	Same as Case 1	Same as Case 1
3 - BV	Feed Receipt, Feed Preparation, and Feeding	5
	In-Container Vitrification	5
	Offgas Treatment	4
4 - CS	Feed Receipt, Feed Preparation, and Feeding	3
	Mixing and Casting	3
5 - SR	Feed Receipt, Feed Preparation, and Feeding	4
	Thermal Reformer	5
	Offgas Treatment	4
	Container Handling and Waste Qualification	3
6 – BV East and West w/Tank Farm (TF) PT	BV	Same as Case 3
	Rotary Filtration	3
	Cesium Ion Exchange (IX)	3
7 – LAW First and BV w/TF PT	Same as Cases 1 and 6	Same as Cases 1 and 6
*SI – Supplemental Immobilization. In Business Cases 6 and 7, tank farm-based pretreatment TRLs are also provided.		

6. ***Early LAW Immobilization Offers Additional Potential Opportunities.*** The Department will carefully consider potential opportunities to commence the pretreatment and immobilization of LAW early; i.e., several years sooner than the WTP will be ready to treat and immobilize HLW.

   This report identifies two basic approaches to immobilize LAW prior to WTP hot operations in 2019. Those approaches are to either start WTP LAW Vitrification Facility operations early (Start LAW First) or to start BV early. As many as 19 additional SSTs could potentially be retrieved by 2019 if early LAW immobilization can be successfully implemented. There are uncertainties associated with being able to both deploy a tank farm-based pretreatment system and bring an early LAW immobilization system on-line in the time frames considered in this report. Nonetheless, the completion of SST retrievals is a significant Hanford Site regulatory and institutional driver due to the risks associated with storing wastes in SSTs for several more decades. The Department notes that:

   - LAW First is not restricted to use with BV,
   - BV could be started early in the 200 East Area or the 200 West Area,
   - CS and SR are unlikely to be at a state of technical readiness to support LAW immobilization by 2014, and
   - The state of Washington would likely support Early LAW Immobilization.

7. ***Non-Cost Factors Differentiate Supplemental LAW Immobilization Approaches.*** The Department considers several non-cost factors to be important to its supplemental LAW treatment and immobilization strategy for Hanford. Table ES-4 summarizes non-cost factors that DOE considers to be useful in comparing the supplemental LAW immobilization technologies. These include technical

readiness, suitability for early LAW immobilization, operational flexibility, retention of long-lived mobile contaminants, and the significance of RCRA permitting issues. The Department concludes that 2nd LAW and BV technologies currently rate higher relative to these other factors than either CS or SR.

Table ES-4. Other LAW Immobilization Factors

Factor*	2nd LAW	BV	CS	SR
Current state of technology for application to Hanford LAW	**H**	**H**	**L**	**M-H**
Supports early LAW immobilization/accelerates SST retrievals	**M**	**M**	**L**	**L**
Operational Flexibility	**M-H**	**H**	**L**	**L**
Retention of long-lived mobile contaminants	**H**	**H**	**L-M**	**M-H**
Status of RCRA-related permitting issue resolution	**H**	**H**	**L**	**L-M**
Likely acceptance of technology by state of Washington	**H**	**M-H****	**L**	**L**
KEY: **H**- High/Favorable **M**- Medium/Moderately Favorable **L**- Low/Unfavorable *Each immobilization approach is ranked on its ability to accommodate or satisfy the non-monetary factor. **If it can be shown to be as good as WTP LAW glass in a disposal site performance assessment.				

8. ***Tank Farm-Based Pretreatment Enables Early LAW Immobilization and Deployment Options.*** Tank farm-based pretreatment is required for LAW First and early BV. SST waste retrievals are currently constrained by the availability of DST space to receive the retrieved wastes. LAW pretreatment in the Hanford Site tank farms could potentially enable LAW to be immobilized prior to the full WTP commencing operations in 2019. Tank farm-based pretreatment, if used in conjunction with early supplemental LAW immobilization (e.g., Business Case 6 – BV in 200 West Area) or LAW First (Business Case 7) could enable additional SST retrievals to occur between 2014 and 2019. Tank farm-based pretreatment could continue beyond WTP PT Facility startup to provide feed to supplemental immobilization and pretreatment redundancy that could allow LAW immobilization to continue independent of the WTP or enable WTP LAW immobilization to occur during WTP pretreatment outages.

Integrated LAW Treatment and Immobilization Strategy

In order to determine the best value to the Government, DOE developed and will refine from time-to-time its Hanford LAW strategy based on best available information and Hanford LAW immobilization-mission optimization analyses in order to determine the best value to the government. Tank farm and WTP information will be analyzed using systems analyses techniques that consider the range of uncertainties associated with key evaluation parameters and integrate tank farm and WTP information bases. The strategy considers the range of information, constraints, requirements, and commitments that govern DOE's proposed LAW pretreatment, immobilization, and disposal operations. These include: conformance with DOE Orders; compatibility with DOE's assessments conducted pursuant to the NEPA process and resultant records of decision; DOE's commitments and requirements pursuant to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement); and factoring in new information obtained from DOE's ongoing investigations. Key elements in DOE's integrated strategy for completing the Hanford Site tank waste LAW fraction treatment and immobilization mission are as follows:

1. ***Complete the pretreatment, immobilization, and disposal of LAW in a timely and cost-effective manner.*** The Department will take reasonable and prudent steps to complete the Hanford WTP PT, HLW, and LAW pretreatment and immobilization mission as quickly as feasible (i.e., within 23 to 35 years following the start of full WTP hot operations in 2019). The Department will identify and test supplemental LAW immobilization technologies and approaches with the objective of increasing the overall robustness of its LAW pretreatment and immobilization capabilities and its operational flexibility.

Planned Near-Term Path Forward:

- ***Include Supplemental LAW Immobilization in the River Protection Project (RPP) mission completion strategy.***
- ***Complete Demonstration Bulk Vitrification System (DBVS).***
- ***Evaluate adding a third melter to WTP LAW and the potential for upgrades to three WTP LAW melters.***

2. ***Include enhancements to the Hanford LAW treatment and immobilization strategy that are viable, financially responsible, and beneficial to the Hanford Site tank waste cleanup mission.*** The Department's objectives in this regard are focused on reducing tank farm-based risks (e.g., immobilizing LAW sooner, accelerating SST retrievals, treating secondary wastes) and increasing operational flexibility.

Planned Near-Term Path Forward:

- ***Conduct detailed planning for WTP LAW First Strategy.***
- ***Evaluate deployment of LAW pretreatment and immobilization in the 200 West and/or East Areas.***
- ***Proceed with DOE O 413.3A, Program and Project Management for the Acquisition of Capital Assets, critical decision process for tank farm-based pretreatment.***
- ***Determine criteria and options to treat secondary waste created during WTP and supplemental LAW pretreatment and immobilization operations.***

3. ***Periodically evaluate and update the Hanford LAW pretreatment and immobilization strategy and associated implementation measures.*** The Department's LAW pretreatment and immobilization strategy will continue to develop as information becomes available from planned tests (e.g., DBVS, tank farm-based pretreatment, additional LAW First analyses) and ongoing System Plan updates, and TC & WM EIS activities. This information will assist DOE in finalizing its integrated Hanford LAW treatment and immobilization strategy.

Planned Near-Term Path Forward:

- ***Complete River Protection Project System Plan updates.***
- ***Complete the TC&WM EIS and Record of Decision***

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Acknowledgement

The authors appreciate the extensive and insightful reviews and comments provided by Dr. David R. Gallay, Logistics Management Institute, McLean, VA; Dr. David S. Kosson, Chair of Civil and Environmental Engineering, Vanderbilt University, School of Engineering, Nashville, TN; and Dr. Ian L. Pegg, Director, Vitreous State Laboratory, The Catholic University of America, Washington, DC.

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Units of Measure

MT	metric ton
MTG/D	metric tons of glass per day
wt%	weight percentage

Acronyms and Abbreviations

AEA	*Atomic Energy Act of 1954*
ART	Advanced Remediation Technology
BDAT	Best Available and Demonstrated Technology
BV	Bulk Vitrification [Facility]
CRR	carbon reduction reformer
CS	Cast Stone [Facility]
CTE	critical technology element
D&D	decontamination and decommissioning
DBVS	Demonstration Bulk Vitrification System
DMR	denitration mineralization reformer
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DST	double-shell tank
DWPF	Defense Waste Processing Facility
EIS	environmental impact statement
EM	U.S. Department of Energy, Office of Environmental Management
EPA	U.S. Environmental Protection Agency
ETC	estimate to complete
FY	fiscal year
GAO	U.S. General Accounting Office
HLW	high-level waste
ICV	In-Container Vitrification™
ILAW	immobilized low-activity waste
INL	Idaho National Laboratory
IWTU	Integrated Waste Treatment Unit
IX	ion exchange
LAW	low-activity waste
LBL	Low-Activity Waste Facility, Balance of Facilities, Analytical Laboratory
LFH	LAW Container Finishing Handling System
LFP	LAW Melter Feed Process System
LLW	low-level waste
LMP	LAW Melter Process System
LOP	Primary Offgas Process System
LVP	LAW Secondary Offgas/Vessel Vent Process System

MACT	maximum achievable control technology
NASA	National Aeronautics and Space Administration
NEPA	*National Environmental Policy Act of 1969*
NO_X	nitrogen oxide
OGTS	Offgas Treatment System
ORP	Office of River Protection
ORR	operational readiness review
PT	Pretreatment [Facility]
RCRA	*Resource Conservation and Recovery Act of 1976*
RPP	River Protection Project
SBW	sodium-bearing waste
SO_X	sulfur oxide
SR	Steam Reforming [Facility]
SRS	Savannah River Site
SST	single-shell tank
TC & WM	Tank Closure and Waste Management
TF	Tank Farms
TFC	Tank Farm Contractor
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
WIPP	Waste Isolation Pilot Plant
WTP	Waste Treatment and Immobilization Plant
WVDP	West Valley Demonstration Project

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1.0 Introduction

The U.S. Department of Energy (DOE) is responsible for the safe storage, retrieval, treatment, and disposal of radioactive and hazardous waste stored in underground tanks at the Hanford Site near Richland, Washington. The Hanford tank waste comprises approximately 60% of the total amount of tank waste DOE manages at the four sites formerly involved in reprocessing spent nuclear fuel for national defense purposes. The large volume and complex chemical and radiological characteristics associated with those wastes present substantial technical and regulatory challenges. The Department has been developing, implementing, and refining its Hanford Site tank farm cleanup and treatment strategies to successfully overcome those challenges since the 1980s, and has made considerable progress.

The Waste Treatment and Immobilization Plant (WTP)[4], which is currently under construction, is unique in its technical sophistication and magnitude. It incorporates valuable experience DOE has gained throughout the weapons complex as well as the engineering insights and lessons learned throughout the world relative to radioactive waste and process engineering. During the several years that WTP construction has been underway (since November 2001), DOE has concurrently been exploring low-activity waste (LAW) immobilization technologies that could supplement the WTP capacity, with a view toward completing the LAW immobilization mission in the same time frame as the high-level waste (HLW) immobilization mission is completed. The Department cannot complete the HLW and LAW immobilization missions in the same time frame unless it supplements the WTP LAW immobilization throughput capacity.

To this end, DOE is preparing the *Tank Closure and Waste Management Environmental Impact Statement* (TC & WM EIS) (DOE/EIS-0356) in accordance with the *National Environmental Policy Act of 1969* (NEPA). The EIS will evaluate the potential short- and long-term health and environmental impacts of the range of reasonable alternatives for dispositioning the Hanford tank waste, tanks, and ancillary infrastructure. Among the decisions DOE expects to make pursuant to this EIS in the next 2 to 3 years are those dealing with the immobilization of LAW and the closure of the Hanford Site tanks and tank farms.

In March 2007, DOE's Assistant Secretary for Environmental Management initiated a compilation of current information on the supplemental LAW pretreatment and immobilization portion of the tank farm cleanup project, including the technical readiness of technologies being considered in the EIS and a "Business Case" evaluation of those technologies. The present study was recognized in the U.S. Government Accountability Office (GAO) report, *NUCLEAR WASTE: DOE Should Reassess Whether the Bulk Vitrification Demonstration Project At Its Hanford Site Is Still Needed to Treat Radioactive Waste* (GAO-07-762, June 2007, p.16). GAO concluded that schedule delays in WTP construction as well as unforeseen issues with the bulk vitrification (BV) demonstration project may render the need to supplement the WTP treatment capacity unnecessary. GAO recommended that DOE (1) reassess the need for supplemental technology, (2) reassess the relative costs and benefits of demonstrating and deploying BV compared to other strategies, and (3) report to Congress on the reassessment before requesting additional funding for the Demonstration Bulk Vitrification System (DBVS) Project.

[4] Under the *National Environmental Policy Act of 1969*, DOE reviewed its strategy to chemically separate the HLW and LAW streams from Hanford tank waste and vitrify the waste was contained in the *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement* (DOE/EIS-0189, August 1996).

The U.S. House of Representatives Energy and Water Development Appropriations Bill for fiscal year (FY) 2008 directs DOE to "reassess the need for the bulk vitrification project, as well as present a defined integrated strategy for low-level waste, and present this strategy to the House and Senate Committees on Appropriations." This study addresses the House Committee direction and GAO recommendations.

2.0 Background

2.1 Hanford

Located on the shore of the Columbia River, DOE's Hanford Site near Richland, Washington, stores approximately 53 million gallons of radioactive and chemically hazardous radioactive wastes in 177 underground tanks. Most of this waste originated from the reprocessing of spent nuclear fuel to recover plutonium for defense purposes.

The DOE River Protection Project (RPP) includes storing, retrieving, treating, and disposing of the tank waste and closing the tanks and tank farms in a manner that is protective of the public health and the environment, and is compliant with relevant laws and regulations. The Department places particular emphasis on protecting the Columbia River, a major natural resource that has economic value to the Pacific Northwest.

The Department manages all Hanford Site tank wastes as HLW, which means that the tanks and wastes come under extensive management controls, high quality standards, and close scrutiny. However, available information indicates that well over 90% of the mixed radioactive waste mass in the Hanford tanks consists of constituents that, if sufficiently well separated from the highly radioactive materials in the tanks, could be immobilized as LAW. The Department could then dispose of the LAW on the Hanford Site as mixed low-level waste (LLW). Such disposal would be pursuant to applicable state and Federal requirements for hazardous and radioactive constituents, respectively.

2.2 Scope

This study addresses four key questions:

1. Should DOE develop a means to supplement the WTP LAW Vitrification Facility?

2. How do the costs and benefits of BV compare with other potential supplemental LAW immobilization strategies?

3. What are the key elements in DOE's integrated Hanford Site tank farm cleanup strategy?

4. Should that strategy include provisions for early LAW treatment and immobilization as well as treatment and immobilization in the Hanford 200 West Area, both of which rely on tank farm-based pretreatment?

These four questions are focused on near-term technology investment decisions, not deployment decisions. The latter will be addressed in accordance with NEPA and DOE Orders.

Four different LAW immobilization technologies are considered: (1) LAW vitrification deployed in a LAW facility, (2) bulk vitrification (BV), (3) cast stone (CS), and (4) fluidized bed steam reforming (SR). These four immobilization technologies, completing all LAW immobilization using just the LAW Facility without supplemental LAW immobilization, and starting LAW immobilization early are evaluated in seven business case strategies considering estimated cost, schedule (HLW and LAW immobilization mission duration), technical readiness, improvements to the single-shell tank (SST) retrieval program, and other pertinent mission-related advantages and disadvantages.

SST Retrieval Rate Constraints – Approximately half of the waste is currently stored in aging SSTs, of which, as many as 67 are known or suspected to be "leakers." From these, as much as one million gallons of wastes have leaked into the Hanford Site tank farm soils in the past. DOE has removed pumpable liquid wastes from the SSTs in order to mitigate the threat of additional leakage during waste storage. Leakage risks increase and are carefully managed when DOE adds liquids to SSTs to retrieve wastes from those tanks. DOE, its regulators, and its stakeholders all seek to remove the waste from the SSTs as soon as possible. The plan to retrieve the wastes from the SSTs is depicted in Figure 1.

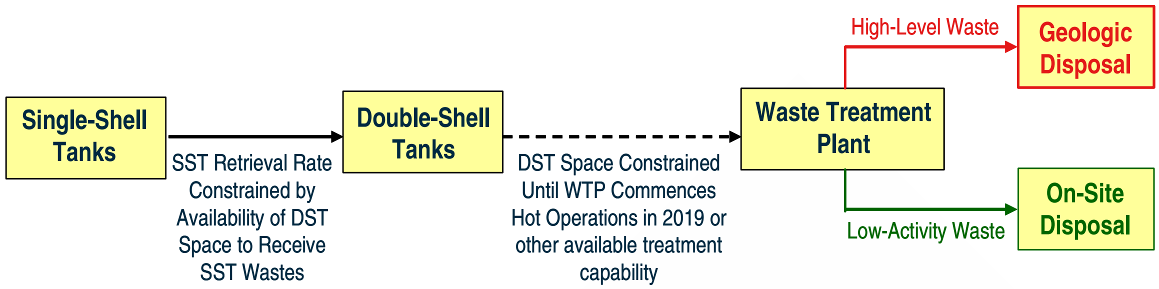


Figure 1. Until WTP Startup, DST Space Will Constrain SST Retrieval Rates

Waste is retrieved from SSTs into *Resource Conservation and Recovery Act of 1976* (RCRA)-compliant double-shell tanks (DST). Waste from the DSTs will be treated in the WTP as HLW and LAW, which will then be disposed of in the proposed geologic repository at Yucca Mountain, Nevada, and on site, respectively. However, the space available in the DSTs to store retrieved SST wastes is and will continue to be limited until the WTP begins hot production-scale operations. Once WTP production operations commence, sufficient wastes will be withdrawn from DSTs to feed the WTP such that the DST space created will keep pace with the anticipated rate of SST retrievals. Until that time, however, the rate of SST retrievals will be constrained.

The Department also evaluates two concepts in this document that have the potential to provide some relief to the current SST retrieval constraints, both involve starting the treatment of LAW prior to the startup of the overall WTP. The Department evaluates commencing LAW treatment in 2014 (approximately 5 years sooner than the WTP Pretreatment [PT] and HLW Facilities will be operational) using two techniques; starting the LAW Facility in 2014 and/or starting one of the supplemental LAW immobilization technologies it is evaluating in 2014. In either case, DOE would need to put into place tank farm-based LAW pretreatment in order to provide pretreated LAW feed to the immobilization facility assumed to be used.

Waste Treatment and Immobilization Plant – The WTP is the cornerstone of the Hanford Site's tank waste treatment project. The WTP is comprised of five major components:

- A ***Pretreatment (PT) Facility*** that will separate the tank waste into HLW and LAW waste streams.
- A ***HLW Vitrification Facility*** that will immobilize the HLW fraction into a glass form.
- A ***LAW Vitrification Facility*** that will immobilize the LAW fraction into a glass form.
- An ***Analytical Laboratory*** (LAB) that will support the operations of the treatment facilities.
- The ***Balance of Facilities*** (BOF) that will provide utilities and other support services to the WTP facilities.

The Department started WTP construction in November 2001. Construction on the PT and HLW Facilities was suspended until recently, pending approval by the Secretary of Energy of a revised seismic ground motion design basis. The Secretary approved the revised seismic ground motion design basis on August 9, 2007. The Department's construction of the LAW Vitrification Facility, BOF, and LAB (LBL) was not impacted by the seismic design basis, and the LBL is now much closer to completion than the PT and HLW Vitrification Facilities. This could enable DOE to start the LAW Vitrification Facility as much as 5 years prior to the startup of the WTP PT and HLW Facilities. That concept, which DOE refers to as "LAW First," is contingent upon DOE being able to pretreat the LAW feed to the WTP LAW Facility prior to the WTP PT Facility starting operations. Accordingly, DOE also addresses LAW First and tank farm-based pretreatment in this study.

WTP Pretreatment – The radioactive materials in the Hanford tanks constitute less than 1% of the roughly 150,000 metric tons (MT) of dry waste mass in the tanks. The Department designed the WTP PT Facility to separate highly radioactive materials in the tank waste from the chemical waste materials that make up the bulk of the tank waste mass as is illustrated in Figure 2.

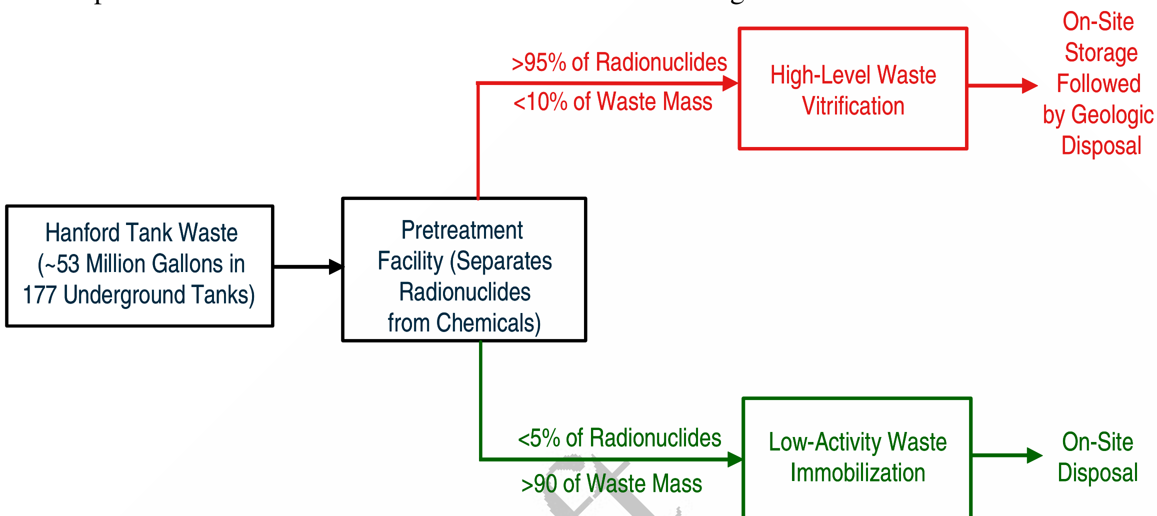


Figure 2. Simplified Tank Waste Flow Diagram

By separating nonradioactive constituents from the HLW, the number of HLW canisters to be disposed of in the proposed Yucca Mountain geologic repository could be reduced, thereby making better use of that valuable resource. Among the most important nonradioactive constituents that DOE will remove from the HLW sludge are various chemical forms of aluminum, chromium, and sodium that can be removed by washing, leaching, and filtration. LAW pretreatment will separate most of the insoluble radionuclides from the liquid LAW stream by filtration and most of the soluble cesium-137 from the LAW feed stream by ion exchange. The Department will then blend the cesium and insoluble radionuclides into the HLW stream prior to vitrification.

Following pretreatment, the total LAW melter feed stream from all tanks will contain 2 to 3 million curies of radionuclides and the HLW melter feed stream will contain approximately 190 million curies of radioactive materials.

HLW Vitrification – The Department designed the WTP HLW Vitrification Facility to immobilize all of the Hanford HLW as borosilicate glass in 23 to 35 years following full WTP startup. The Department will blend the concentrated HLW feed stream produced during pretreatment with glass formers in the WTP HLW Vitrification Facility and then feed the mixture into one of two HLW melters for conversion into borosilicate glass. Molten glass will be removed from the HLW melters by an airlift system and poured into stainless steel canisters, which will be inspected, sampled as necessary, and sealed prior to transfer to an interim storage area. The HLW Vitrification Facility contains two joule-heated melters that are each capable of producing 3 MT of glass per day (MTG/D). Each melter has a dedicated primary and secondary offgas system. Offgas is processed for particulate and radionuclide removal, organic destruction, halide and mercury removal, organic destruction, and nitrogen oxide (NO_X) reduction. Liquids from the offgas system are recycled to the WTP PT Facility where entrained solids are recycled back to the HLW feed stream and liquids are pretreated to remove cesium-137 that is also blended into the HLW feed stream.

WTP LAW Vitrification – The Department designed the WTP LAW Facility to immobilize the low-activity fraction of the tank waste into a borosilicate glass waste form. Concentrated LAW feed from pretreatment will be combined with glass formers and mixed to produce a uniform feed that enters the LAW melters from the top similar to the HLW melter operations. The Department estimates that the amount of LAW waste to be immobilized will be more than 10 times the amount of HLW to be immobilized. The LAW Facility includes two melters, each with a 15 MTG/D throughput, which results in a throughput rate approximately 5 times greater than the HLW Vitrification Facility throughput rate. Accordingly, DOE would need to more than double the WTP LAW immobilization throughput rate using supplemental methods if the HLW vitrification and LAW immobilization missions are to both be completed in a 27-year time frame.

The LAW melter offgas-treatment systems are functionally similar to the HLW offgas systems relative to particulate and radionuclide removal, organic destruction, halides and mercury removal, and NO_X reduction. Liquid from the LAW submerged bed scrubber system will be recycled to the LAW pretreatment evaporator where the liquid will be concentrated and combined with the LAW feed in order to increase the fraction of volatile radionuclides (such as technetium-99) that is captured in the LAW glass. The evaporator condensate will be transferred to the Hanford Effluent Treatment Facility for treatment and disposal as secondary waste. The LAW Vitrification Facility systems for molten glass removal and containerization are functionally similar to the HLW systems.

Supplemental LAW Immobilization – The Department is considering a strategy wherein it would supplement the WTP LAW Facility throughput using a second LAW facility (2nd LAW) or another LAW immobilization approach in order to complete LAW immobilization in the same time frame that HLW immobilization will be completed. This general concept is illustrated in Figure 3. The TC & WM EIS will consider alternatives for supplemental immobilization along with estimates of the time required to complete the mission.

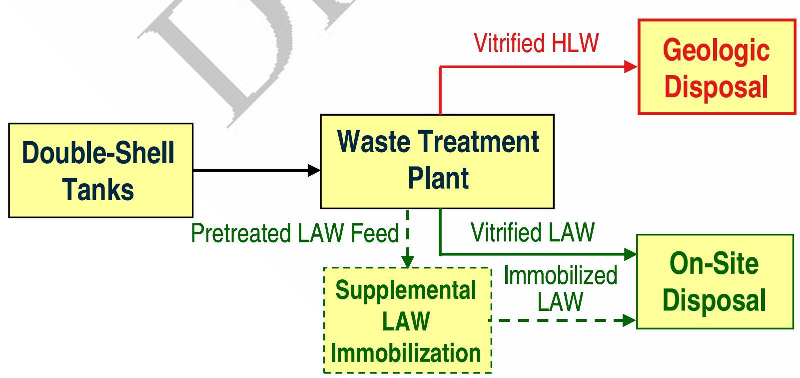


Figure 3. Supplemental LAW Immobilization Could Help Align the HLW and LAW Immobilization Rates

The Department has several choices for supplementing LAW immobilization throughput. Beginning in 2002, DOE started working with experts from the Washington State Department of Ecology (Ecology) and U.S. Environmental Protection Agency (EPA) specifically to identify and evaluate the efficacy of other immobilization technologies that it could potentially use to supplement WTP LAW vitrification. The evaluation team narrowed the most promising technologies to the following four immobilization approaches:

1. Second LAW Facility (2nd LAW).

2. Bulk Vitrification (BV), a joule-heated vitrification process similar to WTP LAW vitrification except the glass melter (a large sea-land type container lined with refractory) also serves as the disposal package. Bulk vitrification is a modular process, which means that it consists of parallel process lines. The modular design allows DOE to add treatment lines if the need arises to add treatment capacity as well as to split the number of BV lines required to supplement the LAW Facility into 200 East Area and 200 West Area BV facilities (see Figure 4). The WTP is located in the 200 East Area. Building a 200 West Area BV facility would require DOE to provide tank farm-based pretreatment to feed that facility since pretreated WTP LAW feed would not be available in the 200 West Area. A 200 West Area BV facility would operate independently of the WTP (e.g., would not generally be subject to the same shutdown causes) and would also free 200 West Area SST retrievals from DST congestion in the 200 East Area since the LAW would not need to be transferred to the 200 East Area DSTs prior to immobilization. Bulk vitrification produces a glass that is comparable to the waste glass form produced in the WTP LAW melters.

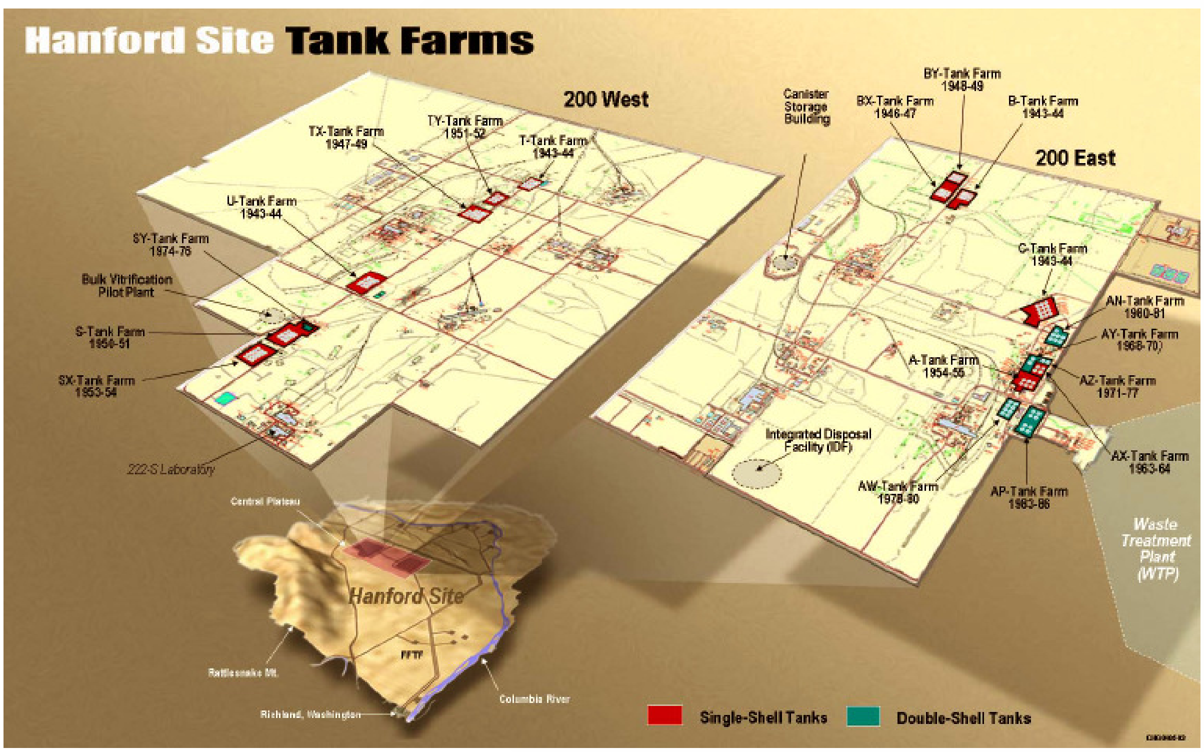


Figure 4. Hanford Site 200 East and 200 West Areas Encompass the Tank Farms

3. Cast Stone (CS), a grout-based approach that is similar to immobilization approaches that are widely used for LLW and mixed wastes by DOE and commercial industry. Cast stone has the advantage of being an ambient temperature process, which simplifies immobilization operations as well as offgas treatment. Being a grout-based process, CS requires a relatively simple process facility as compared

with thermal-based processes. However, the CS process could become more complex for Hanford LAW depending upon whether additional chemical or radiological waste pretreatment processes are necessary to improve waste performance. The Department has not established performance requirements for a Hanford Site CS LAW at this time.

4. Fluidized Bed Steam Reforming (SR), a thermal process that uses steam and chemical additives mixed with the waste to form a granular mineral-like waste form. Steam reforming is widely used in the petrochemical industry and is also used for LLW treatment and immobilization. The Department plans to use SR at its Idaho site to immobilize sodium-bearing wastes (SBW) in its tanks. Hanford Site LAW requires a much more robust (insoluble) waste form than the Idaho SBW because the Hanford LAW will be disposed of on site and the Idaho SBW is intended for disposal at the Waste Isolation Pilot Plant (WIPP). The Department has not established performance requirements for a Hanford Site SR product at this time.

These four LAW immobilization approaches will be analyzed in the TC & WM EIS and are included in the business cases evaluated in this report.

The Department could also commence WTP LAW immobilization approximately 5 years prior to the full WTP coming on line if it is able to provide pretreated LAW feed from a tank farm-based supplemental pretreatment system to the WTP LAW Facility. Accordingly, DOE also evaluates LAW First and tank farm-based pretreatment in this report.

Tank-Farm-Based LAW Pretreatment – The Department could conduct supplemental LAW immobilization in the Hanford Site tank farms rather than near the WTP. In a 200 East Area tank farm setting, 2nd LAW, BV, CS, and SR could receive pretreated wastes either from the WTP PT Facility or from a tank farm-based LAW pretreatment system. The latter could potentially enable LAW immobilization to occur prior to the full WTP coming on line (similar to LAW First), as well as supplement the WTP PT and increase total online efficiency once the WTP PT Facility comes on line. Providing tank farm-based pretreatment to early startup of both WTP LAW and supplemental LAW immobilization may enable the retrieval of up to 19 SSTs prior to the full WTP coming on line in 2019.

The Department is also considering locating a supplemental LAW BV Facility in the 200 West Area to avoid transferring high volumes of LAW across the site and thereby enhance tank farm logistical efficiency. Tank farm-based pretreatment in the 200 West Area would be required to implement this approach. This approach could enable DOE to commence LAW immobilization and retrieve 5 to 10 additional SSTs prior to WTP hot commissioning. It would also allow LAW immobilization in the 200 West Area to operate independent of LAW pretreatment and immobilization in the 200 East Area.

3.0 Summary of LAW Pretreatment and Immobilization Technologies

This section discusses the supplemental pretreatment and immobilization technologies that DOE is considering to treat and immobilize Hanford Site LAW. Additional information on these technologies and references to supporting documentation is provided in DOE/ORP-2007-1, *Technology Readiness Assessment for the Supplemental Treatment Program.* A list of DOE's technology development activities focusing on the RPP missions is provided in Appendix A.

3.1 Tank Farm-Based LAW Pretreatment

LAW must be pretreated prior to immobilization. Pretreatment removes radioactive materials to the extent practicable and ensures waste feeds meet the waste acceptance criteria for the specific immobilization process to be used, as depicted in Figure 5.

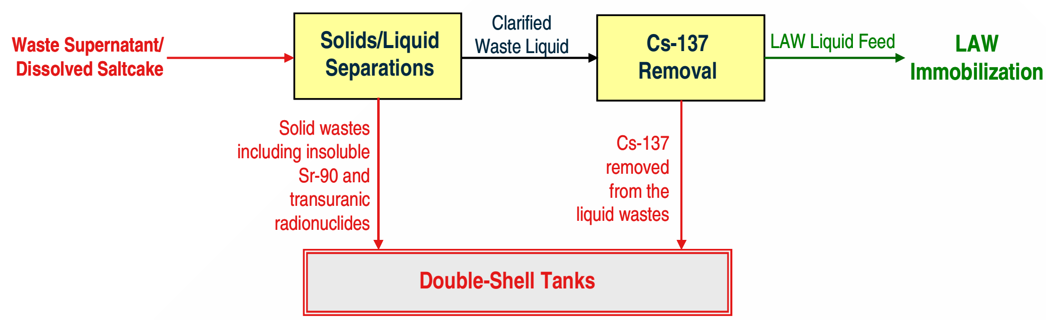


Figure 5. General Schematic for Tank Farm-Based Pretreatment

The solids/liquid separation step removes insoluble solids from the LAW feed. The primary radionuclides removed are insoluble strontium-90 and insoluble alpha-emitting (transuranic) radionuclides. These radionuclides, along with insoluble non-radioactive materials suspended in the liquid, would be discharged back to the DSTs where they will later enter the HLW pretreatment feed stream once the WTP PT Facility comes on line[5]. The Department assumes that rotary microfiltration will be used for solids/liquid separations in the tank farms for purposes of this study.

Following solids/liquid separations, the clarified liquid waste will be pretreated to remove soluble cesium-137 using either ion exchange or fractional crystallization. The cesium-137 removed from the LAW liquid feed stream will be discharged back to the DSTs. The pretreated LAW liquid waste stream can then be immobilized using one of the four supplemental immobilization technologies discussed below.

The conceptual tank farm-based pretreatment systems discussed in this study are not based on formal engineered designs and have not undergone engineering design-based cost or safety evaluations. Accordingly, the systems discussed could require more substantial design features than envisioned in

[5] After the WTP PT Facility comes on line, if the tank farm-based pretreatment system continues operations, the separated HLW feed materials could be combined with the HLW feed in the WTP PT Facility.

this study, which could substantially affect costs. The Department has attempted to account for those uncertainties through Monte Carlo analyses.

Rotary Microfiltration – The rotary microfiltration concept deploys two rotary microfilters and associated pumps, valves, and controls installed within an existing 42-inch diameter DST riser. Supernatant containing less than 0.5 wt% solids would be transferred within the DST to the rotary microfilters. The clarified LAW supernatant (solids removed) would then be transferred to the cesium separation process (either ion exchange or fractional crystallization), while the solid-rich concentrate stream would be discharged back into the DST. During the past decade, DOE has evaluated and tested the rotary microfiltration technology for separating solids and liquids (RPP-31804-VA; WSRC-STI-2006-00073). Demonstrations with Savannah River Site (SRS) tank waste simulants produced 1.5 to 10 times higher filter fluxes than cross-flow filters. SRS designed a 2-rotary microfilter assembly that can be installed through a 39-inch diameter riser into an underground waste storage tank. The SRS has also fabricated and tested a full-scale, single-rotary microfilter unit with simulants. Rotary filtration appears to be a promising technology, but remains to be validated in hot tests. The Department conducted Hanford simulant testing in FY 2007 and is planning to test the technology on actual tank waste at Hanford in FY 2008.

If rotary filtration does not prove to be suitable for deployment at the Hanford Site, solids-liquid separations could be achieved using cross-flow filtration similar to the technology that will be used in the WTP PT Facility. Cross-flow filtration has been successfully tested in many venues including with Hanford tank waste surrogates. However, cross-flow filtration systems are too large to be installed in a DST riser; hence, the system requires a separate shielded facility in which the filtration and associated activities can occur.

Cesium Ion Exchange – Cesium ion exchange for removing radioactive cesium from liquid waste streams has been used extensively, both nationally and internationally, for many years. In a tank farm pretreatment setting, filtered LAW feed would be transferred to a tank that would then be used to feed two cesium ion exchange columns in series. The ion exchange columns (lead column and polishing column) would remove cesium from the clarified LAW solutions to meet the cesium-137 concentration specifications for the LAW immobilization approach to be used. The ion exchange system must be located in a reinforced concrete structure that meets site radiological shielding and seismic requirements. The Department would use the same elutable resin for a tank farm application that it plans to use in the WTP PT Facility. The Department has already conducted extensive laboratory-scale and pilot-scale testing of the WTP PT cesium ion exchange system and resin as part of the WTP Project and will continue to develop this technology in FY 2008 to reach technical readiness for use at Hanford. The Department recently awarded a research contract to evaluate tank-side cesium ion exchange for Hanford wastes under DOE's Advanced Remediation Technology (ART) program.

Fractional Crystallization – Fractional crystallization is an alternative to cesium ion exchange. Fractional crystallization removes radionuclides that are too large to fit within salt crystal lattices when the crystals are formed. The excluded radionuclides would remain in the liquid phase during crystallization and could then be removed by draining the liquids following crystallization and washing the crystals. The Department can repeat the process as necessary to obtain increasing levels of radionuclide separations. Beginning in FY 2005 and continuing to the present, DOE conducted fractional crystallization laboratory-scale tests using simulants and actual Hanford Site tank waste samples. In FY 2007, researchers completed engineering-scale tests using simulants with a prototypical evaporator/crystallizer and a centrifuge. Fractional crystallization offers the additional potential benefit of also removing a portion of the technetium-99 and iodine-129 from the LAW feed, which would not occur with cesium ion exchange. The fractional crystallization system must be located in a reinforced concrete structure that meets site radiological shielding and seismic requirements. Pilot-scale (1/5-scale capacity and full height) testing of a prototypical evaporator/crystallizer integrated with a centrifuge and associated processing vessels is planned to start in FY 2008 at the Savannah River Technology Center.

3.2 Early Evaluation of Supplemental LAW Immobilization Technologies

Following the identification of BV, CS, and SR as possible alternatives to building a second WTP LAW facility by DOE, Ecology, and the EPA in 2002, the Hanford Site Tank Farm Contractor (TFC) issued contracts to technology vendors to create prototypical BV, CS, and SR waste forms using Hanford LAW simulants. The TFC then issued solicitations to the technology vendors to develop preliminary facility designs and costs for implementing those technologies. Based on the information received from the vendors, a TFC Source Evaluation Board recommended proceeding to a field demonstration using the BV technology. The Department subsequently elected to pursue a strategy whereby technology development and testing of Hanford tank waste would focus on BV, DOE's Idaho National Laboratory (INL) would conduct SR testing, and DOE's SRS would conduct grout-based waste form testing. This approach is providing waste form and process information on all three technologies; however, more information specific to Hanford LAW is now available for the WTP LAW and BV approaches than for CS and SR.

3.3 WTP LAW Immobilization

The Department designed the LAW Facility to receive pretreated liquid waste from the WTP PT Facility and convert the pretreated liquid into a solid glass waste form. The average waste loading in the LAW glass is 14 to 20 wt% sodium oxide[6]. The WTP LAW Facility includes waste mixing systems required to combine the waste with glass formers to support the operation of two LAW melters operating at 30 MTG/D. This includes: LAW melter feed batching; vitrification; pouring the molten glass into containers; treating the vitrification offgas effluents; recycling submerged bed scrubber effluents to the WTP PT Facility for concentration and combination with LAW melter feed; and processing the LAW containers by sealing, surface decontamination, weighing, and temperature measurement. The WTP LAW melters are similar to, but much larger than (approximately 10 times the capacity), HLW melters operated at the SRS Defense Waste Processing Facility (DWPF) melter and the West Valley Demonstration Project (WVDP) HLW melter in New York. The WTP LAW technology takes credit for glass waste loading enhancements that have been experimentally evaluated in DOE-sponsored technology development programs.

3.4 Bulk Vitrification

Bulk vitrification uses the same basic technology (joule-heated glass melting) as is used for HLW and LAW vitrification in the WTP LAW melters. The primary differences are that with BV:

- The liquid waste is blended with glass formers and cellulose and then dried before it is put into the melter; and
- Each melter is only used for one batch of waste after which it serves as the disposal container.

A Hanford LAW BV facility would consist of the number of parallel BV lines (melters) required to provide the desired design throughput (RPP-16215) to supplement the LAW Facility. Each line consists of a feed drying system, BV melting system, and an offgas treatment system. The number of BV lines is dictated by the LAW immobilization mission duration and the fraction of the sodium mass to be immobilized by BV. The container is similar in size to a sea-land container. The interior of the container

[6] DOE typically uses sodium as a measure for LAW waste loading because sodium is the most prominent chemical in the tank wastes. Sodium is not used as a metric for HLW loading since nearly all of the sodium will ultimately enter the LAW waste stream.

is insulated with refractory sand and cast refractory panels mortared together to form an inner refractory container to contain the melt. Electrical power is transferred through the glass melt by two graphite electrodes. Following pretreatment, the tank waste is mixed with glass formers and chemical additives, dried to a few wt% water content, conveyed into the BV container, and thermally converted to glass. Because the glass density is considerably higher than the dried waste feed, waste feeding continues during the melt to reduce the amount of void space in the melter/container following vitrification. Each container will hold as much as 44 MT of glass at the completion of vitrification.

The Department has funded a BV development project at the Hanford Site for several years to develop and test the technology. The Department conducted laboratory-scale tests with surrogate and actual Hanford wastes and conducted engineering and full-scale tests with simulated Hanford waste. The Department also funded independent external reviews by subject matter experts to identify potential issues associated with DBVS and developed and implemented plans to address issues that were identified. A full-scale integrated test of BV system components (dryer, bulk vitrification melting system, offgas) was conducted in 2007. Results from that testing are scheduled to be reported in December 2007.

The Department is developing plans, pursuant to its project management order, to conduct DBVS, a hot (radioactive) BV demonstration project that will process actual Hanford tank waste to demonstrate the technology in a full-scale prototypic environment. The DBVS Project would immobilize up to 50 boxes (as much as 2,200 MT of glass) using Hanford tank waste with very low cesium-137 concentrations (from tank S-109). The Department could subsequently use information obtained from that demonstration to design a production system if DOE selects BV as the supplemental LAW technology.

3.5 Cast Stone

Cast stone is a cement-based, monolithic waste form produced by blending Portland cement and chemical additives with LAW. The CS process consists of a feed receipt, preparation, and feeding system; mixing and casting system; and container processing and handling system. Pretreated waste feed would be evaporated to remove a portion of the water and then cooled to 25°C in a holding tank from which it would be fed to the mixing and casting system. The cement ingredients would be staged in individual weighing tanks. The liquid LAW would be pumped to the mixers while the cement ingredients would be fed using auger conveyors and gravity from weighing tanks above the mixers. Once mixed, the waste would be poured into a waste container located below the mixer on a motorized roller conveyor. The sodium waste loading in the CS product is expected to be 7 to 8 wt% sodium oxide versus a 15 to 20 wt% sodium oxide waste loading anticipated for glass. The result would be a substantially higher volume of CS being created than glass if CS were to be used to supplement the LAW Facility. The CS process concept proposed for the Hanford Site (RPP-RPT-26689) is an adaptation of other cement-based waste form production processes successfully used domestically and internationally. The Department has used cement-based systems to immobilize radioactive waste streams similar to LAW at WVDP and SRS. Grout-based waste immobilization approaches have wide application to low-level and hazardous wastes and are prime candidates for Hanford Site non-tank wastes, Hanford tank-farm and WTP operations secondary wastes, as well as the immobilization of residual wastes that may remain in SSTs following waste retrieval.

3.6 Fluidized Bed Steam Reforming

The SR process proposed for Hanford Site LAW would produce a mineralized waste form that would immobilize contaminants of concern in the mineral structure and thereby retard transport by groundwater following waste disposal. For Hanford LAW, the waste would first be mixed with aluminosilicate clay and then injected through an air-atomizing nozzle into the denitration mineralization reformer (DMR).

The DMR uses superheated steam to react the waste and chemical additives in a fluidized bed. As the waste comes into physical contact with the heat and chemical additives, liquids will be evaporated, organic materials will be destroyed, nitrates and nitrites will be converted to nitrogen gas, and the waste will be immobilized into small (5 to 100 micron) granular particles. The granular particles would be combined with a binder and cast into containers.

INL plans to start constructing an SR plant in 2007. Called the Integrated Waste Treatment Unit (IWTU), this plant is intended to process approximately one million gallons of acidic SBW into a carbonate waste form for disposal at WIPP (Thor 2006). However, the carbonate waste form used for the SBW cannot be used for Hanford LAW. Hanford Site LAW would need to be converted into a low solubility mineral-like waste form. The INL IWTU is also substantially smaller and less complicated than would be an SR facility designed to produce a Hanford mineralized waste form for LAW. This is due to the large volume of Hanford LAW, the high pH (caustic) chemistry associated with Hanford LAW, and the large amount of clay additive that is required to keep the caustic materials in the Hanford waste from becoming mastic (sticky) during steam reformation and plugging the DMR injectors.

Steam reforming is a commercially operational technology in use at the Studsvik Processing Facility in Erwin, Tennessee. The Erwin plant processes commercial nuclear power plant waste composed of ion exchange resins, plastics, cellulose, carbon, and oils. The plant has been in operation for over 7 years and has processed more than 200,000 ft^3 of LLW. Steam reforming is used in commercial applications as well as in its application on SBW at Idaho; however, DOE is not aware of any production-scale SR waste treatment facility that produces a mineralized waste form. The Department recently awarded a research contract to evaluate SR for Hanford wastes to the SR vendor under DOE's ART program.

4.0 Business Cases

The Department structured seven business cases that address three basic approaches to LAW immobilization.

- Business Case 1A/1B/1C evaluates completing all LAW immobilization using only the WTP as currently designed.
- Business Cases 2 through 5 evaluate supplementing the LAW Facility using one of the four technical approaches discussed in Chapter 3.
- Business Cases 6 and 7 evaluate commencing LAW immobilization prior to the full WTP commencing hot operations, which requires the use of tank farm-based pretreatment.

4.1 Factors Common to the Business Cases

Several factors common to all or most business cases are discussed below in order to avoid repetition. Business cases not affected by one or more of these factors will be so noted in their respective discussion of advantages and disadvantages.

- **Sodium** – Sodium is the most abundant chemical in the Hanford tank wastes. Sodium limits waste incorporation into LAW waste forms. The Department based all business cases in this report on 60,000 MT of sodium being converted into LAW glass. This is based on the assumption that 48,000 MT of sodium currently in the Hanford Site underground storage tanks will require LAW immobilization along with 3,000 MT of sodium that will be added for tank farm chemistry control, and 9,000 MT of sodium that DOE will add during tank waste pretreatment in the WTP.

  Recent studies, however, indicate that DOE may need to add an additional 30,000 MT of sodium during WTP pretreatment to keep aluminum leached from sludge wastes in solution as the liquid wastes are processed through other WTP pretreatment processes. Therefore, DOE may need to immobilize as much as 90,000 MT of sodium as LAW if WTP pretreatment of the higher sodium additions occur and are not mitigated. The Department is evaluating several approaches to mitigate the potential need for additional sodium; however, any technique deployed will result in additional costs. Mitigating measures might include utilizing a sodium hydroxide recycle process to reuse sodium added during pretreatment, using elevated LAW pretreatment temperatures to decrease sodium addition requirements, and/or removing aluminum using a tank farm-based pretreatment process prior to waste sludge entering WTP pretreatment.

  Sodium-related uncertainties exist across all business cases. If DOE does not implement mitigation approaches and 90,000 MT of sodium needs to be immobilized as LAW, Business Case 1 could be extended an additional 30 years (90-year LAW immobilization mission duration). The Department anticipates that it will better know the magnitude of sodium additions needed to be processed before a final supplemental treatment decision is made, thus enabling it to provide sufficient supplemental LAW immobilization capacity to complete the LAW treatment and immobilization mission within its target time frame. Otherwise, these six business cases could be extended 14 years, resulting in a 41-year LAW immobilization mission duration rather than 27 years. Tank farm-based LAW pretreatment does not significantly affect sodium additions. The Department is evaluating potential sodium mitigation measures (e.g., increased waste loading) that could be used to address the potential for additional sodium additions without adding to either the size of the supplemental LAW immobilization system capacity or the mission duration.

- **LAW and HLW Immobilization Duration –** The Department's estimate for completing the HLW immobilization mission range from 23 to 35 years based on WTP design capacities, target operating efficiencies, and estimated sludge volumes and ranges of chemical properties. For the purposes of this study, DOE assumed that unless the LAW immobilization mission duration was limiting (Business Case 1 only), the HLW immobilization mission could be completed in 27 years following full WTP startup in 2019. The Department sized supplemental LAW processing facilities evaluated in this study to immobilize 60,000 MT of sodium in a 27-year period working in conjunction with the LAW Facility. Since DOE estimates that the LAW Facility will vitrify 1,000 MT of sodium per year (27,000 MT sodium during its 27-year mission), it sized the supplemental LAW immobilization facilities considered in this study to immobilize 33,000 MT of sodium in a 27-year period in Business Cases 2 through 5. In Business Cases 6 and 7, smaller LAW immobilization systems would be required because LAW immobilization is assumed to start in 2014, which results in 32 years of LAW immobilization (5 years prior to full WTP startup and 27 years following full WTP startup).

- **Secondary Wastes –** Secondary wastes produced during LAW immobilization may contain a portion of the technetium-99, iodine-129, and other volatile constituents of concern that were in the LAW feed. The Department assumes that liquid secondary waste mitigation measures may be required for any thermal immobilization approach where treatment temperatures are sufficiently high to cause volatile radionuclides to enter the offgas system. The degree to which radionuclide volatilization occurs depends upon several factors including LAW feed chemistry, volatile contaminant feed concentrations, liquid secondary waste recycle, and treatment temperatures.

  Business Case 7 includes LAW First, in which DOE assumes that the LAW Facility will operate 5 years prior to the WTP PT Facility startup. However, LAW First creates a potential secondary waste issue. During LAW vitrification in the LAW Facility, a portion of the technetium-99 in the waste feed will volatilize and enter the melter offgas stream that is considered to be a secondary waste. Under normal full WTP operations, however, the condensate from that offgas stream would be recycled through a WTP PT Facility evaporator and then back to the LAW melters, thereby, substantially increasing the fraction of technetium-99 that is captured in the LAW glass. However, because recycle to the WTP PT Facility evaporator cannot occur for the first 5 years under the LAW First business case, the technetium-99 in the secondary waste could remain in the secondary waste, which would increase the inventory of technetium-99 that is disposed of in the Integrated Disposal Facility in a non-glass form. In order to mitigate that risk, DOE anticipates using a small temporary evaporator installed near the LAW Facility (or similar solution) to recycle the secondary waste stream and increase technetium-99 capture in the LAW glass waste form during the LAW First 5-year operating period.

- **SST Retrievals –** The number of SSTs that DOE will be able to retrieve prior to the WTP coming on line is limited by the amount of DST space that will be available to receive wastes retrieved from the SSTs. The Department anticipates that this limitation will continue until it is able to immobilize LAW at rates that exceed the rate at which it can retrieve wastes from SSTs. Two of the business cases (6 and 7) evaluate mission approaches wherein LAW immobilization starts approximately 5 years prior to the completion of WTP PT and HLW Vitrification hot commissioning.
  Both approaches would enable additional SST retrievals to occur prior to full WTP startup; however, both approaches require that DOE pretreat the LAW feed in a tank farm-based pretreatment system prior to immobilization.

- **Technology Readiness Assessment (TRA) –** A TRA is a systematic process that assesses the readiness (or Technology Readiness Level [TRL]) of certain technologies–called critical technology elements (CTE)–used in systems. The TRA process is being adapted for use by DOE from applications by other agencies (e.g., DOE, National Aeronautics and Space Administration [NASA]). Notably, the TRA process is being adapted from use in product development applications, to nuclear-chemical engineering process development applications for the U.S. Department of Energy, Office of Environmental Management (EM). Use of the TRA process for evaluating LAW alternative technologies represents the first TRA application by EM and therefore is a pilot study that will serve as a basis for subsequent revisions to the use of the TRA process by DOE. Appendix B describes the process DOE used to assess the WTP LAW immobilization technologies and the various supplemental immobilization and pretreatment technologies presented in the business cases. The TRA results presented in each business case describe the technology development activities required, as a minimum, to advance each business case through completion of full-scale prototype demonstrated in a relevant environment (e.g., testing the prototype in the field with a range of simulants and/or real waste).

- **Costs –** To the extent practicable, DOE based the cost estimates presented in this report on existing information sources. For example, the Hanford tank farm- and WTP-related costs are based on the existing Department-validated tank farm and WTP cost baselines. Those costs are common to all business cases and are the dominant cost components, representing 90% or more of the estimate to complete (ETC) costs for most business cases. The level of confidence in these costs is higher than the individual supplemental technology cost elements because of the advanced state of the WTP design relative to other treatment systems and the baseline review and approval processes associated with the WTP and tank farms. The bases for each of the supplemental treatment and immobilization technology cost estimates is briefly described in each business case that uses one or more of those technologies. A more detailed description of the major assumptions and cost methodologies is summarized in Appendix C.

  Cost uncertainties are substantial in this type of analysis for numerous reasons ranging from the long time frames evaluated to the conceptual nature of the business cases. The Department addressed the various sources of cost uncertainties using Monte Carlo uncertainty analysis techniques. Monte Carlo techniques are widely accepted for dealing with cost and other uncertainties. The Department reports the ETC costs to two figures (nearest billion dollars); however, that should not be construed as an indication of cost accuracy. Costs that are relatively close (i.e., with significant overlapping cost ranges) should be considered to be equivalent for purposes of this study. Costs are reported in net present value dollars to reflect the time value of money as well as in constant FY 2008 dollars to address different perspectives. The costs are dominated by WTP and tank farms operating costs that comprise a majority of the total costs. Thus, Business Cases 2 through 7 all have a comparable cost range.

- **Schedule Uncertainty –** Treatment schedules and durations are strong drivers for costs and tank waste retrieval. The schedule for tank waste retrieval is presumed to be important to environmental risk reduction. This study assumes treatment durations based upon assumptions regarding treatment parameters, schedule assumptions, sodium quantities, and other factors that enable comparisons between the business cases. They are not intended to be accurate projections of the optimized Hanford tank waste cleanup mission schedule. The integrated Hanford tank waste cleanup mission strategy is intended to minimize long-term risk by minimizing the time required to complete tank retrievals.

4.2 Business Case Constructs

Table 1 summarizes the seven business cases. In all cases, the WTP PT and HLW Facilities are assumed to commence hot operations in 2019. For simplification, DOE assumes that the HLW Vitrification Facility has the capability to complete HLW immobilization 27 years following startup. This is well within the 23- to 35-year time frames DOE has predicted previously in various simulations.

Table 1. Summary Overview of the LAW Business Cases

Business Case*		Supplemental LAW Immobilization	Year Waste Immobilization Complete		Comments
			HLW	LAW	
1	A	None	2079	2079	All LAW immobilized in WTP LAW Facility.
	B	None	2046	2079	Same as 1A but build 31 new DSTs to store pretreated LAW and complete PT and HLW immobilization by 2046.
	C	None	2046	2059	Third melter installed in LAW and all three melters upgraded to provide 1,500 MT per year.
2		2nd LAW in 200 East	2046	2046	Same assumptions for Cases 2 through 5. Only the LAW immobilization technology changes.
3	A	BV in 200 East	2046	2046	
	B	3rd Melter in LAW and BV	2046	2046	
4		CS in 200 East	2046	2046	
5		SR in 200 East	2046	2046	
6		BV in 200 East and 200 West	2046	2046	BV in 200 West starts in 2014. BV in 200 East and WTP LAW start in 2019.
7		BV	2046	2046	BV in 200 E and WTP LAW both start in 2014.

The WTP is located in the 200 East Area.

In Business Case 1, DOE assumes that WTP PT and HLW Facilities operations are constrained by the rate at which the LAW Facility can immobilize LAW. This either results in a necessity to slow down the overall WTP throughput rate to match the LAW Vitrification Facility throughput rate (Cases 1A and 1C) or a need to store excess pretreated LAW feed (e.g., build new clean DSTs) until the pretreated LAW can be immobilized in the WTP LAW Facility (Case 1B). A third melter could potentially increase the WTP LAW capacity by one-half to 1,500 MT sodium per year. With such changes, the WTP facility could process approximately 40,000 MT of sodium over the assumed 27-year operating period, reducing the supplemental LAW immobilization system throughput requirements by approximately 40%. Supplemental immobilization would still be required for the remaining 20,000 MT of sodium. This is evaluated as Business Case 1C. An initial assessment (Appendix D) of the costs and benefits of adding a third melter indicates a significant benefit over Cases 1A and 1B because the treatment mission would be shortened to 40 years rather than 60 years. However, installing the third melter does not eliminate the need for supplemental treatment. There does not appear to be any measurable advantage of combining a three-melter WTP LAW Facility with a smaller capacity BV facility. Further evaluation of the benefits and cost of installing a third melter in the WTP LAW Facility is planned.

The WTP LAW Facility includes a third melter bay; however, in Cases 1A and 1B only two LAW melters are assumed. Initially, the WTP LAW Facility was to include three LAW melters with a net throughput of 1,100 MT of sodium per year. In 2003, DOE determined it could replace the three initially planned LAW melters with two higher capacity melters that would provide nearly the same throughput

(1,000 MT sodium per year). Thus, this business case study conservatively assumed that the LAW Vitrification Facility could treat 1,000 MT sodium per year.

The WTP design requires that the LAW Vitrification Facility have the capability to install the third LAW melter. The installation and operation of the third LAW melter will require: installation of the melter, melter support services (including power and cooling water); melter feed systems; melter glass pouring and control systems; and ventilation system upgrades to support the additional heat load in the glass-pouring cave and transfer tunnel. In addition, upgrades to the WTP site electrical power substation and distribution system and cooling water systems would be required to support a third melter. The modification of the LAW Vitrification Facility and WTP site services to accommodate the third melter would delay the early startup of the WTP LAW Facility.

In Business Cases 2 through 7, DOE assumes that sufficient supplemental LAW immobilization capacity is provided through one of several means described in the cases such that the total treatment and immobilization mission is completed 27 years following the WTP PT and HLW Vitrification Facilities commencing hot operations. Business Cases 2 through 5 are essentially the same other than the means used to provide supplemental LAW immobilization; Case 2 assumes 2nd LAW, Case 3 assumes BV, Case 4 assumes CS, and Case 5 assumes SR. Business Case 3A considers BV to provide the entire supplemental immobilization capacity. Business Case 3B considers a supplemental immobilization capacity trade-off provided by a combination of installing a third melter in the WTP LAW Facility and reducing the BV Facility size. Business Cases 6 and 7 address two potential opportunities (early BV and Start LAW First) that DOE is evaluating which could enable it to start vitrifying LAW before the WTP PT and HLW Vitrification Facilities come on line. In both cases, DOE would provide pretreated LAW feed to the LAW immobilization facilities using tank farm-based pretreatment techniques.

4.3 Business Case 1 – WTP LAW Vitrification Only with No Supplemental LAW Immobilization

4.3.1 Business Case 1 Description

Business Cases 1A and 1B both assume that the entire LAW pretreatment and immobilization mission is completed using only the LAW immobilization capabilities provided by the LAW Facility currently being constructed. Business Case 1C assumes a third meter is installed in the LAW Vitrification facility spare melter cell. In Business Cases 1A and 1B, all or part of the WTP would operate 20 years in excess of the WTP 40-year design life. Business Case 1C would complete waste treatment within the WTP 40-year design life. While it is not uncommon in the United States to extend the operating life of major nuclear and other industrial facilities, the use of black cells[7] in the WTP PT and HLW Facilities add to the long-term uncertainties and could complicate design life risk mitigation.

Issues presented by the Business Case 1 construct are that:

- The WTP PT Facility is designed to produce pretreated HLW at a rate that matches the WTP HLW Vitrification Facility throughput. The WTP LAW Facility with two melters is designed to immobilize approximately half of the pretreated LAW feed produced by the WTP PT Facility at full capacity.
- If there is insufficient system capacity to accept the pretreated LAW that is generated coincidental with the HLW, then the WTP pretreatment and HLW vitrification rates must be reduced to match

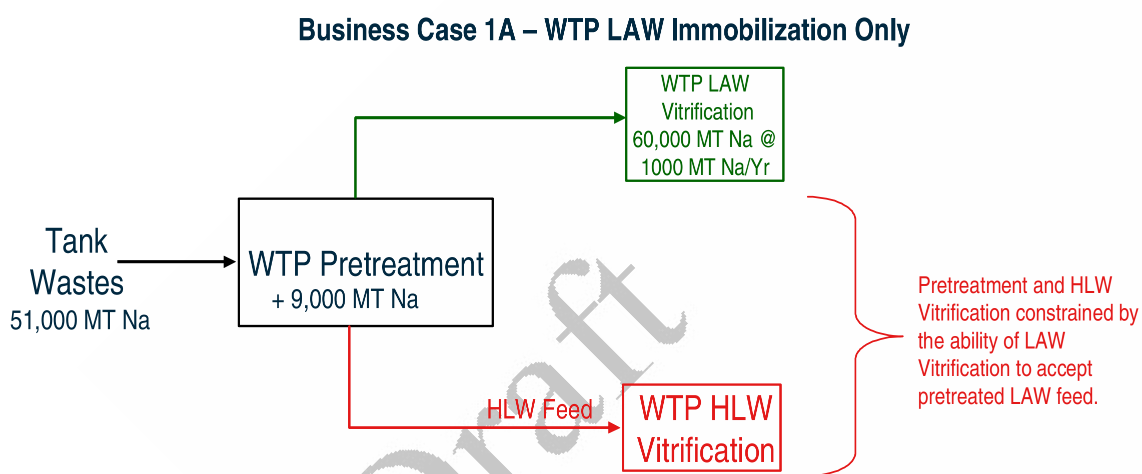
[7] "Black cells" is a term applied to areas in the WTP that will be permanently sealed prior to hot operations, a practice used in the United Kingdom. While the equipment installed in black cells is designed to be highly robust, the facility design does not include means to maintain or replace the equipment and piping in the black cells.

the rate at which pretreated LAW can be accepted. In Case 1A, DOE assumes that the WTP pretreatment and HLW immobilization rates are decreased in order to match the LAW immobilization rate; WTP pretreatment, HLW vitrification, and LAW vitrification all occur over a 60-year mission duration. This would require that the Hanford tank farms and entire WTP be operational throughout that 60-year period.

- The WTP is designed to operate for 40 years. The steps required to increase the WTP operating life to 60 years have not been determined. The Department cannot state with any certainty whether or not critical system components, entire systems, and/or entire facilities would need to be replaced over a 60-year mission duration.
- Installing the third melter would enable the WTP to complete its mission within the 40-year design life. However, continuing to store waste in tanks that are well beyond their design life for this 40-year period increases the risk of additional waste leaks to the environment.

4.3.2 Business Case 1A Description

The Department assumes in Case 1A that the 1,000 MT of sodium per year WTP LAW throughput rate constrains the overall WTP treatment mission resulting in a 60-year mission duration following full WTP hot operations in 2019. During those 60 years, the Hanford tank farms and all WTP facilities (PT, HLW, LAW, BOF, and LAB) must remain operational.



4.3.2.1 Business Case 1A Technical Readiness

The TRA DOE conducted for the WTP LAW vitrification identified and assessed five CTEs. These included: the LAW Melter Feed Process System (LFP) used to prepare the LAW melter feed; the LAW Melter Process System (LMP), which includes the LAW melter; the LAW Primary Offgas Process System/LAW Secondary Offgas/Vessel Vent Process Systems (LOP/LVP) used to treat the LAW melter offgas; the LAW Container Finishing Handling System (LFH) container closure subsystem; and the LFH container decontamination subsystem. The assessment concluded that the CTEs are sufficiently developed to continue to advance the final design. However, the following recommended actions were identified to complete the technology demonstration:

- Integrate prototypical testing of the actual immobilized low-activity waste (ILAW) container inert filling, flange cleaning, inspection, and lidding/delidding equipment in a remote operational environment; and

- Integrate prototypical testing of the actual ILAW container decontamination and smear testing systems in a simulated remote environment.

4.3.2.2 Business Case 1A Costs

Case 1A Costs ($B)		
Technology Development Cost (2008 Constant $)	**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
$0	$27	$56

Case 1A has the highest ETC costs on a present value and constant dollar basis. Case 1A is based on the WTP technologies that are well developed. The Department does not anticipate the need for any near-term technology development funding to implement Case 1A beyond what already exists in the WTP baseline. Case 1A ETC costs are dominated by the 60-year treatment mission duration that leads to treatment mission completion in 2079. During that period of time, supporting tank farm operations and all WTP facility operations would need to continue.

4.3.2.3 Business Case 1A Advantages and Disadvantages

Advantages – The principal advantages of this business case are:

- WTP LAW pretreatment and immobilization processes used in the business case are undergoing extensive design, testing, and evaluation as part of the WTP Project.
- Confidence that the LAW glass waste form will meet waste disposal requirements at the Hanford Site is the highest of any LAW form due to the extensive development, testing, and analysis.
- All treatment-related capital cost is already budgeted within the WTP Project budget.

Disadvantages – The principal disadvantages of this business case are:

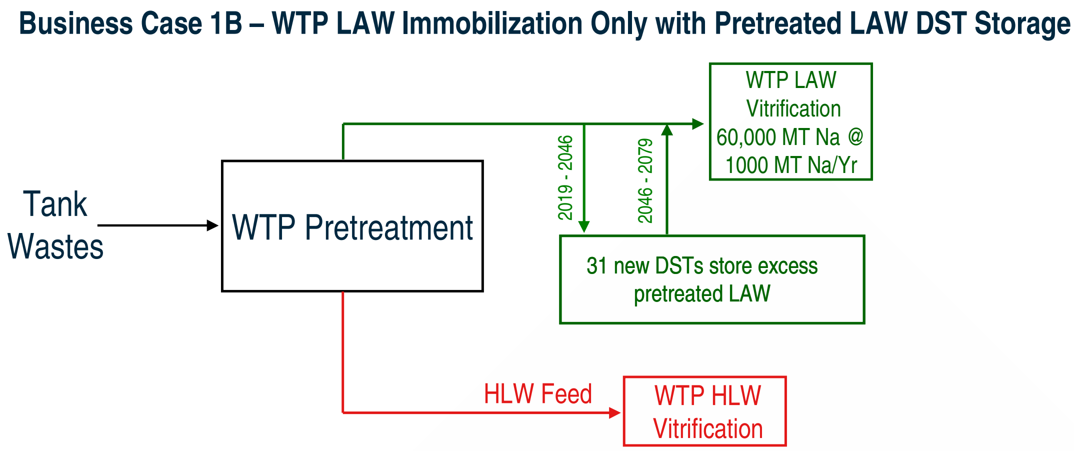
- Very long (60-year) WTP treatment and immobilization mission.
- High ETC cost due to the extended period of tank farm and WTP operations.
- Highest SST leakage risk – increased likelihood because of the potential for SST deterioration during the extended duration of SST waste storage.
- Mission duration exceeds current DST design life, which increases the likelihood that some DST replacements may be required to contain untreated tank waste. The potential DST replacement costs are not explicitly included in the cost projections but are included in the operating cost uncertainty.
- Mission duration exceeds the 40-year WTP design life, which creates unresolved questions regarding the life-extension requirements, particularly for WTP components located within WTP black cells.

4.3.3 Business Case 1B Description

Business Case 1B provides some mitigation of the Case 1A WTP 20-year life-extension risks by building new DSTs to accept pretreated LAW from the WTP PT Facility. This would enable the WTP PT and HLW Facilities to operate at full capacity and complete their treatment missions by 2046, 27 years following the start of full WTP hot operations. This case would only extend the operating duration of the

LAW Vitrification Facility, which does not include black cells; however, it requires the inclusion of up to 31 new DSTs to interim store pretreated LAW until the LAW Facility is able to immobilize that waste[8].

The Department assumes that new DSTs are constructed rather than assuming that it would be able to clean the existing DSTs to a sufficient degree to store the excess pretreated LAW. There are several reasons for this assumption:



- There is no historical basis that the DSTs can be sufficiently decontaminated to store the pretreated LAW without risk of cross-contamination, subsequently requiring additional pretreatment.
- If the pretreated LAW was to become cross-contaminated during storage and that situation was identified after 2046 during LAW staging for LAW vitrification, DOE would no longer have operational facilities to re-pretreat the contaminated wastes. Similarly, DOE would no longer have operational HLW immobilization facilities to vitrify the HLW constituents removed during pretreatment as it is assumed that the PT and HLW Facilities would be shut down and decommissioned once operations were complete in 2046.

4.3.3.1 Business Case 1B Technical Readiness

The technical readiness for Case 1B is the same as for Case 1A.

4.3.3.2 Business Case 1B Costs

Case 1B Costs ($B)		
Technology Development Cost (2008 Constant $)	**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
$0	$27	$49

Case 1B has the second highest ETC costs on a present value and constant dollar basis. This business case avoids approximately $15 billion (constant dollars) in costs to operate the WTP PT and HLW Facilities and current SST and DST tank farms beyond 2046. Approximately $8.5 billion (2008 constant dollars) are added to this business case to design, build, commission, operate, and ultimately decommission the 31 new DSTs

[8] At the time the PT and HLW Facilities complete operations in 2046, the WTP LAW Vitrification Facility would have completed the immobilization of 27,000 MT of sodium leaving 33,000 MT of sodium to be immobilized. In concentrations appropriate for LAW melter feed, that would represent approximately 51 million gallons of feed solution. The Department assumes that it would concentrate the pretreated LAW feed consistent with current tank farm authorization basis-specific gravity limits and practices, which would reduce the stored volume to approximately 31 million gallons. Considering current requirements for emergency space and operations, this would require 31 new DSTs assuming current DST sizes.

assumed. Costs to construct the new DSTs are highly uncertain because those cost estimates are based on different design requirements and market assumptions than are relevant to this business case. The cost of the new DSTs presents substantial uncertainties. The Department's tank cost estimates are based on 1994 cost estimates for DSTs that were to be used for a different purpose and may represent an overestimate. On the other hand, those estimates were only adjusted for average inflation. The adjustments do not account for the substantial differences in commodity costs, qualified nuclear vendors, and nuclear qualified construction labor, which were among the factors that contributed to the substantial increases in the 2005 WTP ETC relative to earlier WTP estimates. Accordingly, while it is possible that the DSTs could be procured at significantly lower costs, the above factors and evolving regulatory requirements could counter any potential savings attributable to simplified designs. These factors are handled as a DST cost uncertainty.

4.3.3.3 Business Case 1B Advantages and Disadvantages

Advantages – The principal advantages of this business case are the same as those identified in Case 1A plus:

- WTP PT and HLW Vitrification Facilities can complete operations in a 27-year period, which is well within their 40-year design lives. Since black cells are only associated with those two WTP facilities, this substantially reduces WTP life-extension risks.
- SST and current DST retrievals and closures can proceed on the same schedule as occurs in Business Cases 2 through 7, which include supplemental LAW immobilization.

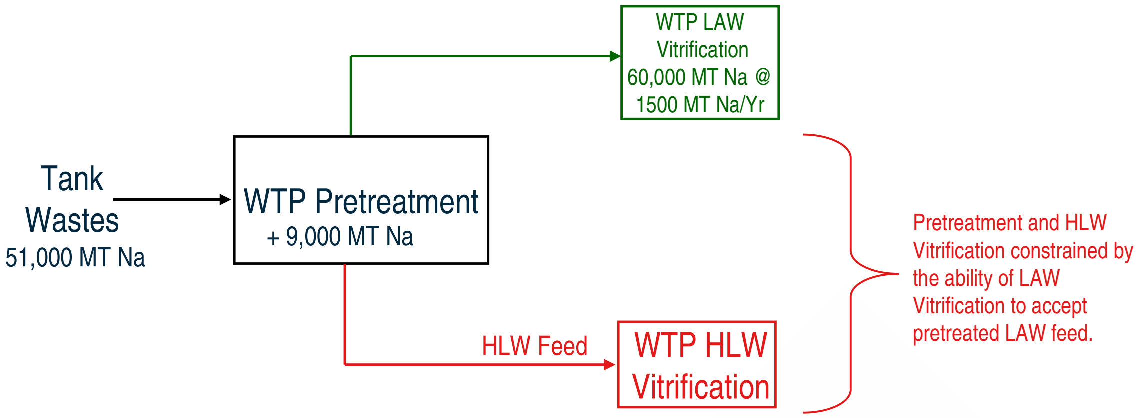
Disadvantages – The principal disadvantages of this business case are:

- High ETC costs due to the 60-year duration of some tank farm and WTP operations as well as the capital costs for new DSTs.
- May require the construction of up to 31 new DSTs that will ultimately require decontamination and decommissioning (D&D) and closure, adding to the Hanford legacy.
- LAW immobilization mission duration exceeds the LAW Facility 40-year design life by 50%.
- WTP PT and HLW facilities are not available after 2046 to mitigate pretreated LAW contamination risks (i.e., HLW residuals from other piping or equipment).

4.3.4 Business Case 1C Description

The Department assumes in Business Case 1C that a third melter is installed in the spare cell and other upgrades are made to the support systems so that the LAW Facility capacity is increased to 1,500 MT of sodium per year. With this increased capacity, the overall WTP treatment mission is 40-years duration following full WTP hot operations in 2019. During those 40 years, the Hanford tank farms and all WTP facilities (PT, HLW, LAW, BOF, and LAB) must remain operational.

Business Case 1C – WTP LAW Immobilization with third Melter



4.3.4.1 Business Case 1C Technical Readiness

The technical readiness for Case 1C is the same as for Case 1A.

4.3.4.2 Business Case 1C Costs

Case 1C Costs ($B)		
Technology Development Cost (2008 Constant $)	**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
$0	$26	$45

Case 1C ETC costs on a present value and constant dollar basis are less than both Cases 1A and 1B. This lower cost results from the operating period being 40 years rather than 60 years. Installing the third melter and operating the LAW Vitrification Facility for 40 years (Case 1C) is lower cost than Case 1B in which DSTs are constructed. During the 40-year mission, supporting tank farm operations and all WTP facility operations would need to continue.

4.3.4.3 Business Case 1C Advantages and Disadvantages

Advantages – The principal advantages of this business case are the same as identified in Case 1A plus:

- The treatment mission can be completed within the WTP 40-year design life.

Disadvantages – The principal disadvantages of this business case are:

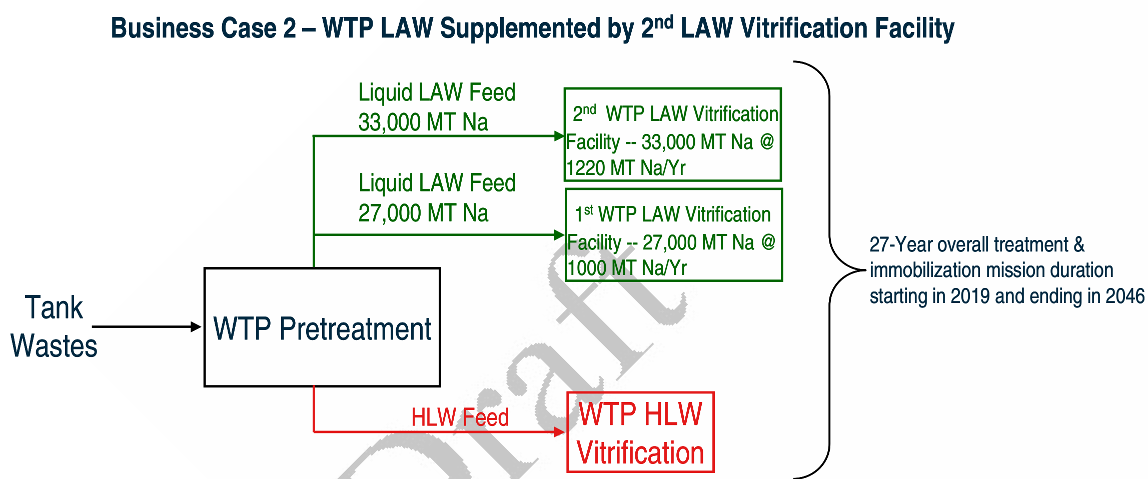
- Long (40-year) WTP treatment and immobilization mission.
- High ETC cost due to the extended period of tank farm and WTP operations.
- High SST leakage risk – increased likelihood because of the potential for SST deterioration during the extended duration of SST waste storage.
- Mission duration exceeds current DST design life, which increases the likelihood that some DST replacements may be required to contain untreated tank waste. The potential DST replacement costs are not explicitly included in the cost projections but are included in the operating cost uncertainty.

4.4 Business Case 2 – WTP LAW Vitrification with Second LAW Vitrification Facility in 200 East Area

4.4.1 Business Case 2 Description

The Department developed Business Case 2 to evaluate building a second LAW facility (2nd LAW) in the 200 East Area to complete the LAW immobilization mission in the same time frame as the HLW immobilization mission is completed (27 years). The 2nd LAW Vitrification Facility design would be very similar to the initial LAW Vitrification Facility but its throughput would be approximately 20% higher given the assumptions in this report. The first LAW Facility would process 27,000 MT of sodium (1,000 MT of sodium per year) during a 27-year treatment mission, which would leave 33,000 MT of sodium to be processed by the 2nd WTP LAW Facility. The Department assumes that LAW pretreatment for both the first and second LAW Vitrification Facilities would be provided by the WTP PT Facility. The Department also assumes that the first and second LAW Vitrification Facilities will both commence hot operations in 2019.

This business case does not factor in all potential enhancements to the LAW Vitrification Facility that could result in a different, more efficient design than is offered by the first generation facility. Neither does it factor in the additional time and costs that might be associated with approving the construction of a facility using a substantially different design.



4.4.2 Business Case 2 Technical Readiness

The technical readiness for Business Case 2 is the same as for Cases 1A and B.

4.4.3 Business Case 2 Cost

Case 2 Costs ($B)		
Technology Development Cost (2008 Constant $)	**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
$0	$25	$40

The ETC costs to implement this business case are $15 to $10 billion less than for Cases 1A and 1B, respectively (in constant 2008 dollars) and approximately $1.8 billion less (~7% comparing mean values) than Business Case 1 ETC costs on a present value basis. Those cost differences are considered significant within the accuracy of this report's analyses. Business Case 2 ETC costs are within the ETC cost uncertainty ranges for BV, CS, and SR. Business Case 2 costs are based on the validated WTP baseline costs for LAW vitrification.

4.4.4 Business Case 2 Advantages and Disadvantages

Business Case 2 is a strong business case due to its firm foundation in the LAW Facility already under construction at the Hanford Site.

Advantages of Business Case 2 – The principal advantages of this business case are the same as those listed in Case 1A plus:

- The business case leverages DOE's research, development, engineering, and reviews in the existing WTP LAW Facility.
- It is based on demonstrated and robust LAW technology.
- Ongoing development work in glass formulation and melters will likely result in substantial LAW facility capacity increase.

Disadvantages of Business Case 2 – The principal disadvantages of this business case are as follows:

- DOE would need to invest in building the second LAW Facility prior to obtaining operating experience with the first WTP LAW Facility.

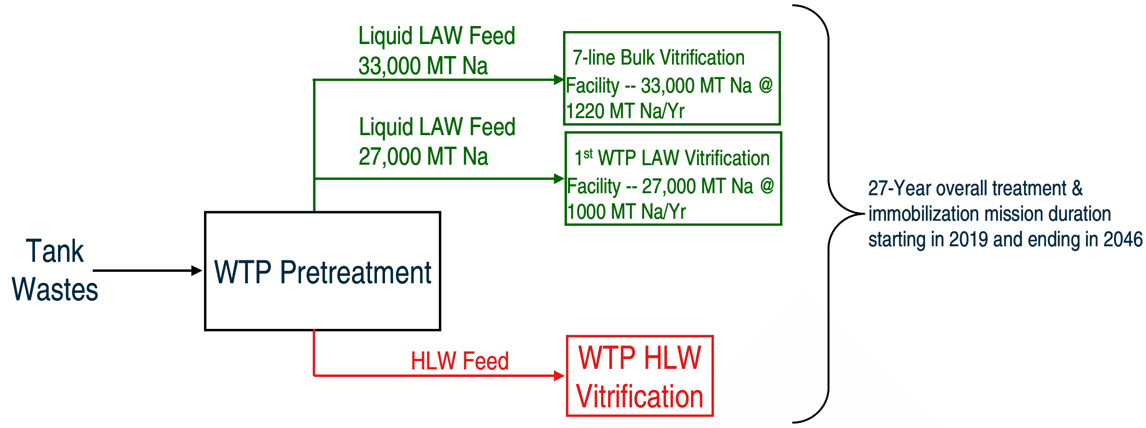
4.5 Business Case 3 – WTP with a Bulk Vitrification Facility in 200 East Area

Business Case 3 includes: Case 3A consisting of the currently designed two-melter WTP LAW vitrification facility supplemented with a seven-line BV facility; and, Case 3B consisting of a three-melter WTP LAW Vitrification facility supplemented with a four-line BV facility.

4.5.1 Business Case 3A Description

Business Case 3A would supplement the LAW Facility with a seven-line BV Facility located in close proximity to the WTP site. Both the LAW Facility and the BV Facility are assumed to commence operations in 2019 in parallel with the WTP HLW and PT Facilities. Both LAW immobilization facilities are assumed to receive all pretreated waste from the WTP PT Facility. The BV Facility is sized (approximately 1,220 MT sodium immobilized per year) to complete the LAW immobilization mission in a 27-year period, which coincides with the assumed HLW immobilization mission duration.
This business case is very similar to Business Case 2 except the second LAW Vitrification Facility in Business Case 2 is replaced by a BV facility with the same throughput.

Business Case 3A – WTP LAW Supplemented by Seven-Line Bulk Vitrification Facility



4.5.1.1 Business Case 3A Technical Readiness

The TRA for Supplemental Immobilization (DOE/ORP-2007-01) determined that the BV technology is in an advanced stage of technology development when considering the component subsystems. The integrated demonstration testing, planned to be complete by the end of 2007, can provide the technical basis for using the technology to support initial design of a full-scale facility. Bulk vitrification has completed full-scale nonradioactive testing, and engineering scale radioactive testing.

The Department focused its current technology work on demonstrating the resolution of technical issues (e.g., glass formulation to mitigate separate salt phase formation, refractory layout to support molten glass containment) identified in large scale testing. Successful completion of this work should allow the technology to proceed into final design of the DBVS Project[9]. Appendix B provides a listing of technology development activities identified in the TRA. Examples of the major activities to develop the BV systems include:

- Developing the feed receipt and feeding system by successful completion of prototypical testing (planned in 2007) on a full-scale dryer.
- Developing the in-container vitrification system by completion of prototypical testing of a full-scale In-Container Vitrification™ (ICV) (planned in 2007).
- Developing the offgas treatment system by testing to demonstrate operation of the sintered metal filter for technetium-99 recycle.
- Completing full-scale non-radioactive and radioactive demonstration testing.

4.5.1.2 Business Case 3A Cost

Case 3A Costs ($B)		
Technology Development Cost (2008 Constant $)	**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
$0.13	$25	$39

The ETC costs to implement this business case are $17 to $7 billion less than those for Cases 1A, 1B, 1C, (in constant 2008 dollars), and approximately $1.4 billion less than the lowest Case 1. ETC costs on a present value basis. Those cost differences are considered significant within the accuracy of this report's

[9] If approved, DBVS would receive waste from a Hanford Site tank (S-109) that has a sufficiently low cesium-137 concentration; pretreatment need only consist of simple solids/liquids separations and selective dissolution.

analyses. Business Case 3A ETC costs are within the ETC cost uncertainty ranges for a second LAW facility, CS, and SR. The BV costs are based on the costs developed under DOE O 413.3A, *Program and Project Management for the Acquisition of Capital Assets*, for the DBVS Project, as well as production-level BV Facility costs that were developed, also in accordance with DOE O 413.3A, for the Hanford tank farm baseline.

4.5.1.3 Business Case 3A Advantages and Disadvantages

Business Case 3A has less technical and cost uncertainty than for CS and SR because DOE has invested in BV development for LAW immobilization since 2003.

Advantages of Business Case 3A – The principal advantages of this business case are:

- Second highest level of technical readiness (WTP LAW is highest).
- Commercially used in other venues (e.g., commercial hazardous waste destruction).
- Modular design concept offers scaling flexibility at lower programmatic risk; i.e., DOE can sequentially add BV lines based on need.
- DOE conducted independent project assessments of the BV technology and is resolving identified issues; e.g., integrated dry/melter test in 2007.

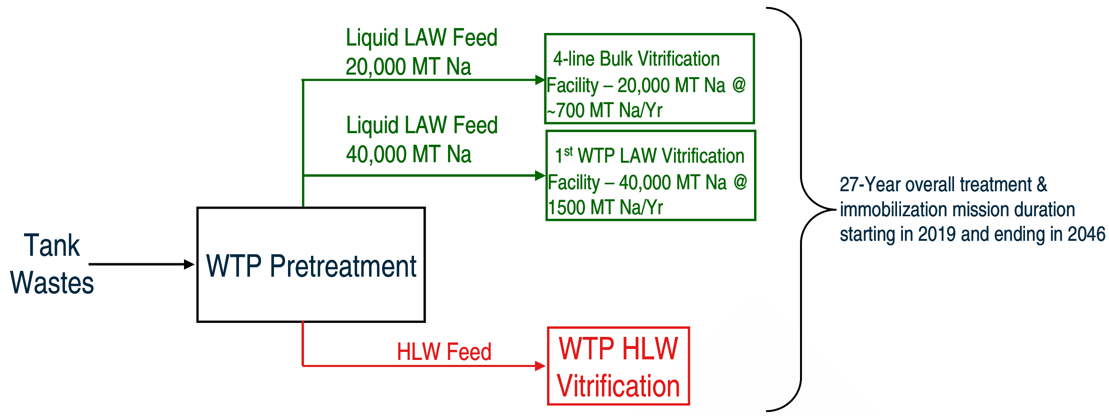
Disadvantages of Business Case 3A – The principal disadvantage of this business case is:

- Additional engineering and testing required to resolve some system issues such as the viability of the sintered filter to recycle technetium-99 in the offgas (DBVS planned to provide resolution).

4.5.2 Business Case 3B Description

Business Case 3B would add a third melter to the LAW Facility and provide a four-line BV Facility located in close proximity to the WTP site. Both the upgraded LAW Facility and the BV Facility are assumed to commence operations in 2019 in parallel with the WTP HLW and PT Facilities. Both LAW immobilization facilities are assumed to receive all pretreated waste from the WTP PT Facility.
The upgraded LAW Vitrification facility is assumed to have a capacity of 1,500 MT sodium per year and the BV Facility is sized (approximately 700 MT sodium immobilized per year) to complete the LAW immobilization mission in a 27-year period, which coincides with the assumed HLW immobilization mission duration. This business case is similar to Business Case 3A except the LAW Vitrification Facility capacity is increased 50% by installing a third melter and the BV facility capacity is reduced from seven process lines to four.

Business Case 3B – WTP LAW with Third Melter Supplemented by Four-Line Bulk Vitrification Facility



4.5.2.1 Business Case 3B Technical Readiness

- The technical readiness for the three-melter LAW Vitrification Facility is the same as described in Case 1A for the two-melter facility and the Case 3A for the BV.

4.5.2.2 Business Case 3B Cost

- The costs for this case are the same as for Case 3A and the same cost comparison analysis would apply.

4.5.2.3 Business Case 3B Advantages and Disadvantages

Business Case 3B has less technical and cost uncertainty than for CS and SR because DOE has invested in LAW Vitrification and BV development for LAW immobilization for many years.

Advantages of Business Case 3B – The principal advantages of this business case are:

- WTP LAW pretreatment and immobilization processes used in the business case are undergoing extensive design, testing, and evaluation as part of the WTP Project.
- Confidence that the WTP LAW glass waste form will meet waste disposal requirements at the Hanford Site is the highest of any LAW form due to the extensive development, testing, and analysis.
- BV is the second highest level of technical readiness (WTP LAW is highest).
- BV commercially used in other venues (e.g., commercial hazardous waste destruction).
- Modular design concept of BV offers scaling flexibility at lower programmatic risk; i.e., DOE can sequentially add BV lines based on need.
- DOE conducted independent project assessments of the BV technology and is resolving identified issues; e.g., integrated dry/melter test in 2007.

Disadvantages of Business Case 3B – The principal disadvantage of this business case is:

- Including the cost of upgrading the WTP LAW Facility and support systems to accommodate a third melter may threaten the WTP Project authorized cost.
- Upgrading the WTP LAW Facility with a third melter may extend the 2014 completion schedule.

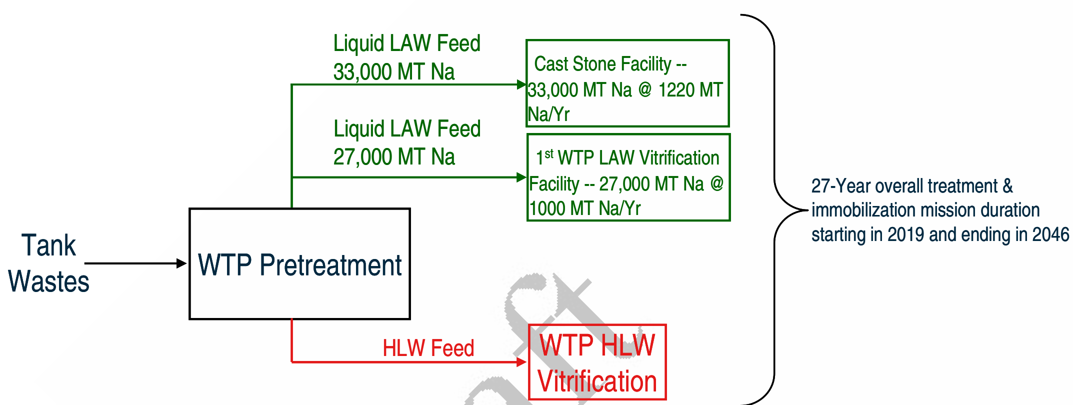
- Additional engineering and testing required to resolve some BV system issues such as the viability of the sintered filter to recycle technetium-99 in the offgas (DBVS planned to provide resolution).

4.6 Business Case 4 – WTP with Cast Stone in 200 East Area

4.6.1 Business Case 4 Description

Business Case 4 would supplement the LAW Facility with a CS facility located in close proximity to the WTP site. Both the LAW Facility and the CS Facility are assumed to commence operations in 2019 in parallel with the WTP HLW and PT Facilities and to receive all pretreated waste from the WTP PT Facility. The CS Facility is sized (approximately 1,220 MT sodium immobilized per year) to complete the LAW immobilization mission in a 27-year period, which coincides with the assumed HLW immobilization mission duration. This business case is very similar to Business Case 2 except the second LAW Vitrification Facility in Business Case 2 is replaced by a CS facility with the same throughput. Previous soil column contamination at Hanford, limited dispersion provided by Hanford's hydrology, and the contaminant inventory that would be immobilized using supplemental LAW technologies may limit the extent to which CS is used as a Hanford LAW waste form.

Business Case 4 – WTP LAW Supplemented by a Cast Stone Facility



4.6.2 Business Case 4 Technical Readiness

The state of Washington has expressed an expectation that any supplemental immobilization technology must be as good as WTP LAW glass. The TRA for Supplemental Treatment (DOE/ORP-2007-01) determined that although grout-based waste forms are widely used at the Hanford Site, other DOE sites, and by commercial industry to stabilize low-level radioactive wastes and hazardous wastes, the CS technology is not sufficiently tested for specific application to Hanford LAW. The TRL reflected durability requirements for the waste form not having been specifically established for Hanford LAW, as well as the lack of prototypic testing with Hanford LAW at this time. Development of the CS waste form for other applications suggests that the technology could be developed for use on Hanford LAW, perhaps with flowsheet modifications to address technetium-99, nitrates, and organics anticipated in Hanford LAW. An extensive development program could be required for Hanford LAW. The Department envisions that it would require large-scale pilot testing in the field with actual wastes (similar to DBVS) for Hanford LAW. Appendix B provides a listing of technology development activities identified in the TRA. Examples of the major activities to develop the CS systems include:

- Establishing waste form acceptance criteria.
- Developing and testing the waste formulations for a bounding range of LAW waste feeds to meet the waste form acceptance criteria.
- Finalizing the project documentation, such as the reliability and maintainability analysis, risk management, configuration management, and draft design.
- Designing and testing the wet cast stone sampling system.
- Defining the specifications and performance acceptance tests for the vendor-supplied mixer.
- Completing prototypic testing of the mixer system.
- Completing non-radioactive demonstration testing on a full-scale mixing and casting system.
- Completing radioactive testing on a pilot-scale mixing and casting system.

4.6.3 Business Case 4 Cost

Case 4 Costs ($B)		
Technology Development Cost (2008 Constant $)	**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
$0.30	$24	$37

The ETC costs to implement this business case are $19 to $12 billion less than for Cases 1A and 1B, respectively (in constant 2008 dollars) and approximately $3 billion less (~12% comparing mean values) than the Business Case 1 ETC costs on a present value basis. Those cost differences are considered significant within the accuracy of this report's analyses; however, they may also be misleading in that DOE does not have the same confidence level that CS can be successfully permitted to treat and immobilize the entire portion of the Hanford LAW that cannot be immobilized by the LAW Facility. Whereas CS is likely to be suitable to immobilizing some portion of the LAW and is considered suitable for Hanford tank farm secondary waste and tank farm residual wastes (e.g., tank residuals), it is not a Best Available and Demonstrated Technology (BDAT) for Hanford LAW tank wastes which creates regulatory uncertainties that would need to be addressed. The technology development costs are based on developing the technology to its full potential for deployment on Hanford LAW; however, the estimated development costs (and full-scale implementation costs) do not take into account (a) additional pretreatment that may be required to address RCRA-related regulatory issues that could potentially arise, or (b) programmatic risks (implementation delays) if significant regulatory risks arise. The Department considers this issue more significant for this business case than for SR (the other non-glass supplemental waste form).

Business Case 4 ETC costs are within the ETC cost uncertainty ranges for a second LAW facility, BV, and SR. The CS costs are based on preliminary designs and cost estimates developed over a short time frame by a vendor in response to a 2003 solicitation issued by the Hanford TFC. This was done as part of DOE's preliminary evaluation of potential supplemental LAW treatment and immobilization technologies. The design and costs have not been subjected to detailed analyses nor validated using the DOE O 413.3A project management procedures. In addition, the design and cost bases were developed under an assumption that technetium-99 would be removed from the waste feed stream, which is not a basic assumption in this analysis. As a result, technology development and ETC costs for CS have substantially more uncertainty than those for Business Cases 1 through 3 due to flowsheet[10] and other uncertainties, including potential pretreatment requirements beyond those for the thermal treatment-based business cases. It is not known whether additional treatment would be required, but if it were, it could substantially increase the ETC costs.

[10]The term flowsheet refers to the detailed description of the chemical processes and mass balances that describe a treatment process.

4.6.4 Business Case 4 Advantages and Disadvantages

Advantages of Business Case 4 – The principal advantages of this business case are:

- Simple process.
- Process used extensively and successfully in the nuclear and hazardous waste industries.
- Process conducted at room temperature using a relatively simple offgas system.

Disadvantages of Business Case 4 – The principal disadvantages of this business case are:

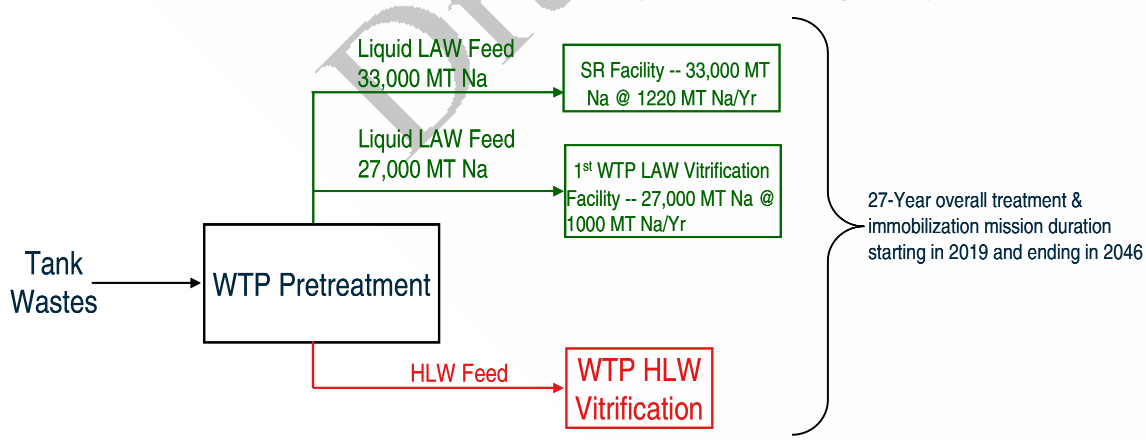
- Acceptability as a primary Hanford LAW waste form is questionable at present.
- ILAW volume significantly greater for CS than for other waste forms considered (approximately twice the volume of WTP LAW glass).
- Flowsheet uncertainties – may require pretreatment for technetium-99, nitrates, and organics for some LAW, which would complicate flowsheet and increase costs.
- Potential RCRA permitting issues due to tank waste RCRA designation.

4.7 Business Case 5 – WTP with Fluidized Bed Steam Reforming in 200 East Area

4.7.1 Business Case 5 Description

Business Case 5 would supplement the LAW Facility with an SR facility located in close proximity to the WTP site. Both the LAW Facility and the SR Facility are assumed to commence operations in 2019 in parallel with the WTP HLW and PT Facilities. Both LAW immobilization facilities are assumed to receive all pretreated waste from the WTP PT Facility. The SR Facility is sized (approximately 1,220 MT sodium immobilized per year) to complete the LAW immobilization mission in a 27-year period, which coincides with the assumed HLW immobilization mission duration. This business case is very similar to Business Case 2 except the second LAW Vitrification Facility in Business Case 2 is replaced by an SR facility with the same throughput.

Business Case 5 – WTP LAW Supplemented by Steam Reforming Facility



4.7.2 Business Case 5 Technical Readiness

The TRA for Supplemental Treatment (DOE/ORP-2007-01) determined that DOE has not established durability requirements for an SR Hanford LAW form and the process has not been prototypically tested with Hanford LAW. Development of the SR process for other site applications suggests that the technology could be developed for use at the Hanford Site; however, DOE anticipates that an extensive technology development program could be required. While DOE has confidence that SR could be designed to produce a competent Hanford LAW waste form, substantial flowsheet uncertainties exist at this time relative to the production of a mineralized waste form using clay additives and the mitigation of any issues associated with the production of large volumes of very small particles (fines) in a volume equal to the mineralized, granular waste product volumes.

The Department has only conducted scoping tests to date for preparation of a monolithic form from the SR mineralized product. While substantial work has been performed by the DOE at the Idaho Operations Office to design a steam reforming facility to treat Idaho site SBW, the formulation and performance requirements for the Idaho carbonate waste form are substantially different from a mineralized Hanford LAW waste form. The Department envisions that it would require large-scale pilot testing in the field with actual wastes (similar to DBVS) for Hanford LAW. Appendix B provides a listing of technology development activities identified in the TRA. Examples of the major activities to develop the SR systems include:

- Characterizing the physical and rheological properties of the pretreated LAW waste and clay mixtures.
- Testing the mixing/blending of the pretreated LAW waste and clay mixtures.
- Developing, testing, and verifying the designs for the spray nozzles to be used in the DMR.
- Developing the thermal reformer system to include integrated, prototypical testing of a pilot-scale DMR (such as the one at Hazen Laboratory in Golden, Colorado).
- Conducting radioactive tests with a small-scale DMR to generate radioactive mineral product to assess the accuracy of the DMR material balance and generate material for mineral product development and characterization.
- Developing the offgas treatment system, including conducting a site-specific testing program with Hanford Site LAW simulants and actual Hanford LAW waste to validate the overall system performance of the DMR, carbon reduction reformer (CRR), and Offgas Treatment System (OGTS).
- Performing Hanford LAW surrogate and actual Hanford LAW testing at an engineering scale, including testing production of the waste form.
- Conducting a full-scale surrogate test to demonstrate system performance.
- Gathering environmental data for permitting a full-scale demonstration test facility, including a RCRA permit, an air permit (National Emission Standards for Hazardous Air Pollutants Permit from EPA), and a construction permit.
- Demonstrating and validating that the gaseous emissions are compliant with regulatory limits, including maximum achievable control technology (MACT) and other environmental standards (overall regulatory acceptance).
- Developing the Container-Handling System and Waste Qualification System, including establishing the system requirements for the monolithic waste form and completing a test program that validates the performance of that waste form.

- Confirming the waste form's performance with the results from the pilot-scale steam reformer test using radioactive LAW.
- Determining the form and retention of technetium and iodine in the waste.
- Establishing waste-form performance criteria.

4.7.3 Business Case 5 Cost

Case 5 Costs ($B)		
Technology Development Cost (2008 Constant $)	**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
$0.36	$26	$41

The ETC costs to implement this business case are $18 to $8 billion less than for Cases 1A and 1B, respectively (in constant 2008 dollars), and approximately $1 billion less (~4% comparing mean values) than Business Case 1 ETC costs on a present value basis. Those cost differences are considered significant within the accuracy of this report's analyses. Business Case 5 ETC costs are within the ETC cost uncertainty ranges for a second LAW facility and SR. The Department derived the SR costs for this business case from the design and cost information that were developed in support of DOE reaching Critical Decision-2 consistent with DOE O 413.3A for the Idaho SBW SR treatment facility.

ETC costs to implement this case are below those for Business Case 1 and, although higher than the other business cases, the lower end of the uncertainty range for Business Case 5 is generally within the upper end of the uncertainty ranges for Business Cases 2, 3, and 4. This is largely attributable to the large uncertainties currently associated with this business case because of the flowsheet uncertainties discussed above.

4.7.4 Business Case 5 Advantages and Disadvantages

Hanford's high-pH, high-sodium wastes present challenges to thermal processes, such as calcining and steam reforming, because of the formation of tar-like mastic substances at elevated temperatures that tend to plug the treatment system. The SR vendor developed a method to process the highly caustic Hanford LAW by adding clay, which resulted in an aluminosilicate (mineral-like) waste form. This is a new technique that is not used commercially. The purpose of the supplemental technology evaluations was to identify cost-effective alternatives to a second LAW vitrification facility, and the process was not perceived to offer any substantive technical or cost advantages over WTP glass. Nonetheless, DOE continued to make limited investments in developing a mineralized waste form through tests at INL and the Hazen Laboratory, to further evaluate the technology.

Business Case 5 Advantages – The principal advantages of this business case are:

- SR is a mature commercial petrochemical technology.
- SR has low sulfur oxide (SO_X) and nitrogen oxide (NO_X) levels in the offgas due to reducing conditions during the reforming process.
- SR is used as an LLW treatment and immobilization technology for certain commercial low-level radioactive waste at production scales in Erwin, Tennessee.
- SR was selected by DOE to treat and immobilize SBW at INL.
- Some Idaho SBW engineering and analysis work could potentially be applied to Hanford LAW.

Business Case 5 Disadvantages – The principal disadvantages of this business case are:

- SR mineralized waste form required for Hanford LAW is not used in other commercial or DOE applications and has not been produced at production scales.
- While making the mineralized waste during small-scale DOE-funded testing, the vendor has frequently encountered processing issues (e.g., product accretions on nozzles, plugging, and pump breakdowns) that resulted in test run terminations. Although these would all appear to be issues that the vendor could resolve with time and funding, until that time these (and other perhaps undiscovered) issues result in significant flowsheet uncertainties.
- The SR mineralized product needed for Hanford LAW is a granular mineral; however, the SR process also creates a substantial volume of very small particles (fines) in quantities essentially equal to the volume of the granular product formed. Uncombusted carbon is also carried over into downstream systems. Information regarding how the fines will perform during disposal and/or how fines production and uncombusted carbon will be mitigated has not yet been developed.
- Cost and time required to reach technical readiness could be significant.

4.8 Business Case 6 – WTP LAW Vitrification and BV Deployed in the 200 West and 200 East Areas

This business case and Business Case 7 evaluate the potential benefits as well as the costs and disadvantages of starting LAW immobilization operations prior to the startup of the full WTP. Early LAW immobilization (2014 is assumed in this report) could potentially be achieved by either starting a supplemental LAW immobilization process early or by starting the LAW Facility early as is evaluated in Business Case 7.

4.8.1 Business Case 6 Description

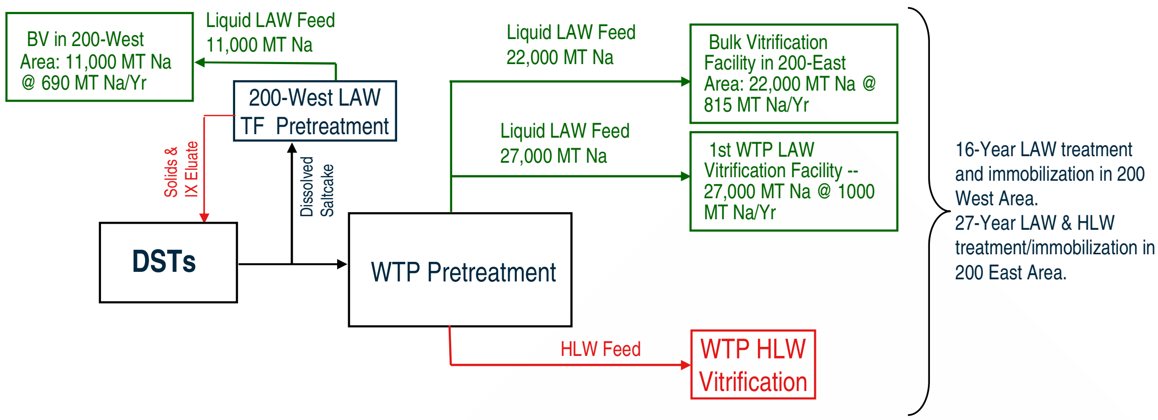
Business Case 6 is based on using the LAW Facility in combination with two multi-line BV facilities, one in the 200 East Area and one in the 200 West Area. The 200 West Area BV Facility is assumed to be a four-line BV facility (700 MT of sodium per year) sized to immobilize 11,000 MT of sodium[11] in 200 West over a 16-year period commencing in 2014. It would receive pretreated LAW feed from a tank farm-based pretreatment facility in the 200 West Area. There is uncertainty associated with DOE's ability to commence hot tank farm-based pretreatment operations by 2014. This uncertainty is primarily associated with the pretreatment system design. The early (2014) operation of the 200 West Area pretreatment and BV facilities (5 years sooner than the WTP startup) creates additional DST space prior to 2019 to support additional SST retrievals. The Department estimates that 5 to 10 additional SST retrievals could occur due to early 200 West Area LAW treatment immobilization.

Deploying tank farm-based LAW pretreatment and immobilization systems in 200 West provides DOE with the flexibility to commence retrieval and treatment of 200 West Area SSTs without heavy reliance on the 200 East Area DSTs which, due to space shortages, will have limited availably prior to the WTP operating and creating DST space, which could take several years. The supplemental pretreatment facility would deploy rotary microfiltration and cesium ion exchange to pretreat the LAW.

[11] There is approximately 23,000 MT of sodium in the 200 West Area tanks; however, approximately 12,000 MT of that sodium is needed to transfer the sludge wastes in the 200 West Area tanks to the DSTs in the 200 East Area, leaving 11,000 MT of sodium to be immobilized in the 200 West Area BV Facility.

In the 200 East Area, the LAW Vitrification Facility and a five-line BV facility are assumed to commence operations in 2019 in parallel with the WTP HLW and PT Facilities. The 200 East Area BV Facility could immobilize approximately 800 MT of sodium per year. The two BV facilities in combination with the LAW Facility would complete the LAW immobilization mission in 2046, the same time when the HLW immobilization mission will be completed.

Business Case 6 – WTP LAW Supplemented by Vitrification in 200-East and West Areas



4.8.2 Business Case 6 Technical Readiness

The TRA for Supplemental Treatment (DOE/ORP-2007-01) determined that the BV technology is in an advanced stage of technology development. Cold (non-radioactive) integrated BV demonstration testing with Hanford tank waste surrogates conducted in 2007 provide the basis to finalize the technology and support initial design of a full-scale facility. Only limited conceptual work has been performed to date on tank farm-based pretreatment at Hanford. Rotary microfiltration has undergone only limited testing to date on simulated tank waste. Extensive testing of the cesium ion exchange technology has been completed to support application to the WTP. However, a detailed assessment of the application of cesium removal technology in the Hanford tank farms cannot be completed until the design concept is developed in greater detail. Based on previous testing and operation of similar systems, DOE anticipates that tank farm-based pretreatment technologies can be readily developed and demonstrated. Costs could significantly increase during design development in response to site-specific requirements and safety considerations.

4.8.3 Business Case 6 Costs

The ETC costs to implement this business case are $16 to $9 billion less than for Cases 1A and 1B, respectively (in constant 2008 dollars) and approximately $2 billion less (~6% less comparing mean values) than the Business Case 1 ETC costs on a present value basis. Those cost differences are considered significant within the accuracy of this report's analyses.

Case 6 Costs ($B)			
Technology Development Cost (2008 Constant $)		**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
TF PT	$ 0.027	$25	$40
BV	$ 0.13		

Business Case 6 ETC costs are within the ETC cost uncertainty ranges for the other supplemental LAW treatment cases. The BV costs were developed on the same basis as those in Business Case 3. The Department derived the tank farm pretreatment costs for this business case from the preliminary design and cost information that was developed in support of DOE reaching Critical Decision-2 consistent with DOE O 413.3A for the Hanford tank farms. The Department has a higher level of confidence in the WTP and BV costs in this business case than for the costs associated with tank farm-based pretreatment. This is because the tank farm-based pretreatment costs are based on preliminary information that is not supported by detailed engineering designs, testing, and cost analysis.

Business Case 6 suffers a cost disadvantage relative to Business Case 3 (also BV). This is attributable to deploying BV in both the 200 East and West Areas, which increases capital, operating, and D&D costs in exchange for the flexibility required to effectively retrieve 200 West Area SSTs prior to, and for the first several years following, WTP startup when DST congestion constrains SST retrievals.

4.8.4 Business Case 6 Advantages and Disadvantages

Business Case 6, like Business Case 3, is built upon the WTP LAW Vitrification and BV technologies. In Business Case 6, however, BV operations are divided into 200 East and 200 West Area operations, the latter being supported by tank farm-based LAW pretreatment. Both splitting the BV operations and adding tank farm-based pretreatment modifies the advantages and disadvantages from those in Business Case 3 as discussed below.

Business Case 6 Advantages – The principal advantages of this business case are the same as for Business Case 3 plus:

- This case enables LAW immobilization to start in 2014, 5 years prior to the completion of WTP hot commissioning.
- Early BV operations are estimated to free up approximately 5 million additional gallons of DST space that could potentially enable DOE to complete approximately 5 to 10 additional SSTs retrievals prior to 2019.
- 200 West Area tank farm-based pretreatment enables BV immobilization operations in the 200 West Area to take place independent of WTP pretreatment operations.
- Early LAW immobilization reduces the supplemental LAW immobilization capacity needed.

Business Case 6 Disadvantages – The principal disadvantages of this business case are the same as Business Case 3 plus:

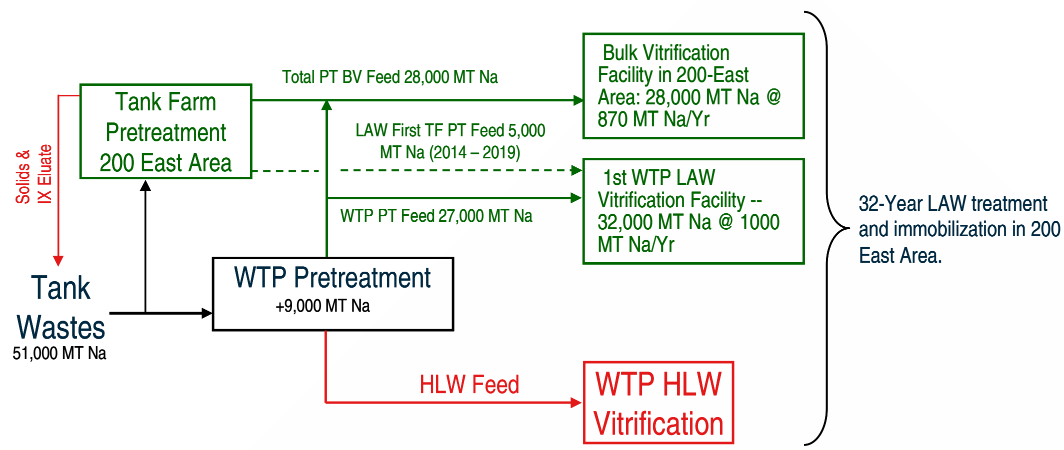
- This business case has higher costs as compared to Business Case 3 (approximately $0.8 billion higher than present value mean cost), which is attributable to (a) providing tank farm pretreatment in the 200 West Area, and (b) building, operating, and decommissioning BV facilities in both the 200 West Area and 200 East Area.
- DOE has not evaluated in detail the feasibility of designing, constructing, and commissioning both the 200 West Area tank farm-based pretreatment facility and the 200 West Area BV Facility by 2014.

4.9 Business Case 7 – Start WTP LAW Vitrification First and Bulk Vitrification in 200 East Area

4.9.1 Business Case 7 Description

This business case is similar to Business Case 3 relative to the basic immobilization technologies; WTP LAW Vitrification and BV in the 200 East Area. The difference in this case is that the LAW Facility and a five-line BV facility[12] in the 200 East Area both commence hot operations in 2014. The "early" start of the LAW Facility is referred to as "LAW First." LAW First is a concept that takes advantage of the currently advanced state of the LAW Facility relative to the WTP PT and HLW Vitrification Facilities; the design and construction of the latter two facilities suffered a two-year interruption due to seismic and technical issues. Those issues did not impact design and construction of the LAW Vitrification Facility, which potentially enables its earlier startup provided pretreated LAW feed that meets the facility's waste acceptance criteria can be provided. This necessitates the use of tank farm-based pretreatment (analogous to the use of that technology in Business Case 6) in order to provide pretreated LAW feed to the WTP LAW melters.

Business Case 7 – WTP LAW First Supplemented by Bulk Vitrification in 200-East Area



The use of LAW First would not prevent the need for supplemental LAW immobilization – LAW First will offset the need to treat LAW containing 5,000 MT of sodium by immobilizing that amount of LAW prior to WTP startup. The Department would still require sufficient supplemental LAW immobilization capability to immobilize approximately 28,000 MT of sodium (a 15% reduction).

LAW First requires that the LAW Facility, BOF, and LAB (LBL) start operations in 2014.

LAW First could also be implemented without an early BV start and or in combination with other supplemental LAW immobilization technologies. Information is provided in Section 4.9.5 isolating the benefits associated with starting LAW first from those associated with the overall business case.

Both the LAW Facility and the BV Facility are assumed to initially retrieve pretreated LAW from the tank farm-based LAW pretreatment facility. Once the WTP PT Facility comes on line, the WTP LAW Facility would receive pretreated LAW feed from that facility. The BV Facility could continue to receive pretreated wastes from the tank farm pretreatment facility or receive pretreated LAW from the WTP PT Facility. Retaining the tank farm-based pretreatment capability could enhance LAW immobilization total time on line; however, a cost trade study has not been conducted at this time to evaluate that approach. The tank farm-based pretreatment facility would deploy rotary microfiltration and cesium ion exchange to pretreat the LAW.

[12] This case uses a 5-line BV Facility rather than the 7-line BV Facility in Business Case 3. Fewer BV lines are required due to both the WTP LAW Vitrification Facility and the BV Facility commencing operations in 2014 – 5 years sooner than in Business Case 3.

If all WTP facilities were to commence operations in 2019 (baseline case), certain liquid secondary waste streams condensed from LAW melter offgas would be recycled to the WTP LAW Pretreatment evaporator where excess water would be removed and the concentrated wastes blended in with the LAW melter feed. This recycle approach enables the LAW melter glass to greatly increase the fraction of technetium-99 that is captured in the LAW glass. Without such recycle, the fraction of technetium-99 released to the Hanford Effluent Treatment Facility as secondary waste to be grouted would increase from 1% to approximately 63% of the technetium-99 in the melter feed. Because the WTP LAW Pretreatment evaporator would not be available for the first 5 years under the Start LAW First concept, DOE assumes that a temporary evaporator (or other techniques) may be required as a surrogate recycle technique to increase technetium-99 incorporation in the WTP LAW glass. Once the WTP PT Facility is operational, recycle would be provided by the LAW feed evaporator.

4.9.2 Business Case 7 Technical Readiness

The technical readiness for Business Case 7 is the same as the technical readiness of Business Cases 1 and 3 for the LAW Facility and BV, respectively, and Business Case 6 for tank farm-based pretreatment.

4.9.3 Business Case 7 Costs

The ETC costs to implement this business case are $16 to $9 billion less than those for Cases 1A and 1B, respectively (in constant 2008 dollars), and approximately $2 billion less (~6% less comparing mean values) than the Business Case 1 ETC costs on a present value basis. Those cost differences are considered significant within the accuracy of this report's analyses.

Case 7 Costs ($B)			
Technology Development Cost (2008 Constant $)		**ETC Mean Cost** (Present Value $)	**ETC Mean Cost** (2008 Constant $)
TF PT	$ 0.027	$25	$40
BV	$ 0.13		

Business Case 7 ETC costs are substantially below those for Cases 1A and 1B and within the ETC cost uncertainty ranges for the other supplemental LAW treatment cases. The BV costs were developed on the same basis as those in Business Case 3.

The Department derived costs for this business case from the design and cost information that were developed in support of DOE reaching Critical Decision-2 consistent with DOE O 413.3A for the Hanford tank farms. The Department has a higher level of confidence in the WTP and BV costs in this business case than for the costs associated with tank farm-based pretreatment. This is because the tank farm-based pretreatment costs are based on preliminary information that is not supported by detailed engineering designs, testing, and cost analysis. The Department assumed that BV would only be carried out in the 200 East Area in order to leverage the investment made in the tank farm-based pretreatment system developed to support LAW First and early BV immobilization.

4.9.4 Business Case 7 Advantages and Disadvantages

Business Case 7 is a relatively strong business case, which, like Business Case 6, is built upon the WTP LAW Vitrification (Case 1) and BV (Case 3) technologies. In Business Case 7, however, both the LAW Facility and the BV Facility commence LAW immobilization operations 5 years prior to full WTP startup, both being supported by tank farm-based LAW pretreatment. Note that the advantages and disadvantages in italics are unique to LAW First being included in this business case.

Business Case 7 Advantages – Advantages of this case are similar to those for Business Case 3 plus the following:

- Starts full-scale LAW immobilization 5 years prior to completing WTP PT and HLW hot commissioning, taking advantage of DOE's WTP investment 5 years sooner than the current baseline.
- Starting LAW First spreads out personnel hiring, training, and operations readiness review requirements. Those activities for the LAW Facility, BOF, and LAB would occur to support 2014 hot LAW vitrification operations. Those for the WTP PT and HLW Vitrification Facilities would occur to support starting hot operations for those two facilities in 2019.
- Trained LAW vitrification personnel from the LAW Facility would provide a trained resource for the 2019 hot startup of the WTP PT and HLW Vitrification Facilities.
- Locating the BV Facility in the 200 East Area requires only one tank farm-based pretreatment facility and enables the early start of both the LAW Facility and BV.
- The combination of LAW First and BV could free up approximately 9.5 million gallons of DST space prior to completing WTP hot commissioning.
- The 9.5 million gallons of DST space could enable approximately 13 to 19 additional SSTs retrievals prior to 2019.
- Tank farm-based pretreatment, if continued past the startup of the WTP PT Facility, could provide backup pretreatment capability during WTP PT Facility outages and increase the overall online availability of LAW immobilization (both BV and WTP LAW vitrification).
- If DOE is able to operate the WTP in a manner that could enable completion of HLW treatment and immobilization in 23 years rather than 27 years (as assumed in this study), early LAW immobilization approaches used in this business case would facilitate also completing LAW immobilization in a 23-year period.

Business Case 7 Disadvantages – The principal disadvantages of this business case are the same as Business Case 3 plus:

- Possible reduction in WTP construction efficiency due to co-located hot LAW operations on WTP construction site.
- LAW First requires modifications to WTP facilities, pipelines, etc. to enable starting up the LAW Facility first.
- May require developing and implementing an interim LAW melter offgas recycle capacity to increase technetium-99 retention in the LAW glass and reduce technetium-99 in secondary wastes discharged to the Effluent Treatment Facility.
- DOE has not evaluated the schedule for designing, constructing, and commissioning the tank farm-based pretreatment and BV facilities by 2014 in detail – additional programmatic risk.

4.9.5 LAW First Only

In addition to the LAW First specific advantages and disadvantages italicized above, LAW First's contribution to shared advantages is separated out below:

- LAW First by itself could free up approximately 4.7 million gallons (net) of DST space, which could potentially support the retrievals of 5 to 10 SSTs.

- Combining LAW First with another supplemental treatment approach would provide the advantages identified in this section and italicized in Section 4.9.4 – those advantages are not uniquely tied to its use with BV as described in Business Case 7. For example, if LAW First were to be combined into Business Case 2 (2nd LAW), the second LAW Facility could be equivalent to the first facility (no increase in throughput needed), the additional SST retrievals and early immobilization could still occur, and the cost increase to implement (based on the present value of the mean costs) would be approximately $0.3 billion.

4.10 Business Cases Summary

The seven preceding business cases provide insights into various approaches that DOE could use to complete the Hanford tank farm cleanup mission. While there are many more combinations of technologies and assumptions that DOE could roll into business cases, adequate information is provided in this report for readers to evaluate possibilities other than those presented. The Department's conclusions are unlikely to change for any reasonable assumption sets used. Table 2 summarizes the costs, advantages, and disadvantages associated with the seven business cases evaluated.

The Department makes the following observations based upon its analysis of the seven business cases:

1. ***Supplemental LAW immobilization is necessary to bring the Hanford tank farms cleanup mission to a timely conclusion.*** The overall Hanford tank waste cleanup mission has already experienced delays, most recently because of seismic and technical issues that impacted the cost and schedule of the WTP. Providing supplemental LAW immobilization reduces the time and cost required to complete that mission. The WTP LAW Vitrification Facility, operating alone, would require 60 years or more to complete immobilization of the Hanford tank waste LAW fraction. That is 33 years longer than the 27-year immobilization mission duration in Business Cases 2 through 7. Moreover, the ETC cost to include supplemental LAW immobilization, regardless of the technology approach evaluated in this report, is significantly less than the cost of immobilizing all LAW in the WTP (Cases 1A and 1B).

2. ***Cost is unlikely to be the primary driver for selecting which LAW immobilization approach should be used to supplement the LAW Facility.*** While the ETC costs do differentiate Cases 1A and 1B from Cases 2 through 7, ETC costs do not differentiate Cases 2 through 7 from each other. Aside from NEPA factors, major drivers appear likely to include:
   - Technical readiness for use with Hanford LAW
   - Supplemental immobilization approach compatibility with the overall Hanford tank farm and WTP flowsheets
   - Deployment/operational flexibility to address waste situations that arise as the mission unfolds
   - DOE's ability to implement an approach in a reasonable time frame that does not further delay the cleanup and closure of the Hanford tank farms

3. ***Potential opportunities exist to start treating and immobilizing LAW several years sooner than full WTP hot startup.*** These include tank farm-based pretreatment, starting the LAW Facility in advance of the WTP HLW pretreatment and immobilization facilities, and/or the early adoption and implementation of supplemental LAW immobilization. The early pretreatment and immobilization of LAW offers potential opportunities to retrieve more SSTs sooner and thereby reduce the risks inherent in continuing to store waste in aging SSTs. Retrieving SSTs sooner is worthwhile from risk, regulatory, and stakeholder perspectives; however, it is dependent on uncertain LAW First and/or early supplemental LAW immobilization schedules, both of which

are tied to uncertain tank farm-based pretreatment schedules. Starting LAW immobilization before the full WTP comes on line also reduces the supplemental LAW immobilization capacity needed (but does not eliminate the need for supplemental treatment). The Department will carefully consider those opportunities and act upon them if they are shown to be viable, effective in reducing mission risks, and safe and cost-effective to implement.

4. ***Technical readiness provides a meaningful discriminator between the supplemental LAW immobilization business case approaches.*** The Department must be able to demonstrate that technologies and components will actually work with the tank wastes considering the potential chemical and radioactive characteristics that may be encountered and the safety envelopes that must be worked within. Two supplemental immobilization approaches, 2nd LAW and BV, are substantially closer to being ready to supplement the WTP LAW Facility than either CS or SR. Both CS and SR require substantial development and testing before either could be ready for production-scale deployment with no certainty of success. The path to technical readiness for CS as a primary Hanford LAW waste form could be complex due to RCRA permitting issues (e.g., nitrates, organics, applicability of HLVIT RCRA standard to LAW) and *Atomic Energy Act of 1954* (AEA)-related issues such as the adequacy of technetium-99 retention in the waste form. Both the RCRA and AEA issues could result in additional LAW pretreatment needs that would add uncertainty, time, and expense to deploy this technology at production scales for Hanford LAW. It may be possible to apply CS to a subset of the Hanford LAW that is sufficiently low in long-lived mobile RCRA and AEA contaminants, thus not requiring additional pretreatment, in order to take advantage of its lower cost. Such LAW immobilization should be considered in conjunction with secondary waste immobilization in CS. The time frame and cost to conduct SR field-based pilot tests with actual wastes would be substantial; comparable to building the INL SBW Facility (approximately 1/10 scale of the Hanford LAW SR Facility).

Table 2. Business Case Evaluation Summary

Business Cases Summary			
Business Case Parameters/Costs		**Business Case Advantages**	**Business Case Disadvantages**
Business Case 1A	**WTP Only**	1. Based on technologies that are technically ready 2. High confidence in LAW glass performance 3. All capital cost already budgeted within WTP Project Baseline	1. Highest ETC cost 2. Highest SST leakage risk 3. Highest potential for DST replacements (>> DST design life) 4. Exceeds WTP 40-year design life resulting in potentially significant life extension needs
Waste Treatment Mission Complete	2079		
Business Case 1B	**WTP Only/New DSTs**	Same as Case 1A plus: 1. WTP Pretreatment and HLW Facilities complete mission in 2046 (27 years) – WTP life extensions for LAW facility only 2. Complete SST and original DST retrievals/closures on the same schedule as Cases 2 - 7	1. High ETC costs 2. May require construction of up to 31 new Hanford DSTs that must ultimately be closed 3. LAW Facility exceeds 40-year design life by 50% 4. WTP Pretreatment and HLW facilities not available after 2046 to mitigate pretreated LAW contamination risks
Waste Treatment Mission Complete	2079		
Business Case 1C	**WTP Only w/3rd melter**	Same as Case 1A plus: 1. Treatment mission can be completed within the WTP 40-year design life.	1. Long (40-year) WTP treatment and immobilization mission. 2. High ETC cost due to the extended period of tank farm and WTP operations. 3. High SST leakage risk – increased likelihood because of the potential for SST deterioration during the extended duration of SST waste storage. 4. Mission duration exceeds current DST design life, which increases the likelihood that some DST replacements may be required to contain untreated tank waste. The potential DST replacement costs are not explicitly included in the cost projections but are included in the operating cost uncertainty.
Waste Treatment Mission Complete	2059		

Table 2. (contd)

Business Cases Summary			
Business Case Parameters/Costs		**Business Case Advantages**	**Business Case Disadvantages**
Business Case 3A	**WTP 2 melter & BV 7-line**	1. Second most developed LAW technology 2. Technology used commercially for hazardous wastes 3. Batch processing increases flexibility, e.g., modular design amenable to scaling to address higher sodium immobilization requirements 4. DOE has conducted independent project assessments of the BV technology and is resolving identified issues; e.g., integrated dryer/melter test in 2007	1. Additional engineering and testing required to resolve some system issues such as the viability of the sintered filter to recycle technetium-99 in the offgas (DBVS planned to provide resolution)
Waste Treatment Mission Complete	2046		
Business Case 3B	**WTP 3 melter & BV 4-line**	Less technical and cost uncertainty than for CS and SR;DOE has invested in LAW Vitrification and BV development for LAW immobilization for many years. 1. WTP LAW pretreatment and immobilization processes used in the business case are undergoing extensive design, testing, and evaluation as part of the WTP Project 2. Confidence that the WTP LAW glass waste form will meet waste disposal requirements at the Hanford Site is the highest of any LAW form due to the extensive development, testing, and analysis 3. BV is the second highest level of technical readiness (WTP LAW is highest) 4. BV commercially used in other venues (e.g., commercial hazardous waste destruction) 5. Modular design concept of BV offers scaling flexibility at lower programmatic risk; i.e., DOE can sequentially add BV lines based on need 6. DOE conducted independent project assessments of the BV technology and is resolving identified issues; e.g., integrated dry/melter test in 2007	1. Including the cost of upgrading the WTP LAW Facility and support systems to accommodate a third melter may threaten the WTP Project authorized cost 2. Upgrading the WTP LAW Facility with a third melter may extend the 2014 completion schedule 3. Additional engineering and testing required to resolve some BV system issues such as the viability of the sintered filter to recycle technetium-99 in the offgas (DBVS planned to provide resolution)
Waste Treatment Mission Complete	2046		

Table 2. (contd)

Business Cases Summary			
Business Case Parameters/Costs		**Business Case Advantages**	**Business Case Disadvantages**
Business Case 4	**WTP & CS**	1. Simple process 2. Widely used for nuclear and hazardous wastes 3. Low-temperature process	1. Acceptability as a primary Hanford LAW waste form is questionable 2. May require additional pretreatment for technetium-99, nitrates, and organics 3. Possible RCRA issues 4. Highest immobilized waste volume
Waste Treatment Mission Complete	2046		
Business Case 5	**WTP & SR**	1. Technology used in industrial applications 2. Used to immobilize some commercial nuclear wastes 3. Selected by DOE for INL SBW 4. Some Idaho SBW engineering and analysis work could be applied to Hanford LAW 5. Low SO_X and NO_X emissions	1. Mineralized waste form required for Hanford not in use commercially or by DOE 2. Substantial development required to resolve flowsheet issues related to Hanford LAW; e.g., process interruptions, fine particle production, dispersion issues with granular product and fines 3. Cost and time required to reach technical readiness
Waste Treatment Mission Complete	2046		
Business Case 6	**WTP w/ BV 200 E & 200 W (2014)**	Same as Business Case 3 plus: 1. Starts LAW immobilization 5 years prior to completing WTP hot commissioning 2. Enables 5 - 10 additional SST retrievals prior to WTP hot operations; equivalent to ~5 million gallons 3. Enables LAW immobilization in 200 West Area to operate independent of the WTP 4. Early LAW immobilization reduces the supplemental LAW immobilization capacity needed	Same as Business Case 3 plus: 1. Programmatic risk to deploy 200 West Area PT and BV by 2014 2. Higher cost than Case 3 due to deployment in 200 West Area and 200 East Area (two smaller facilities are more expensive than one large facility)
Waste Treatment Mission Complete	2046		

Table 2. (contd)

Business Cases Summary			
Business Case Parameters/Costs		**Business Case Advantages**	**Business Case Disadvantages**
Business Case 7	**WTP with Bulk Vitrification 200 East (2014) and Start LAW 1st (2014)**	Same as Business Case 3 except no BV in 200 West Other advantages include: 1. One tank farm-based PT facility serves both LAW First and BV 2. Nearly double the equivalent DST space created in Business Case 6 (9.5 million gallons) 3. Enables up to 19 additional SST retrievals prior to WTP PT and HLW hot operations 4. Separates ORR reviews, employee hiring, and operator training from that required for the WTP PT and HLW 5. LAW personnel will provide trained resources for other WTP facilities 6. Backup treatment capability during WTP PT outages. 7. Flexibility to accommodate shorter HLW mission duration (e.g., 23-year duration) if achievable	Same as Business Case 3 plus: 1. Additional cost and programmatic risk to provide 200 East Area-based pretreatment and LAW immobilization by 2014 2. Possible reduced WTP construction efficiency due to nuclear operations within WTP site footprint 3. Requires modification to WTP and tank farm facilities/piping/ storage tanks to accommodate LAW First 4. Requires interim mitigation of secondary wastes containing technetium-99
Waste Treatment Mission Complete	2046		

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5.0 Conclusions and Integrated LAW Strategy

5.1 Conclusions

The Department maintains that the analyses in this report support the following conclusions with regard to its strategy to complete the immobilization of LAW at Hanford.

5.1.1 Supplemental LAW Immobilization Accelerates LAW Immobilization Mission Completion

As illustrated in Figure 6, supplemental LAW immobilization can dramatically accelerate the Hanford Site tank farms cleanup mission. Operating alone, the WTP LAW Vitrification Facility would require 60 years (until 2079) to complete the immobilization of Hanford LAW (Business Case 1). That is more than twice the mission duration in Business Cases 2 through 7. The Department is unaware of any reasonable rationale for extending the Hanford cleanup mission duration to that extent. Accordingly, DOE will continue to position itself to use supplemental LAW immobilization to complete the Hanford tank waste cleanup mission.

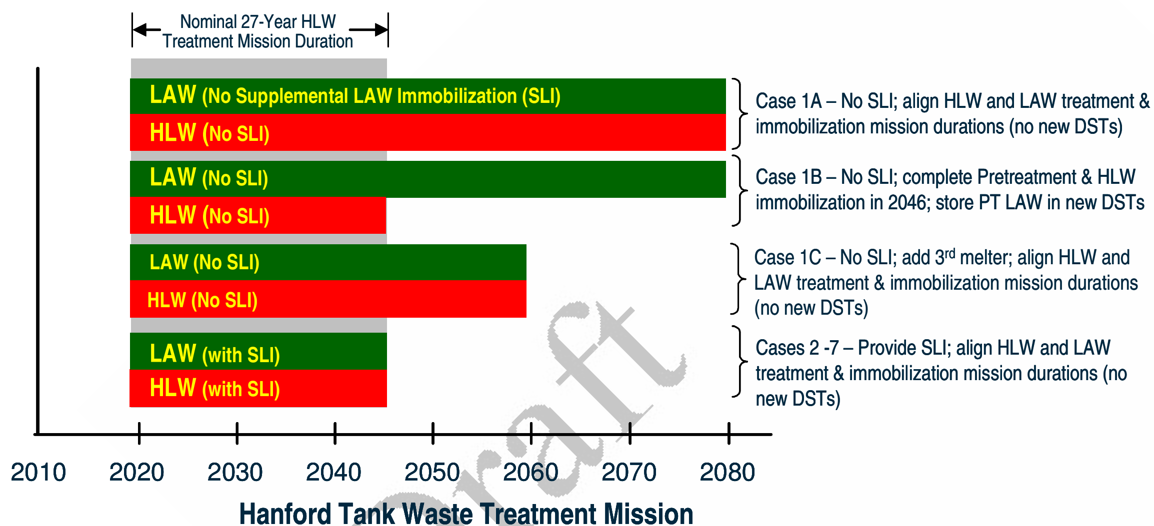

Figure 6. Supplemental LAW Immobilization Decreases LAW Mission Duration

The Department recognizes that estimates of the time required to complete HLW treatment (currently between 23 and 35 years following the start of full WTP hot operations) are uncertain. There are numerous factors that can influence where within (or outside) DOE's estimated HLW immobilization mission duration range HLW immobilization will actually be completed. Those factors include varying waste chemistry impacts on HLW pretreatment, average waste loading in HLW glass, and the actual average percentage of time that HLW pretreatment and vitrification operations are on-line. Regardless of at what point within DOE's mission duration estimates HLW pretreatment and immobilization are actually completed, supplemental LAW immobilization will play a critical role in completing the overall tank waste mission more rapidly.

5.1.2 Supplemental LAW Immobilization Enables More Rapid SST Retrievals

The WTP PT Facility is designed to supply pretreated LAW at approximately twice the rate that the WTP LAW Facility is able to immobilize LAW; i.e., if only the WTP LAW Facility is used to immobilize LAW the WTP PT Facility throughput rate could be constrained[13] to half of its design capacity. Adding supplemental LAW immobilization would enable the WTP PT Facility to operate at its design rate. This, in turn, would create additional space in existing Hanford DSTs twice as rapidly as would occur with the WTP LAW Facility operating alone. The additional DST space created by supplemental LAW immobilization would lead to SST retrievals being completed approximately 20 years following full WTP startup (e.g., 2039).

Completing SST retrievals is a significant Hanford regulatory and institutional driver due to the environmental risks attributed to storing wastes in SSTs. The Department has taken measures to mitigate SST leakage risks (e.g., interim stabilization, use of low hydraulic head retrieval techniques to reduce leakage driving source, and more accurate leakage detection systems); however, the risk of leakage will continue as long as wastes are stored in SSTs, increasing each time DOE adds water to retrieve SST wastes. Given the potential for SST integrity degradation over time, reducing the time required to complete all SST waste retrievals is a meaningful risk reduction approach.

5.1.3 Supplemental LAW Immobilization is Cost Effective

Providing supplemental LAW immobilization is less expensive than not providing supplemental immobilization. The ETC costs to include supplemental LAW immobilization in Business Cases 2 through 7 are significantly less than the cost to immobilize all LAW in the WTP as occurs in Business Cases 1A and 1B. Business Case 1C costs are within uncertainty ranges of Cases 2 through 7 but has a 13-year longer mission duration. The ETC costs for Cases 1A and 1B are substantially higher than the ETC costs for Case 2 through 7 because of the extended LAW immobilization mission duration as shown in Table 3[14].

[13] In Case 1B, new DSTs are assumed to be constructed to mitigate this constraint.

[14] The ETC costs do not include past (sunk) costs and, although based on the best available information, include significant uncertainties due to the conceptual nature of the business cases evaluated. The Department used Monte Carlo techniques to help quantify cost uncertainties and it used statistical methods to establish the cost means in both constant and present value dollars.

Table 3. Business Case ETC Cost Summary

Business Cases	Near-Term Development Costs (2008 Constant $ B)		ETC Mean Costs (Present Value $ B)	ETC Mean Cost (2008 Constant $ B)
1A – WTP LAW Only (HLW and LAW Vitrification end 2079)	0		27	56
1B – WTP LAW Only (New DSTs to enable 2046 HLW and PT completion)	0		27	49
1C – WTP LAW Only with third melter and upgrades to all three melters	0		26	45
2 – WTP LAW with 2nd LAW Vit Facility in 200 East Area	0		25	40
3A – WTP with BV in 200 East Area	0.13		25	39
3B – WTP with three LAW melters and BV in 200 East Area	0.13		25	39
4 – WTP with CS in 200 East Area	0.30		24	37
5 – WTP with SR in 200 East Area	0.36		26	41
6 – WTP LAW and BV in the 200 West and 200 East	TF* PT	0.027	25	40
	BV	0.13		
7 – WTP LAW First and BV in 200 East Area	TF PT	0.027	25	40
	BV	0.13		

*Tank Farms

Business Case 1B evaluated building additional DSTs to store pretreated LAW and thereby allow DOE to shut down WTP pretreatment and HLW vitrification operations by 2046, thirty-three years prior to the completion of LAW immobilization. That approach did not result in a significant cost decrease, however, based on the cost assumptions and analyses in this report. Only the use of supplemental LAW immobilization to complete the LAW immobilization mission in a substantially reduced time period (relative to Case 1) was effective in reducing the overall ETC costs and that cost reduction is statistically significant. Cases 2 through 7 cost $1 to 3 billion less in present value dollars (and $8 to 19 billion less in constant dollars) than Cases 1A or 1B.

5.1.4 ETC Costs Do Not Adequately Differentiate Between Supplemental LAW Technologies

Cost, at least within the levels of uncertainty in this report, does not appear likely to be a major factor for DOE to use in differentiating between Business Cases 2 through 7. The case-to-case cost differences between Cases 2 through 7 are relatively small and all have overlapping cost uncertainty regions due largely to the costs not being underpinned by detailed engineering designs and analyses. When viewed in the context of the overall ETC cost to complete each business case, the cost contribution due to supplemental LAW immobilization is relatively small, ranging from 5 to 13% of the total ETC cost. Figure 7 illustrates the relatively minor cost contribution to the total EAC costs from supplemental treatment as a function of the LAW immobilization technology in present value dollars.

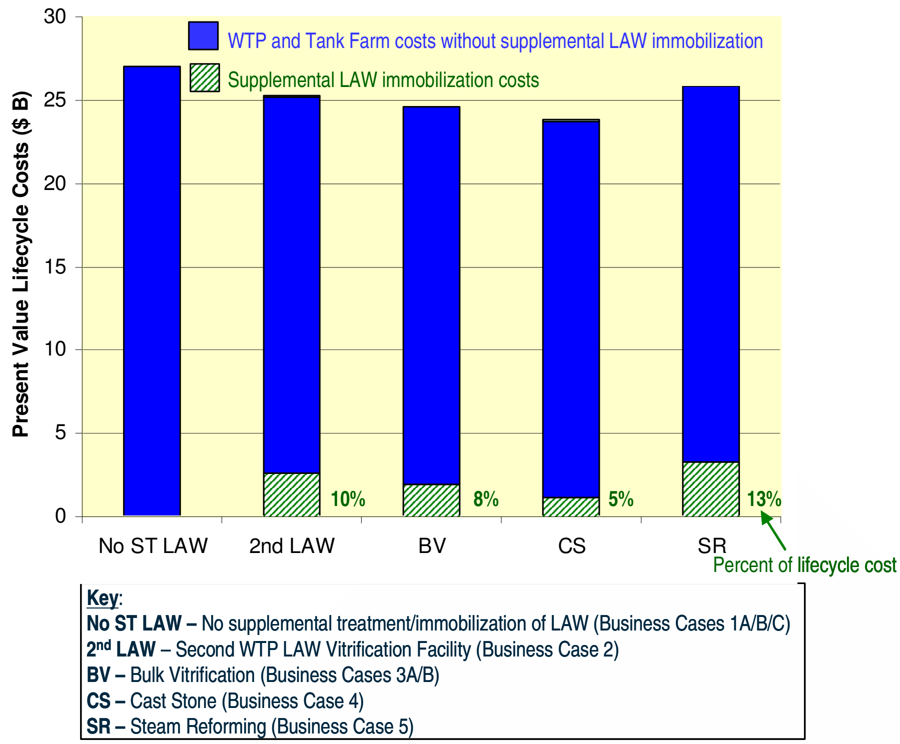

Figure 7. Supplement LAW Immobilization Costs

Figure 8 provides a similar illustration of the relative costs for business cases in constant dollars; refer to Appendix D, Figure D-1 for Business Cases 1C, 3A, and 3B. Figure 9 provides additional detail regarding the ETC costs to implement 2nd LAW, BV, CS, and SR technologies. The intent of the cost analysis behind Figure 9 was to have all immobilization technologies at equivalent levels of technical readiness (e.g., equivalent levels of engineering design and equivalent laboratory and pilot testing with actual tank wastes). That does not mean, however, that all of the immobilization technologies would provide similar levels of performance.

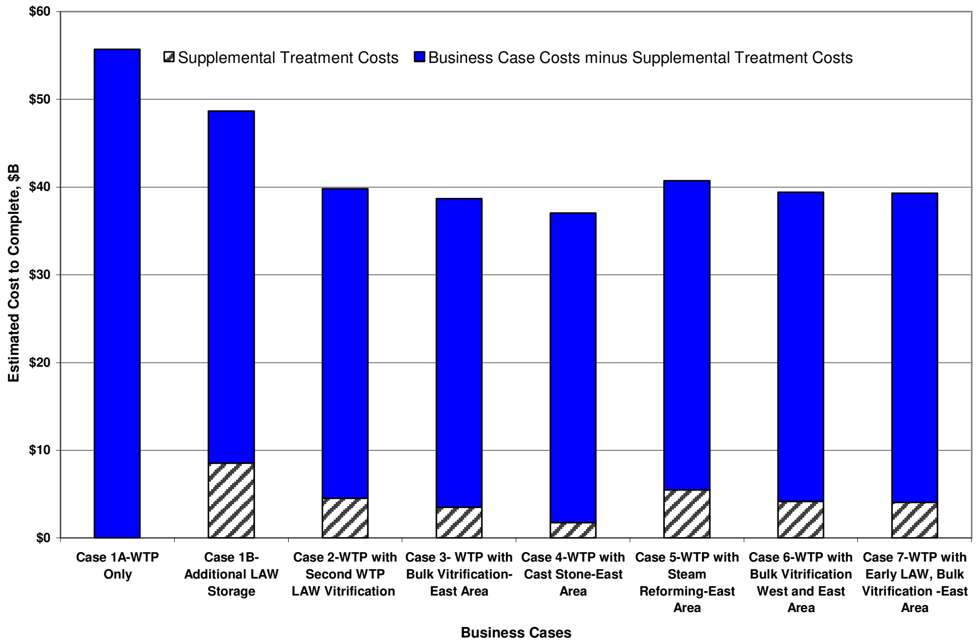

Figure 8. Estimate of Mean ETC Costs (2008 Constant Dollars)

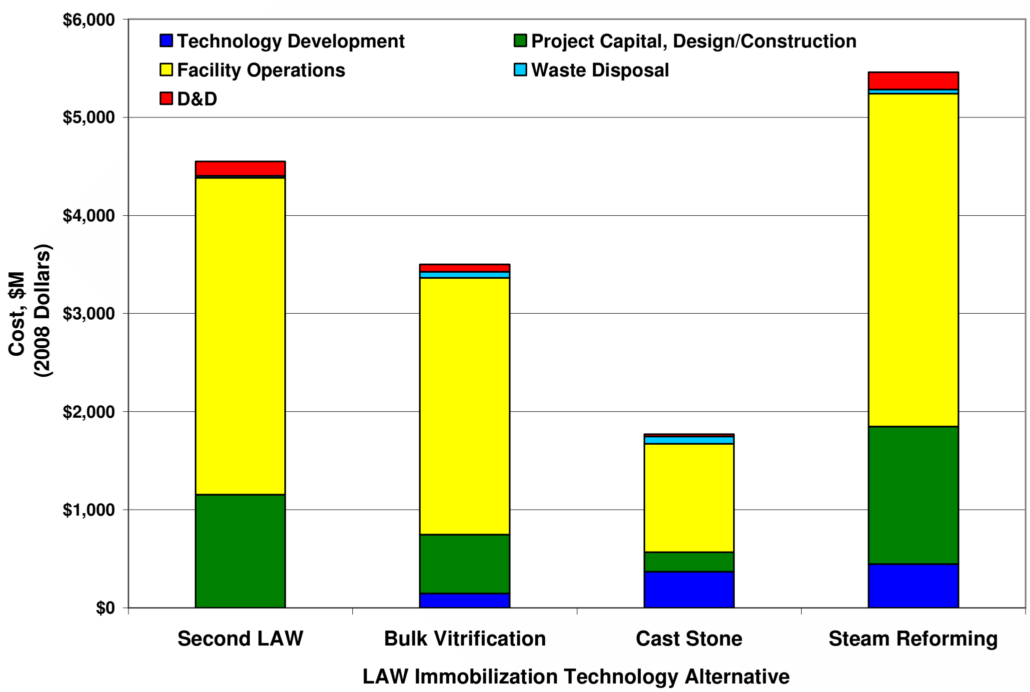

Figure 9. Comparison of Supplemental LAW Treatment Mean ETC Costs (2008 Constant Dollars)

The Department's confidence in glass waste forms is high based on analyses it has already performed for the WTP LAW glass and BV glass. The same is not true for CS and SR waste forms. For example, DOE does not know whether, in a Hanford geologic and hydrologic setting, CS will adequately immobilize the anticipated inventories of long-lived radioactive constituents it estimates will be contained in 50% or more of the Hanford LAW. Similarly, DOE anticipates potential RCRA permitting issues if it proposes to use CS to immobilize 50% of the LAW due to the current RCRA designation for Hanford tank wastes (listed and characteristic constituents). The process to obtain necessary DOE M 435.1-1 disposal authorization approval and State-issued RCRA permit approval required to use SR for 50% of the LAW has not been initiated and the issues are not known. The Department's basis for assuming a mineralized waste form produced by SR could provide sufficient immobilization capabilities is largely theoretical at this time. The SR mineralized waste form has had only limited testing and is not used commercially.

5.1.5 Technical Readiness Discriminates Between LAW Immobilization Approaches

The supplemental LAW technologies evaluated in this report are at differing levels of technical readiness relative to their possible use in pretreating and immobilizing Hanford LAW. Table 4 summarizes the TRLs DOE determined for the LAW technologies considered in this report. While all technologies identified are potentially viable for Hanford LAW immobilization, the near-term development cost and time required to bring CS and SR to readiness levels on par with either building a second WTP LAW facility or BV are noteworthy (see also Section 5.1.4). The Department does not anticipate that either CS or SR could be available for full-scale implementation in the same time frame as building a second WTP LAW facility or BV.

Table 4. Business Case Technology Readiness Level Summary

Business Case and SI* Approach	Critical Technology Elements(Systems)	TRLs
1 - WTP LAW Only	Container Sealing	5
	Decontamination	4
	LAW Melter Feed	6
	LAW Melter	6
	Melter Offgas and Vessel Vent Process	6
2 – 2nd WTP LAW	Same as Case 1	Same as Case 1
3 - BV	Feed Receipt, Feed Preparation, and Feeding	5
	In-Container Vitrification	5
	Offgas Treatment	4
4 - CS	Feed Receipt, Feed Preparation, and Feeding	3
	Mixing and Casting	3
5 - SR	Feed Receipt, Feed Preparation, and Feeding	4
	Thermal Reformer	5
	Offgas Treatment	4
	Container Handling and Waste Qualification	3
6 – BV East and West w/TF-based PT	BV	Same as Case 3
	Rotary Filtration**	3
	Cesium ion exchange (IX)**	3
7 – LAW First and BV w/ TF-based PT	Same as Cases 1 and 6**	Same as Cases 1 and 6

* SI – Supplemental Immobilization
** Tank farm-based pretreatment TRLs are provided in Cases 6 and 7 only

5.1.6 Early LAW Immobilization Offers Additional Potential Opportunities

This report identifies two basic approaches that it could use to start production-scale immobilization of LAW prior to the full WTP starting hot operations in 2019. The two approaches are Start LAW First[15] and/or start BV early. In addition to obtaining a head start in immobilizing the large mass of LAW requiring pretreatment and immobilization, early LAW immobilization would provide DOE with an opportunity to retrieve as many as 19 additional SSTs (beyond those already planned for retrieval) by 2019. The completion of SST retrievals is a significant Hanford Site regulatory and institutional driver due to the perceived risks associated with storing wastes in SSTs for several more decades. Therefore, the Department will consider opportunities to commence the treatment and immobilization of LAW several years sooner than the WTP will be ready to treat and immobilize HLW. Early LAW immobilization provides several mission benefits regardless of the technique used. The common benefits are:

- Starts the LAW immobilization process 5 years sooner than occurs in the current baseline based on the assumptions in this report. Given the fact that LAW constitutes 90% of the waste volume to be treated, moving forward is prudent in its own right. Early immobilization reduces the amount of supplemental LAW immobilization necessary (e.g., throughput requirements for the supplemental LAW treatment facility; it does not eliminate the need for supplemental LAW immobilization).
- Creates DST space to enable additional SST retrievals prior to WTP hot operations. For example, DOE estimated that Business Case 6 would result in 5 to 10 additional SST retrievals while Business Case 7 would result in approximately twice that number. Enabling additional SST retrievals over the next decade is an important factor.
- The state of Washington would likely support Early LAW Immobilization.

Starting LAW First (Business Case 7) offers additional benefits as listed below:

- The Department would obtain potentially valuable WTP operations information through early WTP LAW operations that could be factored into a second LAW vitrification facility design (if DOE selects that supplemental LAW immobilization approach).
- Starting LAW First spreads out personnel hiring, training, and operations readiness review (ORR) activities. Those activities for the LAW Facility, BOF, and LAB would occur 5 years sooner to support 2014 hot LAW vitrification operations than they will occur to support the WTP PT and HLW Vitrification Facilities. Accordingly, the lessons learned could be factored into the ORR and training for the PT and HLW Facilities.
- Trained LAW vitrification personnel from the LAW Facility would provide a trained resource for the 2019 hot startup of the WTP PT and HLW Vitrification Facilities. This is a win-win situation. Staff and managers trained on the WTP LAW, BOF, and LAB will have opportunities for promotions in WTP PT and HLW Facilities while management responsible for the operations of those facilities will be able to recruit from (and train new staff at) the operating facilities.

Only Business Cases 6 and 7 offer the potential to support a substantial number of additional SST retrievals prior to the full WTP starting up in 2019. Both cases require tank farm-based pretreatment that

[15] The Department combined Start LAW First with BV in Case 7 to provide two early LAW immobilization approaches working together. It could have combined Start LAW First with any of the other LAW immobilization approaches. If combined with building a second WTP LAW Facility, for example, the second WTP LAW Facility would not have been operational by 2014.

includes solids/liquids separations and cesium removal[16]. The Department faces uncertainties, however, with being able to deploy a tank farm-based pretreatment system by 2014 and with bringing an early LAW immobilization system on line by 2014. The Department would, therefore, need to make a determination of mission need relative to the deployment of a tank farm-based LAW pretreatment system for Business Cases 6 or 7 in the near future to allow time to develop this capability.

5.1.7 Tank Farm-Based Pretreatment Required for Early LAW Immobilization and Deployment Options

Tank farm-based pretreatment is required for LAW First and early BV. SST waste retrievals are currently constrained by the availability of DST space to receive the retrieved wastes. LAW pretreatment in the Hanford Site tank farms could potentially enable LAW to be immobilized prior to the full WTP commencing operations in 2019. Tank farm-based pretreatment, if used in conjunction with early supplemental LAW immobilization (e.g., Business Case 6 – BV in 200 West Area) or LAW First (Business Case 7) could enable additional SST retrievals to occur between 2014 and 2019. If the tank farm-based pretreatment was continued beyond WTP PT Facility startup, it could provide pretreatment redundancy that could allow LAW immobilization to continue independent of the WTP and/or enable WTP LAW immobilization to occur during WTP PT outages.

5.1.8 Non-Cost Factors Differentiate Supplemental LAW Immobilization Approaches

As discussed in the preceding sections, a number of non-cost factors differentiate the LAW immobilization approaches under DOE consideration. Table 5 summarizes those and other important factors that are useful in comparing the supplemental LAW immobilization technologies.

As previously discussed, both 2nd LAW and BV are currently more technically ready to deploy for Hanford LAW than either CS or SR. The Department has extensively evaluated 2nd LAW and BV and invested in their maturation for Hanford LAW. As a result, LAW First and BV can support early LAW immobilization (e.g., 2014 start).

Table 5. LAW Immobilization Approach Comparison Based on Non-Monetary Factors

Factor*	2nd LAW	BV	CS	SR
Current state of technology for application to Hanford LAW	H	H	L	M-H
Supports early LAW immobilization/accelerates SST retrievals	M	M	L	L
Operational Flexibility	M-H	H	L	L
Retention of long-lived mobile contaminants	H	H	L-M	M-H
Status of RCRA-related permitting issue resolution	H	H	L	L-M
Likely acceptance of technology by state of Washington	H	M-H**	L	L

KEY: **H**- High/Favorable **M**- Medium/Moderately Favorable **L**- Low/Unfavorable
*Each immobilization approach is ranked on its ability to accommodate or satisfy the non-monetary factor.
**If it can be shown to be as good as WTP LAW glass in a disposal site performance assessment.

Bulk vitrification offers the flexibility both with regard to its modular design (e.g., flexibility to easily add or remove treatment lines to adapt to changes in the amount of sodium to be treated, changes in HLW throughput rate, ease of deployment in 200 West Area to reduce early DST congestion).

[16] The DBVS differs from this case in that selective dissolution rather than cesium ion exchange can be used for cesium-137 pretreatment. There are insufficient tanks with suitably low cesium concentrations to support the use of selective dissolution at full production levels for an extended period of time. Business Cases 6 and 7, therefore, require cesium ion exchange, which is a more complex process than selective dissolution to deploy for Hanford LAW pretreatment. Both DBVS and production-level BV also require solids/liquids separations.

Cast stone and SR both face more significant permitting issues than a second LAW facility or BV. Both vitrification technologies are considered to be BDAT for RCRA purposes.

5.2 Integrated LAW Treatment and Immobilization Strategy

The Department developed and will refine from time-to-time its Hanford LAW strategy based upon updated information and Hanford LAW immobilization-mission optimization analyses in order to determinate the best value to the government. It will continue to analyze tank farm and WTP information using systems analyses techniques that consider the range of uncertainties associated with key evaluation parameters and integrate tank farm and WTP information bases. Its objective is to further improve the integration of detailed tank farm data into WTP design and operations planning in order to minimize the likelihood of significant disconnects.

The Department's strategy considers the range of information, constraints, requirements, and commitments that govern DOE's proposed LAW treatment, immobilization, and disposal operations. These include, for example, conformance with DOE Orders, compatibility with DOE's assessments conducted pursuant to the NEPA process and resultant records of decision, DOE's commitments and requirements pursuant to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement), and factoring in new information obtained from DOE's ongoing investigations.

Key elements in DOE's integrated strategy for completing the Hanford Site tank waste LAW treatment and immobilization mission are as follows:

1. ***Complete the treatment, immobilization, and disposal of LAW in a timely and cost effective manner.*** The Department will take reasonable and prudent steps to complete the Hanford WTP PT, HLW, and LAW pretreatment and immobilization missions to within the lower to mid range of its current Hanford tank waste treatment and immobilization mission duration estimates; i.e., within 23 to 35 years following the start of full WTP hot operations in 2019. The Department will identify and test supplemental LAW immobilization technologies and approaches with the objective of increasing the overall robustness of its LAW treatment and immobilization capabilities and its operational flexibility.

Planned Near-Term Path Forward:

- ***Include Supplemental LAW Immobilization in the RPP mission completion strategy.*** The use of one or more supplemental LAW immobilization technologies to align the HLW and LAW treatment and immobilization mission durations will bring the tank waste immobilization mission to a more timely and cost-effective end than relying solely on the LAW Facility.
- ***Complete DBVS.*** The Department has shown BV to be one of two leading candidates for supplementing the LAW Facility to complete the Hanford tank waste cleanup mission. Completing the DBVS Project will resolve any remaining technology issues and would provide DOE with the flexibility to use either LAW vitrification approach in its cleanup mission.
- ***Evaluate potential WTP LAW enhancements.*** The Department continues to maintain the capability to install a third LAW melter and will continue to evaluate potential enhancements to increase the WTP LAW Facility net throughput capacity, including installing a third melter. Lessons learned in the design and construction of the current facility, improvements in melter design and glass-melting performance resulting from ongoing development, and better understanding of mission needs could lead to a higher capacity second LAW vitrification facility at an equivalent or lower cost.

2. ***Include enhancements to the Hanford LAW treatment and immobilization strategy that are viable, financially responsible, and beneficial to the Hanford Site tank waste cleanup mission.*** The Department's objectives are focused on reducing tank farm-based risks (e.g., immobilizing LAW sooner, accelerating SST retrievals, treating secondary wastes) and increasing its operational flexibility.

Planned Near-Term Path Forward:

- ***Conduct detailed planning for WTP LAW First Strategy.*** Starting the LAW Vitrification Facility prior to the HLW PT and HLW Vitrification Facilities has the potential to enable additional SST retrievals, provide early insights into WTP LAW immobilization and tank farm waste delivery operations, and allow DOE to conduct its WTP personnel hiring and training for hot operations for LAW 5 years ahead of the WTP PT and HLW Facilities. The Start LAW First concept does not preclude the use of any supplemental LAW immobilization technology. The Department will address the remaining technical, regulatory, and fiscal uncertainties associated with deploying the WTP LAW Facility in 2014.
- ***Evaluate deployment of LAW treatment and immobilization in the 200 West Area.*** DST storage and transfer constraints in the 200 East Area that are envisioned to persist for several years following the full WTP commencing hot operations have the potential to constrain DOE's ability to retrieve and treat wastes in the 200 West Area. By providing LAW pretreatment and immobilization in the 200 West Area, DOE would have an enhanced ability to retrieve and treat wastes from the 200 Area SSTs, thereby, more rapidly reducing environmental risks associated with those tanks.
- ***Proceed with DOE O 413.3A critical decision process for tank farm-base pretreatment.*** Tank farm-based LAW pretreatment is necessary if LAW is to be immobilized by LAW First or BV prior to the startup of the full WTP as well as to enable LAW immobilization in the Hanford 200 West Area. Engineering designs, analyses, and flowsheets are necessary to more fully understand the costs, risks, and benefits associated with tank farm-based LAW pretreatment. The Department will address the technical, regulatory, and fiscal uncertainties regarding its ability to deploy tank farm-based pretreatment in 2014 and proceed toward a determination of mission need pursuant to DOE O 413.3A, *Program and Project Management for the Acquisition of Capital Assets*.
- Determine criteria and options to treat secondary liquid waste created during WTP and supplemental LAW pretreatment and immobilization operations. The secondary liquid waste generated by the LAW immobilization facilities must be treated prior to disposal in the State-approved liquid disposal site. The fraction of the liquid waste that contains the bulk of the radionuclides will be solidified and disposed of on site as low-level mixed waste. The Department must establish disposal site waste acceptance criteria for the solidified secondary liquid waste and must determine the approaches it will use to treat and solidify that waste.

3. ***Periodically evaluate and update the Hanford LAW pretreatment and immobilization strategy and associated implementation measures.*** The Department's LAW pretreatment and immobilization strategy will continue to develop as information becomes available from planned tests (e.g., DBVS, tank farm-based pretreatment, additional LAW First analyses), ongoing System Plan updates, and TC & WM EIS activities. This information will assist DOE in finalizing its integrated Hanford LAW treatment and immobilization strategy.

Planned Near-Term Path Forward:

- ***Complete River Protection Project System Plan updates.*** The System Plan provides a means to assemble and evaluate information obtained from tank farm operations and testing along with information obtained from WTP design and testing. The WTP Contractor typically evaluates WTP performance in strict accordance with contract requirements. This practice, while contractually correct, tends to underestimate certain aspects of the WTP performance, inadequately address factors/risks that could influence WTP performance beyond WTP hot commissioning, and be less current with information developed during its ongoing testing and evaluations. The System Plan provides the means for evaluating lifecycle performance with more flexibility than is inherent in WTP contract-related analyses.
- ***Complete the TC & WM EIS and Record of Decision.*** The TC & WM EIS and Record of Decision are needed for a number of Hanford tank farm cleanup initiatives including the selection of a supplemental LAW immobilization technology, LAW First, and tank farm-based pretreatment. Accordingly, DOE will proceed with due care towards the timely completion of those documents.

6.0 References

71 FR 5655, "Notice of Intent To Prepare the Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, WA," *Federal Register*, February 2, 2006.

24590-WTP-RPT-RT-06-001, 2006, *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644*, Bechtel National, Inc., Richland, Washington.

DoD 2004, *Acquisition System Guidebook*, DODI 5000.2, U.S. Department of Defense, November 17, 2004.

DOE O 413.3A, 2006, *Program and Project Management for the Acquisition of Capital Assets*, U.S. Department of Energy, Washington, D.C.

DOE/ORP-2007-01, October 2007, *Technology Readiness Assessment for the Supplemental Treatment Program*, U.S. Department of Energy, Office of River Protection, Richland, Washington.

DOE/EIS-0356, *Environmental Impact Statement for the Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland, WA*, Notice of Intent at 71 FR 5655, February 2, 2006.

GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Can Improve Weapon System Outcomes*, U.S. Government Accountability Office, July 1999.

GAO-07-762, *NUCLEAR WASTE: DOE Should Reassess Whether the Bulk Vitrification Demonstration Project At Its Hanford Site Is Still Needed to Treat Radioactive Waste*, U.S. Government Accountability Office, June 2007.

National Environmental Policy Act of 1969, 42 U.S.C. 4321-4347, as amended.

Nolte, William L., et al., *Technology Readiness Level Calculator, Air Force Research Laboratory*, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003.

Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq., as amended.

RPP-16215, 2003, *Production Bulk Vitrification System, Pre-conceptual Engineering Report*, AMEC Earth & Environmental, Inc., DMJMH+N, and RWE NUKEM Corp, Richland, Washington.

RPP-31804-VA, 2006, *SpinTek Rotary Microfilter Testing Status*, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-RPT-26689, 2003, *Containerized Cast Stone Facility Pre-Conceptual Design Report*, Fluor Federal Services, Richland, Washington, August 2003.

Thor 2006, *Steam Reforming Application for Treatment of DOE Sodium Bearing Tank Wastes at Idaho National Laboratory for Idaho Cleanup Project*, J. B. Mason et al., Waste Management Conference, Thor Treatment Technologies LLC, pg. 1.

WSRC-STI-2006-00073, 2006, *Testing And Evaluation of the Modified Design of the 25 Disk Rotary Microfilter*, D. T. Herman, M. R. Poirier, and S. D. Fink, Savannah River National Laboratory, Aiken, South Carolina.

Appendix A. List of Ongoing Technology Development in Support of the RPP Mission

Technology	Description	Developer	When
Melter Enhancements	Identification of design improvements and advanced glass formulations for RPP wastes and WTP joule melters	CUA Vitreous State Labs and PNNL	Continue FY08 and beyond as funded
Ultrafiltration	Construction and test of WTP PT Facility ultrafilter system/operation	WTP/BNI	FY08/09
Pulse Jet Mixers	Test of mixing for Newtonian slurries	WTP/BNI	FY08
Pipe Plugging	Develop DOE Slurry Manual with preferred characterization and transport methods	ORP/SRS	FY08
Caustic/Oxidative Leaching Studies	Bench scale testing on leaching	Tulane University	FY08
Rotary Microfiltration	Test of rotary microfilter with HA simulant.	SRNL	FY08
Fractional Crystallization	Pilot scale system being constructed 1/5 scale for test	SRNL	FY08/09
Small Column Ion Exchange (SCIX)	Report test of a modular SCIX with resorcinol formaldehyde (RF) resin	ORNL	FY08
Electro-Chemical Sodium Separation	Full scale tests of ceramic membrane	Ceramatec	FY08
Steam Reforming (SR)	Test of SR process/product with RPP simulant	THOR Treatment Technologies	FY08/09
Bulk Vitrification	Construction and test of prototypic pilot (full-scale) system for test with actual RPP waste (DBVS)	CHG/AMEC	FY09 to FY13
Near-Tank Cesium Removal	Test of Near-Tank Cesium Removal process for application at Hanford	Parsons	FY08/09
Near-Tank Sludge Leaching	Test of Near-Tank Sludge Leaching process for application at Hanford	Parsons	FY08/09
Cold Crucible Induction Melter (CCIM)	Demonstration of CCIM to address the flowsheet for SRS Tank Waste Vitrification and retrofit of CCIM in DWPF hot cell, replacing the current joule-heated induction melter	AREVA	FY08/09
Secondary Waste Disposal Requirements	Expert panel define a path for identifying waste performance criteria for immobilized secondary waste	CRESP	FY08 +
Site Waste Retrieval Support	Optimize retrieval processes for specific wastes, demonstrate fluidic pipe unblocking, etc.	FIU, NVE, ICET	FY08+

Acronyms:

AMEC	AMEC Earth and Environmental, Inc.
CHG	CH2M HILL Hanford Group, Inc.
CRESP	Consortium for Risk Assessment with Stakeholder Participation
CUA	Catholic University of America
DBVS	Demonstration Bulk Vitrification System
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility
FIU	Florida International University
ICET	Institute for Clean Energy Technology at Mississippi State University
NVE	NuVision Engineering, Inc.
PNNL	Pacific Northwest National Laboratory
PT	Pretreatment [Facility]
RPP	River Protection Project
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
WTP	Waste Treatment and Immobilization Plant

Appendix B. Technology Readiness Assessment Results

B.1 Description of Technology Readiness Assessment

In 1999, the U.S. General Accounting Office (GAO) produced a report (GAO/NSIAD-99-162) that examined the differences in technology transition between the U.S. Department of Defense (DoD) and private industry. The GAO concluded that the DoD took greater risks and attempted to transition emerging technologies at lesser degrees of readiness compared to private industry and that the use of immature technology increased the overall program risk and led to substantial cost and schedule overruns. The GAO recommended that the DoD adopt the use of National Aeronautics and Space Administration's (NASA) Technology Readiness Levels (TRL) as a means of assessing technology readiness before design transition. In 2001, the DoD Deputy Undersecretary for Science and Technology issued a memorandum that endorsed the use of the Technology Readiness Assessment (TRA) process to develop TRLs for new major programs. Guidance for assessing technology readiness was incorporated into the *Defense Acquisition Guidebook* (DoD 2004), which defines a TRA as follows:

> "A TRA is a systematic, metric-based process and accompanying report that assesses the readiness of certain technologies [called Critical Technology Elements (CTEs)] used in systems."

The TRA process consists of three parts: (1) identifying critical technology elements (CTE), (2) assessing the TRL of each CTE using an established readiness scale, and (3) preparing the TRA report. The CTE identification process involves breaking the project under evaluation into its component systems and subsystems and determining which of these are essential to project success, and either represent new technologies, are combinations of existing technologies in new or novel ways, or will be used in a new environment. If some of the CTEs are judged to be below the desired level of readiness, the TRA is followed by development of a technology maturation plan that identifies the additional development required to attain the desired level of readiness.

The U.S. Department of Energy (DOE) is conducting a pilot program that includes this study to evaluate the use of TRAs in its projects. The TRA process is being adapted for use by DOE from applications by other agencies (e.g., DOE, NASA). Notably, the TRA process is being adapted from use in product development applications to nuclear-chemical engineering process development applications for U.S. Department of Energy, Office of Environmental Management (EM). Use of the TRA process for evaluating LAW alternative technologies represents the first TRA application by EM and therefore is a pilot study that will serve as a basis for subsequent revisions to the use of the TRA process by DOE. The purpose of the TRAs conducted in support of this report was to determine the readiness level of the technologies as applied to the treatment of Hanford Site tank LAW.

The TRL scale used for the Hanford Site TRAs is shown in Table B.1. The DoD policy requires that testing of a prototypical design in a relevant environment be completed before incorporation of the technology into the final design of the facility. Thus, for DoD, a TRL 6 must be achieved prior to proceeding to Milestone B, which is the entrance point for the initiation of a system acquisition program.

The testing requirements used for the Hanford Site TRAs are compared to the TRLs in TableA.2. These definitions provide a convenient means to display the relationship between the scale of testing, fidelity of testing system, testing environment, and the TRL. The goal is to achieve a TRL 6 prior to incorporation of the technology into the final design. In order to attain a TRL 6, testing must be completed at an engineering or pilot scale, with testing of the system fidelity that is similar to the actual application and with a range of simulated waste and/or limited range of actual waste, if applicable.

The Department's (DOE) assessment of the TRLs was aided by a TRL Calculator that was originally developed by the U.S. Air Force (Nolte et al. 2003) and modified by the DOE Assessment Team. This tool is a standard set of questions addressing hardware, software program, and manufacturability questions and is implemented in Microsoft Excel™. The set of questions provide the criteria used to assess and determine the TRL numerical value. The TRL Calculator produces a graphical display of the TRLs achieved and was used by the Assessment Team in establishing TRLs.

Table B.1. Technology Readiness Levels Used in this Assessment

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	The technology is in its final form and operated under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties.

Table B.2. Relationship of Testing Requirements to the TRL

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Laboratory	Similar	Relevant
4	Laboratory	Pieces	Simulated
3	Laboratory	Pieces	Simulated
2	Paper	Paper	Paper
1	Paper	Paper	Paper

1. Full Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot Scale < Full Scale (Typical)
   Lab Scale < 1/10 Full Scale (Typical)
2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)
3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

B.2 Summary of LAW Treatment TRA Results

The TRA conducted to support this report were performed by DOE following the process described above. Results from the two TRAs identified below were utilized to support the business case study presented in this report. Table B.3 provides a summary of the TRLs related to each business case.

Table B.3. Business Case Technology Readiness Level Summary

Business Case and SI[*] Approach	Critical Technology Elements(Systems)	TRLs
1 - WTP LAW Only	Container Sealing	5
	Decontamination	4
	LAW Melter Feed	6
	LAW Melter	6
	Melter Offgas and Vessel Vent Process	6
2 – 2nd WTP LAW	Same as Case 1	Same as Case 1
3 - BV	Feed Receipt, Feed Preparation, and Feeding	5
	In-Container Vitrification	5
	Offgas Treatment	4
4 - CS	Feed Receipt, Feed Preparation, and Feeding	3
	Mixing and Casting	3
5 - SR	Feed Receipt, Feed Preparation, and Feeding	4
	Thermal Reformer	5
	Offgas Treatment	4
	Container Handling and Waste Qualification	3
6 – BV East and West w/TF PT	BV	Same as Case 3
	Rotary Filtration	3
	Cesium ion exchange	3
7 – LAW First and BV w/TF PT	Same as Cases 1 & 6	Same as Cases 1 & 6

*SI – Supplemental Immobilization. In Business Cases 6 and 7, tank farm-based pretreatment TRLs are also provided.

Table B.4 provides a summary of the Waste Treatment and Immobilization Plant (WTP) Low-Activity Waste (LAW) results from 07-DESIGN-042, *Technology Readiness Assessment for the Waste Treatment Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification.*

Table B.5 provides a summary of the supplemental treatment and immobilization results from DOE/ORP-2007-01, *Technology Readiness Assessment for the Supplemental Treatment Program.*

Table B.4. Technology Readiness Level Summary WTP LAW Critical Technology Elements

Critical Technology Element/Description	Technology Readiness Level	Rationale
ILAW Container Finishing Handling System (LFH) Container Sealing Subsystem The ILAW container sealing subsystem press fits and locks a flat circular lid into a circular groove in the container neck.	**5**	The container sealing system design is based on existing technologies but has not been demonstrated as an integrated prototypical system in an operating environment.
LFH Decontamination Subsystem The LFH decontamination subsystem sprays carbon dioxide (CO_2) pellets at immobilized low-activity waste (ILAW) container surfaces to remove radioactive contamination. The sublimed CO_2 and dislodged contamination are contained by a vacuum system and shroud.	**4**	The ILAW container decontamination design is based on existing technology concepts, but has not been demonstrated as an integrated, prototypical system in a relevant environment. Testing on a laboratory scale of the CO_2 spray to decontaminate flat-metal specimens has been completed; testing did not demonstrate the WTP Project's requirement on surface decontamination levels. Integrated testing of the robot, CO_2 spray, and shrouding system has not been carried out on the complex surfaces of the ILAW container.
LAW Melter Feed Process System (LFP) The LFP mixes LAW Facility waste and glass formers to provide feed for the LAW melters.	**6**	There has been extensive WTP and vendor testing to demonstrate the adequacy of the mixing systems.
LAW Melter System (LMP) The LMP is the LAW melter system that melts mixtures of LAW and glass formers.	**6**	The LAW melter has a significant development basis in previous DOE projects and developmental tests for the WTP. However, risk remains with the availability of MA758, a high chromium (Cr) alloy used for the LAW bubbler assembly. An alternate bubbler material of construction should be identified.
LOP/LVP The LOP/LVP is the LAW Melter Offgas and Vessel Vent Process Systems that remove aerosols, gases, and particulates generated by the LAW melters and vessel vent streams.	**6**	The LOP/LVP have a significant technology basis. Two of 12 maximum achievable control technology (MACT) destruction and removal efficiency (DRE) tests for naphthalene conducted on a prototypical system did not attain the required destruction efficiency. Engineering analysis shows that the WTP system should attain MACT standards based on higher capacities of the plant unit operations as compared to the pilot plant unit operations.

Table B.5. Technology Readiness Level Summary for Supplemental Pretreatment and Immobilization Critical Technology Elements

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology to a TRL of 6
Supplement Pretreatment Technologies			
Rotary Microfiltration The function of the rotary microfiltration technology is to remove insoluble solids from the LAW tank waste feeds. This technology is a precursor to selective dissolution, cesium ion exchange, and fractional crystallization technologies for cesium removal.	**3**	The rotary microfiltration technology was determined to be TRL 3 because no specific testing has been completed to support the proposed application at the Hanford Site to remove solids from the LAW waste feeds. The technology concept has not been developed beyond basic concept sketches, and documentation supporting the development of the technology has not been prepared (e.g., project planning documentation, research and technology plan, exit criteria for science and technology development). The rotary microfiltration technology is commercially available, has had significant testing and development by the Savannah River National Laboratory, and has been operated at full scale with simulants for potential application at SRS. The technology could be rapidly matured to support design implementation.	Major activities to develop the rotary microfiltration technology include the following: • Develop the design application concept and functional requirements for the rotary microfilter to provide a basis for definition of the technology development and testing requirements. • Complete prototypical testing with simulants and radioactive waste at the appropriate scale to support full-scale design implementation. Testing scale is envisioned to be full scale for nonradioactive testing and engineering scale for radioactive testing. • Document the relationships critical to filter performance that show how the filters behave in the LAW application and which bound the performance.
Cross-Flow Filtration System The function of the cross-flow filtration technology is to remove insoluble solids from the LAW tank waste feeds. This technology is a precursor to the selective dissolution, cesium ion exchange, and fractional crystallization technologies for cesium removal.	**3**	The cross-flow filter technology was determined to be TRL 3 because the technology concept has not been developed beyond simple concept sketches, and documentation supporting the development of the technology has not been prepared (e.g., project planning documentation, research and technology plan, exit criteria for the science and technology development). Limited technology testing of the cross-flow filter was completed as part of the WTP contract. However, this testing has been limited to filtration of solids, which are larger compared to those in the proposed LAW treatment application. The testing is not adequate to encompass the range of conditions for application to Hanford Site waste. The technology could be rapidly matured to support design implementation.	Major activities to develop the cross-flow filtration technology include the following: • Develop the design application concept and functional requirements for the cross-flow filter to provide a basis for definition of the technology development and testing requirements. • Complete prototypical testing with simulants and radioactive waste at the appropriate scale to support full-scale design implementation. Testing scale is envisioned to be full scale for nonradioactive testing and engineering scale for radioactive testing. • Document the relationships critical to filter performance that show how the filters behave in the LAW application and which bound the performance.

Table B.5. (contd)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology to a TRL of 6
Supplement Pretreatment Technologies			
Cesium Ion Exchange System The function of the cesium ion exchange technology is to remove cesium-137 from filtered LAW using elutable ion exchange resin. This technology is based on the WTP technology investment. The cesium ion exchange technology was considered for use with the rotary microfiltration or cross-flow filtration (solid-liquid separation) technologies in the tank farms to remove insoluble solids and cesium from the LAW feeds.	**3**	The cesium ion exchange technology was determined to be TRL 3 because the technology concept has not been developed beyond simple concept sketches for application in the Hanford Site tank farms and documentation supporting the development of the technology has not been prepared (e.g., project planning documentation, research and technology plan, exit criteria for the science and technology development). The chemistry and physical properties of the spherical resorcinol formaldehyde (RF) resin have been demonstrated at laboratory and pilot scale with similar process conditions. However, the column internals were not prototypical for the Hanford Site tank farm application. The capability was not demonstrated to remove greater than 99% by volume of the spent resin from the column. The cesium ion exchange technology could be rapidly matured following a detailed development of the functional requirements.	Major activities to develop the cesium ion exchange technology include the following: • Develop the design application concept and functional requirements for the Cesium Ion Exchange System to provide a basis for definition of the technology development and the testing requirements. • Complete the prototypical testing with simulants and radioactive waste (if required) at engineering/bench scale to support full-scale design implementation. • Complete ion-exchanger physical degradation testing, such as osmotic shock and crushing, for irradiated, spherical Resorcinol Formaldehyde resin samples. • Develop and demonstrate a conceptual process to remove hydrogen and other gases generated in the ion exchange columns.
Bulk Vitrification Technology			
Feed Receipt, Preparation, and Feeding System The function of the Feed Receipt, Preparation, and Feeding System is to prepare pretreated LAW feed by drying and blending it with glass-forming chemicals for vitrification in the ICV System.	**5**	The subsystems of the Feed, Receipt, Preparation, and Feeding System are determined to be TRL 5 because the system has been tested using 22- and 130-L dryers with simulated waste. The scaling parameters for the dryer technology are known. Test 38D, which will be conducted in 2007, is intended to verify the scaling parameters with an actual 10,000-L dryer.	Major activities to develop the feed receipt and feeding system include successful completion of prototypical testing (planned in 2007) on a full-scale, 10,000-L dryer to verify operation and support definition of the final design requirements.
In-Container Vitrification™ (ICV) The function of the ICV is to vitrify the pretreated LAW. The ICV melter equipment consists of a power supply, electrode assemblies, and a melt container with lid. The ICV technology uses electrical heating via electrodes to melt the waste/glass former blend. The cooled and sealed ICV becomes the disposal package.	**5**	The ICV Glass Melting and Container Systems were determined to be TRL 5 because of the extensive pilot- and full-scale testing that has been completed to develop the technology, including the design requirements for the ICV (container design, refractory design, electrode layout, lid design). Several issues remain with the technology that are planned for demonstration in future tests. These include adjustments to the glass formulation and operating conditions to mitigate the formation of	Major activities to develop the in-container vitrification system include completion of prototypical testing of a full-scale ICV (planned in 2007) to demonstrate mitigation of the molten ionic salt phase. This testing would be based on a Tank S-109 simulant feed that appears to represent a "worst" (bounding) case for immobilization in the ICV.

Table B.5. (contd)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology to a TRL of 6
Supplement Pretreatment Technologies			
		salt phases in the glass. The solution to the molten ionic salt issue has not been tested for all waste types.	
Offgas Treatment System (OGTS) The function of the OGTS is to treat the feed dryer and ICV offgas before release.	**4**	The OGTS is determined to be TRL 4 because the sintered metal filter dust capture and recycle function has not been tested. This testing is required to demonstrate the sintered metal filter's ability to capture and recycle particulates, which include technetium (rhenium is used as a surrogate) in the ICV offgas. This testing would provide reasonable assurance that a majority of the technetium-99 in the ICV would be incorporated in the vitreous waste form.	Major activities to develop the offgas treatment system include prototypical testing (planned in 2007) to demonstrate operation of the sintered metal filter dust capture and recycle function. Cross-technology effects between the ICV and the sintered metal filters are not completely understood. This testing would allow the process interfaces between components/subsystems in the OGTS to be more completely evaluated and the final design to be specified.
Steam Reforming Technology			
Feed Receipt, Preparation, and Feeding System The function of the Feed Receipt, Preparation, and Feeding System is to prepare pretreated LAW feed by mixing the waste with aluminosilicate clay and using air-atomizing nozzles to inject the waste clay slurry into the DMR.	**4**	The Feed Receipt, Preparation, and Feeding System was determined to be TRL 4 because high-fidelity prototypes of the subsystems have not been successfully tested in a relevant environment. Integrated, prototypical testing at the pilot scale is required for the Hanford Site waste forms/simulants to verify the final design concept before completing the design of the actual full-scale system. Based on testing at the IWTU at the DOE Idaho Site, the feed nozzles for the DMR would require development and verification testing.	Major activities to develop the feed receipt and feeding system include the following: • Characterize the physical and rheological properties of the pretreated LAW waste and clay mixtures. • Test the mixing/blending of the pretreated LAW waste and clay mixtures. • Develop, test, and verify the designs for the spray nozzles to be used in the DMR.

Table B.5. (contd)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology to a TRL of 6
Supplement Pretreatment Technologies			
Thermal Reformer System The function of the DMR System is to (a) receive the waste from the Feed Receipt, Preparation, and Feeding System, (b) react the waste with chemicals and heat to evaporate the water, (c) reform the organics, (d) convert nitrates and nitrites into nitrogen gas, and (e) convert the inorganic constituents into a granular sodium aluminosilicate product. The function of the product receiver/cooler is to cool and mix the products received from the various system components. The mixed product is then transferred to the disposal container.	**5**	The DMR was determined to be TRL 5 because high-fidelity prototypes of the subsystems have not been tested with the Hanford Site LAW waste compositions used to produce mineral forms. However, much work has been completed on waste forms other than the Hanford Site waste simulant. High-fidelity testing has been conducted on the DMR at Hazen on a mineralization flowsheet; actual waste has been treated at the Studsvik Processing Facility for 7 years; and the design of the DMR for the Idaho IWTU (a 48-inch DMR vessel) has been completed and fabrication is underway. Design elements (including size, materials of construction, corrosion allowances, system connections, and structural integrity) should apply directly to a Hanford LAW installation. Additional testing with LAW simulant, while useful for other process considerations such as product performance, would provide only limited information on the DMR design.	Major activities to develop the thermal reformer system include integrated, prototypical testing of a pilot-scale DMR (such as the one at Hazen) to: • Support development and demonstration of the proposed Hanford Site mineral waste form. • Verify the final design concept of the DMR before completing the design for the actual full-scale system. Radioactive testing on a small scale DMR is required to generate radioactive mineral product to assess the accuracy of the DMR material balance and generate material for mineral product development and characterization.

Table B.5. (contd)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology to a TRL of 6
Supplement Pretreatment Technologies			
Steam Reforming Technology			
Offgas Treatment System (OGTS) The function of the OGTS is to treat the process gases and entrained solids from the DMR. These gases are transported to the CRR vessel, where any carbon compounds are converted to carbon dioxide and water and the acid gases are neutralized. The process gases are then transported to the OGTS. The OGTS would reduce the temperature of the hot gas received from the CRR vessel and filter out any hazardous solids from the offgas before the offgas exits to air from the stack.	**4**	The CRR and OGTS were determined to be TRL 4 because high-fidelity prototypes of all of the subsystems have not been tested using Hanford Site simulated waste. Integrated, prototypical testing data to support confirmation of the OGTS design has been generated at the pilot scale for the INL IWTU and the Studsvik Processing Facility. The Hanford LAW design would be adapted from these design concepts.	Major activities to develop the off gas treatment system include conducting a site-specific testing program with Hanford Site LAW simulants and actual Hanford LAW waste to validate the overall system performance of the DMR, CRR, and OGTS. Specific testing would include the following: • Perform Hanford LAW surrogate and actual Hanford LAW testing at an engineering scale, including testing production of the waste form. • Conduct a full-scale surrogate test to demonstrate system performance. ▪ Gather environmental data for permitting a full-scale demonstration test facility, including a *Resource Conservation and Recovery Act of 1976* (RCRA) permit, an air permit (National Emission Standards for Hazardous Air Pollutants Permit from the EPA), and a construction permit. ▪ Demonstrate and validate that the gaseous emissions are compliant with regulatory limits, including MACT and other environmental standards (overall regulatory acceptance). ▪ Establish the technical parameters for design and operation of a full-scale facility for the CRR and OGTS. ▪ Provide optimization of throughput, consumables, utilities, and waste-volume reduction.

Table B.5. (contd)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology to a TRL of 6
Supplement Pretreatment Technologies			
Steam Reforming Technology			
Container-Handling System and Waste Qualification System The function of the Container-Handling System is to fill the disposal containers with a blended mixture of the steam-reformed mineral product and binder, seal the container, and decontaminate the outside of the container, as required.	**3**	The Container-Handling System and Waste Qualification System were determined to be a TRL 3. Although the Container-Handling System has an extensive operating history at other facilities, the Waste Qualification System of the FBSR LAW monolithic waste form has not been demonstrated on Hanford Site LAW in a prototypical, integrated testing with Hanford LAW simulants. To date, limited experimental work (laboratory and pilot scale) has been completed, and no engineering-scale tests have been performed on the Hanford LAW using the FBSR process. Further experimental measurements and study are required using both radioactive LAW monolithic waste and LAW simulants. DOE has not established the system requirements for the monolithic waste form. Until waste acceptance criteria are determined, the acceptability of all waste forms is uncertain. Waste form qualification (including regulatory acceptance) is required for the steam-reformed monolith produced from the Hanford LAW. A waste monolith is required because the mineral waste alone does not meet the compressibility standards, and it does not meet the requirements for the intruder scenario needed for the Integrated Disposal Facility performance assessment.	Major activities to develop the Container-Handling System and Waste Qualification System includes establishing the system requirements for the monolithic waste form and completing a test program that includes the following to validate the performance of the monolithic waste form: • Gather technical data to support a full-scale demonstration test, permitting, design, and operations. • Produce a granular, mineralized alkali-aluminosilicate-based waste using the LAW surrogate. • Produce a waste monolith that meets the waste acceptance criteria to be used for vitrified LAW disposal at the Hanford Site. • Demonstrate large-scale, in-container monolith techniques. • Confirm the waste form's performance with the results from the pilot-scale steam reformer test using radioactive LAW. • Reduce the carbon in the mineral waste to maximize the waste volume reduction. • Validate the waste performance qualification to meet the Hanford Site waste acceptance criteria. • Validate the waste loading performance and facility throughput. • Generate the radioactive product from actual Hanford Site waste for waste form qualification. • Determine the form and retention of technetium and iodine in the waste.

Table B.5. (contd)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology to a TRL of 6
Supplement Pretreatment Technologies			
Cast Stone Technology			
Feed Receipt, Preparation, and Feeding System The function of the Feed Receipt, Preparation, and Feeding System is to receive the pretreated LAW and waste form reagents and prepare them such that, when mixed together in the proper formulation, this mixture would form a durable, solid waste known as cast stone.	**3**	The Feed Receipt, Preparation, and Feeding System was determined to be TRL 3. While the system primarily consists of equipment with demonstrated technology, the performance criteria for this application have not been fully defined. The Feed Receipt, Preparation, and Feeding System could move to TRL 6 quite rapidly because the pilot-scale step can be bypassed, as the technology has been demonstrated and the full-scale equipment can be designed and operationally tested before startup.	Major activities to develop the feed receipt and feeding systems include following: • Establish the LAW feed receipt and feed delivery criteria and test the full range of LAW waste feeds. • Define the specifications and performance acceptance tests for vendor-supplied components. • Finalize the project documentation, such as the reliability and maintainability analysis, risk management, configuration management, and draft design.
Mixing and Casting System The function of the Mixing and Casting System is to fill the disposal containers with a blended mixture of the treated LAW waste and waste form reagents; seal the container; decontaminate the outside of the container, as required; and allow the final product to cure, thereby making the cast stone waste form.	**3**	The Mixing and Casting System technology was determined to be TRL 3. While the technology for designing the equipment has been demonstrated in industry and other nuclear applications, the waste form performance criteria have not been established and an acceptable waste formulation has not been developed and tested.	Major activities to develop the Mixing and Casting System include establishing the waste form acceptance criteria and development and testing to formulate an acceptable cast stone waste form for LAW immobilization. The major technology development activities include the following: • Develop and test the waste formulations for the full range of LAW waste feeds to meet the waste form acceptance criteria. • Design and test the wet cast stone sampling system. • Define the specifications and performance acceptance tests for the vendor-supplied mixer. Complete prototypic testing of the mixer system. • Define the criteria, and complete testing on the subsystems that would be used to survey and decontaminate the cast stone container. • Complete nonradioactive demonstration testing on a full scale mixing and casting system. Complete radioactive testing on a pilot scale mixing and casting system.

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Appendix C. Cost Basis Summary Description and Assumptions

C.1 Methodology

Cost estimates for each of the seven Business Cases were derived from existing information. Cost information was either used as presented or adjusted based on the specific technical assumptions of the business cases. The quality of the information varied between the business cases and the specific supplemental pretreatment and supplemental immobilization technologies.

Costs are presented in several ways in this document. Point value deterministic estimates for the business cases are presented on an annual and total basis, in Table B.1. These costs are divided into the major cost elements, such as Waste Treatment and Immobilization Plant (WTP) costs, Tank Farm Operations costs, and Supplemental Pretreatment and Supplemental Immobilization costs. Project costs as noted in Table B.1 included Technology Development, Engineering, and Construction. Operations costs included facility operating costs, waste disposal, and decontamination and decommissioning (D&D). These costs are presented in constant 2008 dollars and discounted dollars. All costs are presented as "to go" costs [estimate to complete (ETC)] from 2008 to the end of the mission.

Due to the varied quality of the cost information, an estimate of uncertainty for each major cost element was also established. These uncertainties are used to provide a probabilistic estimate of the mean ETC cost for each business case. Crystal Ball software was used to estimate these mean costs as both constant 2008 dollar and discounted costs. The uncertainty range (low, mid, and high) used for each of the major costs elements are presented in Table B.2. A triangular probability distribution was assumed in all cases. These uncertainties vary from a cost element with low uncertainty, such as the WTP project capital (-5% to 5%) to a large uncertainty such as Cast Stone (CS) Facility project cost (0% to 100%). The uncertainty ranges were established by the authors of this report and contractor staff familiar with the projects and technologies.

Costs presented in the body of the business case study are probabilistic and are used for comparative purposes. These costs are higher than the deterministic estimates provided in Table B.1.

C.2 Major Assumptions

1. All business cases assume that waste treatment operations commence in 2019, except Business Cases 6 and 7, which assume low-activity waste (LAW) immobilization operations commence in 2014.

2. The waste treatment rate for all business cases is assumed to remain constant over the treatment period. A total of 60,000 metric tons (MT) of sodium is to be immobilized.

3. The LAW waste treatment schedule durations for Cases 1A and 1B were determined based on the waste treatment capability of the WTP. The waste treatment duration is dictated by the time to treat the entire quantity of LAW. An additional 4 and 8 years is added to the mission to decommission the WTP facilities and tank farm facilities for Cases 1A and Case 1B, respectively. These business cases have a mission duration of 77 and 80 years, respectively.

4. Business Cases 2 through 6 were assumed to have a treatment mission duration of 27 years, which is dictated by the time to treat the high-level waste in WTP. The capacity of the supplemental immobilization technologies (e.g., Second LAW Facility [2nd LAW], Bulk Vitrification [BV], Cast Stone [CS], and Stream Reforming [SR]) is specified to complete the treatment mission in 27 years.

An additional 3 to 5 years is added to the mission schedule to complete decommissioning of the WTP and supplemental treatment facilities.

5. Business Case 7 is assumed to commence treatment operations in 2014. The waste treatment duration for Business Case 7 is determined to be 32 years. An additional 5 years is added to the mission schedule to complete decommissioning of the WTP and supplemental treatment facilities.

6. All costs are escalated to calendar year 2008 dollars from their original estimate. The costs are presented as Constant Dollar cost (e.g., 2008) and discounted costs. The discount rate assumed in all business cases is 3% per year.

7. Costs are presented for each of the seven business cases in the elements:
   - WTP Project – includes WTP capital construction, WTP operations, and WTP D&D.
   - Tank Farm Operations/Closure – includes tank farm operations, tank waste retrieval and tank closure (D&D).
   - Supplemental Treatment –includes all ETC costs for the specific supplemental treatment technology: technology development, project capital costs, operations, waste disposal, and facility D&D.

8. The WTP Project costs include the fiscal year (FY) 2008 through FY 2020 WTP Project costs as detailed in the *Independent Validation review of the May 2006 Estimate at Completion for the Hanford Waste Treatment and Immobilization Plant Project (August 28, 2007),* prepared by the U.S. Army Corp of Engineers. These are the capital costs for the construction of the facilities and support commissioning of the WTP. WTP operations costs for steady state operations were developed by ORP (ORP November 14, 2004) and used as a basis for operating the WTP. Operating costs were estimated in full-year increments.

9. The WTP operations costs were based on the *Proposed Basis of ROM Estimate for WTP Steady State Operations*, Rev. 2, November 18, 2004, Office of River Protection, Richland, Washington. These costs were adjusted from an assumed 2000 LAW containers to 1,277 LAW containers per year and escalated from 2004 to 2008 dollars. The total annual operating costs are estimated to be $294 million.

10. The tank farm operations costs were based on the Level 5 escalation described in *Alignment of TFC Lifecycle Baseline BCR RPP-06-003 Rev.1 for PBSs ORP-0014& Headquarters-HLW-0014X.* The tank farms costs are not assumed to be heavily dependent on the tank waste retrieval sequence or rate.

11. The BV Facility Project costs are based the four-line 200 East Area BV Facility from the Tank Farm Baseline (BCR-RPP-0603, Rev 1.0).

12. The BV Facility operations cost is based on the scaling from the four-line 200 East Area BV Facility operations cost in the Tank Farm Baseline (BCR-RPP-0603, Rev 1.0).

13. The new CS Facility Project cost is based on the Fluor Federal Services prepared document, *Containerized Cast Stone Facility*, as submitted to CH2M HILL Hanford Group, Inc., August 2003 (letter John Smets [Fluor] to Roger Powell [CH2M HILL Hanford Group], *100% Preconceptual Design Report*, dated August 20, 2003).

14. The new CS Facility Project operating cost is based on the Fluor Federal Services prepared document, *Containerized Cast Stone Facility*, as submitted to CH2M HILL Hanford Group, Inc., August 20, 2003.

15. The new SR Facility Project cost is based on the Memorandum for Joel T. Case, Federal Project Director for Sodium Bearing Waste Idaho Operations Office, from David Garman, *Approval of Performance Baseline (Critical Decision-2) and the Associated Baseline Change Proposal, Long Lead Procurements and Site Preparation (Critical Decision CD-3B) and the Project Execution Plan for the Sodium Bearing Waste Treatment Project,* dated December 29, 2006.

16. The capital costs and operations costs for the supplemental pretreatment facilities are based on the Tank Farm Baseline (BCR-RPP-0603, Rev 1.0).

17. Capital costs for the supplemental treatment and immobilization facilities were scaled from existing facility cost estimates with a specified capacity. The capital costs scaling relationships is:

    Capital Cost of Facility A = Capital Cost of Facility B x [Capacity Facility A/ Capacity Facility B] ^ 0.60

    This scaling relationship is based on the cost estimating methodology described in the section on Estimating Equipment Costs by Scaling in Peters and Timmerhaus, *Plant Design and Economics for Chemical Engineers*, McGraw Hill Book Company, Third Edition, 1980, pg. 166.

18. Operating Costs for the treatment facilities were scaled from existing facilities where possible based on the method used for Capital Cost scaling. Operating Cost of Facility A = Operating Cost of Facility B x [Capacity Facility A/ Capacity Facility B] ^ 0.60. Operating costs were estimated in full-year increments.

    The BV Facility costs were assumed to scale linearly with the number of BV lines.

19. Technology development costs for the supplemental treatment technologies are based on a preliminary assessment of technology development requirements as described in Appendix B.

20. Decontamination and decommissioning costs are derived from the tank farm baseline for WTP. Decontamination and decommissioning costs for the other technologies are assumed to be 10% of the capital costs.

Table C.1. Summary of Annual Costs for Business Case Alternatives *(Note: Business Case costs are presented in Constant Dollars (2008) and Discounted Dollars, Costs do not include uncertainty)**

Description	Fiscal Year, Cost in $M																										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031 to 2038	2039 to 2046	2047 to End of Mission	Total, $M
Case 1A																											
WTP Only-Constant	948	984	949	984	1,026	1,157	1,193	1,272	1,293	1,173	1,170	1,014	813	798	794	771	795	807	764	783	815	798	846	6,440	4,076	17,004	49,466
WTP Only-Discounted Costs	948	956	894	900	912	998	999	1,034	1,020	899	870	733	570	543	525	495	495	488	448	447	451	429	442	2,980	1,478	3,414	24,369
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	10,237	18,465
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,726	6,767	24,044
Case 1B																											
WTP Only, New Double Shell Tanks-Constant	948	984	949	985	1,034	1,169	1,212	1,335	1,452	1,395	1,170	1,084	856	870	944	980	1,019	881	854	951	1,042	1,041	938	7,786	5,208	7,871	44,956
WTP Only, New Double Shell Tanks-Discounted Costs	948	956	894	902	918	1,009	1,015	1,085	1,146	1,069	870	783	600	593	624	629	635	533	502	542	577	559	489	3,596	1,901	1,590	24,966
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	4,287	12,515
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,726	0	17,277
New Double Shell Tanks Project	0	0	0	2	7	13	19	63	160	222	0	58	19	49	126	186	201	50	49	126	186	201	50	824	456	0	3,068
New Double Shell Tanks Operating	0	0	0	0	0	0	0	0	0	0	0	12	24	24	24	24	24	24	41	41	41	41	41	522	675	3,584	5,140
Case 2																											
WTP with Second WTP LAW Plant-Constant	948	984	972	1,030	1,118	1,272	1,366	1,444	1,465	1,346	1,262	1,221	927	912	908	885	909	921	878	898	929	912	960	7,354	4,831	655	37,306
WTP with Second WTP LAW Plant-Discounted Costs	948	956	916	942	994	1,097	1,144	1,174	1,157	1,031	939	882	650	621	600	568	566	557	516	512	514	490	501	3,398	1,756	199	23,630
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	539	8,767
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,567	0	17,118
Supplemental Treatment (Second LAW Vitrification Facility) Project	0	0	23	46	92	115	173	173	173	173	92	92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,152
Supplemental Treatment (Second LAW Vitrification Facility) Operations	0	0	0	0	0	0	0	0	0	0	0	114	114	114	114	114	114	114	114	114	114	114	114	913	913	115	3,312
Case 3																											
WTP with Bulk Vitrification (East Area) -Constant	948	1,034	979	1,008	1,051	1,159	1,193	1,320	1,415	1,319	1,292	1,151	901	886	882	859	882	895	851	871	903	886	934	7,144	4,622	588	35,975
WTP with Bulk Vitrification (East Area)-Discounted Costs	948	1,004	922	922	934	1,000	999	1,074	1,117	1,011	961	832	632	603	583	551	550	542	500	497	500	476	488	3,302	1,681	179	22,808
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	539	8,767
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,567	0	17,118
Supplemental Treatment (Bulk Vitrification) Project	0	50	30	24	25	3	0	49	122	147	122	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	620
Supplemental Treatment (Bulk Vitrification) Operations	0	0	0	0	0	0	0	0	0	0	0	88	88	88	88	88	88	88	88	88	88	88	88	704	704	49	2,512
Case 4																											
WTP with Cast Stone (East Area) -Constant	948	1,009	994	1,029	1,071	1,202	1,238	1,330	1,326	1,213	1,203	1,057	843	827	823	800	824	837	793	813	844	828	876	6,677	4,155	553	34,113
WTP with Cast Stone (East Area)-Discounted Costs	948	980	937	941	952	1,037	1,037	1,081	1,047	929	895	764	591	563	544	514	514	506	466	464	468	445	457	3,088	1,512	168	21,847
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	539	8,767
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,567	0	17,118
Supplemental Treatment (Cast Stone) Project	0	25	45	45	45	45	45	58	33	40	33	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	428
Supplemental Treatment (Cast Stone) Operations	0	0	0	0	0	0	0	0	0	0	0	30	30	30	30	30	30	30	30	30	30	30	30	237	237	13	842

Table C.1. (contd)

Description	Fiscal Year, Cost in $M																										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031 to 2038	2039 to 2046	2047 to End of Mission	Total, $M
Case 5																											
WTP with Steam Reforming (East Area) - Constant	948	1,009	1,012	1,066	1,161	1,310	1,393	1,472	1,433	1,313	1,244	1,187	911	896	892	869	893	905	862	882	913	896	944	7,226	4,703	633	36,975
WTP with Steam Reforming (East Area)-Discounted Costs	948	980	954	976	1,032	1,130	1,167	1,197	1,131	1,006	926	858	639	610	590	558	556	548	506	503	505	482	493	3,340	1,710	193	23,537
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	539	8,767
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,567	0	17,118
Supplemental Treatment (Steam Reforming) Project	0	25	64	82	135	153	200	200	140	140	75	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,289
Supplemental Treatment (Steam Reforming) Operations	0	0	0	0	0	0	0	0	0	0	0	98	98	98	98	98	98	98	98	98	98	98	98	785	785	93	2,843
Case 6																											
WTP with Bulk Vitrification (East/West Area) -Constant	948	1,085	1,099	1,152	1,172	1,210	1,257	1,375	1,456	1,357	1,333	1,181	940	924	920	897	921	934	842	862	893	861	909	6,942	4,420	579	36,470
WTP with Bulk Vitrification (East/West Area) -Discounted Costs	948	1,053	1,036	1,054	1,041	1,044	1,053	1,118	1,150	1,040	992	853	659	629	608	576	574	565	494	491	494	463	474	3,210	1,608	176	23,406
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	539	8,767
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,567	0	17,118
Supplemental Treatment-Pretreatment (West) Project	0	17	37	44	37	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	154
Supplemental Treatment-Pretreatment (West) Operations	0	0	0	0	0	0	14	14	14	14	14	14	14	14	14	14	14	14	4	4	4	0	0	0	0	0	177
Supplemental Treatment-Bulk Vitrification (West) Project	0	83	113	124	108	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	464
Supplemental Treatment-Bulk Vitrification (West) Operations	0	0	0	0	0	0	50	50	50	50	50	50	50	50	50	50	50	50	11	11	11	0	0	0	0	0	636
Supplemental Treatment-Bulk Vitrification (East)- Project	0	0	0	0	0	0	0	40	100	120	100	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	399
Supplemental Treatment-Bulk Vitrification (East) Operations	0	0	0	0	0	0	0	0	0	0	0	63	63	63	63	63	63	63	63	63	63	63	63	503	502	40	1,798
Case 7																											
WTP with Bulk Vitrification (East) Early--Constant	948	1,102	1,143	1,204	1,215	1,227	1,381	1,460	1,481	1,361	1,358	1,085	884	868	856	834	857	870	826	846	878	861	909	6,943	4,420	579	36,398
WTP with Bulk Vitrification (East) Early - Discounted Costs	948	1,070	1,077	1,102	1,080	1,059	1,157	1,187	1,169	1,043	1,010	784	620	591	566	535	534	526	485	483	486	463	474	3,210	1,608	176	23,445
WTP Project	690	674	658	643	628	613	598	584	571	557	544	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,957
WTP Operations	0	0	0	0	0	0	0	0	0	0	0	294	294	294	294	294	294	294	294	294	294	294	294	2,351	2,351	539	8,767
Tank Farm Operations/Closure	258	310	291	341	399	544	595	687	722	615	625	524	519	504	500	477	501	513	470	490	521	504	552	4,089	1,567	0	17,118
Supplemental Treatment-Pretreatment Project	0	28	64	76	64	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	261
Supplemental Treatment-Pretreatment Operations	0	0	0	0	0	0	25	25	25	25	25	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	147
Supplemental Treatment-Bulk Vitrification (East) Project	0	90	130	144	125	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	531
Supplemental Treatment-Bulk Vitrification (East) Operations	0	0	0	0	0	0	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	503	503	40	2,113
Early WTP LAW Vitrification	0	0	0	0	0	0	101	101	101	101	101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	503

*Refer to Appendix D for cases not shown; Business Cases 1C and 3A/B to be included in Revision 1.

Table C.2. Summary of Cost Uncertainties used in Business Case Cost Estimates

Cost Element	Uncertainty Range			Comments
	Low	Mid	High	
Common Cost Elements				
WTP Project Capital	-5%	1%	5%	Cost estimate independently validated in late CY 2006, therefore uncertainly considered low.
WTP Operations Case 1A	-5%	25%	35%	Cost estimate based on DOE detailed assessment, large uncertainty reflects potential cost to replace facilities due to long operating duration.
WTP Operations Case 1B, 2-7	-5%	10%	15%	Cost estimate based on DOE detailed assessment.
WTP Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.
Tank Farm Operations	-5%	15%	25%	Cost estimate based on DOE baseline, large uncertainty reflects potential cost to replace facilities due to long operating duration.
Case Specific Assumptions				
Case 1B: WTP Only, 2 line LAW Plant, New LAW Storage Tanks				
LAW Storage facility project costs	-50%	0%	25%	Cost uncertainty range reflects uncertainty in requirements for additional LAW storage tanks.
LAW Storage facility Operations	-5%	10%	25%	Cost estimate derived from scaling of current Tank Farm baseline. Comparable uncertainties assumed.
LAW Storage facility Decontamination and Decommissioning	0%	25%	50%	Cost estimate based on DOE Tank Farm baseline. Large uncertainty in cost due to long time before action.
Case 1C: WTP LAW Only with Third Melter and Upgrades to all Three Melters – refer to Appendix D; additional information to be included in Revision 1.				
Case 2 WTP with Second WTP LAW Vitrification Facility (East Area)				
Second WTP LAW Vitrification facility project costs	-10%	0%	10%	Cost uncertainly low due to mature development of WTP design.
Second LAW Vitrification facility Operations	-5%	0%	10%	Cost estimate based on DOE detailed assessment.
Second LAW Vitrification facility Waste Disposal	0%	25%	50%	Large uncertainty in waste disposal costs reflects new disposal facility not yet commissioned.
Second LAW Vitrification facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.

Table C.2. (contd)

Cost Element	Uncertainty Range			Comments
	Low	Mid	High	
Case 3A: WTP with Bulk Vitrification facility (East Area)				
Bulk Vitrification Technology Development	0%	10%	20%	Low uncertainty reflects advanced stage of Bulk Vitrification technology development.
Bulk Vitrification facility project costs	0%	20%	50%	Large uncertainty in facility project costs reflects uncertainty in scaling of production facility design from demonstration facility design.
Bulk Vitrification facility Operations	0%	5%	20%	Cost estimate based on detailed assessment on Bulk Vitrification demonstration facility.
Bulk Vitrification facility Waste Disposal	0%	25%	50%	Large uncertainty in waste disposal costs reflects new disposal facility not yet commissioned.
Bulk Vitrification facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.
Case 3B: WTP with Three LAW melters and BV in 200 East Area – refer to Appendix D; additional information to be included in Revision 1.				
Case 4: WTP with Cast Stone Facility (East Area)				
Cast Stone Technology Development	0%	25%	50%	Large uncertainty reflects low state of development for Hanford application and uncertainty in development requirements.
Cast Stone facility project costs	0%	50%	100%	Large uncertainty in facility project costs reflects uncertainty in technical requirements for facility.
Cast Stone facility Operations	0%	30%	100%	Large uncertainty due to cost estimate based on small-scale facility with incomplete waste processing definition.
Cast Stone facility Waste Disposal	0%	25%	50%	Large uncertainty in waste disposal costs reflects new disposal facility not yet commissioned.
Cast Stone facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.

Table C.2. (contd)

Cost Element	Uncertainty Range			Comments
	Low	Mid	High	
Case 5: WTP with Steam Reforming Facility (East Area)				
Steam Reforming Technology Development	0%	25%	50%	Large uncertainty reflects low state of development for Hanford application and uncertainty in development requirements.
Steam Reforming facility project costs	0%	50%	100%	Large uncertainty in facility project costs reflects uncertainty in technical requirements for facility.
Steam Reforming facility Operations	0%	25%	50%	Large uncertainty in operations costs due to scaling from similar facility (e.g., Bulk Vitrification).
Steam Reforming facility Waste Disposal	0%	25%	50%	Large uncertainty in waste disposal costs reflects new disposal facility not yet commissioned.
Steam Reforming facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.
Case 6: WTP with 2 Bulk Vitrification Facilities (East and West Area)				
Tank Farm Pretreatment Technology Development	0%	25%	50%	Large uncertainty reflects low state of development for Hanford application and uncertainty in development requirements.
Tank Farm Pretreatment facility project costs	0%	50%	100%	Large uncertainty in facility project costs reflects uncertainty in technical requirements for facility.
Tank Farm Pretreatment facility Operations (West Area)	-5%	10%	25%	Cost estimate derived from scaling of current Tank Farm baseline. Comparable uncertainties assumed.
Tank Farm Pretreatment facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.
Bulk Vitrification facility Technology Development	0%	10%	20%	Low uncertainty reflects advanced stage of Bulk Vitrification technology development.
Bulk Vitrification facility project costs (East Area/West Area)	0%	20%	50%	Large uncertainty in facility project costs reflects uncertainty in scaling of production facility design from demonstration facility design.
Bulk Vitrification facility Operations (East Area/West Area)	0%	5%	20%	Cost estimate based on detailed assessment on Bulk Vitrification demonstration facility, uncertainty considered low.
Bulk Vitrification facility Waste Disposal	0%	25%	50%	Large uncertainty in waste disposal costs reflects new disposal facility not yet commissioned.
Bulk Vitrification facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.

Table C.2. (contd)

Cost Element	Uncertainty Range			Comments
	Low	Mid	High	
Case 7: WTP with Bulk Vitrification Facility (East Area)- Early Operations				
Bulk Vitrification facility Technology Development	0%	10%	20%	Low uncertainty reflects advanced stage of Bulk Vitrification technology development.
Bulk Vitrification facility project costs (East Area)	0%	20%	50%	Large uncertainty in facility project costs reflects uncertainty in scaling of production facility design from demonstration facility design.
Bulk Vitrification facility Operations (East Area)	0%	5%	20%	Cost estimate based on detailed assessment on Bulk Vitrification demonstration facility, uncertainty considered low.
Bulk Vitrification facility Waste Disposal	0%	25%	50%	Large uncertainty in waste disposal costs reflects new disposal facility not yet commissioned.
Bulk Vitrification facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.
Tank Farm Pretreatment Technology Development	0%	25%	50%	High uncertainty reflects low state of development for Hanford application and uncertainty in development requirements.
Tank Farm Pretreatment facility project costs (East Area)	0%	50%	100%	Large uncertainty in facility project costs reflects uncertainty in technical requirements for facility.
Tank Farm Pretreatment facility Operations (East Area)	-5%	10%	25%	Cost estimate derived from scaling of current Tank Farm baseline. Comparable uncertainties assumed.
Tank Farm Pretreatment facility Decontamination and Decommissioning	0%	25%	50%	Large uncertainty in cost due to long time before action.
WTP LAW Vitrification facility-Early Operations	-5%	10%	15%	Cost estimate based on DOE detailed assessment, large uncertainty reflects potential cost to replace facilities due to long operating duration.

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Appendix D. Initial Assessment of the Benefits of the Adding a Third WTP LAW Melter

An initial study to determine the relative cost benefits of adding a third Low-Activity Waste (LAW) melter to the Waste Treatment and Immobilization Plant (WTP) LAW Facility was conducted. This study assessed two cases as follows:

1. Installing a third melter in the WTP LAW Facility spare melter cell with no additional LAW immobilization (supplemental treatment) (Business Case 1C); and
2. The 3-melter LAW Facility used in combination with bulk vitrification (BV) to support treatment of the tank waste in a 27-year operating period (Business Case 3B).

<u>Conclusions</u>

Estimates of the mean costs to complete the River Protection Program (RPP) mission with two- and three-melter WTP LAW Facilities are compared in Figure D1. This graph shows the following:

- When comparing the cases in which only the WTP facilities are to be constructed and operated (e.g., Business Cases 1A, 1B, and 1C), there is a significant cost advantage in installing and operating a third LAW melter (Case 1C), compared to cases in which only two LAW melters are installed (Business Case 1A, Case 1B). This cost advantage is directly attributable to the reduced processing schedule of Business Case 1C, which is 40 years, compared to the 60-year processing schedule of Business Cases 1A and 1B.

- Addition of LAW immobilization capability, as in Case 1C, is preferred based on cost, over the construction and operation of 31 additional double-shell tanks as assumed in Business Case 1B.

- There is no significant cost difference in installing and operating a third LAW melter when comparing Business Case 3A (two-line LAW facility plus seven-line BV facility) and Business Case 3B (three-line LAW facility plus four-line BV facility).

- Cases with supplemental immobilization (Business Cases 2 through 7) are beneficial over the WTP LAW Facility-only cases in that they complete the treatment mission in 27 years rather than 40 to 60 years. This shorter period reduces the risk of additional waste leaking into the environment from the tanks that are, or will be, well beyond their design life.

<u>Method</u>

The two business cases assessed provide a basis for evaluating the relative benefits of adding a third LAW melter to the WTP LAW Facility. These cases were compared to existing cases in the LAW business case study (DOE/ORP-2007-03). The estimate to complete (ETC) costs were estimated in constant 2008 dollars and discounted dollars. Costs were discounted at a rate of 3% per year. Monte Carlo uncertainty analysis was used to address cost estimate uncertainties.

The two business cases are:

- Third WTP LAW Melter (Case1C). This case is a modification of Case 1A in the LAW business case study. The third melter increases the treatment rate of the LAW Facility from 1,000 to

1,500 metric tons (MT) of sodium per year, thereby reducing the overall processing time from 60 years to 40 years.

- Third WTP LAW Melter with Bulk Vitrification (Case 3B). This case is a modification of Business Case 3A in the LAW business case study. The third WTP LAW melter increases the treatment rate of the LAW Facility from 1,000 to 1,500 MT of sodium per year, thereby reducing the amount of sodium that is treated in the 200 East Area BV facility such that only four BV process lines are required, compared to the seven BV process lines in Business Case 3A. The waste processing duration is 27 years.

Key Assumptions

1. The addition of the third LAW melter increases the design capacity of the LAW Facility to 45 MT glass per day (MTG/D) with a total sodium treatment rate of 1,500 MT sodium per year. This compares to the two-melter LAW Facility, which has an assumed 30 MTG/D and a total sodium treatment rate of 1,000 MT odium per year.
2. The cost of the facility improvements to support the third LAW melter has not been detailed. During WTP contract discussions with the WTP Contractor, Bechtel National, Inc. (BNI), it was indicated that the costs associated with the addition of the third LAW melter, which includes process equipment, facility modifications, and site modifications (cooling capacity) are approximately \$200 million. An uncertainty estimate of $\pm$ 50% is assumed for this equipment/facility cost.
3. The capital cost difference between a seven-line BV facility and a four-line BV facility is \$157 million based on estimated BV cost estimates in Business Cases 3 and 6.
4. The incremental operating cost for the third LAW melter is estimated to be \$29 million/year and the incremental operational cost savings for a four-line BV facility versus a seven-line BV is \$37 million/year.
5. The third WTP LAW melter equipment and facility improvements can likely be made beginning in fiscal year (FY) 2009 (October 2008) and be completed by FY 2013 (March 2013) (the completion of cold commissioning), based on the WTP Construction Project Datasheet. The installation of the third LAW melter will require that cold commissioning be initiated on the two other LAW melters while installation on the third LAW melter is completed.
6. The LAW Facility is to commence hot operations coincident with the balance of the WTP facilities in early calendar year 2019.

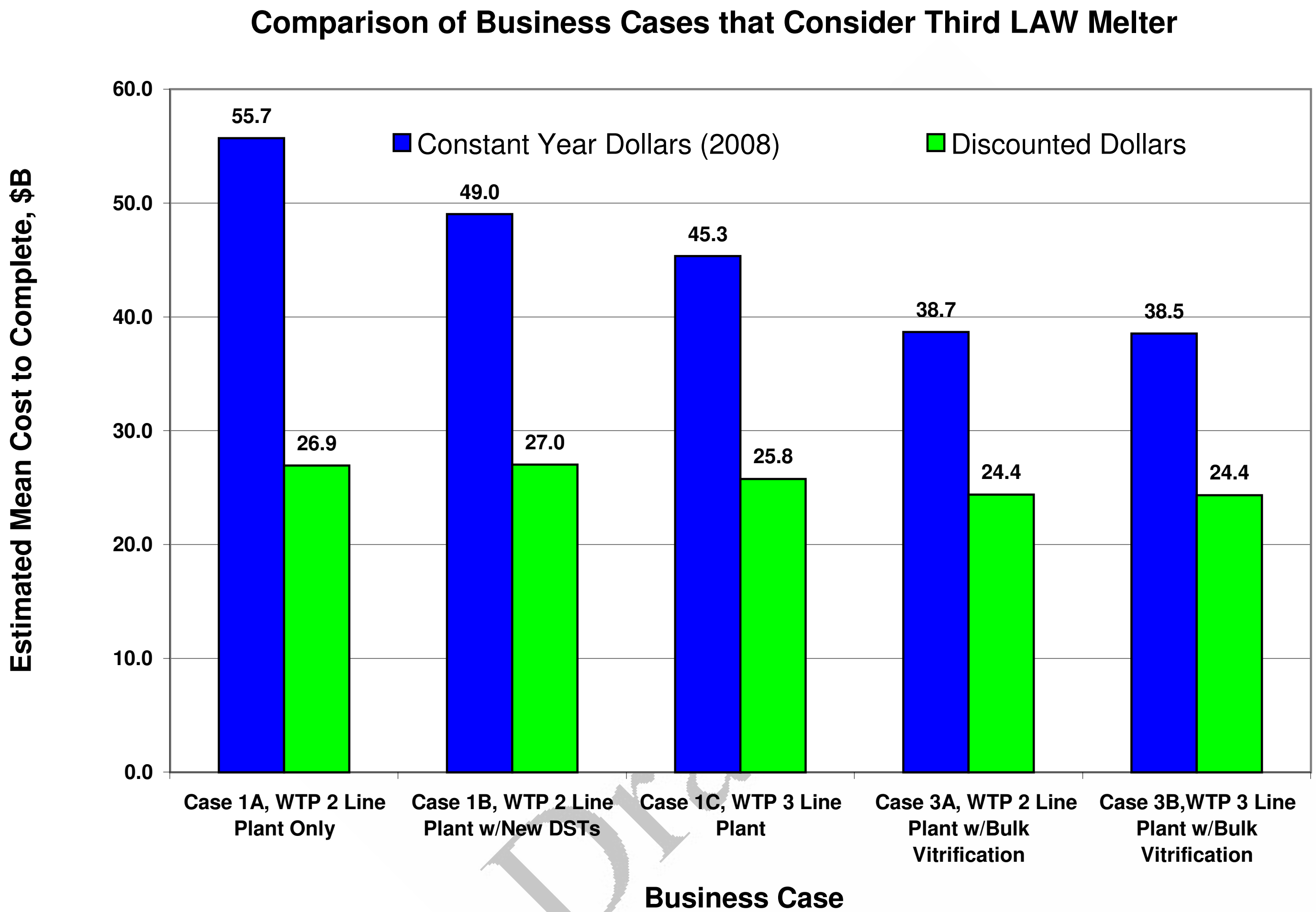

Figure D.1. Business Case Comparison