The Waste Treatment Plant, a Work in Progress

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ABSTRACT

There are many challenges in the design and construction of Department of Energy's (DOE) Waste Treatment and Immobilization Plant (WTP) at the Hanford site. The plant is being built to process some 55 million gallons of radioactive waste from 177 underground tanks. Engineering and construction are progressing on this largest project in the DOE complex.

This paper describes some of WTP's principal recent challenges and opportunities and how they are being addressed to minimize impact on the project, enhance the capabilities of the facilities, and reduce risk. A significant new development in 2005 was the need to account for higher seismic accelerations than originally specified for the facility structures and equipment. Efforts have centered on continuing design and construction with minimal risk, while the final seismic design spectra was developed. Other challenges include development of an alternative cesium ion exchange resin to minimize the risk from reliance on a single product, implementing advanced analytical techniques to improve laboratory performance, adopting a thinner walled high level waste (HLW) canister to reduce waste volume and mission duration, and commissioning a comprehensive external flowsheet review of the design, along with its underpinning technologies, and projected plant operability.

These challenges make it clear that WTP is a work in progress, but the challenges are being successfully resolved as the design and construction move on to completion.

INTRODUCTION

On the Hanford site, a few miles west of the Columbia River 55 million gallons of radioactive and chemical waste from cold war plutonium production are stored in 177 underground tanks. At least a million gallons of this waste has leaked. The DOE has awarded Bechtel National (BNI) a contract to design and construct the world's largest radioactive waste treatment plant to turn the waste into glass and place it in stainless steel canisters for safe and permanent disposal. The WTP will process some 50 million gallons of radioactive waste from 177 underground tanks. The plant is progressing well in engineering and construction.

The WTP is comprised of three main facilities: The Pretreatment (PT) facility performs separation and concentration of the waste received from the underground tanks. The HLW Vitrification facility immobilizes the high level fraction of the waste in glass using melters. Similarly, the Low Active Waste

(LAW) facility vitrifies the low-level waste fraction. A large separate analytical lab building performs all the process chemistry analyses necessary to ensure good glass is being produced.

Construction on facility started with first concrete in July 2002. Ultimately some 250,000 cubic yards of concrete with 40,000 tons of rebar and 27,000 tons of embeds will be placed, and 200 miles of mostly small-bore piping will be installed in the three processing buildings.

WORK IN PROGRESS

Five major challenges and opportunities are described below:

- Revised ground motion
- Development of an alternative cesium ion exchange
- Application of advanced techniques in the analytical laboratory
- Adoption and proof-testing of a thinner walled HLW canister
- The comprehensive flowsheet review

Revised Ground Motion

Late in 2004, after extensive review and analysis, the Office of River Protection (ORP) determined that an increase in seismic accelerations of structures and equipment up to 40% was possible, based on new borehole data. Simply put, the new data indicated that the actual soil layer thickness and interbed layers at the WTP site could have an amplifying effect on the seismic ground motion. [Fig. 1].

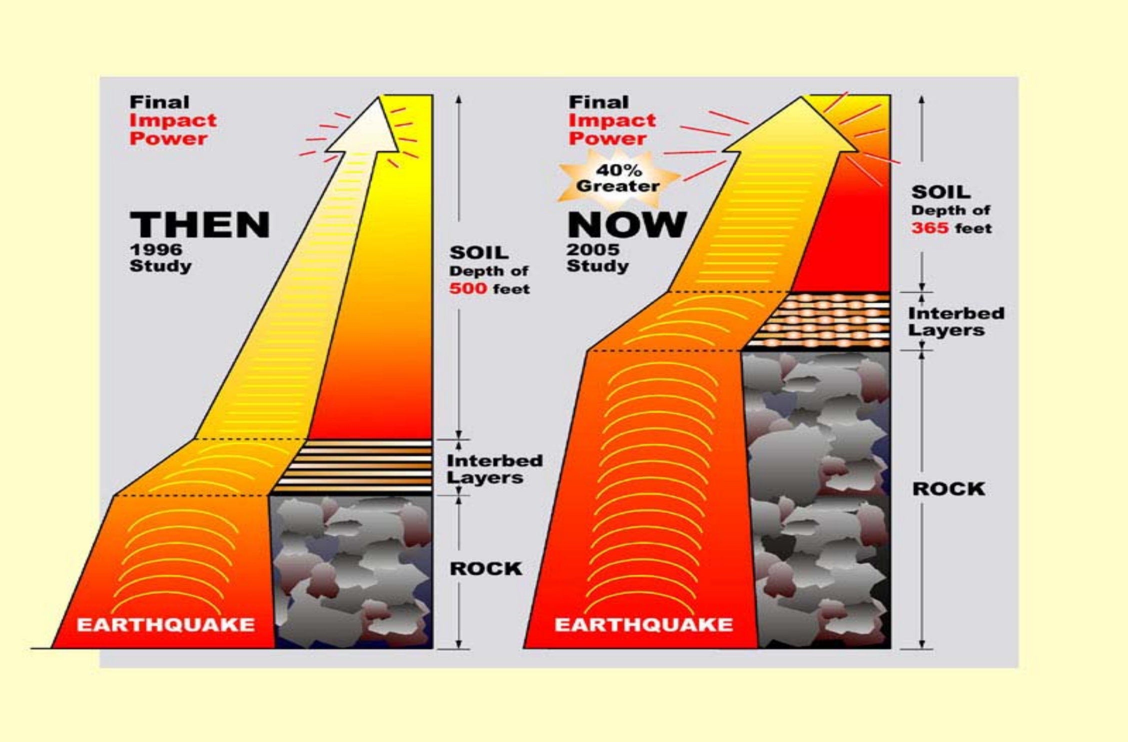


Fig. 1. Comparison of original and new attenuation data

A plan was then developed with Bechtel National, Inc. (BNI) to minimize disruption to the project as this new criteria was implemented. There were three principal components of the plan:

- Implementation of a controlled program to allow design and construction efforts to proceed by using interim seismic criteria until a new dynamic analysis of the affected facilities could be completed;
- An evaluation of analytical techniques and assumptions to determine where there may be excess conservatism that could be reduced, and;
- Completing the dynamic analysis expeditiously to establish the new seismic criteria (these analyses translate ground motion criteria into in-structure seismic loads that can be used for more detailed design).

Design margins in the erected structures evaluated to date have been shown to be adequate to accommodate the new criteria. This was made possible in large part because DOE had anticipated the change and had previously included specific conservatisms in the original structural design criteria and invoked more stringent conditions than required by the applicable codes and standards for similar facilities.

A controlled process was developed to analyze and release all new structural elements for construction, ensuring that it would meet the interim criteria. ORP had BNI develop and use bounding interim criteria as a basis for continuing the design and construction prior to the development of the final in-structure response and loads. BNI proposed and ORP approved using a multiplying factor of 1.4 on previous seismic loads to allow fabrication and construction to proceed. Release forms were used to document the rationale on a case-by-case basis for proceeding with construction prior to the development of the final criteria.

Some 14,000 previously issued engineering deliverables (calculations, drawings, and requisitions) for Seismic Category I and II Structures, Systems and Components are impacted by the change in criteria. Additional quantities of concrete, steel, and pipe supports are anticipated. To reduce or eliminate the extent of required design changes, work was initiated to eliminate unnecessary conservatisms in the design. To facilitate the process and expedite approvals, ORP developed a close working relationship with all stake holders, BNI, and the Defense Nuclear Facilities Safety Board (DNFSB) staff . A peer review team (PRT) was established to review issues and endorse changes. Membership includes experts from DOE, BNI, and other nationally recognized subject experts. The DNFSB staff is also heavily involved in this process. To date, there have been agreements reached to change the required demand/capacity ratios in structures form 0.85 to 1.0, to allow credit for inelastic energy absorption in the design of structures, piping, and components, and to eliminate other conservatisms.

BNI has also worked to increase the precision of the structural design analyses for RGM including updated soil properties, improved analysis models, and use of recently available equipment data. BNI acquired latest version of software (SAP2000) for more precise structural analysis than previously possible.

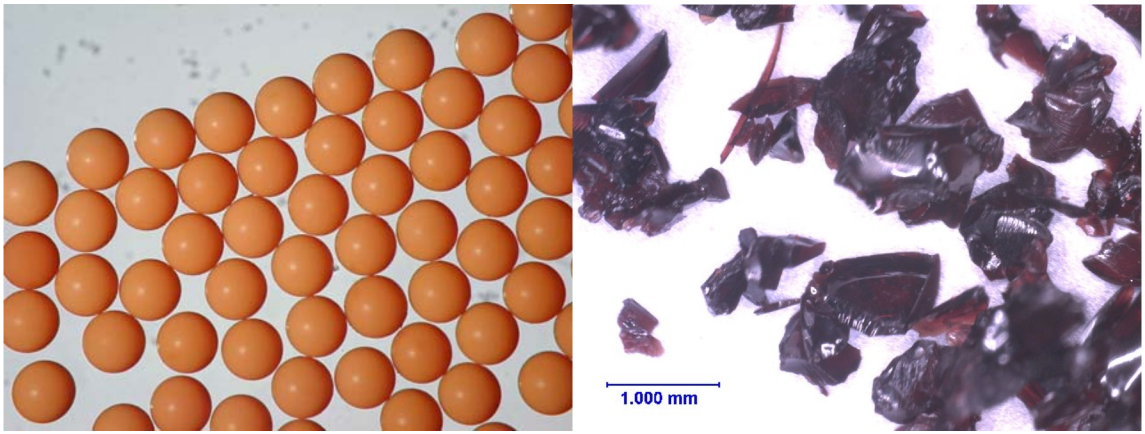
The soil structure interaction dynamic re-analysis of the HLW and PT facilities was completed on schedule in August 2005 and the use of the interim criteria has been phased out with the introduction of the final criteria [1, 2].DOE has concurred with the revised seismic design criteria. DOE also engaged the US Army Corps of Engineers (USACE) to review BNI’s design criteria and analytical methodology developed to address the revised ground motion. Their concurrence was received in December 2005.

The project is proceeding to implement the revised criteria in new design and is working on the effort necessary to re-assess existing design.

Alternative Cesium Ion Exchange Resin

A specific, proprietary resin is part of the design basis of the cesium ion exchange system, which is crucial in producing large quantities of feed for the LAW facility. ORP has determined that development of an alternate resin could appreciably reduce performance risk and possibly operating cost. BNI was tasked with studying options and recommending which alternative offered the best chance. Resorcinol formaldehyde (RF) was the option selected, and work has proceeded with qualifying RF as a suitable alternative. Testing to date has been very positive.

The task involved an engineering study, development of an implementation plan, and three stages of testing. The engineering study team included WTP staff, consultants, and personnel from Savannah River National Laboratory (SRNL) and the Pacific Northwest Division of Battelle (PNWD). The study began with 30 candidate resins. These were narrowed to 4 options based on their stability in the waste, non-proprietary, prior production experience of at least 75 gallons, ability to be accommodated by the existing facility, and demonstrated performance. These four were then tested and scored based on performance (40%), cost (25%), schedule (20%) and safety and environmental (15%). RF was selected as the resin most likely to meet WTP needs. A dozen varieties of RF were tested in 2003 and spherical macroporous resorcinol formaldehyde was selected for further testing in stages 2 and 3. Figure 2 depicts the spherical RF resin as compared to the SuperLig® product.



Spherical RF

Super Lig® 644

Fig. 2. Comparison of spherical RF and SuperLig® 644 ion exchange resins

The spherical RF resin offered the following advantages over other options:

- Best elution - 7x better than SuperLig® and 20x better than ground gel RF (GGRF)
- Best hydraulics
- Best mechanical durability (10x less breakdown than SuperLig®)
- Lower cost than SuperLIg®and comparable to GGRF
- Avoid the SuperLig® technical risks

Hydraulically, spherical RF showed superior performance in bed compression, percent swell (acidic to basic), bed fluidity, and chance of bed channeling after multiple cycles. Spherical RF also had greater radiation stability (lower capacity reduction after a given exposure compared to SuperLig®), and more estimated cycles to disposal (40 to 60, compared to 5 to 15 for GGRF and SuperLig®) [3]. On the downside, the spherical RF did not have the production scale-up record of GGRF.

Stage 2 testing is underway and is to demonstrate scale-up performance, confirm the ability to be produced reliably in large quantities, and qualification for commissioning. Hydraulic scale-up testing progressed from 3” to 12” to 24” (1/2 size) column diameters. Throughput scaled from the test columns indicated no WTP flow rate restrictions while meeting all Cs-137 removal requirements at the design maximum facility throughput.

Scale-up to 100-gallon lot size production has been successfully demonstrated at two facilities. The production process has been improved and cesium removal capacity has been doubled since 2004. Manufacturing variability caused by material impurities has been eliminated.

Development activities to go include produce of the 5th and 6th 100 gallon lots while verifying they meet contract requirements for cesium removal, complete mapping of acid limits to prevent resin nitration, determine the hydrogen generation rate, and complete toxicity characteristic leachate procedure (TCLP) testing. Stage 2 will complete in 2006. Stage 3 testing supports resin production for commissioning and resolves any post-commissioning information needs.

Of particular interest is the hydraulic performance of the resin. Quarter- and half-scale testing of the SuperLig product revealed difficulties and potential risks in its performance, largely caused by the irregular morphology of the resin as shown in Figure 2. Similar quarter and half-scale testing of spherical RFl resin indicated no difficulties or potential risks associated with large-scale use with the resin performance meeting all WTP needs.

The development of an alternative resin has proceeded quite successfully, and there is little concern about the remaining testing work revealing problems. Testing to date indicates the RF alternative resin is superior to the design baseline resin based on testing to date, and re-designation of RF as the design baseline is being evaluated.

Improved Analytical Methodology for HLW

In making HLW glass a key process step is taking a sample of the waste feed combined with glass former and confirming the vitrified product will meet requirements. The original design involved conventional techniques employing wet chemical dissolution processes to prepare the sample for analysis. It was recognized that advanced analytical techniques already deployed in other industries could afford marked improvement in turnaround time, reduce waste, and reduce lab personnel exposure. Because of its importance in glass qualification for disposal, the technology had to be demonstrated as sound, reliable, and defensible.

The laser ablation (LA)/inductively coupled plasma (ICP)/atomic emission spectroscopy (AES) was methodology selected for development for use in the WTP.

A comparison of the conventional chemistry and laser ablation steps is given in the Table I below:

Table I. Comparison of wet chemistry and laser ablation

Wet Chemistry (37 hours)	Laser Ablation (5 hours)
1. Sample arrives form process as a slurry to lab hotcells	1. Sample arrives form process as a slurry to lab hotcells
2. Sample is put in NaOH solution	2. If necessary, standard glass formers are added to the sample
3. Mixture is microwaved	3. Glass coupon is made
4. Mixture is dissolved in nitric acid	4. Glass is placed in laser ablation chamber in hotcell and sample is ablated
5. Mixture is diluted by 100 to 1000 to reduce exposure	5. Flowing argon gas carries the ablated material in the ICP-AES (in a glove box next to the hotcell) for analysis
6. Small portion of dilution is removed from hotcell	
7. Mixture is analyzed on ICP-AES in laboratory	

The wet chemistry process involves complex steps with opportunities for error and cross-contamination. It also entails large waste volumes and the use of aggressive chemicals. It requires direct operator handling with some direct exposure and the accuracy is diminished due to the dilution step. In contrast, laser ablation is comparatively simple and quick, does not require aggressive chemicals, and requires limited sample processing. There is no dilution, sample transfer step, or operator handling with attendant exposure.

Cold and hot method development work has been completed at SRNL and PNWD labs with very favorable results to date [4, 5], including:

- A reduction in the analytical time by a factor of 5
- Elimination of wet chemical dissolution and sample transfer wastes
- Acceptable analytical results
- A projected 90% reduction in personnel radiation exposure

Overall, what was projected to be a 37-hour process using conventional means to make the glass sample, grind it up, and analyze it has the potential to scaled back to a 5-hour or so sequence. The cost savings during operation are estimated to be considerable.

The last step in qualifying the LA/ICP/AES approach is a full hot cell demonstration. A hot cell system will be procured and actual Hanford tank waste samples will be used. A glass standards library will also be developed in this last phase.

The equipment (in a non-radioactive setup) is depicted in Figure 3 below. On the right is the laser ablation unit, which will be modified and placed in the lab hotcell in WTP Lab and in the center is the ICP-AES unit, which is interfaced to the hotcell.

Fig.3. LA/ICP/AES equipment

Cold and hot method development work has been completed at SRNL and PNWD labs with very favorable results to date, including:

- A reduction in the analytical time by a factor of 5
- Elimination of wet chemical dissolution and sample transfer wastes
- Acceptable analytical results
- A projected 90% reduction in personnel radiation exposure

Overall, what was projected to be a 37-hour process using conventional means to make the glass sample, grind it up, and analyze it has the potential to scaled back to a 2-hour or so sequence. The cost savings during operation are estimated to be considerable.

The last step in qualifying the LA/ICP/AES approach is a full hot cell demonstration. A hot cell system will be procured and actual Hanford tank waste samples will be used. A glass standards library will also be developed in this last phase.

Thin-Walled HLW Canister

An opportunity was identified to use a thinner wall HLW canister. With the same outside diameter, more waste could be placed in each container thereby reducing the total number of canisters produced in the mission and sent for permanent disposal.

Vitrified HLW product is poured into stainless steel canisters. The canisters are seal welded, undergo surface decontamination, and are temporarily stored until being sent for permanent storage in a federal repository.

The HLW glass product and waste package must be designed and tested to ensure compliance with the DOE Office of Civilian Radioactive Waste Management (DOE-RW) requirements for accepting HLW for disposal at the federal repository [6]. The HLW canisters designed for the WTP are 4.5-meters long by 0.61-meter outside diameter and contain borosilicate glass. The final waste package will weigh over

3,200 kilograms. The HLW canisters qualified by West Valley Demonstration Project (WVDP) and Defense Waste Processing Facility (DWPF) are 3.0-meters long and have the same outside diameter of 0.61-meters. The WTP canisters are therefore some 50% taller and heavier. The Waste Acceptance System Requirements Document (WASRD) defines the requirements the filled HLW package must meet for acceptance in a HLW federal geologic repository.

The baseline canister design was based on the WVDP design with a 0.95-cm (0.375”) sidewall with a top and bottom head design similar to the WVDP canister design. A key design requirement is to withstand a drop test. Analyses showed that a thinner-walled canister could withstand the drop forces as well as the thicker version. An alternate canister design was proposed that had the same top and bottom head design as the baseline, but the sidewall thickness was reduced to 0.34-cm (0.1345”). The alternate design increased the internal volume of the canister by 4%. Even though this seems small, the total number of canisters produced would be reduced by an estimated 480 canisters over the Hanford waste treatment mission. This equates to approximately one year’s operation with a considerable reduction in operating costs.

Both canisters underwent significant engineering analysis and testing to satisfy WTP design requirements, interim storage requirements, Department of Transportation requirements, and federal repository requirements. As noted above, one of the most demanding requirements with regard to the design of the canister is the WASRD, which requires the HLW canister to withstand a drop test of 7 meters onto a flat, essentially unyielding surface without breach or dispersing radionuclides. In addressing this requirement, Bechtel engineering performed computational modeling and physical testing on both HLW canister designs under the drop test condition. Computational modeling consisted of conducting finite element analysis to determine the expected strain energy density at drop impact. The acceptable performance criterion was that the strain energy density of the canister material did not exceed 90% of the strain energy density of material rupture. Computational modeling was followed by physical testing. The physical tests were conducted to complete the High Level Waste Qualification reporting requirements.

Physical testing consisted of filling, cooling, and welding the HLW canisters under prototypic conditions. The canisters were also subjected to the drop test per the WASRD criterion. The canisters were filled at Duratek’s Columbia Maryland LAW pilot plant with 1150^0C non-radioactive molten borosilicate glass and cooled prototypically. The fill and cooling conditions were monitored and controlled to match the WTP pour cave and finishing line temperatures. Once the canisters reached ambient temperature, the canister geometry was measured and documented to ensure the canisters met the straightness, cylindricity, and bulge requirements as defined by the Waste WASRD. The canisters were then shipped to SRNL where they were seal welded using a prototypic autogenous gas tungsten arc welder (spare welder obtained from WVDP and identical to the one planned for WTP). The canister was subjected to a helium leak test, as defined by the WASRD, to ensure the gas leak rate for sealing is less than $1x10^{-4}$ ref-cc/sec.

The canisters were then subjected to a 7-meter bottom drop test onto a flat unyielding surface (Figure 4). Prior to being drop tested, the canisters were etched with strain circles for determining surface strain after the drop test. The criterion utilized for measuring success after the drop test was to conduct a helium leak test for detecting any breach of the canister. The canisters underwent post-drop analysis that included straightness, cylindricity, canister geometry, and strain circle analysis for comparison to the finite element model analysis.

Both canisters passed the drop test and were shown to meet or exceed all the requirements [7]. WTP will proceed to use the thinner-walled version for production.

Fig. 4. Thin-walled canister staged for the drop test

Comprehensive External Flowsheet Review

BNI initiated a Comprehensive Flowsheet Review as requested by the DOE/ORP. Extensive support was provided in assembling a team of nationally recognized technical experts, providing logistical and coordination of the overall review effort, and by providing initial briefings on numerous WTP processes and components. Bechtel supported the technology, engineering, and operations review effort as a full time assignment of Engineering, R&T, and Operations staff specialists. Numerous requests for small group meetings and documentation have supported the review teams’ technically broad assessment of the facilities. Primary areas of interest are analytical modeling, systems design for waste evaporation, ion exchange, waste filtering, and the spatial arrangement and features of the PT and HLW black cells and hot cells. Several spatial model (3D) presentations have been made depicting the mechanical handling components of the PT and HLW cells. Both HLW and LAW melters, melter maintenance, the canister and container finishing line design have also been an area of focused review. Areas of concern, where greater depth of review has been required, have been supported with the development of technical data to supplement existing engineering and R&T documentation; examples include LAW and HLW melter pour cave capacity and presentation of mass balance flowsheet data in formats that facilitate the review process. The final report is expected in March 2006.

CONCLUSION

The challenges are real and significant, making WTP a real “work in progress” – but the response to the challenges show that solutions are in hand and ORP’s approach to proactively teaming with headquarters, BNI, and the regulators is effectively expediting the resolution and closure of the issues. Some of the recent significant works in progress have included:

- Successful conversion to a higher seismic design criteria that has minimized disruption to ongoing fabrication and construction
- Identification of a suitable alternative ion exchange resin that will reduce operational risks and costs
- Development of a superior analytical test capabilities using laser ablation/inductively coupled plasma/atomic emission spectroscopy techniques to dramatically improve HLW sample turnaround time
- Qualification of a thin-walled HLW canister design that will reduce waste volume, and
- Underwent a rigorous and comprehensive flowsheet review to confirm the adequacy and suitability of the design

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