LIFE EXTENSION OF AGING HIGH-LEVEL WASTE TANKS

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ABSTRACT

The Double Shell Tanks (DSTs) play a critical role in the Hanford High-Level Waste Treatment Complex, and therefore activities are underway to protect and better understand these tanks. The DST Life Extension Program is focused on both tank life extension and on evaluation of tank integrity. Tank life extension activities focus on understanding tank failure modes and have produced key chemistry and operations controls to minimize tank corrosion and extend useful tank life. Tank integrity program activities have developed and applied key technologies to evaluate the condition of the tank structure and predict useful tank life. Program results to date indicate that DST useful life can be extended well beyond the original design life and allow the existing tanks to fill a critical function within the Hanford High-Level Waste Treatment Complex. In addition the tank life may now be more reliably predicted, facilitating improved planning for the use and possible future replacement of these tanks.

INTRODUCTION

The Hanford Site in south central Washington State has 54 million gallons of high-level waste in 177 aging tanks. One million gallons of waste have already leaked from 67 of the older Single Shell Tank (SSTs). The present 28 DSTs have not leaked. The prevention of future leakage and potential contamination of the Columbia River is a high priority of the U.S. Department of Energy. The River Protection Project was formed to develop a Hanford Waste Treatment Complex that will retrieve, treat, and safely dispose of the Site's high-level waste.

Hanford's low-carbon steel DSTs are key to retrieval, treatment, immobilization and disposal efforts that are currently planned for the next 30-50 years. These newer million gallon tanks now store over 20 million gallons of high-level waste. The DSTs are the staging tanks that will supply waste feed to the Waste Treatment Plant to produce an immobilized waste form for safe long-term storage. As the DST waste volume is retrieved for treatment the waste from the older

SSTs will be retrieved and transferred to the DSTs. The mobilized, diluted SST waste will represent an additional 100 million gallons to be transferred through the DSTs.

It is therefore essential that the useful life of the DSTs be fully understood for the planning baseline and that the useful tank life is extended as much as practicable to support the needs of the Hanford Waste Treatment Complex. The River Protection Project is accomplishing these objectives under a corrosion mitigation program that includes primarily tank integrity inspections, assessments, and chemistry control.

DST INTEGRITY ASSESSMENTS

The DSTs were built in six increments starting in 1968 and continuing through 1986, with various design parameters (see Table I). Over the years, the measurement and recording of actual DST parameters and conditions has been spotty and inconsistent, starting as far back as the new construction phase. For example, the actual as-built tank wall thickness measurements were never recorded, and the ongoing tank wall conditions for both the interior primary tank wall (in contact with the high-level liquid wastes), and the annulus side wall (in contact with the atmosphere and cooling air flows) were never systematically evaluated. Due to the programmatic need to extend many of these tanks well beyond their original design life, a robust program of tank integrity inspections, assessments, and chemistry control has been undertaken. The purpose is to both create a tank condition baseline to measure future changes against, and to provide detailed information for engineering assessments which may lead to changes in tank operating parameters or programmatic direction.

Table I. Hanford Double Shell Tank History and Design Parameters

Tank Farm→	**AY**	**AZ**	**SY**	**AW**	**AN**	**AP**
Constructed	1968-70	1971-77	1974-76	1978-80	1980-81	1983-86
Number of Tanks	2	2	3	6	7	8
Design Life (yrs.)	30-40	20-30	50	50	50	50
Years in Service	30	25	24	21	20	15
Initial Service	mid-1971	late-1976	1977	mid-1980	1981	1986
Type of Steel	A515	A515	A516	A537	A537	A537
Capacity (Mgal.)	1	1	1.162	1.162	1.162	1.162
Max. Waste Depth –ft	30.3	30.3	35.2	35.2	35.2	35.2
Max. Specific Gravity	1.6	1.6	1.7	2	2	2
Max. Heat (Btu/hr)	4,000,000	4,000,000	50,000	100,000	100,000	100,000

The DST Integrity Program generally follows the guidelines for structural integrity programs for tank systems (1), which were developed from 1994–1997 by a committee of experts who have become known as the Tank Structural Integrity Panel (TSIP). The TSIP guidelines advocate a structured approach to assessing structural integrity as a basis for identifying necessary management options to ensure leak tightness and structural adequacy over the life of the tanks' mission. This was augmented in May 2001 by the convening of the DST Life Extension Workshop at Pacific Northwest National Laboratory (PNNL). An Expert Panel (EP) was formed from key participants in the Life Extension Workshop to perform additional review and evaluation. The

DST Life Extension Workshop and the subsequent EP meetings performed a comprehensive, expert review and assessment of all pertinent technical information associated with DST operations and inspections relative to DST corrosion concerns. Additionally, the EP provided pertinent, prioritized recommendations (2) that, if implemented, should maximize the potential for extending DST useful life to support Hanford's mission needs.

Non-destructive Testing/Evaluation

The tank integrity baseline assessments are being accomplished primarily through ultrasonic testing (UT) and visual/video examination (VT). The UT is accomplished in the annulus region, and the VT is done both in the annulus and tank interior. All this testing must be done remotely due to the hazardous nature of tank contents, the high radiation fields associated with the waste (DSTs contain a total of about 80 MCi of ^{90}Sr and ^{137}Cs), and the space restrictions for access to the tank interiors and annulus regions. Meeting these special remote entry requirements and size constraints has required the development and procurement of specialized and unique equipment.

Small video cameras with pan and tilt extension arms (designed to fit through a 4" tank riser) are used in the tank interior and annulus regions. The cameras are capable of extended operation in a 250 R/hr. radiation field, and have provisions for cooling and minimization of contamination. Robotic crawlers have been developed to carry UT (plus a video camera for positioning) equipment into the annulus through 24" and 12" risers, and then to traverse horizontally and vertically along the vertical tank walls. A magnetic wheeled robotic crawler carrying a UT instrument, with a recently deployed strap extension, to reach the bottom curved portion of the tank (knuckle), is shown in Figure 1 below:


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Fig. 1. Crawler Robot with P-Scan Ultrasonic Tester and Transducer Extension Arm.

However, several challenges still remain for implementation of a comprehensive tank UT inspection: a) the magnetic crawler P-scan transducers cannot reach the predicted highest stress region of the lower knuckle, b) there is very limited access (slots in the cement base) for tank bottom UT inspection, c) walls with severe corrosion cannot be inspected, and d) pit depth on the annulus side can not be readily measured. Solutions to these problems are well underway as described below.

A new, specialized UT device (tandem-synthetic aperture focusing technique or T-SAFT), is being developed for DST use through a collaborative effort with the U.S. Department of Energy EM-50 Tanks Focus Area (TFA) program. The T-SAFT device essentially "sees" around the bend in the knuckle for detection of cracks (i.e., stress-corrosion cracking), and is projected to be in service at Hanford in late Fiscal Year (FY) 2002 or early FY 2003. An existing bottom tank crawler is being modified to provide more accessibility to the ventilation slots in the concrete bottom pad, allowing UT measurements along the tank bottom, and is also expected to be operational in FY 2002. A hydro-blast equipped robot crawler, capable of removing rust from the annulus surfaces, has been used in the heavily rusted regions of DST 241-AY-101. Additionally, a laser based device (capable of mounting on the magnetic crawler) for measuring annulus side corrosion pit depth is being prepared for selective post-cleaning utilization.

An alternative or supplemental technology to UT inspections, which is currently under consideration, is Electro-Magnetic Acoustic Transducer (EMAT) inspection. The present UT scans of tank walls generally only examine about 1% of the total surface area. EMAT technology has the potential to screen larger portions of the tank surface, even over corroded regions, compared with current UT methods. This could reveal areas of potential concern (e.g., wall thinning from localized corrosion) for application of the more precise UT scan. EMAT technology is being developed for tank inspection use through another EM-50 TFA initiative.

UT and Visual Examination Results

The DST visual and UT technical baseline efforts are well underway and when completed, will be repeated on a 5-year cycle. At the end of FY 2001, 12 of the 28 DSTs had been UT surveyed, and 8 DSTs were video inspected. The UT inspections have detected four instances of notable localized pitting or crevice-like corrosion at previous waterlines (AN-102, AN-105, AP-108 and AY-101), along with the detection of a significant original construction defect (a crack-like indication in AP-108) that will be periodically re-inspected to assess if there is any growth. The video examinations have shown notable corrosion on the inner tank dome surfaces, as well as significant annulus corrosion in AY-101 along with an interior stain that potentially could be the result of a pinhole leak. The interior stain and the annulus corrosion are shown in Figure 2.

Fig. 2. Interior stain (left) and Annulus Corrosion (right) in DST AY-101.

A recent engineering study of DST annulus ventilation, and recent video inspection results on tanks with long-term inoperable annulus ventilation systems (e.g., 7 year outage in AY-101), confirm the importance of maintaining operational annulus ventilation systems to avoid significant tank wall corrosion and prolong tank life. A change is being made to the Hanford Tank Farms Technical Safety Requirements (TSR) to incorporate an administrative control requiring an operable DST annulus ventilation system. The UT and visual inspection results show notable interior tank wall pitting and thinning from waterline corrosion, also highlight the importance of maintaining DST waste chemistry within specification; which will be discussed in more detail in the next section.

DST WASTE CHEMISTRY CONTROL

The Hanford process waste liquids were generally adjusted to a pH >10 prior to discharge into the SSTs. Nitrate-induced Stress Corrosion Cracking (SCC) in the Savannah River Site (SRS) non-stress relieved SSTs, and the subsequent investigation in the 1970s established early chemistry limits to control SCC.

The DSTs were originally designed to operate with their contents at pH 8-14. These chemistry limits were based on the SRS work. The SRS work determined that the corrosion of low carbon steels, like those used in the construction of the DSTs, was dependent on the concentrations of hydroxide $[OH^-]$, nitrate $[NO_3^-]$, and nitrite $[NO_2^-]$ anions in the liquid waste. Additionally, it was determined that carbonate, phosphate, sulfate, silicate, fluoride, and chloride constituents in low concentrations had little effect on corrosion potential.

However, in the early 1980s, during preparation of the Environmental Impact Statements (EIS) for DSTs in the AW and AN tank farms, it was found that the available corrosion data did not adequately describe all wastes proposed for storage in the DSTs. Also, the chemistry limits had to be adjusted to keep hydroxide-to-nitrite ratios within the acceptable range as the wastes were concentrated in the Hanford 242-A evaporator. This DST waste chemistry adjustment was accomplished by adding caustic (concentrated sodium hydroxide solution) to the supernatant.

In response to these EIS findings, an extensive experimental data development task was initiated at PNNL. This program generated several thousand corrosion test coupons exposed to non-radioactive chemical simulants representing waste compositions consistent with known and expected waste chemistry ranges (3). The results of these coupon tests showed that, in general, corrosion outside the DST design limits was observed only in very dilute nitrite and hydroxide solutions and in high-concentration hydroxide solutions at elevated temperatures. Also, SCC was observed only on highly stressed U-bend specimens in solutions with high nitrate and low hydroxide concentrations or in high hydroxide solutions at high temperatures.

Based on this work, new chemistry control limits were set in 1984. However, supplemental work at PNNL in 1994 identified that the presence of nitrite $[NO_2^-]$ was important even when there were low concentrations of nitrate $[NO_3^-]$. As a result, the chemistry limits were modified to include the ratio of nitrate to hydroxide plus nitrite in dilute regions. The present chemistry limits used for the DST corrosion control are summarized in Table II.

Table II. Current Hanford DST Waste Chemistry Limits

$[NO_3^-]$ Range	**Parameter**	**Waste Temperature Range (°F)**		
		T < 167	**167 ≤ T ≤ 212**	**T > 212**
$[NO_3^-] \le 1.0\underline{M}$	$[OH^-]$	$0.01\underline{M} \le [OH^-] \le 8\underline{M}$	$0.01\underline{M} \le [OH^-] \le 5\underline{M}$	$0.01\underline{M} \le [OH^-] < 4\underline{M}$
	$[NO_2^-]$	$0.011\underline{M} \le [NO_2^-] \le 5.5\underline{M}$		
	$[NO_3^-]/([NO_2^-] + [OH^-])$	< 2.5		
$1.0\underline{M} < [NO_3^-] \le 3.0\underline{M}$	$[OH^-]$	$0.1([NO_3^-]) \le [OH^-] < 10\underline{M}$		$0.1([NO_3^-]) \le [OH^-] < 4\underline{M}$
	$[OH^-] + [NO_2^-]$	$\ge 0.4([NO_3^-])$		
$[NO_3^-] > 3.0\underline{M}$	$[OH^-]$	$0.3\underline{M} \le [OH^-] < 10\underline{M}$		$0.3\underline{M} \le [OH^-] < 4\underline{M}$
	$[OH^-] + [NO_2^-]$	$\ge 1.2\underline{M}$		
	$[NO_3^-]$	$\le 5.5\underline{M}$		

Maintaining the correct waste chemistry minimizes general corrosion, pitting corrosion, and any potential for SCC in these stress-relieved DSTs. Unfortunately, in the past, there were many instances where DST waste chemistry was allowed to remain out of specification for extended periods of time (e.g., in the worst case, DSTs AN-102 and AN-107 were out of specification for 17 years). No action was taken to return tanks minimally outside of their chemistry specifications although it was realized that this would potentially decrease tank life. Over the last decade limited resources were prioritized to resolving immediate safety issues and implementing a high-level waste treatment capability allowing the tanks to be retrieved and ultimately closed. Long-term risk mitigation activities, such as adjustment of minimally out of specification tank chemistry, were therefore not funded in favor of the resolution of immediate risks.

The DSTs were constructed of good alloys, with thick, stress relieved walls, which appear to have weathered this past neglect. However, if the DSTs are to remain viable for the expected duration of the mission, waste chemistry must be maintained within specifications in accordance with Table II. DST waste chemistry compliance to specifications is now a Technical Safety Requirement (TSR) in recognition of its importance. These protective TSR level controls are coupled with requirements for frequent sampling and analysis of tank chemistries, to verify both compliance and the effect of any chemical additions that have been made to adjust chemistry. Furthermore, there has been work performed to increase the accuracy of caustic depletion models that predict when tanks will become out of specification. This predictive basis will support proactive management; it will facilitate timely planning and budgeting to ensure tank chemistry is maintained in specification.

ADDITIONAL DST LIFE EXTENSION OPTIONS

The EP made several additional recommendations (2) and options for DST life extension, and these are being pursued and evaluated. These options to be accomplished in FY 2002 include:

- Continued development of Electrochemical Noise (EN) probes for direct, real time, detection of in-tank corrosion. [This is an EM-50 TFA project that has already had several in-tank EN probe assemblies in place at Hanford (see Figure 3).]
- Develop DST repair technologies and options, such as weld repair, epoxy patches, and mechanical plugs. This is also an EM-50 TFA sponsored program being led by the Savannah River Site.
- Develop a waste heel lay-up procedure to ensure that pumped down tanks remain free of corrosion.
- Evaluate the modifications necessary to inhibit dilute additions (e.g., condensate return water, piping flush water, etc.) to the DST waste.
- Continue development and deployment of T-SAFT and EMAT (as discussed in the UT section above).

Fig. 3. Third generation EN probe design used in DST AN-105.

The above listings are just a sampling of the recommendations under development and evaluation, and Reference 2 contains a complete description of these life extension options. The EP will reconvene to review new test and evaluation data, newly developed models and test results for natural mixing mechanisms (for caustic to enter into the sludge/salt-cake layers at the tank bottom), and the feasibility of longer term studies to better define SCC on the extended time scale the DSTs will need to remain in service.

CONCLUSION

The DST Life Extension Program has two key goals: 1) maximize the useful life of the DSTs and 2) evaluate DST integrity to accurately predict useful tank life. Program results to date indicate that the useful life of the tanks can be extended beyond their design life. These tanks can therefore provide an extended waste receiving and staging function for the Hanford High-Level Waste Treatment Complex. The DST Life Extension Program is also developing the necessary capabilities to baseline tank integrity and extrapolate out to derive expected tank life. This will allow the Hanford High-Level Waste Treatment Complex to accurately plan for the use of and the potential replacement of these critical DSTs over the course of High-Level Waste retrieval and treatment at the Hanford Site.

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