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Revision 0

Overview of Hanford Single Shell Tank (SST) Structural Integrity - 12123

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-08RV14800

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ABSTRACT

To improve the understanding of the single-shell tanks (SSTs) integrity, Washington River Protection Solutions, LLC (WRPS), the USDOE Hanford Site tank contractor, developed an enhanced Single-Shell Tank Integrity Project in 2009. An expert panel on SST integrity, consisting of various subject matters experts in industry and academia, was created to provide recommendations supporting the development of the project. This panel developed 33 recommendations in four main areas of interest: structural integrity, liner degradation, leak integrity and prevention, and mitigation of contamination migration. Seventeen of these recommendations were used to develop the basis for the M-45-10-1 Change Package for the Hanford Federal Agreement and Compliance Order, which is also known as the Tri-Party Agreement.

The structural integrity of the tanks is a key element in completing the cleanup mission at the Hanford Site. There are eight primary recommendations related to the structural integrity of Hanford SSTs. Six recommendations are being implemented through current and planned activities. The structural integrity of the Hanford SSTs is being evaluated through analysis, monitoring, inspection, materials testing, and construction document review.

Structural evaluation in the form of analysis is performed using modern finite element models generated in ANSYS®. The analyses consider in-situ, thermal, operating loads and natural phenomena such as earthquakes. Structural analysis of 108 of 149 Hanford SSTs has concluded that the tanks are structurally sound and meet current industry standards. Analyses of the remaining Hanford SSTs are scheduled for FY2013.

Hanford SSTs are monitored through a dome deflection program. The program looks for deflections of the tank dome greater than ¼ inch. No such deflections have been recorded. The tanks are also subjected to visual inspection. Digital cameras record the interior surface of the concrete tank domes, looking for cracks and other surface conditions that may indicate signs of structural distress.

The condition of the concrete and rebar of the Hanford SSTs is currently being tested and planned for additional activities in the near future. Concrete and rebar removed from the dome of a 65-year-old tank is being tested for mechanics properties and condition. Results indicated

stronger than designed concrete with additional Petrographic examination and rebar testing ongoing. Material properties determined from previous efforts combined with current testing and construction document review will help to generate a database that will provide continuing indication of Hanford SST structural integrity.

INTRODUCTION

The Hanford Single-Shell Tank Integrity Project (SSTIP) was developed as a means to implement Single-Shell Tank Integrity Expert Panel (Panel) recommendations related to structural integrity, leak integrity, leak identification and prevention, and mitigation of contaminant migration. The structural integrity of Hanford Single-Shell Tanks (SSTs) is not a current concern, but is a sensitive topic that spans decades back before Hanford Double-Shell Tanks (DSTs) were constructed. The large number (count = 149) of SSTs and varying operating histories places a great deal of emphasis on the unknowns associated with these buried reinforced concrete structures. The SSTIP activities implementing Panel recommendations look to develop a better understanding of the structural integrity of Hanford SSTs.

SST STRUCTURES

Hanford Single-Shell Tanks are either 20-ft diameter (200-series, count = 16) or 75-ft diameter (100-series, count = 133) reinforced concrete structures, buried underground on the Hanford Site. The SSTs are typically recognized by their alphanumeric identifier containing the facility designation, farm name, and tank number.

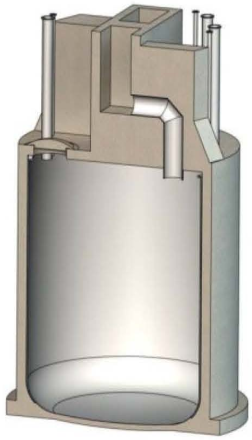
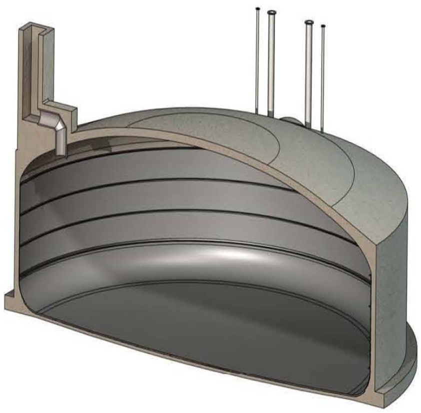
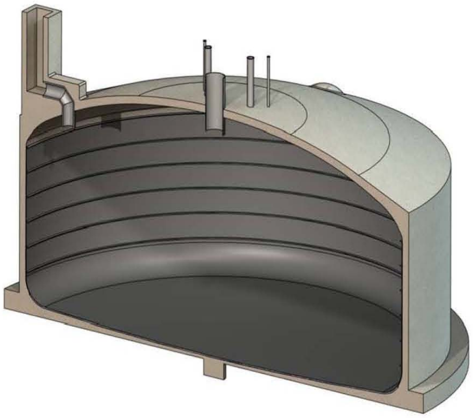
For example: 241-C-106

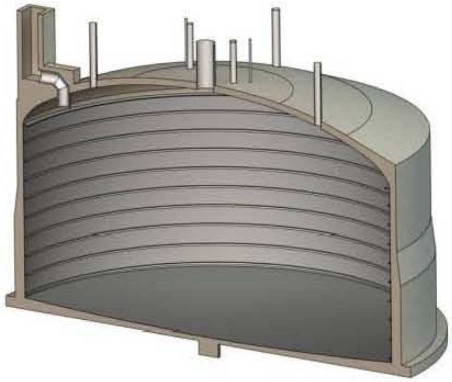
Where:

- 241 is the facility designation for Waste Storage Tank (WST)
- C is the identifier C-farm
- 106 is the number, identifying it as 100-series, or 75-ft diameter SST

From a structural perspective, the SSTs are broken down into tank types, relating to the age and design of the structures. There are 4 types of SSTs and 3 subtypes of the Type IV SSTs. The Type I tanks reflect the original design of the SSTs. Production facilities generated more waste than originally anticipated and required more disposal capacity than the Type I tanks could afford. This led to the construction of the 75-ft diameter Type II tanks. The 75-ft diameter size was not changed after that. Increased need for storage after that led to the construction of more, taller tanks (Type III and IV SSTs). Table 1 provides descriptions of the SST structures.

Table 1. Single-Shell Tank Structure Details

	Type I Single-Shell Tank: • Diameter = 20-ft • Height = 25-ft 7-in • Wall Thickness = 12-in • Footing Thickness = 18-in • Concrete design strength = 3000-psi • Rebar yield strength = 40,000-psi • Capacity = 55-kgal
	Type II Single-Shell Tank: • Diameter = 75-ft • Wall Height = 21-ft • Wall Thickness = 12-in • Dome Height = 8-ft 8-in • Dome Thickness = 15-in • Footing Thickness = 24-in • Concrete design strength = 3000-psi • Rebar yield strength = 40,000-psi • Capacity = 530-kgal
	Type III Single-Shell Tank: • Diameter = 75-ft • Wall Height = 27-ft • Wall Thickness = 15-in • Dome Height = 8-ft 8-in • Dome Thickness = 15-in • Footing Thickness = 24-in • Concrete design strength = 3000-psi • Rebar yield strength = 40,000-psi • Capacity = 758-kgal

<table>
<tr>
<td></td>
<td>Type IVa Single-Shell Tank:

• Diameter = 75-ft
• Wall Height = 35-ft 8-in
• Upper Wall Thickness = 15-in
• Lower Wall Thickness = 24-in
• Dome Height = 8-ft 9-in
• Dome Thickness = 15-in
• Footing Thickness = 23-in
• Concrete design strength = 3000-psi
• Rebar yield strength = 40,000-psi
• Capacity = 1000-kgal</td>
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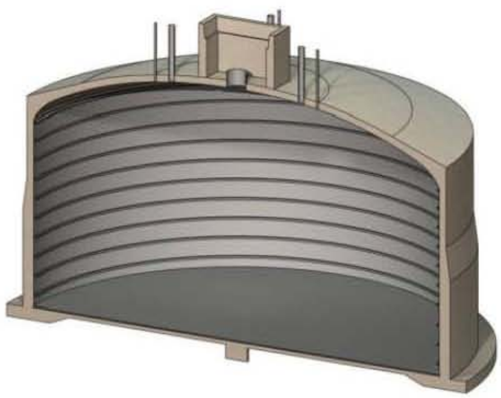
<td></td>
<td>Type IVb Single-Shell Tank:

• Diameter = 75-ft
• Wall Height = 37-ft
• Upper Wall Thickness = 15-in
• Lower Wall Thickness = 24-in
• Dome Height = 8-ft 9-in
• Dome Thickness = 15-in
• Footing Thickness = 24-in
• Concrete design strength = 3000-psi
• Rebar yield strength = 40,000-psi
• Capacity = 1000-kgal</td>
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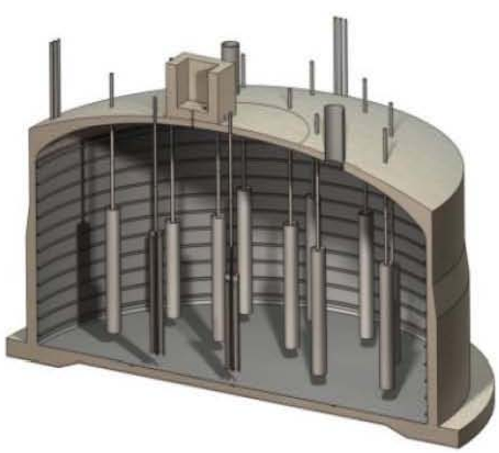
<td></td>
<td>Type IVc Single-Shell Tank:

• Diameter = 75-ft
• Wall Height = 38-ft
• Upper Wall Thickness = 15-in
• Lower Wall Thickness = 24-in
• Dome Height = 6-ft 9-in
• Dome Thickness = 15-in
• Footing Thickness = 36-in
• Concrete design strength = 4000-psi
• Rebar yield strength = 40,000-psi
• Capacity = 1000-kgal</td>
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STRUCTURAL INTEGRITY RECOMMENDATIONS

The Single-Shell Tank Integrity Expert Panel presented the Tank Operations Contractor (TOC) with a series of recommendations to develop an enhanced Single-Shell Tank Integrity Project. Eight of the Panel recommendations focused on structural integrity. The Panel prioritized their recommendations, SI-1 as most important.

The following is a list each of the original structural integrity recommendations and provides a brief description of the intent.

- **Recommendation SI-1, Perform Modern Structural Analyses:** The Panel recommends performing modern structural analyses (including seismic) on representative samples of SSTs. Such analyses are necessary to understand the structural integrity of the SSTs during a seismic event. The analysis will be useful in answering the following questions: How much rebar must remain to achieve adequate structural integrity under a major seismic event? What is the level of confidence that at least this amount of rebar cross-sectional area exists and will remain present for the operating life of the tanks (e.g., 20 to 50 additional years)? What is the minimum required concrete strength?
- **Recommendation SI-2, Perform Dome Deflection Surveys:** The Panel recommends continuation of the current dome deflection survey program. The program should be augmented to obtain dome deflection data near the haunch of the domes. The dome surveys are important as any future potential for dome collapse would be preceded by excessive downward dome deflection. The haunch data is important to determine whether dome deflections are due to downward displacement of the dome or of the footing under the sidewall.
- **Recommendation SI-3, Obtain and Test Sidewall Core:** The Panel recommends obtaining and testing a vertical core from the entire depth of the sidewalls for two tanks that have leaked and had been operated at high temperatures for extended periods. Such cores will provide important data about the structural condition of concrete and rebar in the sidewalls.
- **Recommendation SI-4, Perform Non-Destructive Evaluation of Concrete:** The Panel emphasizes the importance of the hierarchical aspect of this recommendation. Initially, the Panel recommends the application of two technologies: (1) visual inspection of domes to identify cracks in excess of 1/16 inch wide, rust stains on the concrete, or spalling of concrete, and (2) utilization of a 'thumper' truck to determine the modulus of the dome concrete. The modulus correlates with concrete strength and controls the degree of deformation that will occur under loading.

  Further development and deployment of non-destructive evaluation technologies such as guided wave propagation should occur in the event initial SSTIP activities (e.g., visual inspection, modeling, vertical core results) indicate potential concrete degradation.

- **Recommendation SI-5, Test Dome Concrete and Rebar 'Plugs':** Current plans call for the cutting of holes in the SST domes to facilitate the use of retrieval equipment. The Panel recommends the following tests on concrete and rebar 'plugs' removed from domes during cutting: (1) concrete compression and bend tests; and (2) rebar diameter measurement and tensile tests. These tests will provide an opportunity to obtain data on the condition of the dome concrete and rebar.
- **Recommendation SI-6, Develop Engineering Mechanics Document:** The Panel recommends the development and up-to-date maintenance of a living document containing the best current understanding of engineering mechanics properties of each tank. Such a document is an important reference in understanding both the current and future structural integrity of the SSTs and will be useful in defining input information for future tank evaluations.
- **Recommendation SI-7, Test Effects of Waste Exposure on Structural Integrity:** The Panel recommends measuring the physical and mechanical properties of concrete exposed for more than 28 days to simulated waste. Based on these measurements, the effects of waste/concrete/rebar reactions and temperature on the structural integrity of the tank walls should be estimated. These tests will assist in determining whether liquid waste that has leaked through the steel liner and the concrete walls could have damaged the concrete and rebar.
- **Recommendation SI-8, Study the Deployment of Corrosion Potential Mapping:** The Panel recommends studying the feasibility of performing corrosion potential measurements to assess the condition of rebar in the SSTs. If potential mapping can be successfully deployed, it has the potential to detect active corrosion.

STRUCTURAL INTEGRITY IMPLEMENTATION

The Tank Operations Contractor, Washington River Protection Solutions (WRPS) programmatically reviewed the eight structural integrity recommendations in consultation with the U.S. Department of Energy (DOE). It was decided that all but two structural integrity recommendations would be implemented into the SSTIP.

The two recommendations were not selected partly because of lack of tank access, and partly because WRPS wanted to provide sufficient resources to the recommendations that would be implemented. The basis provided for not implementing SI-7 and SI-8 is as follows:

- **Recommendation SI-7, Test Effects of Waste Exposure on Structural Integrity:** This recommendation is not being pursued at this time. The data collected previously is deemed adequate in conjunction with the work being done to collect a core sample from 241-A-106. The data from this core along with data from 241-SX-108 and 241-SX-115 will provide a basis for estimated concrete properties.

- **Recommendation SI-8, Study the Deployment of Corrosion Potential Mapping:** This recommendation is not being pursued at this time. To deploy this system would require additional development. If the concrete integrity has been maintained, the rebar will not degrade. Should concrete degradation be identified as a potential risk, then work on rebar integrity would be pursued.

STRUCTRAL INTEGRITY ACTIVITES

SI-1, Perform Modern Structural Analyses

WRPS subcontracted Pacific Northwest National Laboratories to perform the SST Analysis of Record (AOR). The AOR is being performed in a two phase approach. The initial phase consists of researching construction and operating histories, performing preliminary analysis to understand the extent of analysis to be performed, and developing structural evaluation criteria based on requested information, consensus standards, and required analytical methods. A second phase consists of performing detailed finite element modeling and analysis for each SST type. A report is to be generated per tank type, providing insight into the structural integrity of the SSTs based on known or assumed conditions. Figure 1 displays a 180 degree view of an SST finite element model that is used to perform the AOR. The view in Figure 1 shows different colored layers (or sections) of finite elements utilized in performing structural analysis.

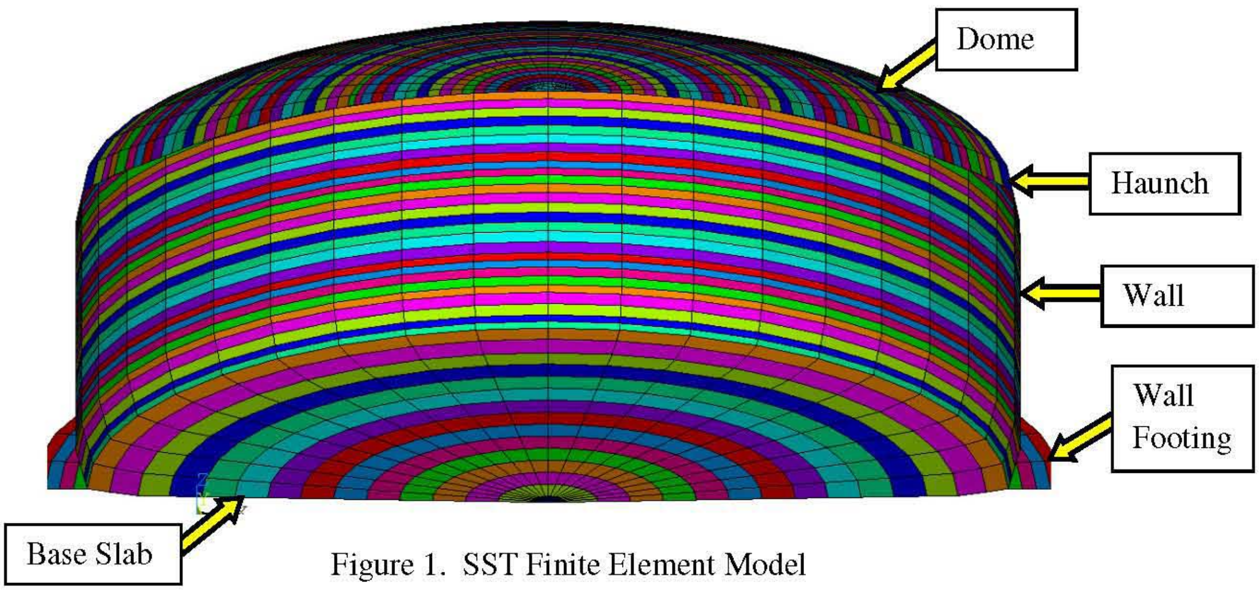

Figure 1. SST Finite Element Model

The modern finite element analyses consider the effects of dead, live, thermal, and operating loads, in addition to natural phenomena hazards including earthquakes. The SST AORs include additional performance indicators such as limit load analyses and tank dome and wall buckling analyses. The SST AORs also evaluate the effects of dome penetrations appurtenances, such as large concrete boxes or pits above the dome. The analytical models include the reinforced concrete SST structures and the surrounding soil. A matrix of concrete, soil, and waste configurations was utilized. Each AOR report is peer review by recognized industry experts. To date, the AORs have been completed for the Type II and Type III SSTs. Peer reviewers of the Type II and III analyses have agreed with the results and conclusions that based on the assumed condition of the concrete, the tanks are structurally sound. The AOR, coupled with results from other implemented structural integrity recommendations will provide a basis for determination of SST structural integrity.

SI-2, Perform Dome Deflection Surveys

The existing SST dome surveys are conducted per RPP-26516, *SST Dome Survey Program*. The program requires that all SSTs will be evaluated on a 24 month cycle ± 2 months. Action is required if a deflection in excess of ¼ inch is identified. The handling and processing of SST dome survey data is per TFC-ENG-FACSUP-C-10, "Control of Dome Loading."

Recent evaluation of the dome survey program identified some deficiencies that have been documented in the Problem Evaluation Request, CH2M-PER-2007-2302. As a result of the problem evaluation request (PER), Engineering has prepared a benchmark matrix which specifically identifies the benchmark deficiencies and required repairs. This work is in progress. WRPS has completed all monument installations, benchmark (riser and pit tab) installations for 241-A, AX, C, B, and BY farms. Benchmark installations scheduled to be completed in FY2012 for 241-SX, S, U and TX farms.

To date, there are no SST dome surveys that indicate the tank structures are approaching the deflection criteria, thus no distress is detected.

SI-3, Obtain and Test Sidewall Core

WRPS technical staff has identified 241-A-106 as the next SST that will be sidewall cored. Although 241-A-106 is a sound tank, it was selected because it has the highest thermal operating history of the SSTs. Because concrete degradation is linked with high thermal operation, 241-A-106 should provide a bounding case for sidewall coring that meets the intent of the Panel's recommendation. Figure 2 shows a brief segment of the thermal history of SST 241-A-106, showing peak temperature of 594º F and 80+ month duration over 300º F.

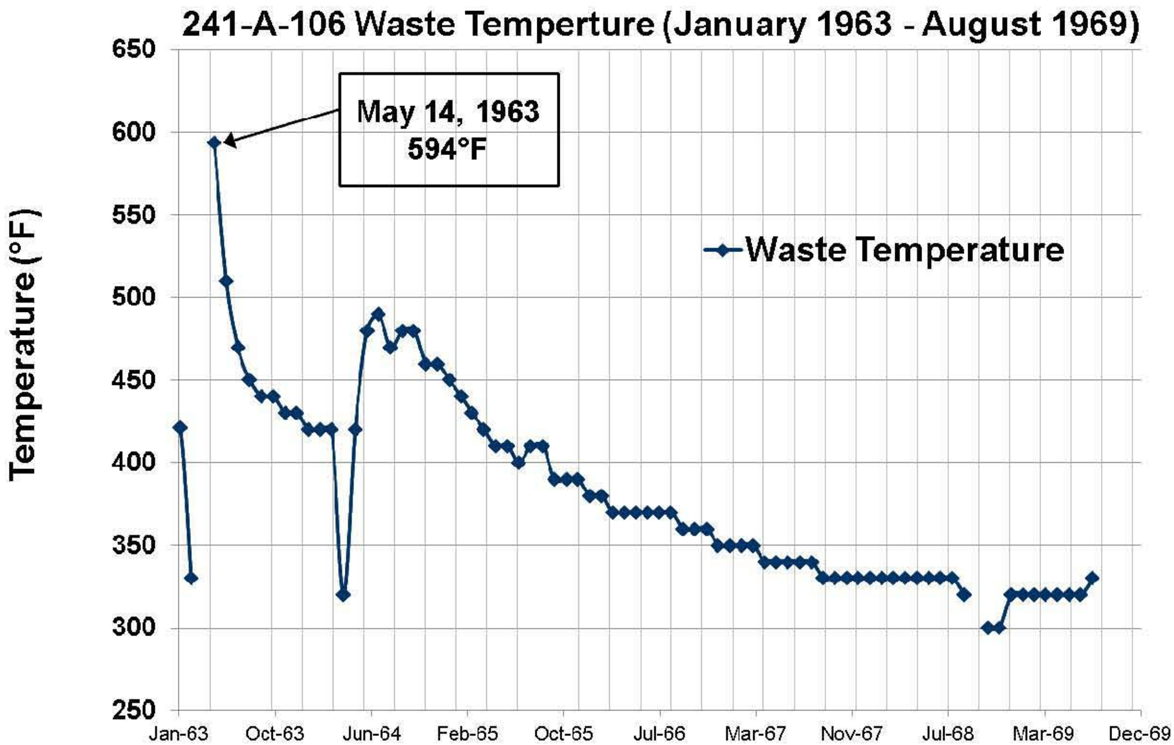

Figure 2. SST 241-A-106 Thermal Profile

The goal of the SST Sidewall Coring activity is to remove intact cores for the entire depth of the sidewall, and half of the footing. The cores will be transported to a qualified testing laboratory and undergo mechanic testing and Petrographic examination similar to the 241-C-107 Cores mentioned further in this paper. This activity is planned to be performed from above the ground surface. The sidewall coring activity will require excavation down to the top of the tank wall, placement of a caisson, securing a guide tube to the tank, and mobilization of the drill rig and associated cooling water recirculation system. Figure 3 shows the planned configuration for sidewall coring.

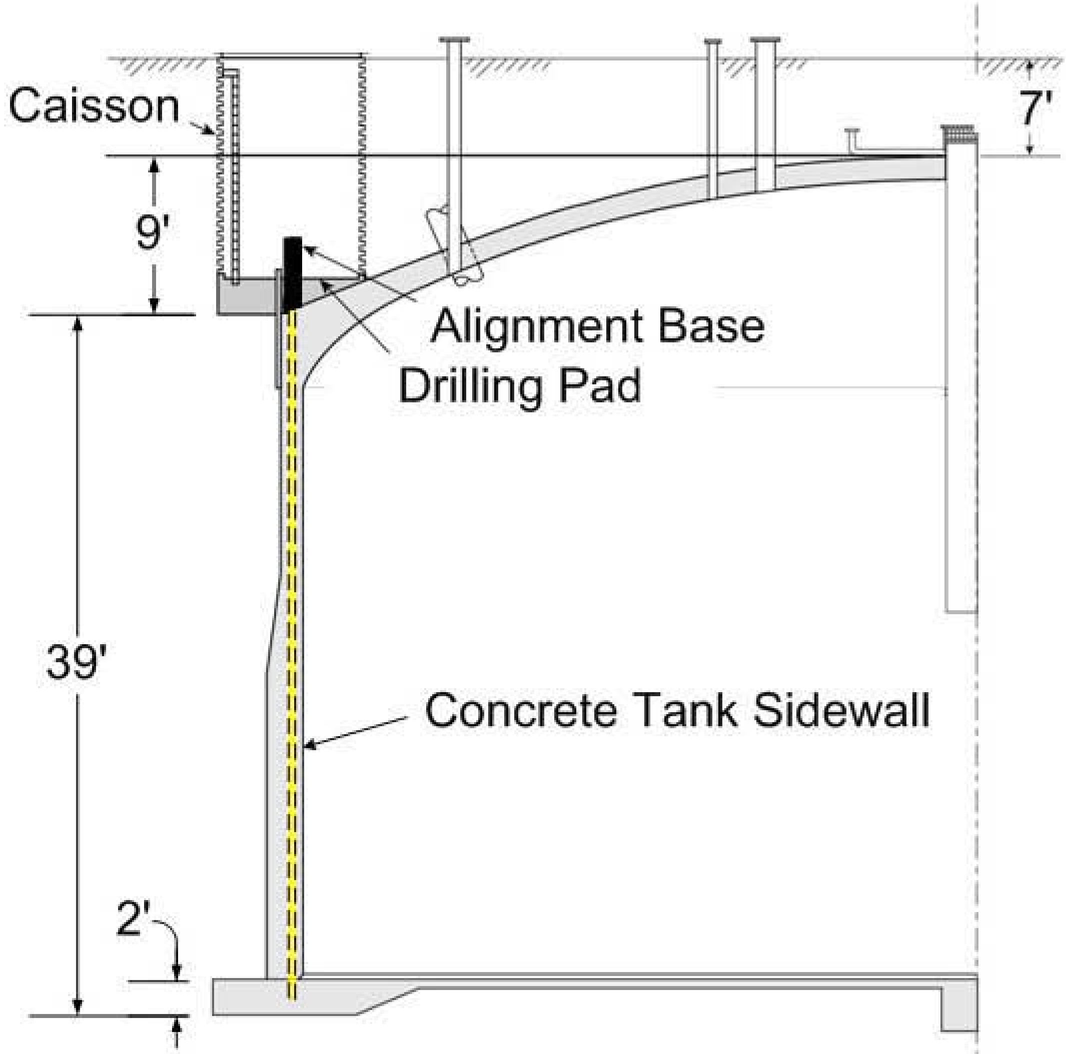

Figure 3. A-106 (Type IVb) SST Sidewall Coring Schematic

To accomplish this, WRPS has hired Energy Solutions to perform SST sidewall coring. Criteria were developed such that the coring activity would not adversely affect the leak or structural integrity. A 4-in core barrel was selected and a 2-in clearance was identified, to keep the core barrel away from the horizontal wall rebar. Figure 4 shows a section of SST 241-A-106, with the 4-in diameter core barrel superimposed, highlighting the clearance.

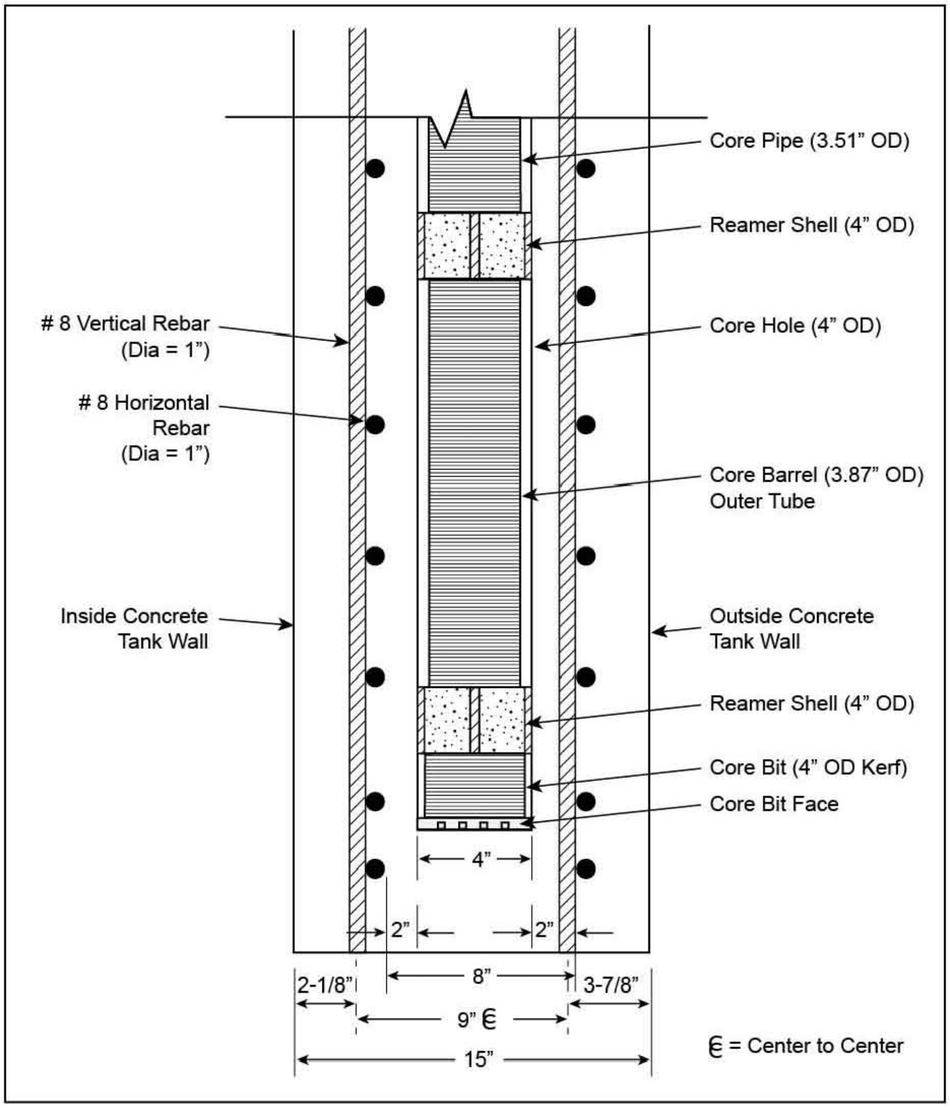

Figure 4. SST Sidewall Coring Wall Cross-Section

The intent of the coring demonstration is to core a reinforced concrete wall, having similar construction characteristics to the Type IVB SST tank sidewalls intended to be cored during Phase 2. The key objective is to prove (by demonstration) that vertical core requirements can be obtained and maintained. The objectives of the concrete coring demonstration are as follows:

- Demonstrate that the coring method and tooling can successfully core and retrieve concrete samples;
- Demonstrate how the prefabricated alignment base serves as a starter for installing the guide casing and support the ability to control vertical axis deviation;
- Demonstrate that the core hole Z axis depth readings can be accurately measured;

- Demonstrate the X-Y axes verticality of the cored hole can be maintained within calculated tolerances to prevent the bit from breaking out through the concrete wall or cutting of horizontal hoop rebar;
- Demonstrate that the coring fluid circulation system provides for adequate hole cleaning; and
- Demonstrate that the coring fluid can be controlled, contained, and with minimal waste volume produced.

All demonstration objectives were met. The selected coring method proved to be extremely successful in retrieving intact core suitable for strength testing and was able to achieve and maintain vertical alignment within the required deviation tolerances. The maximum allowable vertical angle of deviation as specified in the Plan is 0 degrees, 10 minutes, 25 seconds (0°, 10', 25"). The calculation for this angle is based on a completed core hole with a depth of approximately 55 ft from ground surface (~ 38 ft of SST concrete wall and 17 ft of guide tubing) and a maximum allowable horizontal deviation of 2 in. at total depth. For the demonstration, a total of 33.31 ft of concrete was cored and recovered. The final depth of the core hole measured from the top of diverter was 38.6 ft (includes 5.29 ft of guide tubing). The final vertical angle of deviation was 0 degrees, 3 minutes, 41 seconds (0°, 03', 41"), with a final horizontal deviation measured at approximately 0.42 in. Extrapolating the measured angle of deviation to a 55 ft deep core hole, the horizontal deviation would measure 0.707 in. Both the vertical angle of deviation and the horizontal deviation of the demonstration core hole are well within the limits specified by the plan, RPP-PLAN-47370. The verticality surveying method was implemented effectively and equipment proved to be easy to operate and successfully demonstrated the ability to accurately measure and verify verticality of the core hole.

The initial design of the drilling fluid circulating system did not perform as expected and had to be modified to achieve the desired controls. The reconfiguration of the circulating system resulted in full containment and control of the circulating fluid and allowed for excellent hole cleaning.

The demonstration is considered a success in meeting all objectives and supports the decision to move forward with Phase 2 to obtain vertical core samples from the entire depth of a SST haunch, sidewall, and footing tentatively scheduled for fiscal year 2013.

SI-4 Completed FY 2010 and FY 2011 Visual Inspections

The criteria provided to tank farm inspectors for the examination of the reinforced concrete dome include the identification of concrete spalling, rust stains, cracks ≥ 1/16-in wide, and visible reinforcing steel patterns. All of these indications would suggest a certain level of degradation of the concrete dome. A primary focus of the inspections was the tank haunch section of the concrete dome where extensive cracking would suggest too high of a demand on the reinforced dome in its current condition.

Where possible, images from current in-tank inspections were compared to historical images of the same region. A photo comparison of 241-B-102 is provided in Figure 5. Visual inspection of Tank 241-B-102 and all other tanks inspected in FY 2010 and FY2011 did not reveal any degradation of the concrete dome and haunch.

Figure 5. Comparative Photographs of Tank 241-B-102 Haunch Region

Tanks inspected FY 2010:

Tanks inspected in Fiscal Year (FY) 2010 include SSTs 241-A-105, 241-A-106, 241-AX-102, 241-B-102, 241-BY-110, 241-C-110, 241-S-101, 241-S-103, 241-S-104, 241-S-108, 241-SX-101, and 241-U-104. Results of the inspections showed no detectable change in the concrete dome condition from previous inspections. No areas of concern were noted in any of the FY 2010 inspected SST reinforced concrete domes.

Tanks inspected FY 2011:

Tanks inspected in Fiscal Year (FY) 2011 include SSTs 241-AX-101, AX-103, T-112, C-112, B-106, AX-104, T-102, TX-101, TX-104, U-106, C-101, SX-107. Results of the inspections showed no detectable change in the concrete dome condition from previous inspections. No areas of concern were noted in any of the FY 2011 inspected SST reinforced concrete domes.

Planned Future Work

It was originally planned to continue SST visual inspections at a rate of 12 per year, but funding shortfalls have temporarily suspended this effort.

SI-5 Test Dome Concrete and Rebar 'Plugs'

A 55-inch diameter section of reinforced concrete (RC) was removed from the dome of C-107 in December 2010. Post-installed HILTI HDA™ undercut anchors were installed to facilitate rigging of the section. These anchors were used to provide attachment points for the rigging used to support the plug while it was being cut and to remove it from the tank after cutting .The 55-inch section was cut from the tank using a combination of high pressure water and a garnet abrasive. The RC section was removed completely intact, double wrapped in plastic, and placed in an isolated area in 241-C farm. Figure 6 displays the unwrapped, intact 55-inch section of RC removed from 241-C-107

Figure 6. SST 241-C-107 Dome Plug

The plug was inspected in the field. During the inspection the following actions were taken:

- Measure full depth of 'Plug'
- Measure depth to top mat of rebar
- Measure depth to bottom mat of rebar
- Photograph 'Plug', cracks, voids, rebar, and aggregate

The field inspection revealed that the concrete was in good condition, with no noticeable cracks or voids. The placement of the rebar generally matched the design drawings, with the benefit of slightly more concrete cover than designed.

A total of fourteen nominally 4.2" diameter cores were removed from the plug and sent to CTL Group in Skokie, IL for testing. Of the 14, 12 cores were underwent mechanics testing and 2 were set aside for Petrographic examination.

Prior to mechanics testing, the following inspection was performed on the concrete cores:

- Measure diameter and length
- Measure any cracks
- Measure any voids
- Photograph the core, cracks, voids, rebar (if any), aggregate

The core inspections reveled that minimal cracking was present and only minor voids present.

The 12 cores subjected to physical testing underwent tests for the following:

- Transverse Natural Frequency ASTM C215
- Modulus of Elasticity – ASTM C469
- Poisson's Ratio – ASTM C469
- Compressive Strength – ASTM C39

Table 2. SST 241-C-107 Concrete Core Physical Test Results Summary

Core Number	Average Transverse Frequency (Hz)	Dynamic Modulus (ksi)	Elastic Modulus (ksi)	Poisson Ratio	Compressive Strength (psi)
C-107#1	6493	6700	5900	0.20	9890
C-107#2	6527	6900	6500	0.23	9670
C-107#3	6480	6800	6000	0.24	9290
C-107#5	6447	6700	5950	0.24	8530
C-107#6	6443	6900	6000	0.23	9030
C-107#11	6253	6300	5850	0.23	6810
C-107#12	6373	6500	5800	0.21	5890
C-107#13	6313	6400	5750	0.23	6800
C-107#15	6343	6600	5900	0.23	7530
C-107#17	6480	6700	6100	0.19	7800
C-107#19	6320	6400	5550	0.20	6840
C-107#20	6393	6600	5950	0.20	8850

From the values presented in Table 2, the compressive strength averaged 8000-psi, which is more than 2.5 times the design strength of 3000-psi. The modulus of elasticity and Poisson ratio are in agreement with the higher strength concrete.

Based on the results of petrographic examination, the concrete represented by the 2 cores is in good condition. No distress (cracking or excessive micro-cracking) is observed in either core. The concrete does not show any evidence of chemical attack, significant alkali-aggregate reactions, or other deleterious mechanisms involving aggregates and/or hydrated cement.

The concrete in both cores exhibits good physical paste properties. Apart from localized softer paste at the immediate top surface, the paste in the cores is hard and dense through the depth of the concrete. Distribution of aggregates and other paste constituents is uniform. Macroscopically, the cores are well consolidated (no large voids). Additionally, the depth of carbonation for the cores was shallow, approximately 0.04 to 0.08 in. (1 to 2 mm) from the top surface.

The remaining work for the SST 241-C-107 dome 'plug' consists of removing, inspecting and tensile testing the rebar.

SI-6 Develop Engineering Mechanics Document

The engineering mechanics document will be prepared and maintained by WRPS to contain the current best understanding of engineering mechanics properties of each tank. The mechanics document will contain information on concrete and rebar properties related to those use in the structural analyses and those determined from Non-destructive Testing and physical testing.

SST Structural Integrity Summary

Results from the completed tasks related to structural integrity have been favorable. The structural analyses of record for the Type II and Type III SSTs indicate that the tanks are structurally sound. Available SST dome surveys show that dome deflection is not a concern, based on the current loads on the tanks. The demonstration of SST sidewall coring successfully proved that actual tank coring can be performed. The real objective, yet to be performed, is to obtain actual concrete cores from the sidewall of SST 241-A-106. The completed visual inspections do not reveal any signs of concrete degradation in the dome and haunch regions of the associated SSTs. Actual test results from concrete cores removed from the dome of SST 241-C-107 show that the concrete is in good condition and has higher strength than predicted.

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