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Office of River Protection
P.O. Box 450, MSIN H6-60
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SEP 2 7 2010

10-ESQ-286

Ms. Jane A. Hedges, Program Manager
Nuclear Waste Program
Washington State
Department of Ecology
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Richland, Washington 99354

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EDMC

Dear Ms. Hedges:

COMPLETION OF HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER (HFFACO) INTERIM MILESTONE M-045-91, DUE SEPTEMBER 30, 2010

This letter documents completion of the HFFACO Interim Milestone M-045-91. This milestone requires that the U.S. Department of Energy, Office of River Protection (ORP) establish a panel of technical and nationally recognized experts to provide a report on Single-Shell Tank (SST) integrity assurance review and submit to the Washington State Department of Ecology an agreement change package with HFFACO interim milestones as necessary to implement the Panel's recommendations within 90 days of the reports submittal.

ORP assembled a panel of technical and nationally recognized experts in 2009 and 2010 to review available data from retrieved SSTs and report their findings and recommendations. The Expert Panel issued two reports: RPP-RPT-43116, "Expert Panel Report for Hanford Single-Shell Tank Integrity" (Attachment 1); and RPP-RPT-45921, "Second Expert Panel Report for Hanford Site Single-Shell Tank Integrity Report" (Attachment 2), thereby completing the interim milestones first action. RPP-PLAN-45082, "Implementation Plan for the Single-Shell Tank Integrity Project," has also been attached for your information (Attachment 3).

Attachment 4, Change Form M-45-10-01, is submitted for your approval and completes the second action by establishing two HFFACO interim milestones and ten target dates to implement recommendations from the Expert Panel's Reports, RPP-RPT-43116 and RPP-RPT-45921.

If you have any questions, please contact me, or your staff may contact Stacy Charboneau, Assistant Manager, Tank Farms Project, (509) 373-3841.

Sincerely,

David A. Brockman, Manager
Office of River Protection

ESQ:GMN

Attachments (4)

cc: See page 2

5.2.4

M.045.91

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TPA Administrative Record (S-2-4)
WRPS Correspondence

Attachment 1
10-ESQ-286
(103 Pages)

RPP-RPT-43116,
"Expert Panel Report for Hanford Single-Shell Tank Integrity"

S

DOCUMENT RELEASE FORM

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EXPERT PANEL REPORT FOR HANFORD SITE SINGLE-SHELL TANK INTEGRITY PROJECT

M. T. Terry, Perot Systems Government Services

Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-08RV14800

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Abstract: Two expert panel workshops were held on leak and structural integrity of single-shell tanks at the Hanford Site. The goal was to provide recommendations to Washington River Protection Solutions, LLC for implementation of an enhanced single-shell tank integrity project. The panel focused on four key elements for the tank integrity project: confirmation of tank structural integrity, assessment of the likelihood of future tank liner degradation, leak identification and prevention, and, mitigation of contaminant migration.

This report describes the issues discussed during and following the workshops, the final recommendations of the workshop panel, and the rationale for those recommendations.

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Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project

M.T. Terry
Perot Systems Government Services

K.D. Boomer
Washington River Protection Solutions, LLC

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ABSTRACT

Two expert panel workshops were held on leak and structural integrity of single-shell tanks at the Hanford Site. The goal was to provide recommendations to Washington River Protection Solutions, LLC for implementation of an enhanced single-shell tank integrity project. The panel focused on four key elements for the tank integrity project:

- Confirmation of tank structural integrity.
- Assessment of the likelihood of future tank liner degradation.
- Leak identification and prevention.
- Mitigation of contaminant migration.

The workshops were held in Richland, Washington on January 26-29, 2009 and April 29-May 1, 2009. In the first workshop, the panel received presentations outlining the history and current status of the Hanford Site's Single-Shell Tank Farms and related projects. The panel developed issues for follow-up at the conclusion of the workshop. The second workshop focused on additional clarification of issues and development of panel recommendations.

Workshop participants included Department of Energy, academic, and industry experts in the fields of stress corrosion cracking, soils and vadose zone, electrochemistry, materials, and non-destructive evaluation.

This report describes the issues discussed during and following the workshops, the final recommendations of the workshop panel, and the rationale for those recommendations.

EXECUTIVE SUMMARY

The Single-Shell Tank Integrity Panel (the Panel) was tasked with providing Washington River Protection Solutions, LLC (WRPS) with recommendations to support the development of an enhanced Single-Shell Tank Integrity project (SSTIP).

Wastes in both the Hanford Site's single-shell (SST) and double-shell tank (DST) systems are slated for treatment in a Waste Treatment and Immobilization Plant (WTP) that is currently under construction. Delays to the initiation of operation of the WTP will necessitate extended storage of tank wastes. These delays provide the impetus for a more robust SSTIP.

The Panel developed recommendations based on the proceedings of two workshops and the research and deliberation of the Panel and its members.

In the first workshop, the Panel considered a broad range of SST issues, including: current status, chemistry, retrieval technologies, structural integrity requirements and status, corrosion, stress corrosion cracking (SCC) and design impacts from the Savannah River Site, vadose zone characterization, leak detection, monitoring and mitigation; and non-destructive evaluation.

During this workshop, the Panel developed individual work assignments to research specific areas of interest (Martin and Terry, 2009). Based on this research and subsequent requests for additional information, the Panel held a second workshop to develop recommendations.

In developing its recommendations, the Panel agreed on three overarching values that should guide the SSTIP. First, SSTIP activities should not adversely impact final disposition of tank waste. Such disposition of SST wastes requires retrieval from the tanks and treatment in the WTP. These two activities require certain physical and chemical waste characteristics that must be integrated into decision-making for the SSTIP.

Second, SSTIP activities should be strategically focused on programmatic needs. This acknowledges the pitfalls of developing SSTIP activities that may be of interest scientifically, but offer little prospect for directly supporting the programmatic needs of safe storage, retrieval, treatment and disposal of SST wastes.

Third, SSTIP activities should protect public and worker health and safety.

The Panel has prioritized its recommendations both overall (discussed in Section 2) and within four key elements: (1) confirmation of tank structural integrity (denoted by 'SI'), (2) assessment of the likelihood of future tank liner degradation (denoted by 'LD'), (3) leak identification and prevention (denoted by 'LIP') and (4) mitigation of contaminant migration (denoted by 'MCM').

The recommendations are as follows, presented in their respective prioritization within each of the key elements.

Confirmation of tank structural integrity

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.

Assessment of the likelihood of future tank liner degradation

Recommendation LD-1, Expand Leak Assessment Reports: The Panel recommends continuing the preparation of Leak Assessment Reports for each tank farm. The Panel found the Leak Assessment Report for 241-A and 241-AX tank farms to be very helpful in understanding the status of data and information about both known and assumed leaker tanks. The discussion for each tank should include an operations summary, an operations history, an analysis of the leak location and cause, a waste loss estimate, the nature and extent of ground contamination, and a conclusion.

Recommendation LD-2, Avoid inadvertent addition of water and chloride to SSTs: To avoid creating conditions that could lead to liner corrosion, the Panel recommends operational procedures be implemented to prevent the inadvertent addition of water and chloride ion to the SSTs. The impact of water intrusion and unintended increases in chloride ion concentrations should be evaluated on a tank-by-tank basis.

Recommendation LD-3, Examine "non-compliant" wastes at 25° C: The Panel recommends selected "non-compliant" SST waste simulants be examined at 25° C. "Non-compliant" wastes are those that fail to meet specific temperature, nitrite, nitrate, and hydroxide concentration criteria. The examinations will provide information on the propensity for pitting, cracking, and corrosion at the liquid-air interface (LAI) or corrosion of the liner in the vapor space. This testing should be coordinated with the DST testing program.

Recommendation LD-4, Develop and Deploy Guided Wave Technology: The Panel recommends the development and deployment of guided wave, ultrasonic technology to assess the presence of macroscopic degradation of the steel liner. A design study should be undertaken to determine the optimum parameters and feasibility of an Electro-Magnetic Acoustic Transducer (EMAT) system for this application. If shown feasible, and other SSTIP activities raise concerns about liner integrity, the EMAT system should be deployed.

Recommendation LD-5, Determine Ammonia Corrosion Control Concentration: Ammonia in sufficient concentrations has the potential to inhibit liner corrosion. The Panel recommends laboratory testing to determine the concentration of ammonia required to control corrosion in the liquid phases of the solid and supernatant layers, at the LAI and on the exposed liner in the vapor spaces. This testing should be coordinated with the DST testing program.

Recommendation LD-6, Assess SST Waste Compositional Variation: The Panel recommends determining whether compositional variations in the solid layers of the SSTs deviates from general SST and DST programmatic assumptions about composition. If so, testing work may need to be performed to evaluate the propensity for stress corrosion cracking (SCC) and corrosion.

Three factors may have given rise to novel compositions in the SSTs. First, the wastes might have become layered and inhomogeneous as a consequence of waste transfer operations that mixed several waste types. Second, groundwater and rainwater might have infiltrated into waste tanks through cracks in the dome or sidewalls. Third, corrosive chloride ions have been introduced to the SSTs through operational additions of sodium hydroxide.

Recommendation LD-7, Assess Deployment of Local Non-Destructive Evaluation Techniques: The Panel recommends assessing the feasibility of deploying candidate local

measurement techniques (such as fluid coupled ultrasound, ultrasonic guided waves implemented using EMATs, and vibrothermography) operated as end effectors on a mechanical apparatus (such as robotic arms) deployed in the SSTs. Deploying such technologies should be based on the outcomes of other NDE recommendations (e.g. discovery of cracks via visual inspection) and a cost benefit analysis that analyzes the difficulties of employing candidate local measurement techniques.

Recommendation LD-8, Consider Installation of Corrosion Potential Probe: If recommended laboratory studies indicate SST chemistries aggressively foster corrosion or SCC under tank operating conditions, the Panel recommends installing a probe similar to that employed in the DSTs to measure corrosion potential. This information can be used to further assess the likelihood for corrosion or SCC.

Recommendation LD-9, Consider Testing Tank Liner Hardness: The feasibility and cost of removing small samples from the tank liner for hardness testing should be evaluated. If feasible and cost effective, samples should be removed from a tank that experienced high temperatures to determine if hardness increases, which could impact structural integrity, have occurred.

Recommendation LD-10, Consider Applying Direct Current Potential Drop to SSTs: The Panel recommends studying the feasibility of applying Direct Current Potential Drop (DCPD) to the SSTs for the purpose of locating tears in the liner. The DCPD technique is based on injecting current into a metallic component and measuring the resulting voltage (potential) at selected points. Such study could include both theoretical modeling as well as simple laboratory experiments. Once feasibility is established, a DCPD system should be developed for implementation.

This recommendation, along with consideration of local NDE techniques (Recommendation LD-8), provide a suite of techniques to assess liner degradation based on the outcome of other tests and observations, as well as the feasibility of deployment.

Recommendation LD-11, Analyze Stress Relaxation of Tank Liners: The Panel recommends analysis or experimental study of stress relaxation in tank liner steels to determine whether SCC is a possibility in the future.

Leak identification and prevention

Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced SST Monitoring: The Panel recommends continuing current Leak Detection Monitoring and Best Management Practices to monitor for leaks. Further, the Panel recommends installing enhanced monitoring based on potential leak risks at each tank farm. The 241-T Tank Farm Interim Cover Test has proved an excellent system for tracking infiltration of meteoric water. Increasing the depths and expanding the aerial extent of monitoring similar to this test will provide an excellent system for early detection and tracking of leaks.

Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs: The Panel considered the addition of absorbents to the SSTs to further immobilize liquids. However, the Panel recommends avoiding the addition of water-insoluble solid absorbents to the SSTs as such additives do not appear effective in immobilizing water and will interfere with the future retrieval of wastes, and may adversely impact WTP operations.

Recommendation LIP-3, Continue Use of High Resolution Resistivity: The Panel recommends continuing utilization of High Resolution Resistivity for leak detection outside of tanks. High Resolution Resistivity can detect a 5,000 to 10,000 gallon leak by utilizing existing dry-wells to measure soil resistivity. The technique has been effectively demonstrated during recent waste retrieval activities.

Recommendation LIP-4, Seek Engineering Methods to Increase Water Removal by Pumping From SSTs: The Panel recommends seeking engineering solutions for the removal of additional tank liquids by pumping. While the Panel acknowledges further removal of liquids by pumping will be challenging, it is a safe and potentially efficient and cost effective method for the removal of liquids from the tanks.

Recommendation LIP-5, Evaluate Sludge and Saltcake Liquid Leak Rates: The Panel recommends evaluating liquid leak rate assessments of sludge and saltcake from the Savannah River Site to determine if the results are applicable to SSTs.

There is currently no evidence that liquid is leaking from the interim stabilized (retrieved) tanks that contain supernatant, sludge or saltcake. Nor is there evidence that new stress corrosion cracks have developed since the tanks were stabilized. Information as to whether liquid would leak out of sludge or saltcake through stress corrosion cracks is important when considering continued use of the SSTs.

Recommendation LIP-6, Investigate Leak Detection Technologies for Tanks With Less Than 24 Inches of Waste: The Panel recommends investigating and developing technologies to allow for leak detection in tanks with waste levels of less than 24 inches. Limitations of current leak detection technologies (Liquid Observation Wells and ENRAF™) do not allow for leak detection in these SSTs below 24 inches.

Recommendation LIP-7, Evaluate Effect of Lowering SST Waste Temperature: The Panel recommends evaluating the effect of lowering the temperature of representative waste types to determine its practical impact on drainage rates.

Recommendation LIP-8, Assess the Feasibility of Testing for Ionic Conductivity Between Inside and Outside of SSTs: The Panel recommends performing experiments to assess the viability of testing ionic conductivity between the inside and outside of SSTs. An ionic path between the inside and outside of SSTs could be indicative of cracks through the liner and concrete. If techniques can reliably measure such ionic conductivity, it would be useful in demonstrating whether breaches exist in SSTs.

Recommendation LIP-9, Consider Cathodic Protection for Rebar and Exterior of Tank Liner: The Panel recommends that cathodic protection (CP) not be deployed for use in protecting the interior of SSTs where supernatant, sludge and/or saltcake is present. The Panel further recommends that CP be considered as an option to protect the exterior of the tank liner and rebar, should evidence arise that either has corroded.

CP has the potential to suppress corrosion in the SSTs. CP has not been applied to the DSTs due to concerns that waste chemistry may lead to SCC. These issues, as well as difficulties associated with frequent replacement of electrodes, inserting electrodes into the saltcake and high CP currents have led the Panel to recommend against applying CP to the interior of the SSTs. This recommendation is tempered by the possibility of applying CP to the interior of SSTs with little or no nitrite.

Recommendation LIP-10, Evaluate Coating of Tank Liners and Installation of Polymeric Bladder: The Panel recommends evaluating both the coating of the tank liners with a material resistant to corrosion and cracking; and the deployment of a polymeric bladder to line SSTs. Many different metals, ceramics, intermetallics and polymers have the potential to be thermally sprayed onto the tank liners to reduce leakage concerns during retrieval.

Storing waste in polymeric bladders has been used successfully in the petroleum industry for the elimination of leaks in storage tanks. A bladder made of this material could line a tank if its reliability were shown to be extremely high. The Panel acknowledges that difficulties associated with introducing materials into SSTs may reduce the feasibility of implementing this recommendation.

Recommendations LIP-11, Avoid Heating and Active Ventilation Strategies for Removing Additional Water from SSTs: The Panel recommends against pursuing strategies for removing water from tanks that include active ventilation or heating. Such strategies would be expensive, heating will increase the risk of pitting corrosion and SCC, and heating could increase the risk of unacceptably vigorous exothermic reactions.

Recommendation LIP-12, Avoid Strategies to Immobilize Waste Through the Addition of Gelling Agents: As a general programmatic practice, the Panel recommends against the addition of gelling agents. Existing gelling techniques will be difficult to implement, may complicate WTP operations, and may increase the corrosivity of the waste. However, individual tank-by-tank instances may arise in which gelling a tank may be a wise option (e.g. to stop a significant tank leak or if new gelling techniques were developed).

Mitigation of Contaminant Migration

Recommendation MCM-1, Install Surface Barrier Over SST Farms: The Panel recommends design and implementation of a surface barrier to reduce recharge at the SSTs. Sources of water (leaking pipes, vaults, etc.) that could contribute to subsurface water deep percolation should also be identified and controlled. New control/barrier measures should be prioritized based on the risk associated with past and/or future releases at each tank farm.

Recommendation MCM-2, Evaluate Subsurface Leak Mitigation Technologies: A number of viable candidate subsurface leak mitigation strategies were identified in a 1994 Feasibility Study (FS). The Panel recommends evaluating leak mitigation technologies utilizing this FS as a selection guide.

- Bench scale studies on candidate technologies should be conducted.
- Demonstration in a Hanford Site field setting should be performed where appropriate.
- Currently ongoing tests, such as the injection apatite reactive zone, should be considered for application at the SST farms.
- An updated FS should be performed, using updated risk assessment methodologies and modern performance assessment technologies, with the objective of selecting a SST leak mitigation strategy and potentially a final SST Closure strategy.
- It is recognized that an updated FS and risk-based selection process may also conclude that little additional benefit can be derived from implementing a subsurface barrier in addition to implementing a surface barrier.

The Panel also prioritized its 'top ten' primary recommendations that form the foundation of a robust SSTIP. As is outlined in Section 2, these primary recommendations should be pursued at the initiation of the SSTIP. The primary recommendations are as follows.

Recommendation SI-1, Perform Modern Structural Analyses
Recommendation SI-2, Perform Dome Deflection Surveys
Recommendation SI-3, Obtain and Test Sidewall Core
Recommendation SI-4: Perform Non-Destructive Evaluation of Concrete
Recommendation LD-1, Expand Leak Assessment Reports
Recommendation LD-2, Avoid inadvertent addition of water and chloride to SSTs
Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced External SST Monitoring
Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs
Recommendation LIP-3, Continue Use of High Resolution Resistivity
Recommendation MCM-1, Install Surface Barrier Over SST Farms

KEY WORDS

cathodic protection; concrete degradation; concrete mechanical properties; corrosion; corrosion chemistry; corrosion limits; corrosion potential; expert panel; guided wave; Hanford Site leak immobilization; leak integrity; leak prevention; non-destructive evaluation; seismic loading; single-shell tank; single-shell tank integrity; stress corrosion cracking; structural integrity; subsurface contaminant; surface barrier; tank chemistry; waste simulants

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LIST OF TERMS

Abbreviations and Acronyms

BMP	best management practices
CP	cathodic protection
CPP	cyclic potentiodynamic polarization
DBTT	ductile to brittle transition temperature
DC	direct current
DCPD	direct current potential drop
DST	double-shell tank
EIS	electrochemical impedance spectroscopy
EMAT	electro-magnetic acoustic transducer
EPDM	ethylene-propylene-diene monomer
ERT	electrical resistivity tomography
FS	feasibility study
FY	fiscal year
HAZ	heat affected zone
HDS	heat dissipation center
HRR	high resolution resisitivity
ICM	interim corrective measure
IR	infrared
ITS	in-tank-solidification
LAI	liquid-air interface
LDM	leak detection monitoring
LOW	liquid observation well
MT	manual tape
NDE	non-destructive evaluation
ORP	Office of River Protection
PET	point electrode technique
PNNL	Pacific Northwest National Laboratory
RF	radio frequency
SCE	saturated calomel electrode
SCC	stress-corrosion cracking
SCRT	steel casing resistivity technique
SGE	surface geophysical exploration
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SSRT	slow strain rate test
SST	single-shell tank
SSTIP	Single-Shell Tank Integrity Project
TBP	tri-butyl phosphate
UT	ultrasonic testing
WMA	waste management area
WRPS	Washington River Protection Solutions, LLC
WTP	waste treatment and immobilization plant

Units of Measure

C	Celsius
cP	centipoise

cm	centimeter
F	Fahrenheit
ft	foot
g	gravity
gal	gallon
gpm	gallons per minute
in.	inch
Jc	fracture toughness
kHz	kilohertz
K	static fracture toughness
kJ	kilojoule
Ksi	kips per square inch
L	liter
M	molar
m	meter
MHz	megahertz
mm	millimeter
MPa	MegaPascal
MPa-m^{½}	ductile fracture toughness
mV	millivolt
Pascal	Newtons/meter^2
ppm	parts per million
psi	pound per square inch
S	second
SpG	specific gravity
S_y	yield stress

INTRODUCTION

1.1 Overview and Background

Radioactive and hazardous chemical waste is stored in 177 carbon steel tanks at the Hanford Site in southeast Washington State. 149 of the tanks are Single-Shell Tanks (SSTs) and 28 are Double-Shell Tanks (DSTs). The DSTs were constructed between 1968 and 1986.

The 149 SSTs were constructed in twelve groupings (known as 'farms') between 1943 and 1964. Figure 1 is a photo of an SST farm under construction. The SSTs were built with four different nominal volumes:

- Sixteen 55,000-gallon tanks, which are the 200 Series tanks in 241-B, 241-C, 241-T, and 241-U Farms.
- Sixty 530,000-gallon tanks, which are the 100 Series tanks in 241-B, 241-BX, 241-C, 241-T, and 241-U Farms.
- Forty-eight 758,000-gallon tanks, which are the 100 Series tanks in 241-BY, 241-S, 241-TX, and 241-TY Farms.
- Twenty-five 1,000,000 gallon tanks, which are the 100 Series tanks in 241-A, 241-AX and 241-SX Farms.

The SSTs received alkaline waste from multiple nuclear fuel processing operations, starting in 1944. The initial radioactive wastes were principally derived from three different chemical

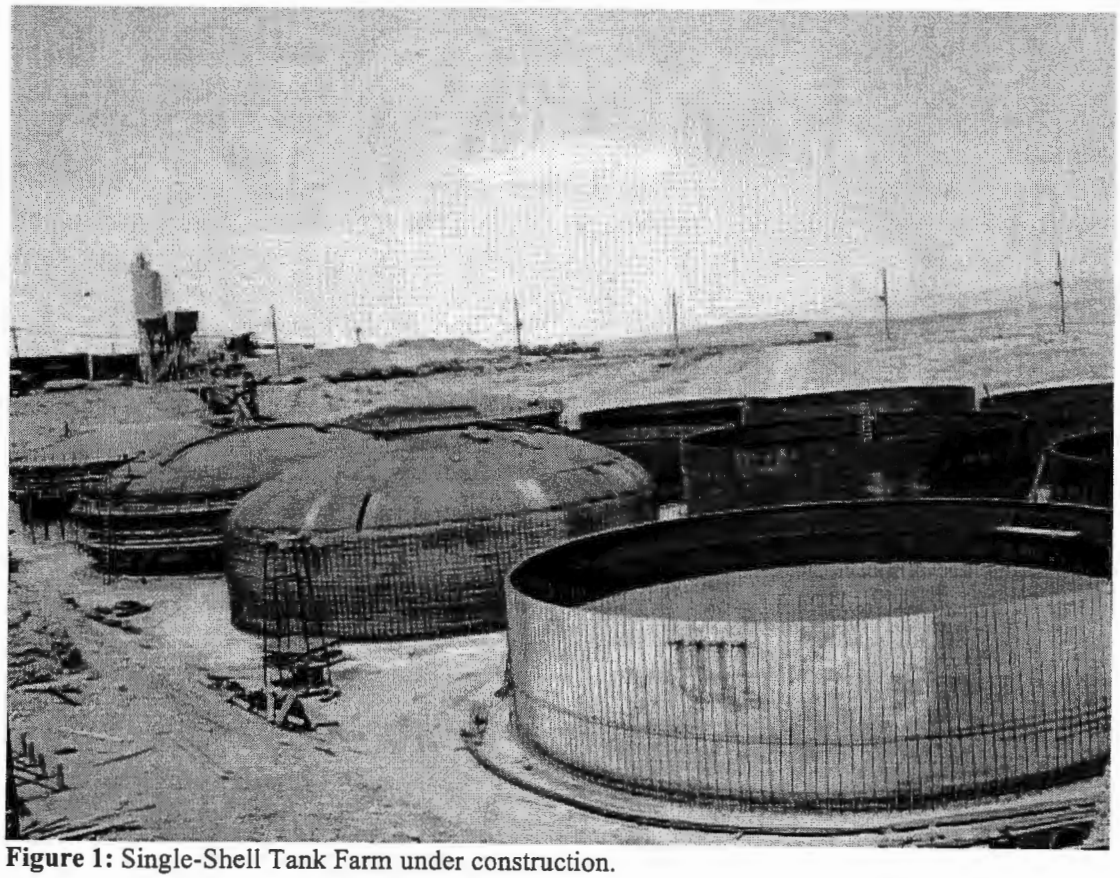

Figure 1: Single-Shell Tank Farm under construction.

processing operations, each of which produced several different types of waste. The bismuth phosphate process, the REDOX process, and the PUREX process were designed to recover plutonium from irradiated reactor fuels. The bismuth phosphate wastes that were discharged to the tanks were later processed to recover uranium from the wastes by using the tributyl phosphate (TBP) process. Potassium ferrocyanide was used to scavenge cesium ion from this waste. The oldest tanks (241-B, 241-C, 241-T, and 241-U farms) were constructed to receive the wastes from bismuth phosphate plants. REDOX and PUREX wastes were stored in the 241-S, 241-A, 241-AX and 241-SX farms, which were designed to hold boiling wastes so that water could be removed from the tanks to conserve space for the retention of radioactive materials. Later operations, including the in-tank solidification (ITS) and outside-tank evaporation, were used to remove water and concentrate the wastes.

Waste additions to the SSTs ceased in 1980 and pumpable liquids have been transferred from the SSTs to the DSTs. The SSTs currently contain ten million gallons of sludge, twenty million gallons of salt cake, and one hundred thousand gallons of supernatant liquid. Sixty-seven of the SSTs are assumed to have leaked as much as one million gallons of waste to the vadose zone under the tanks.

SST wastes are slated for retrieval and treatment in a Waste Treatment Plant and Immobilization (WTP) that is currently under construction. Technical issues have delayed the schedule for initiating operations of the WTP. The delays to the WTP will necessitate extended storage in the SSTs—most of which are currently beyond their design life.

The extension of the SST's mission has created an incentive for the tank farm contractor, Washington River Protection Solutions, LLC (WRPS) to develop an enhanced SST integrity project (SSTIP). WRPS created an expert panel on SST integrity (Panel) to provide recommendations to support the development of such a project.

The Panel developed recommendations based on the proceedings of two workshops and the research and deliberation of the Panel and its members.

In the first workshop, the Panel considered a broad range of issues, including: current status, chemistry, retrieval technologies, structural integrity requirements and status, corrosion, stress corrosion cracking (SCC) and design impacts at the Savannah River Site, vadose zone characterization, leak detection, monitoring and mitigation; and non-destructive evaluation.

At this workshop, the Panel developed individual work assignments to research specific areas of interest (Martin and Terry, 2009). Based on this research and subsequent requests for more information from WRPS, the Panel held a second workshop to develop recommendations.

In developing its recommendations, the Panel agreed on three overarching values that should guide the SSTIP. First, SSTIP activities should not adversely impact final disposition of tank waste. Such disposition of SST wastes requires retrieval from the tanks and treatment in the WTP. The waste must have certain physical and chemical characteristics for successful retrieval and treatment, and this must be considered when designing the SSTIP.

Second, SSTIP activities should be strategically focused on programmatic needs. This value acknowledges the pitfall of developing an SSTIP that includes activities that may be of interest scientifically, but offer little prospect for directly supporting programmatic needs.

Third, SSTIP activities should protect public and worker health and safety.

The Panel's recommendations are focused on the following four key elements that form the foundation of the SSTIP:

- Confirmation of tank structural integrity;
- Assessment of the likelihood of future tank liner degradation;
- Leak identification and prevention; and,
- Mitigation of contaminant migration.

This report outlines the results of workshop discussions and Panel deliberations. It includes the rationale and prioritization of the Panel's recommendations.

The Panel was tasked with providing recommendations to support development of a robust SSTIP—not to develop criteria allowing the reuse of SSTs for routine storage. Although this issue was clearly outside the Panel's scope, it arose during the Panel's deliberations several times. As a result, the Panel has included Section 7 to reflect its brief consideration of this issue.

2.0 PRIORITIZATION AND SUMMARY OF RECOMMENDATIONS

The Panel's primary focus was to provide WRPS with recommendations supporting development of a SSTIP. Toward this goal, the Panel has prioritized its recommendations in two ways: (1) overall prioritization, and (2) prioritization within four key elements of a SSTIP.

The logic behind the Panel's two prioritization schemes arose from the many uncertainties associated with the SSTs and the development of the SSTIP. For example, the inaccessibility of the concrete, rebar and liner of the SSTs alone raises many uncertainties. As a result, the SSTIP must remain flexible in applying different technologies and activities as the project progresses and data and information are collected.

The recommendation numbering scheme is based on the four key SSTIP elements: (1) confirmation of tank structural integrity (denoted by 'SI'), (2) assessment of the likelihood of future tank liner degradation (denoted by 'LD'), (3) leak identification and prevention (denoted by 'LIP') and (4) mitigation of contaminant migration (denoted by 'MCM').

2.1 Overall Prioritization of Recommendations

The Panel's overall prioritization places each recommendation into one of two categories: (1) primary recommendations (including current tank farm activities and recommendations for new activities), and (2) secondary recommendations.

The first category is composed of primary recommendations that comprise the 'top ten' activities forming the foundation for the SSTIP. These activities should be pursued at the initiation of the SSTIP.

The other category is made up of secondary recommendations. While of a lower priority than the primary recommendations, the importance of the secondary recommendations should not be minimized. The Panel assumes many of these recommendations will be implemented for two

reasons. First, many of these activities consist of relatively inexpensive, simple documentation or laboratory work that could yield important information to support the SSTIP. Additionally, secondary recommendations could quickly become high priorities if indications of a problem that could impact SST integrity arise. For example, if a high priority such as visual inspection of domes identifies cracking of concrete, several secondary activities (e.g., Non Destructive Evaluation techniques) would be necessary to further address the cracking.

2.1.1 Summary of Primary Recommendations

The primary recommendations represent the 'top 10' priorities that form the foundation of a SSTIP. In its review of existing information and data, the Panel found WRPS is currently performing many activities critical to a robust SSTIP. These programmatic activities are reflected in three primary recommendations (SI-2, LD-1 and LIP-1). These three recommendations acknowledge these important project building blocks, emphasize the importance of continuing them and, where necessary, recommend modifications. The other seven primary recommendations are not components of current SST programmatic activities.

The primary recommendations are as follows.

Recommendation SI-1, Perform Modern Structural Analyses
Recommendation SI-2, Perform Dome Deflection Surveys
Recommendation SI-3, Obtain and Test Sidewall Core
Recommendation SI-4: Perform Non-Destructive Evaluation of Concrete
Recommendation LD-1, Expand Leak Assessment Reports
Recommendation LD-2, Avoid inadvertent addition of water and chloride to SSTs
Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced External SST Monitoring
Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs
Recommendation LIP-3, Continue Use of High Resolution Resistivity
Recommendation MCM-1, Install Surface Barrier Over SST Farms

2.1.2 Summary of Secondary Recommendations

The secondary recommendations are as follows.

Recommendation SI-5, Test Dome Concrete and Rebar 'Plugs'
Recommendation SI-6, Develop Engineering Mechanics Document
Recommendation SI-7, Test Effects of Waste Exposure on Structural Integrity
Recommendation SI-8, Study the Deployment of Corrosion Potential Mapping
Recommendation LD-3, Examine "Non-Compliant" Wastes at 25° C
Recommendation LD-4, Develop and Deploy Guided Wave Technology
Recommendation LD-5, Determine Ammonia Corrosion Control Concentration
Recommendation LD-6, Assess SST Waste Compositional Variation
Recommendation LD-7, Assess Deployment of Local Non-Destructive Evaluation Techniques
Recommendation LD-8, Consider Installation of Corrosion Potential Probe
Recommendation LD-9, Consider Testing Tank Liner Hardness
Recommendation LD-10, Consider Applying Direct Current Potential Drop to SSTs
Recommendation LD-11: Analyze Stress Relaxation of Tank Liners

Recommendation LIP-4, Seek Engineering Methods to Increase Water Removal by Pumping From SSTs

Recommendation LIP-5, Evaluate Sludge and Saltcake Liquid Leak Rates
Recommendation LIP-6, Investigate Leak Detection Technologies for Tanks With Less Than 24 Inches of Waste
Recommendation LIP-7, Evaluate Effect of Lowering SST Waste Temperature
Recommendation LIP-8, Assess the Feasibility of Testing for Ionic Conductivity Between Inside and Outside of SSTs
Recommendation LIP-9, Consider Cathodic Protection for Rebar and Exterior of Tank Liner
Recommendation LIP-10, Evaluate Coating of Tank Liners and Installation of Polymeric Bladder
Recommendation MCM-2, Evaluate Subsurface Leak Mitigation Technologies
Recommendations LIP-11: Avoid Heating and Active Ventilation Strategies for Removing Additional Water from SSTs
Recommendation LIP-12: Avoid Strategies to Immobilize Waste Through the Addition of Gelling Agents

2.2 Prioritization of Recommendations Within SSTIP Key Elements

As is outlined in the Executive Summary, the Panel also prioritized its recommendations within each of the four key elements: (1) confirmation of tank structural integrity, (2) assessment of the likelihood of future tank liner degradation, (3) leak identification and prevention, and (4) mitigation of contaminant migration.

As the knowledge base from SSTIP activities evolves, it is likely the emphasis on one or more of the SSTIP's key elements will also evolve. Moreover, variations in funding from year-to-year will also drive resource decisions for the SSTIP. The prioritization of recommendations within each key element is intended to provide WRPS relative priorities for consideration when making resource decisions as the SSTIP is initiated and as it progresses.

As the report chapters were prepared before the prioritization effort was completed, the recommendations are not presented in order of priority in their respective chapters. The recommendations within each key element are presented as follows in order of priority.

2.2.1 Prioritization of Structural Integrity (SI) Recommendations

The prioritized structural integrity related recommendations are as follows.

Recommendation SI-1, Perform Modern Structural Analyses
Recommendation SI-2, Perform Dome Deflection Surveys
Recommendation SI-3, Obtain and Test Sidewall Core
Recommendation SI-4: Perform Non-Destructive Evaluation of Concrete
Recommendation SI-5, Test Dome Concrete and Rebar 'Plugs'
Recommendation SI-6, Develop Engineering Mechanics Document
Recommendation SI-7, Test Effects of Waste Exposure on Structural Integrity
Recommendation SI-8, Study the Deployment of Corrosion Potential Mapping

2.2.2 Prioritization of Liner Degradation (LD) Recommendations

The liner degradation recommendations, in priority order, are as follows.

Recommendation LD-1, Expand Leak Assessment Reports
Recommendation LD-2, Avoid Inadvertent Addition of Water and Chloride to SSTs
Recommendation LD-3, Examine "Non-Compliant" Wastes at 25° C

Recommendation LD-4, Develop and Deploy Guided Wave Technology
Recommendation LD-5, Determine Ammonia Corrosion Control Concentration
Recommendation LD-6, Assess SST Waste Compositional Variation
Recommendation LD-7, Assess Deployment of Local Non-Destructive Evaluation Techniques
Recommendation LD-8, Consider Installation of Corrosion Potential Probe
Recommendation LD-9, Consider Testing Tank Liner Hardness
Recommendation LD-10, Consider Applying Direct Current Potential Drop to SSTs
Recommendation LD-11: Analyze Stress Relaxation of Tank Liners

2.2.3 Prioritization of Leak Identification and Prevention (LIP) Recommendations.

The prioritized recommendations related to leak identification and prevention are the following.

Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced External SST Monitoring
Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs
Recommendation LIP-3, Continue Use of High Resolution Resistivity
Recommendation LIP-4, Seek Engineering Methods to Increase Water Removal by Pumping From SSTs
Recommendation LIP-5, Evaluate Sludge and Saltcake Liquid Leak Rates
Recommendation LIP-6, Investigate Leak Detection Technologies for Tanks With Less Than 24 Inches of Waste
Recommendation LIP-7, Evaluate Effect of Lowering SST Waste Temperature
Recommendation LIP-8, Assess the Feasibility of Testing for Ionic Conductivity Between Inside and Outside of SSTs
Recommendation LIP-9, Consider Cathodic Protection for Rebar and Exterior of Tank Liner
Recommendation LIP-10, Evaluate Coating of Tank Liners and Installation of Polymeric Bladder
Recommendations LIP-11: Avoid Heating and Active Ventilation Strategies for Removing Additional Water from SSTs
Recommendation LIP-12: Avoid Strategies to Immobilize Waste Through the Addition of Gelling Agents

2.2.4 Prioritization of Mitigation of Contaminant Migration (MCM) Recommendations

The prioritized recommendations related to mitigation of subsurface migration are as follows.

Recommendation MCM-1, Install Surface Barrier Over SST Farms
Recommendation MCM-2, Evaluate Subsurface Leak Mitigation Technologies

3.0 CONFIRMATION OF TANK STRUCTURAL INTEGRITY

3.1 OBSERVATIONS CONCERNING THE CURRENT CONDITION OF TANKS

3.1.1 Observations Concerning Current Conditions of Concrete Domes

Surveys have been conducted on all of the SSTs approximately every two years since the early 1980s. A maximum allowable decrease in the dome elevation of 0.24 inches, relative to the baseline measurement, has been specified as the acceptable limit for SSTs.

Analytical studies summarized in Section 6.4 of Abatt (Abatt, 2002) indicate a safety factor of approximately 3.0 or larger against dome collapse for the in-situ soil overburden load. An

evaluation of the safety factor as a function of the increase in dome deflection over initial baseline measurements was conducted on Tank 241-C-106. This evaluation indicated a safety factor of approximately 2.5 for an additional downward deflection of 0.24 inch, and approximately 2.0 for an additional deflection of 0.48 inch. Thus, adequate safety margin exists if dome deflections do not increase more than 0.48 inch.

Remote visual inspection of the underside of the SST concrete domes does not indicate signs of concrete cracking, rust stains, or spalling of the concrete. One would not expect concrete cracks on the underside of the dome except possibly in the haunch area. Cracks in excess of 1/16 inch wide would indicate tensile yielding of the reinforcing steel (rebar). Cracks in excess of 1/8 inch wide are of significant structural concern. Rust stains or spalling of concrete indicate rebar corrosion.

3.1.1.1. Recommendation SI-2: Perform Dome Deflection Surveys

The current program of conducting dome deflection surveys on all SSTs at 24-month intervals should be continued. Additionally, it is important to assess whether deflection data can also be obtained near the haunch of the dome as well as at the center. With deflections taken only at the center, a determination of whether the deflection is due to downward displacement of the dome or due to downward displacement of the footing under the sidewall cannot be made.

This remains an important task because any future potential for dome collapse would be preceded by excessive downward dome deflection (e.g., greater than 0.5-inch).

3.1.1.2. Recommendation SI-5: Test Dome Concrete and Rebar 'Plugs.'

New risers are likely to be installed in the dome of at least some of the SSTs. It would be desirable, to the extent practical, to cut the riser hole in the concrete domes in a manner such that the concrete and rebar can be removed intact. Careful visual inspection for concrete cracks, voids, rebar condition, and any signs of distress should then be performed on the "plug." Concrete cores should be obtained from the intact removed concrete and concrete compression tests should be performed. Rebar diameters should be measured and tensile tests should be performed on rebar samples.

If intact concrete plugs are removed from the dome to install new risers, this recommended task is a high priority opportunity to improve knowledge of the dome strength.

3.1.2 Observations Concerning Current Conditions of Concrete Walls

Gillen (Gillen, 1982) reports the results of concrete strength tests made on a core cut vertically through the depth of the sidewall of Tank SX-115. It has been estimated that the concrete near the bottom of the sidewalls was exposed to service temperatures between 212° Fahrenheit (F) and 280° F for at least two years.

Concrete compression strength in the sidewall core tests ranged between 3825 pounds per square inch (psi) and 6960 psi with a mean value of 5550 psi. While all samples exceeded the 3000 psi design strength, a decrease in strength with depth in the sidewall was observed.

Visual examination of the cores indicated visible cracks with lengths ranging from 2 to 10 inches long, and a number of air voids up to 1 inch long. These air voids are likely indicators of poor

concrete placement during construction. No other signs of concrete degradation or chemical attack were reported.

Daniel, et al. (Daniel, et al., 1982a) reports tests on concrete and reinforcing steel under load at 180° F after exposure to waste solutions. Specimens representing wall sections of a waste storage tank were exposed to simulated waste slurry, simulated salt cake solution, and a control solution for periods varying from 3 to 36 months.

In all cases, there was not indication of attack on either the concrete or steel. Even though solutions penetrated to the reinforcement in the tests of specimens subjected to flexural loading, no evidence was found of rusting, cracking, disruption of mill scale, or loss of strength of the reinforcing steel. Petrographic examination of the concrete showed no evidence of adverse reactions between the solutions and the concrete or the steel.

Thus, preliminary indications have shown that the concrete and rebar in the tank walls remain in good condition.

3.1.2.1. 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. This activity would be similar to the core obtained from Tank 241-SX-115.

Careful visual inspection and concrete compression strength testing should be performed on the recovered core. If any rebar steel is cut in the recovered core, this rebar should be carefully inspected, thickness measured, and tensile tested. However, care should be taken not to cut any significant fraction of hoop reinforcement (rebar) at any level.

3.2 LIKELIHOOD OF SST CATASTROPHIC COLLAPSE

The following assessment is based on the concrete conditions described in the previous section, and previously conducted analyses of the tanks summarized by Abatt (Abatt, 2002).

3.2.1 Potential for Collapse Under Non-Seismic Loading

There is no indication of significant degradation or distress of the dome or haunch regions of the tanks. Given the current state of knowledge of the tanks, collapse of the concrete dome is not a likely event under in-situ loading unless significant degradation of the concrete or rebar in the dome or haunch area was to occur in the future. Furthermore, dome collapse under in-situ loading in the future would be preceded by signs of significant distress such as:

- Excessive downward dome deflection (greater than 0.5-inch);
- Cracking of concrete (crack widths greater than 1/8-inch); and,
- Significant rust stains or spalling on concrete surfaces.

Existing analytical studies of the concrete sidewalls indicate large safety margins exist for in-situ soil loading provided the material design strengths have not seriously degraded. Furthermore, the in-situ loading is essentially axisymmetric and therefore can be resisted by the concrete alone, i.e., very little reliance on rebar strength is needed. Lastly, collapse of the sidewalls only becomes likely if a significant zone of concrete has degraded to the point that it has essentially become rubble. No indications of any such degradation exist.

Therefore, so long as dome downward deflection (since the original baseline) has not exceeded 0.5 inch, the Panel considers there to be a negligibly small probability of a sudden catastrophic collapse under non-seismic loading. This statement presupposes no substantial increase of loading on the tank dome.

3.2.2 Potential for Collapse Under Major Seismic Event

A major (significant) seismic event is characterized by peak ground acceleration in excess of 0.15 gravity (g) and a magnitude in excess of 5.5 on the Richter magnitude scale. Existing analytical studies indicate an adequate safety margin exists for such a seismic event so long as the material design strengths have not seriously degraded. Both hoop and vertical reinforcing steel is needed in the sidewalls to resist the bending stresses that occur under seismic loading. The concrete in the sidewalls must remain intact (i.e., not turned to rubble) and retain some currently unspecified minimum compression and shear strength.

Although good performance under a seismic event is likely, the Panel is not yet prepared to make any fully definitive statement concerning the structural integrity of the tanks under an unlikely major seismic event such as the $4x10^{-4}$ annual frequency of exceedance ground motion being considered for other facilities at the Hanford Site. Good structural performance will depend on the condition of the rebar in the sidewalls as well as the rebar connecting the sidewalls to the basemat. Good structural performance during a major seismic event will also depend on the condition of the concrete in the lower region of the sidewalls. Although the Panel does not expect that major corrosion of this rebar or major degradation of the concrete has occurred, the actual condition of this rebar and concrete is somewhat uncertain.

Before a definitive statement can be made about the seismic structural integrity of the SSTs a modern structural analyses, including seismic loading, needs to be performed on a representative tank. This analysis needs to include the potential for loss of rebar cross-sectional area due to corrosion and potential concrete degradation from exposure to high temperature and leaking waste. 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?

3.2.2.1. Recommendation SI-1: Perform Modern Structural Analyses

Modern structural analyses, including seismic loading, should be performed on representative samples of SSTs. Reasonable bounding estimates of material properties should be used in these analyses. A range of seismic levels (about three levels) should be considered including the $4x10^{-4}$ annual frequency of exceedance ground motion level. For each seismic level considered, the amount of rebar cross-sectional area that must remain in order to achieve structural integrity of the sidewalls and connectivity to the basemat, and the minimum required concrete compressive strength should be determined. The likelihood that these minimum strength properties exist should also be assessed.

3.2.3 Recommendation SI-6: Develop Engineering Mechanics Document

The information items listed in Table 1 are needed to assess both the current and likely future structural integrity of the SSTs. This information is needed for each SST. This information should

be kept current over the remaining life of each tank in a document that can be referenced and used to define input information for future tank evaluations.

It is the Panel's understanding that the information requested in Table 1 exists for each tank but is not generally collected into an easily available document.

Table 1: Recommended Contents of Best Current Understanding of Engineering Mechanics Properties Document.

Steel Liners

- Wall thicknesses considering estimated corrosion plus estimated current corrosion rate
- Material properties and chemistry
- Estimated bulge size and shape at base of tank walls, if any, and expected cause of this bulge

Concrete Wall and Dome

- Estimate of current material properties of concrete and rebar
- Estimate of rebar degradation resulting from tank leakage
- Estimated dome deflection, if any, and expected cause of this deflection
- Expected zones of high residual dome stress from prior loading

Current Contents

Estimated physical characteristics of the tank contents for each stratified layer, including:

- Depth
- Specific gravity
- Bulk modulus
- Elastic Modulus
- Shear modulus
- Shear Strength if any
- Viscosity

3.3 NON-DESTRUCTIVE EVALUATION OF TANK CONCRETE

The elastic modulus of concrete is an important structural analysis input, controlling the degree of deformation that will occur under various loading situations. In addition, the modulus is correlated with the concrete strength. Severe decreases in modulus imply both increased deformation and decreased strength under load (stress = modulus x strain).

Elastic modulus is valuable although difficult to obtain for the SSTs. The non-destructive evaluation (NDE) of SSTs presents significant challenges because of a lack of access. Many of the techniques that are routinely used in NDE are not easily applied to SSTs because the surfaces of the concrete and steel liner are not directly accessible. Deployment of these techniques is possible, but not without significant effort to gain access. Given the cost, logistical and practical issues, a graded approach is recommended.

Ideally, the mode of degradation in a structure is understood, including both the nature and likely locations of expected defects (e.g., a fatigue crack in a region of high cyclic stress). However,

tank history and environmental uncertainties make this ideal situation unobtainable. Given these uncertainties, the exact nature and location of the expected defects is unknown. One cannot solely rely on an inspection targeted at a very local region and flaw type. Instead, one must be concerned about the existence of "unknown unknowns" and must look more broadly. This implies either an inspection with 100% coverage, which is generally impracticable in the large and inaccessible geometry of the SSTs, or a sampled inspection. The latter can only provide general confidence about the nature of the degradation processes that are underway.

All available data suggest that the integrity of the concrete tank is excellent, particularly the dome for which visual observation is possible. Not as much information is available about the sidewalls, for which there is no visual access. Structural analysis using properties considered to be "reasonable" suggest that there should be little concern under static loading. However, a possible concern could exist under seismic loads if the concrete at the bottom of the walls were "rubbelized." The recommendation that follows is motivated by the desire to determine the most accurate concrete properties possible for use in the structural analysis.

3.3.1 Recommendation SI-4: Perform Non-Destructive Evaluation of Concrete

The Panel emphasizes the importance of the hierarchical aspect of this recommendation. The relatively simple technologies (visual inspection and utilization of a 'thumper' truck) should be pursued first. Additional development and deployment of technologies should occur in the event SSTIP activities (e.g., visual inspection, modeling, vertical core results) indicate potential concrete degradation. At this point, depending on the severity of the concerns, additional technologies such as guided wave propagation or the development of more localized concrete integrity measurement techniques should be pursued.

First, the Panel recommends performing a one-time remote visual inspection of the underside of the concrete domes for all SSTs. Ideally this inspection would include the entire dome, with a focus on the haunch region. If this is not feasible, the haunch regions near risers should be the focus. The inspection should identify cracks in excess of 1/16 inch wide. No such cracks should be found on the underside of the dome. If any such cracks are found, an analytical assessment of the cause of the cracks should be made.

The inspection should also look for signs of rust stains on the concrete, or spalling of concrete. These conditions are strong indicators of rebar corrosion.

This visual inspection should be repeated in the future for any SST for which dome downward movement has increased more than 0.25 inches during the prior two-year period (see Recommendation SI-2). Such an increase is an indicator of a potential problem.

Second, the Panel recommends measuring the frequencies of SST vibrations by using a commercially available 'thumper' truck such as that used in seismic and vibration analysis. As the truck shakes the earth, the dome response would be measured by accelerometers attached at strategic points. The modulus of the dome could be inferred from displacements and resonant frequencies. Comparing the observed data to the predictions of structural vibration models, with the modulus varied to obtain best fit, would enable this inference. It is likely that the analysis would show that the measurements are most sensitive to the modulus of the dome.

Guided wave propagation is the third technology in the hierarchy (a discussion of the general properties of guided waves is found in Section 4.3.2). Guided wave propagation should only be pursued if evidence of concrete degradation emerges from other SSTIP activities.

Guided wave energy could be propagated down the sidewalls. A 'rubbelized' region would produce a reflection earlier than produced by the geometrical discontinuity of the knuckle. Such a measurement would require the development of special transducers. Wavelengths significantly larger than the thickness of the wall (e.g., several feet) would likely be necessary (e.g., frequencies on the order of a few kilohertz (kHz) or lower). Special instrumentation would have to be developed for this purpose, but no fundamental barriers are anticipated in that development.

Should guided wave measurements raise concerns about the integrity of the concrete in a particular region (e.g., near the knuckle), more local measurements should be made to quantify that degradation. Carino (Carino, 2002) discusses a wide range of established candidate techniques available for SSTs. Recent research developments are discussed in Dobbmann and Wiggenhauser (Wiggenhauser, 2008). All of the techniques require local access to the wall of the tank. Should conditions dictate the need to recover such information, a small hole would have to be excavated in the soil along the outer wall of the tank to allow the access required for the instrumentation to be inserted.

3.4 ANALYSIS OF SIMULATED WASTE IMPACTS ON REBAR AND CONCRETE

3.4.1 Reactions with liquid wastes

Liquid waste that has leaked through the steel liner and the concrete walls could have damaged the concrete and rebar. Several unknowns exist concerning this potential damage: 1) the size of the crack in the liner and the associated volume of concrete in contact with the waste, 2) the effect of the waste solution on the concrete and rebar, 3) the duration the waste was in contact with the concrete, and 4) the impact of the concrete/rebar interaction with the liquid waste on the structural integrity of the tank walls. Issues related to leaks are discussed in more detail in Sections 4.1 and 4.2.

Crack sizes in the liners of known "leakers" have not been measured; therefore, it is not possible to estimate the volume of concrete exposed to liquid waste. However, a possibility exists that significant cracks resulted from "bubble" formation in the tank bottoms (discussed in Section 4.1). These large cracks would expose a significant volume of concrete to the waste in the wall-base junction area, raising a concern for the structural stability of the tanks.

There have been studies of the interaction of SST waste with concrete (RPP-10435, 2002). These studies "indicate a large range of potential concrete damage depending on the volume and temperature of the liquid waste fluids coming in contact with the concrete." This same report (RPP-10435, 2002) stated SSTs exposed to high temperatures "could have experienced concrete strength reductions of up to 35%, depending on the temperature history of the tank." The global damage to concrete strength caused by high temperatures is potentially far more damaging than the local damage caused by interaction of SST waste with tank walls (temperature impacts are further discussed in Section 4.2).

RPP-10435 (RPP-10435, 2002) references a 1976 study by the Portland Cement Association (SA-202, 1976). The concrete tested was made specifically for the test and matched an ASTM Type II with a calcium aluminate content of 6-8%. A total of 120 samples with dimensions of 3 x 3 x 11 ½ inches were tested. The samples were cured for 28 days before testing. Eighteen of the 120 samples contained 8 inch long No. 4 round, deformed rebar. The base solution in which the concrete bars were immersed was: 2 molar (M) sodium aluminate, 0.1 M sodium chloride, 0.2 M sodium carbonate, 0.5 M sodium sulfate, 0.1 M sodium fluoride and 0.2 M sodium phosphate. To

this base solution were added the following variable solution chemistries: 4 M, 7 M and 10 M sodium hydroxide, zero, 1M/1M and 3M/3M sodium nitrate/sodium nitrite. Tests were conducted at 50°, 100° and 150° C and examined following 1-, 2-, 3- and 6-month exposures. Tests were also conducted in $Ca(OH)_2$ at the same temperatures. Length change, weight change and sonic modulus were measured as a function of exposure time.

Length change was considered the most useful parameter related to concrete durability. Changes were also observed with time and temperature for each type of measurement. A failure criterion of 0.1% length change was adopted. By this criterion all samples failed within 1 month at 150° C, within 3 months at 100° C and within 6 months at 50° C except samples stored in the three 10 M sodium hydroxide, 10 M sodium hydroxide + 1M/1M and 3M/3M sodium nitrate/sodium nitrite. These latter samples were not much below the 0.1% failure limit, however. Weight change was not deemed a reliable measure of durability because crystallized salt formed during the 21-day drying period following exposure to the simulated wastes. Therefore, this weight gain offset the likely weight loss during exposure. Sonic modulus measurements showed decreases associated with cracking of concrete samples, but the trend did not follow that of length change. It appeared some crack filling occurred from salts that formed during the drying period. Cracking of the samples was characterized as minor to severe, which is consistent with the length changes observed. The samples were still intact and not reduced to rubble, nor was there evidence of rebar corrosion. Samples exposed to calcium hydroxide showed no deterioration in properties.

In summary, temperature was the dominant variable in causing a change in length. Solution chemistry was less a factor, with the exception of calcium hydroxide, which showed no effect on the concrete. Basically, all samples failed or were close to failing the length change criteria within six months at all temperatures and in all solutions.

This study can be criticized for the brevity of the 28-day concrete curing period—the samples were still "green" when exposed to the simulated waste solutions. This is further evidenced by the shrinkage observed after 1 month for samples exposed at 100° and 50° C. A second criticism is the lack of property measurements performed on the samples. . The failure criterion of 0.1% length change appeared to be arbitrary. A simple compressive strength test would have been very informative.

Later studies (Daniel, Stark and Kaar, 1982a; Daniel, Stark and Kaar, 1982b; Kaar and Stark, 1981; Kaar and Stark, 1979) were performed using similar concrete reinforced with steel rebar. These samples, however, were cured 28 days in 100% RH and another 27 days before being exposed to the test solutions. The solution contacted the concrete in only a local region as defined by a tank of the solution in contact with the concrete test specimens. The test solutions were named the simulated Waste Solution and the simulated Double-Shell slurry solution. The simulated Waste Solution was 7M sodium hydroxide, 3M sodium nitrate, 3M sodium nitrite, 2M sodium aluminate, 0.1 M sodium chloride, 0.2 M sodium carbonate, 0.5 M sodium sulfate and 0.1 M sodium fluoride. The Double-Shell slurry solution was 7.3M sodium hydroxide, 6.0 M sodium nitrate, 4.5 M sodium nitrite, 4.3 M sodium aluminate, 0.7 M sodium carbonate, 0.2 M sodium sulfate and 0.3 M sodium phosphate. The samples were 9 x 12 inch cross sections, 36 inches long. In the Daniel, Kaar, Stark, 1982a study, the samples were first exposed for 13 months in simulated waste solution; followed by 12 months in the Double-Shell slurry.

Daniel, Stark and Kaar (Daniel, Stark and Kaar, 1982b) also reported on exposures up to 36 months. All tests were conducted at a temperature of 82° C. The samples were exposed to the simulated waste solutions while under either a compressive stress of 500 psi or flexure with a rebar stress of 10,000 or 20,000 psi. The flexure test samples were first flexed to produce cracks

before exposure to the test solution. The primary purpose of these tests was to ensure steel rebar was exposed to the test solution. No effects were observed on the appearance or properties of the rebar. This was demonstrated by removal of the rebar from the concrete and tensile testing. The strength of the rebar was identical to the original material after 36-month exposure. The authors state that no visual change to the concrete from exposure to these solutions was observed. No physical or mechanical tests were conducted on the concrete.

The high pH SST waste could result in sulfate-alumina (sulfate attack), alkali-silica, alkali-carbonate or calcium hydroxide leaching reactions. A sulfate-alumina reaction occurs when calcium aluminate (C_3A) in the concrete reacts with calcium sulfate. A common reaction product is Ettringite [$(CaO)_6(Al_2O_3)(SO_3)_3$-$32H_2O$]. Alkali silica reactions can produce significant expansion in concrete and cause structural problems. This is mostly seen as a reaction between the hydroxyl ions in the alkaline cement pore solution and silica within the concrete. The same holds for the alkali-carbonate reaction, which is less common than that of the alkali-silica. Alkali in the waste would also contribute to the alkali-silica reaction. The hydroxyl ion first dissolves the silica, followed by absorption of the alkali-metal ions by the dissolved silica products producing an alkali-silica gel. Cracking occurs when the alkali-silica gel absorbs water (Shah and Hookham, 1998).

In a reaction with the simulated waste, penetration of the concrete would be necessary to allow significant alkali reaction. The leaching of soluble calcium hydroxide is another possible reaction. Although this may lead to cracking, it is unlikely it would account for expansion. The lack of dimensional change for samples immersed in $Ca(OH)_2$ suggests the reaction that caused the dimensional change in the simulated waste could have been either $Ca(OH)_2$ leaching, sulfate-alumina (because of the calcium aluminate additive) or alkali-silica reaction. It is possible that all three reactions occurred. Natural sand used in the concrete would provide the silica for the alkali-silica reaction.

Portland Cement Association studies (SA-202, 1976; Daniel, Stark and Kaar, 1982a; Daniel, Stark and Kaar, 1982b; Kaar and Stark, 1981; and Kaar and Stark, 1979) showed no rebar corrosion. This is not surprising since the high pH of the concrete and waste should provide the steel an adherent and protective magnetite passive film. Rebar corrosion in roadways can be induced by the presence of Cl^- or CO_2. In the case of reinforced concrete roadways and bridges, CO_2 from the environment lowers the pH near the rebar such that the protective magnetite layer is not stable. The addition of Cl^- as deicing salt may accelerate the corrosion rate of rebar in the passive state. While Cl^- is possibly present in the wastes and groundwater and was present in the test solutions, its concentration is low. Also, CO_2 access to the tank walls is limited. Therefore, rebar corrosion is not considered a significant issue although concrete property reductions will result from waste and temperature exposure.

3.4.2 Effects of waste temperature

Abrams (Abrams, 1979) conducted a study into the effect of elevated temperatures on concrete. Modulus of elasticity, Poisson's ratio, compressive strength and splitting tensile strength were measured and reported for exposure at 121°, 177° and 232° C. Concrete samples with 3,000 psi and 4,500 psi strengths were tested. A drop in the elastic modulus occurred rapidly, then slowed with time (up to 900 days with a 25% drop at 121° C and 50% drop at 232° C after 900 days.) The compressive strength did not show the same rapid drop as the elastic modulus and also showed a smaller overall decrease with a decrease of about 30% at 232° C after 900 days. The splitting tensile strength showed a similar response to the compressive strength.

3.4.3 Recommendation SI-7: Test Effects of Waste Exposure on Structural Integrity

Studies should determine the effects of simulated waste on concrete properties using samples cured longer than 28 days and measuring physical and mechanical properties of the exposed concrete. The effects of waste/concrete/rebar reactions and temperature on the structural integrity of the tank walls should then be estimated.

3.5 CORROSION POTENTIAL MEASUREMENTS OF REINFORCING STEEL IN CONCRETE OF SINGLE-SHELL TANKS

Knowledge of the condition of SST reinforcing steel is required to assess the structural integrity of the tanks. It is difficult to inspect the reinforcing steel in the tank structures using common non-destructive inspection techniques due to the poor tank access and the composite nature of reinforced concrete. Corrosion potential mapping is one candidate indirect technique for assessing the condition of the rebar and concrete in proximity to the rebar. Actively corroding reinforcing steel can result in spalling of the concrete and reduced structural integrity. Procedures for corrosion potential mapping of reinforced concrete are described in ASTM C876-91 (ASTM C876-91, 1999). This test method covers the estimation of the corrosion potential (electrical half-cell potential) of uncoated reinforcing steel in field for the purpose of determining the corrosion activity of the reinforcing steel.

The test method described in ASTM C876-91 (ASTM C876-91, 1999) is suitable for in-service evaluation and is applicable to reinforced concrete structures regardless of size or depth of concrete cover over the reinforcing steel. The results obtained cannot be used to directly estimate the structural properties of the steel or of the reinforced concrete structure. It is often necessary to use other data such as chloride contents, depth of carbonation, delamination survey findings, rate of corrosion results, and environmental exposure conditions, in addition to potential measurements, to formulate conclusions concerning corrosion activity of embedded steel and its probable effect on the service life of a structure. Nevertheless, corrosion potential measurements are a useful tool to assess whether the reinforcing steel is passive or is actively corroding.

The procedure described in the standard consists of placing a reference (half-cell) electrode on the surface of the concrete and measuring the potential of the reinforcing steel with respect to the reference electrode using a high impedance voltmeter. The impedance of the voltmeter must be sufficiently high so the potential measurement is not affected. A sponge, wetted with a conductive electrolyte, is used to provide a low resistance ionic conduction path between the reference electrode and the concrete.

Figure 2 is a schematic showing the circuitry for performing a corrosion potential measurement. Note that electrical connection to the reinforcing steel is required, but the connection does not have to be in close proximity to the location of the reading. However, a continuous electrical (electronic) path between the electrical connection and the rebar being measured must exist. This requirement is normally satisfied in a reinforced concrete structure containing uncoated reinforcing steel by the presence of multiple wire ties between the individual segments of the reinforcing steel. In the case of the waste tanks, a single connection to a riser would be sufficient, assuming that all of the risers are electrically continuous with the rebar. This could be confirmed by means of simple resistance measurements between risers.

In most cases, a concrete structure survey is performed, which consists of a series of potential measurements in a grid pattern on the surface of the structure. While there is no pre-defined minimum spacing between measurements on the surface of the concrete, the spacing should be

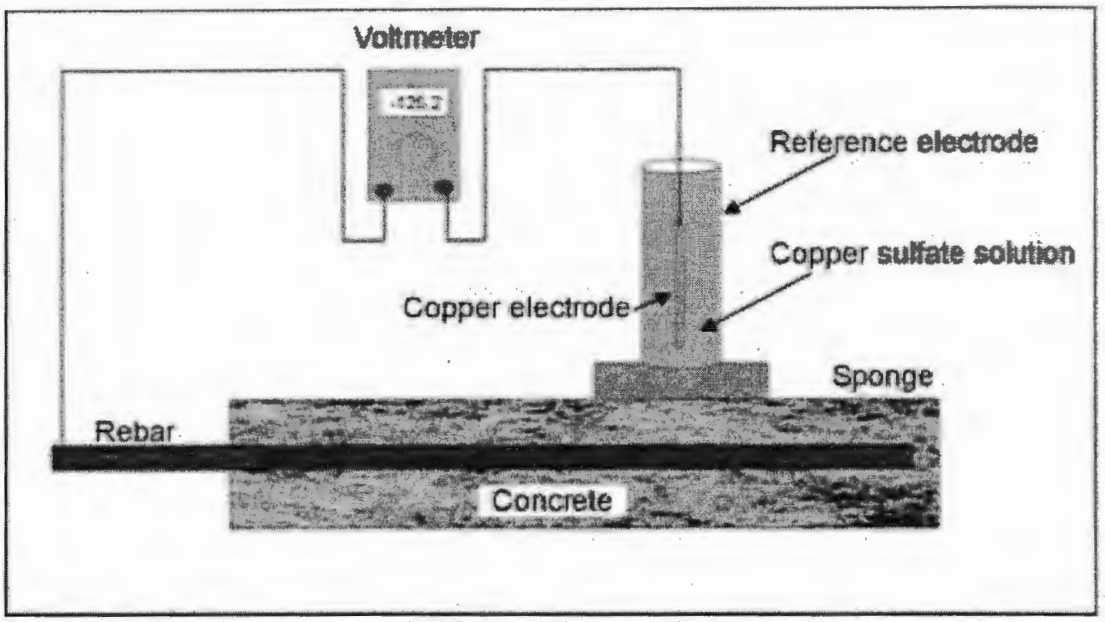

Figure 2: Schematic showing circuitry for corrosion potential measurement.

consistent with the structure being investigated. A spacing of about 4 feet has been found satisfactory for the evaluation of bridge decks. Generally, larger spacings increase the probability that localized corrosion areas will not be detected.

An equi-potential contour map is the most common technique for presenting the results of the potential measurements. An example is given in Figure 3. This map provides a graphical delineation of areas where corrosion activity may be occurring. In the example shown, active corrosion would be expected in the areas with the most negative potentials. In situations where the reinforcing steel is passive (not corroding), the corrosion potentials would be less negative and there would be less variation in the corrosion potentials over the surface of the concrete.

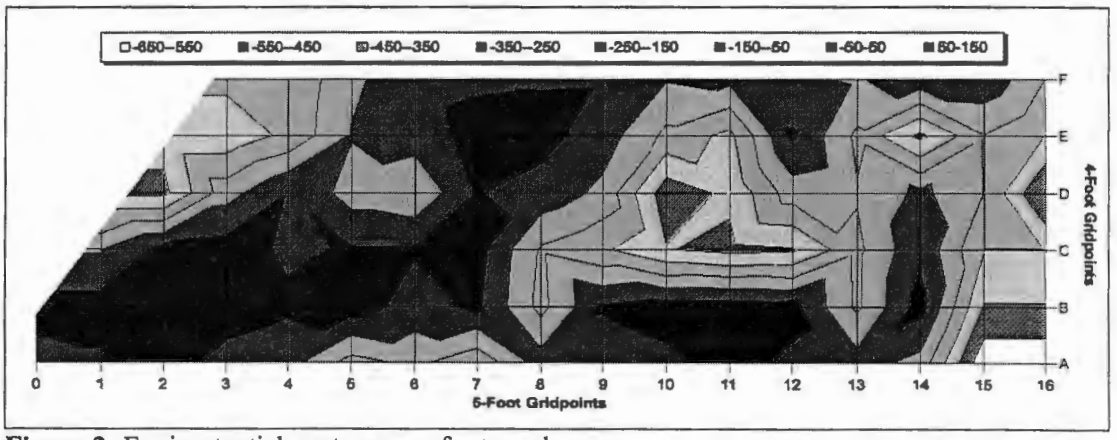

Figure 3: Equi-potential contour map for tunnel ramp.

There likely will be challenges in applying this technique to the SSTs. With the possible exception of the tank dome, direct access to the concrete structure is extremely limited. Therefore, it will be necessary to place the reference electrode in the soil adjacent to the tank. This might create issues with conductivity between the reference electrode and the concrete. On

the other hand, there is a long history of monitoring the potential of underground steel structures such as tanks and pipelines. It might be necessary to perform finite element modeling to establish the area of the tank sensed, based on the soil resistivity and the distance of the reference electrode from the tank wall.

3.5.1 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. Issues that need to be addressed include the electrical continuity between the risers and the rebar mat, the area sensed by the potential measurement, and the ability of the potential measurement to detect active corrosion. A combination of resistance measurements between risers, modeling, and direct examination of a portion of the dome, following mapping, could help resolve these issues.

3.6 SUMMARY OF THE PRIORITIZATION OF STRUCTURAL INTEGRITY RECOMMENDATIONS

Following are the recommendation titles, in order of priority, for the SSTIP confirmation of tank structural integrity key element.

- Recommendation SI-1: Perform Structural Analyses
- Recommendation SI-2: Perform Dome Deflection Surveys
- Recommendation SI-3: Obtain and Test Sidewall Core
- Recommendation SI-4: Perform Non-Destructive Evaluation of Concrete
- Recommendation SI-5: Test Dome Concrete and Rebar 'Plugs'
- Recommendation SI-6: Develop Engineering Mechanics Document
- Recommendation SI-7: Test Effects of Waste Exposure on Structural Integrity
- Recommendation SI-8: Study the Deployment of Corrosion Potential Mapping

4.0 ASSESS THE LIKELIHOOD OF FUTURE TANK LINER DEGRADATION

4.1 ORIGINS OF STEEL LINER FAILURES

4.1.1 Introduction

Alkaline radioactive wastes from the processing of irradiated uranium have been stored in the SSTs since 1944. The initial radioactive wastes were principally derived from three different chemical processing operations, each of which produced several different types of waste. The bismuth phosphate process, the REDOX process, and the PUREX process were designed to recover plutonium from irradiated reactor fuels. The bismuth phosphate wastes that were discharged to the tanks were later processed to recover uranium from the wastes by using the TBP process. Potassium ferrocyanide was used to scavenge cesium ion from this waste. The oldest tanks, which are in 241-B, 241-C, 241-T, and 241-U farms, were constructed to receive the wastes from bismuth phosphate plants, while the later REDOX and PUREX wastes were stored in the 241-S, 241-A, 241-AX and 241-SX farms, which were designed to hold boiling wastes so that water could be removed from the tanks to conserve space for the retention of radioactive materials. Later, other operations including in-tank solidification and outside-tank evaporation were used to remove water and concentrate the wastes.

The vadose zone under the Hanford Site has been contaminated by the leakage of waste from the SSTs during the past 60 years. At the present time, 67 SSTs are known or presumed to have leaked (Roger, 2008). Seven of these 67 (Tanks 241-A-105, 241-BX-102, 241-SX-110, 241-SX-113, 241-SX-115, 241-T-106, and 241-U-104) have each leaked more than 50,000 gallons of waste (Rifaey, 2002, Appendix D). These leaks resulted from failures of the steel liners. One objective of ongoing investigations at the Hanford Site is to determine whether the other leaks were also caused by failure of the steel liner or mishaps during waste transfer operations such as the failure of couplings or transfer lines (Johnson and Field, 2008).

The origins of the major leaks and the possible origins of some other leaks are discussed in the next sections.

4.1.2 Waste Corrosion of the Liner

Corrosion testing began early at the Hanford Site (Endow, 1952; Endow, 1954a; Endow, 1954b; Endow and Sanborn, 1954; Groves, 1953; Groves, 1954; Groves, 1958; Gruber 1957; Mallett, 1954; Parks, 1957; Pitzer, 1952; Sanborn, 1949; Sanborn, 1952; Stivers, 1957; Walker, 1958; and Ward, 1953).

The results of the early tests have been summarized by Lini (Lini, 1975) and Rifaey (Rifaey, 2002, Appendix D). In brief, the early laboratory and field work examined the corrosive properties of bismuth phosphate, metal, REDOX and PUREX wastes. The results of these tests, which are discussed by Lini and Rifaey, implied that general corrosion, pitting corrosion, or SCC were not sufficiently severe to threaten the integrity of the steel liners.

Maness (Maness, 1963 and Maness, 1974) investigated the corrosive properties of relatively concentrated solutions of sodium nitrate and ammonium nitrate. Although the outcome of the tests depended upon the properties of the metal specimens, Maness found that SCC could occur with these solutions at their boiling points. He observed that weldments were especially vulnerable to nitrate ion induced SCC. Moore (Moore, 1971 and Moore, 1975) carried out C-ring tests that demonstrated some waste simulants (including a simulant of PUREX waste) did not cause cracking. He also found that SCC occurred in 50 weight % sodium nitrate at the boiling point (Moore, 1971). In general, these two investigations demonstrated sodium nitrate solutions (over 5 M) and some waste simulants caused SCC of carbon at storage temperatures over 100° C. The same failure mode was also observed with simulated mixtures of salt cake wastes. It was recognized that significant variations in pH of the stored wastes had occurred and that SCC occurred more readily in the nitrate ion rich simulants when the pH was below 10. This testing program identified the threat of nitrate ion induced SCC when the pH was less than 10 and the temperature exceeded 100° C.

The need for additional waste storage space led to the intentional concentration of waste solutions with attendant increases in the concentrations of the non-volatile components in the liquid phases. The partial solidification of wastes resulted in the formation of liquids with high concentrations of sodium hydroxide. It was recognized that exposure of carbon steel to these very alkaline solutions may result in sodium hydroxide induced SCC. Although mixed results were obtained in the testing programs, it was concluded that concentrated sodium hydroxide solutions with compositions similar to the Hanford Site wastes could cause SCC of the steel liners at temperatures above 100° C (Payer et al., 1975 and Moore, 1975). The reality of this threat has recently been discussed by Wiersma (Wiersma, 2008) who concluded that sodium hydroxide induced SCC was responsible for the failure of certain waste tanks (Type IV) at the Savannah

River Site. These tanks contained more than 5 M sodium hydroxide at temperatures between 50° and 100° C.

Lini (Lini, 1975), who first summarized the results of the testing programs, concluded that the general corrosion rates were too small to be responsible for tank failures and the observations regarding pitting corrosion were so difficult to interpret that they were not useful for predictive purposes. However, Lini affirmed that liquids with 6 to 8 M nitrate ion at temperatures near 100° C and a stress of 50 to 100 % of the yield strength can cause SCC over relatively short time periods. He emphasized the special vulnerability of weldments to SCC.

Subsequent testing programs, which are discussed in Section 4.2, have confirmed the general findings of Lini and provided more evidence regarding the role of nitrate ion and hydroxide ion induced SCC in waste tanks.

4.1.3 Operations and the Origins of Major Leaks

Seven tanks (241-A-105, 241-BX-102, 241-SX-110, 241-SX-113, 241-SX-115, 241-T-106, and 241-U-104) of the 67 known or presumed leaking tanks experienced major leaks as noted in Section 4.1. The conditions under which these tanks and some related tanks were operated are discussed in this section to illustrate the conditions under which major leaks occurred.

The waste streams sent to tanks had different thermal characteristics. The bismuth phosphate, TBP and metal wastes were warmed by the decay of radioactive isotopes, but temperatures in the waste tanks that held these wastes were generally manageable. The situation was very different for REDOX and PUREX wastes. Radionuclide decay in these two wastes heated the aqueous solutions in the tanks to their boiling points in a matter of months. The 241-A, 241-AX, and 241-SX tank farms were designed to retain these boiling liquids for years. Nevertheless, two of the five tanks in 241-A farm and nine of the fifteen tanks in 241-SX farm leaked. Tanks 241-A-105, 241-SX-110, 241-SX-113, and 241-SX-115 experienced major leaks.

Johnson and Field recently reviewed, compiled and evaluated SST information about known and assumed leakers and produced a useful Leak Assessment Report (Johnson and Field, 2008). To date, Johnson and Field's work includes a published Leak Assessment Report for the 241-A and 241-AX tank farms (Tanks 241-A-103, 241-A-104, 241-A-105, 241-AX-102 and 241-AX-104). The Panel found this Leak Assessment Report very helpful in understanding the status of data and information about the subject tank farms.

The Leak Assessment Report concludes that the ground contamination associated with Tanks 241-AX-102 and 241-AX-104 resulted from leaks in external Dresser couplings or nearby condensate lines rather than from a failure of the tank liners (Johnson and Field, 2008). The evidence for leakage from Tank 241-A-103 is also questionable according to their analysis.

Rogers (Rogers, 2008) indicates that Tanks 241-SX-104 and 241-SX-107 through 115 are known or presumed to have leaked. Tanks 241-SX-110, 241-SX-113, and 241-SX-115 experienced large leaks.[1]

[1] The as yet unpublished report regarding the 241-SX farm indicates that the soil contamination associated with Tank 241-SX-104 did not occur as a consequence of the failure of the steel liner.

Godfrey and Schmidt (Godfrey and Schmidt, 1969) provided an assessment of the status of the SX Farm. Rifaey (Rifaey, 2002, Appendix D) included this information in the assessment of tank integrity. The main features of the 1969 investigation are summarized in Table 2.

The 241-SX tanks were constructed as the first tanks designed to contain self boiling wastes. More important, the connection between the bottom plate and the side wall was made without a curved knuckle. Rather the side wall and the bottom were welded with a fillet joint at the juncture of the side wall and the bottom plate.

In contrast with the substantive commentary regarding the operation of these tanks at high temperature and the bulging of the steel liners, there is only brief commentary concerning corrosion of the liners. Rifaey (Rifaey, 2002, Appendix D) suggests hydroxide ion induced SCC was partially responsible for the failure of Tank 241-SX-113.

Rifaey (Rifaey, 2002, Appendix D) has described the leaks in Tanks 241-BX-102 and 241-T-106. Since they appear to have failed in the same manner, they are discussed together. Tank 241-BX-102 was first filled with waste in 1948. Between 1959 and 1969, radioactivity was detected in a nearby drywell. Although the origin of this radioactivity is apparently disputed, Rifaey concludes it arose from a leak in Tank 241-BX-102. In 1969, the readings in the drywell were declining, but increased when operations were initiated. The readings increased steadily and additional drywells were drilled to determine the extent of the contamination. The pattern of contamination implies

Table 2: **SX Tank Farm waste history.**

Tank (241-)	Preheated	Preheated Interval	Liquid Heel Used	First Waste Added	Waste Type	Boil with waste	Boil Began	Failure Date	Bulge Inspection	Bulge Observed	Present Status
SX-101	No		No	May-54	REDOX	Yes	Nov-54	None	No		Sound
SX-102	No		No	Sep-54	101 Cascade	No		None	No		Sound
SX-103	No		No	Nov-54	102 Cascade	No		None	No		Sound
SX-104	No		No	Feb-55	REDOX	Yes	Jun-55	None	No		Leaker
SX-105	No		No	May-55	104 Cascade	No		None	No		Sound
SX-106	No		No	Jun-54	Condensate	No		None	No		Sound
SX-107	No		Yes	Mar-56	REDOX	Yes	Jun-56	1964	Yes	Yes	Leaker
SX-108	No		No	Nov-55	REDOX	Yes	Jun-56	1962	Yes	Yes	Leaker
SX-109	No		No	Sep-55	REDOX	Yes	Dec-55	1965	Yes	No	Leaker
SX-110	Yes	7 Months	No	Nov-60	REDOX	No	Jan-61	1976	No		
SX-111	No		No	Jun-56	REDOX	Yes	Nov-56	1974	No		Leaker
SX-112	No		No	Feb-56	REDOX	Yes	Mar-56	1969	Yes	Yes	Leaker
SX-113	No		No	Feb-58	REDOX	Yes	Apr-58	1958	Yes	Yes	Leaker
SX-114	No		No	Nov-56	REDOX	Yes	Jun-57	1972	No		Leaker
SX-115	Yes	11 Months	Yes	Nov-59	REDOX	Yes	Nov-59	1965	No		Leaker

Note 1: Except for Present Status, the information is found in Godfrey and Schmidt (1969).

Note 2: Roger (2008) reports the present status of these tanks.

that waste was released on the southeast edge of the concrete shell near the tank footing. It was concluded the tank wall failed by pitting corrosion 22 inches above the tank bottom (Rifaey, 2002, Appendix A).

Tank 241-T-106 received first cycle decontamination waste and cladding waste (Anantatmula, Schwenk and Danielson, 1994). Rifaey concludes that Tank 241-T-106 failed in the same manner as Tank 241-BX-102 (Rifaey 2002, Appendices A and D) on the basis of the observation that drywell readings exhibited the same pattern. However, the leak in Tank 241-T-106 was much larger, approximately 115,000 gallons of waste leaked from the tank (Rifaey, 2002, Appendix D).

Tank 241-U-104 was placed in service in 1945 when it received metal waste. Rifaey (Rifaey, 2002, Appendix A) indicates the waste in this tank boiled. This waste was removed from the tank in 1953, and inspection of the interior of the tank by periscope revealed no abnormalities (Roberts, 1961). After the removal of waste in 1956, it was discovered that the steel liner had bulged upward by approximately five feet in the center of the tank (Cluckey, 1956; Operations Managers Reports, 1956, 1958; Rifaey, 2002, Appendix A). Approximately 50 % of the tank bottom was covered with liquid. Photographs of the steel bottom showed that it buckled, but did not indicate the bottom had ruptured. Additional photographs of the liner walls and concrete dome lacked sufficient resolution to determine whether corrosion had occurred. Water was added to the tank in July, 1956 to determine whether it was leaking. Initial water level measurements suggested the tank was sound. In 1961, it was discovered that approximately 45,000 gallons of water had leaked from the tank between July, 1957 and March, 1961 (Hanson, 1961; Roberts, 1961). The tank was declared a confirmed leaker in 1961.

Approximately 55 tons of diatomaceous earth was added to the tank in 1972 to absorb the remaining water (Brevick, 1996). The diatomaceous earth addition did not appear effective as radioactivity was detected in a drywell between Tanks 241-U-104 and 241-U-105 in September of 1978. The leak was attributed to Tank 241-U-104, which contained 4.25 feet of wet and dry solids. The small amount of liquid in the waste appeared in two small shallow pools approximately five feet in diameter.

4.1.4 Contributory Factors

First, the steel liners were not heat treated to relieve stresses associated with weldments and were therefore especially susceptible to SCC. This vulnerability is well documented in the corrosion literature. Another construction feature that apparently contributed to the failure of the tanks in the SX farm involved the replacement of the "radiused knuckle" region by a single, essentially perpendicular fillet welded joint between the bottom and the side wall. Rifaey (Rifaey, 2002) describes this vulnerability.

Second, although important uncertainties remain about the waste compositions delivered to the SSTs during early years of operation[2], it is evident that many SST wastes could cause pitting and

[2] The tanks were not sampled on a regular basis. However, one report (Sanborn, 1949) concerning wastes in Tanks 241-T-101, 241-T-102, and 241-T-103 provides insight regarding their actual compositions. Two of these tanks are presumed to have leaked. The pH of these bismuth phosphate process wastes were between 9.8 and 10.1. The temperatures varied from 35° to 80° C. The solutions contained 3M sodium ion and 0.6M nitrate ion with modestly smaller amounts of carbonate, sulfate, and phosphate ions. Little is known about the nitrite ion content, but Anderson (Anderson, 1990) implies that it was not used in the process.

cracking under the storage conditions. Plant records indicate nitrate ion wastes were stored at pH less than 10 and many of the wastes had low concentrations of nitrite ion. Indeed, Anderson (Anderson, 1990), who has formulated the chemical compositions of the principal process wastes, indicates that only cladding waste contained nitrite ion. Later operations led to the concentration of wastes and the selective increase in the concentration of the very soluble sodium hydroxide.

Third, the original waste tanks were operated at relatively high temperatures. Some tank farms were maintained at temperatures greater than 100° C for years. These operating conditions had several important consequences.

The rates of pitting, SCC and corrosion at the LAI increased with temperature.

High temperature operations also altered the physical properties of the encasements. Asphalt coating softens between 30° and 150° C. These temperatures were reached or exceeded in many tanks. Streaks and stains shown in sidewall photographs indicate asphalt has flowed down the inside of the steel liners (Rifaey, 2002, Appendix A). Some stains originate from asphalt that overflowed the top of the liners, other stains appear associated with pits or cracks.

High temperature operations concentrated the waste solutions and caused solids to precipitate on the bottom of the tanks. Superheated water entrapped in these poorly heat conducting solids produced steam that caused frequent bumping and, occassionally, vigorous explosions that expelled waste from the tanks.

Bumping was a recognized problem during the early operations of 241-S farm (Rifaey, 2002). 241-A, 241-AX and 241-SX farms were designed to contain boiling wastes. The energetic events presumably added to liner stresses. The bottom plate in at least one 241-SX tank had numerous plastically deformed ridges approximately 6 inches high and 1 to 2 feet in length (Rifaey, 2002, Appendix A). These ridges were attributed to thermal expansion of the bottom plate. Rifaey (2002, Appendix D) asserts that simple two dimensional calculations show a temperature difference of 70° C is sufficient to "create a thermally induced structural instability in a flat plate of A283, Grade C carbon steel and that tanks which received boiling waste may have been subjected to thermally induced loads sufficiently high to fail the bottoms."

4.1.5 Leak Origins and Paths

Leaks described in Section 4.1.3 did not all originate in the same manner. One small leak occurred high on the side wall in Tank 241-A-105. Although its origin has not been determined, this leak apparently occurred below the surface of the supernatant layer. These circumstances are compatible with either pitting or SCC.

The major leaks in Tanks 241-BX-102 and 241-T-106 (which did not contain boiling waste) occurred on the side wall, presumably in the knuckle region of the tanks. These leaks have been attributed to corrosion at the Liquid Air Interface (LAI) in tanks that were left stagnant for years.

The major leaks that occurred in Tanks 241-A-105 and the 241-SX farm probably occurred due to mechanical ruptures. Other leaks may have originated from pitting, SCC, or weakening of the mechanical strength of steel plates by pitting or SCC. One of the explanations for failure postulates that SCC of the steel liner provided a leak path that allowed liquid to seep into spaces between the bottom of the steel liner and the concrete base. Heating vaporized this trapped liquid and led to substantial pressures, adding to the stress on the steel. Regardless of exact cause, these

ruptures created leak paths that allowed the liquids in the steel liner to contact the concrete side walls, basemats, and footings.

Serious ruptures in the steel liners were responsible for several major leaks. These ruptures occurred near the juncture of the tank bottom and the sidewall. The other major leaks occurred near the center of the bottom and at locations low on the sidewalls.

4.1.6 Correlations between waste types and leaks

Attempts have been made to correlate waste compositions with leaking tanks. Hill and Simpson (Hill and Simpson, 1994) identified 49 different waste types (for example, wastes from the REDOX or PUREX processes) and consolidated the wastes into 30 characteristic groups. They then systematically sorted the SSTs according to types of waste. In some cases, only one type of waste was sent to a tank, in other instances, two or more waste types were sent to the same tank. Anantatmula, Schwenk, and Danielson (Anantatmula, Schwenk, and Danielson, 1994), compared the waste type information provided by Hill and Simpson (Hill and Simpson, 1994) with the tank leak histories. They found a significant correlation between certain waste types and leakage. Several waste types caused leaks in all of the tanks in which they were stored and accounted for approximately 50% of leaking tanks. These waste types included REDOX waste and its variants, the waste delivered to the 241-C-200 farm known as hot semi-works waste, first and second recycle decontamination wastes from the bismuth phosphate process, and certain TBP wastes. Anantatmula, Schwenk, and Danielson (Anantatmula, Schwenk, and Danielson, 1994) found "a direct correlation between the high nitrate ion/low hydroxide ion concentration of the stored waste types and the leak status for the majority of leaking tanks."

The waste groupings used by Hill and Simpson have subsequently been modified on the basis of improved process information histories and analytical information about the compositions of the wastes in the SSTs (Agnew, 1997; Agnew and Corbin, 1998; Place and Higley, 2007). In the course of this work, Agnew and his associates developed a methodology for estimating waste tank compositions based on process waste transfer history. In principle, the model can be used to estimate the composition of a waste tank at any desired time.

4.1.7 Conclusion

Laboratory and field work implies several factors contributed to the failure of the steel liners. First, the liners of the SSTs were not heat treated to remove stresses in the weldments and some tanks were constructed without knuckles. Second, the wastes were potentially corrosive; some wastes had high nitrate ion concentrations and low nitrite ion concentrations at pH less than 10. Subsequently, wastes with high hydroxide ion concentrations were stored in the tanks. Third, some tanks were operated at the boiling point of the waste for years. These conditions enhanced corrosion rates and led to thermal excursions that super heated water trapped beneath the solid layers causing bumping and vigorous steam eruptions. Collectively, these chemical and physical conditions caused failure of the liners by pitting, SCC and mechanical ruptures,.

4.1.8 Recommendation LD-1: Expand Leak Assessment Reports

The ongoing work on the preparation of Leak Assessment Reports for each tank farm should continue. The Panel recommends, however, the discussion about each tank be expanded to include documentation and commentary on the locations and causes of the observed leaks. The discussion for each tank should include an operating summary, an operating history, an analysis

of the leak location and cause, a waste loss estimate, commentary on the nature and extent of ground contamination, and a conclusion.

4.2 ASSESSMENT OF CHEMICAL PROPENSITY FOR FUTURE LEAKS IN SINGLE-SHELL TANKS

4.2.1 Introduction

High concentrations of hydroxide ion at high temperature and high concentrations of nitrate ion can cause various forms of corrosion (SCC, pitting, LAI) of the steel liners of the SSTs. In principle, corrosion can occur on the walls above the waste surfaces, at the LAI, and in the liquids of the supernatant and solid layers. The nitrate ion corrosion hazard is mitigated in many tanks by the presence of nitrite and hydroxide ions, ammonia and low storage temperatures.

This evaluation of the future corrosion hazard of unretrieved SSTs was performed by comparing temperatures and average compositions of the liquids in the supernatant and solid layers with two related indices: the nitrite ion/nitrate ion concentration ratio and the Corrosion Chemistry Control Limits presently used for DSTs.

The composition of wastes remaining in retrieved SSTs, the novel compositions that may exist in heterogeneous solid layers, the consequences of the intrusion of water, and the possible accumulation of chloride ion are also considered.

4.2.2 Temperatures and Chemical Compositions in the Unretrieved SSTs

The current chemical compositions of many SSTs have been determined by the analysis of cores from the supernatant and solid layers. Compositions of SSTs that have not been cored have been inferred through engineering estimates based on tanks containing similar waste types, examination of historical records regarding waste transfer operations, and current temperatures of waste layers. Information compiled by Meacham (Meacham, 2008) has been used to evaluate the future corrosion threat.

The SST wastes have been cooling for many years. Twenty are stored below 30° C, six between 40° and 50° C, eight between 50° and 60° C, four between 60° and 70° C and three between 70° and 77° C.

The nitrate ion contents range from about 0.3 to 6.5 M. The concentrations of the principal corrosion inhibitors also have broad ranges. The measured and estimated concentrations of hydroxide ion range from about 0.01 M to nearly 5 M, and the nitrite ion contents range from 0.01 to approximately 3.8 M. Not surprisingly, the waste compositions in the SSTs are similar to the compositions in the DSTs.

The concentrations of nitrate, nitrite and hydroxide ions and the waste temperatures are summarized in Appendix B.

4.2.3 Previous Test Work

The results of the early testing work were discussed in Section 4.1.2. Subsequent investigations at the Hanford and Savannah River sites (Danielson et al., 1994; Divine, et al., 1985; Donovan, 1977, 1981; Lini, 1975; Manass, 1974; Mickalonis, 1997; Ondrejcin, 1974, 1976, 1978, 1983; Payer, et al., 1975, 1977; Wiersma and Parish, 1997; Zapp and Hobbs, 1992; Zapp, 1994, 1998)

and ongoing investigations since 2000 (Brossia, 2008a, 2008b; Brossia, et al., 2006; Carranza, et al., 2006; Durr, 2005; Hoffman and Subramanian, 2008; Wiersma, 2008; Hoffman, et al., 2008), have examined the factors that govern rates of liner corrosion. These investigations established that corrosion rates depend upon steel properties, potential, temperature, concentrations of aggressive substances (such as nitrate ion), and inhibitors (such as nitrite and hydroxide ion).

The testing programs generally examined the influences of potential, temperature and composition on corrosion and often used Cyclic Potentiodynamic Polarization (CPP) and Slow Strain Rate Testing (SSRT) for the study of waste simulants.

The CPP test provides information regarding the corrosion potential and the propensity for the solution to cause pitting corrosion (ASTM, 2003). The specimen is first scanned in the anodic direction, then the scan direction is reversed at a pre-determined potential or current. Any hysteresis (increase in current during the backscan relative to the upward scan) provides an indication of pitting, while the size of the loop relates to the amount of pitting. If pitting occurs, the potential at which the current increases rapidly, the pitting potential, and the potential at which the current drops significantly during the backscan, the repassivation potential, are measures of susceptibility to pitting. These critical potentials can be compared to the corrosion potential.

The SSRTs define the compositional and potential regions where SCC does or does not occur (ASTM, 2006). The specimen, immersed in the test simulant, is slowly strained to failure while being maintained at a specific potential or while left at the free corrosion potential. The failure strain is noted and the fracture surface of the specimen is then examined visually and by scanning electron microscopy for evidence of SCC.

The testing programs have identified waste compositions vulnerable to pitting corrosion, corrosion at the steel-LAI, and nitrate ion promoted SCC.

4.2.4 Evaluation of Corrosion Risk in the Unretrieved SSTs

Two criteria were employed to assess the propensity for corrosion in the present compositions in the unretrieved SSTs.

First, the nitrite ion/nitrate ion concentration ratio was examined in each layer (for which compositional information was available). The results of the testing programs discussed in Sections 4.1.2 and 4.2.3 indicate that SCC does not occur in Hanford Site waste simulants at open circuit potentials when the nitrite ion to nitrate ion concentration is greater than 0.1, the pH is greater than 11, and the temperature is less than 50° C (Brossia, 2008a and 2008b).

Second, the Corrosion Control Chemistry Limits (Kirsch, 1984; HNF-SD-WM-TSR-006, 2008; Powell, 2009) established for DSTs at temperatures less than 75° C were applied to the SST wastes. These more complicated limits depend on the amount of nitrate ion in the waste. When the nitrate ion concentration is greater than 3 M, the hydroxide ion content must be greater than 0.3 M and the sum of the nitrite ion and hydroxide ion concentrations must be greater than 1.2 M. When the nitrate ion concentration is between 1.0 and 3.0 M, the hydroxide ion content must be greater than 0.1 M nitrate and the sum of the nitrite ion and hydroxide ions must be greater than 0.4 M nitrate. When the nitrate ion concentration is less than 1.0 M, the hydroxide ion content must be greater than 0.01 M and nitrite ion and hydroxide ions must be greater than 0.011 M.

Table 3: Temperatures and compositions of SST supernatant and interstitial liquids.

Tank	Layer	Temp. °C	OH^- (Molar)	OH^- (pH)	NO^-_2 (Molar)	NO^-_3 (Molar)	Compliance Test (Ratio)	Compliance Test (DST Limits)
Unretrieved Wastes								
241-B-102	Supernatant	18.1	1.00	14.0	0.18	3.50	0.05	Not compliant
241-B-102	Solid	18.1	1.00	14.0	0.19	3.50	0.05	Not compliant
241-B-103	Supernatant							
241-B-103	Solid	17.3	1.00	14.0	0.19	3.52	0.05	Not compliant
241-B-104	Supernatant							
241-B-104	Solid	21.5	1.00	14.0	0.19	3.48	0.05	Not compliant
241-B-105	Supernatant							
241-B-105	Solid	18.6	1.00	14.0	0.19	3.48	0.05	Not compliant
241-B-106	Supernatant	17.6	1.00	14.0	0.19	3.50	0.05	Not compliant
241-B-106	Solid	22.9	1.00	14.0	0.19	3.50	0.05	Not compliant
241-B-107	Supernatant							
241-B-107	Solid	16.0	1.00	14.0	0.14	5.34	0.03	Not compliant
241-B-109	Supernatant							
241-B-109	Solid	20.0	1.00	14.0	0.19	3.50	0.05	Not compliant
241-B-203	Supernatant	20.2	1.00	14.0	0.03	0.91	0.04	Compliant
241-B-203	Solid	16.5	1.00	14.0	0.03	0.91	0.04	Compliant
241-B-204	Supernatant	19.0	1.00	14.0	0.03	0.56	0.05	Compliant
241-B-204	Solid	16.7	1.00	14.0	0.03	0.56	0.05	Compliant
241-C-110	Supernatant	20.8	1.00	14.0	0.10	0.97	0.10	Not compliant
241-C-110	Solid	23.8	1.00	14.0	0.10	0.97	0.10	Not compliant
241-T-102	Supernatant	17.8	0.00	11.6	0.50	1.76	0.28	Not compliant
241-T-102	Solid	17.8	0.00	11.6	0.50	1.76	0.28	Not compliant
241-T-108	Supernatant							
241-T-108	Solid	16.2	1.00	14.0	0.19	3.50	0.05	Not compliant
241-T-109	Supernatant							
241-T-109	Solid	22.6	1.00	14.0	0.19	3.50	0.05	Not compliant
241-T-110	Supernatant	18.6	1.00	14.0	0.00	0.30	0.00	Not compliant
241-T-110	Solid	18.0	1.00	14.0	0.00	0.30	0.00	Not compliant
241-T-201	Supernatant	19.2	1.00	14.0	0.01	0.74	0.01	Not compliant
241-T-201	Solid	20.6	1.00	14.0	0.01	0.74	0.01	Not compliant
241-TX-116	Supernatant		0.15	13.2				
241-TX-116	Solid	21.1	0.15	13.2	0.23	6.11	0.04	Not compliant
241-TX-117	Supernatant							
241-TX-117	Solid	21.1	1.00	14.0	0.19	3.50	0.05	Not compliant
241-TY-101	Supernatant							
241-TY-101	Solid	18.6	1.00	14.0	0.18	3.50	0.05	Not compliant
241-U-203	Supernatant	18.8	0.28	13.4	0.42	2.32	0.18	Not compliant
241-U-203	Solid	19.1	0.28	13.4	0.42	2.32	0.18	Not compliant
Note 1	The temperatures and compositions were obtained from Meacham (2008).							
Note 2	The assumed leakers are shown in gray on the left							
Note 3	Ratios that less than 0.11 and wastes that are not compositionally compliant are shown in gray on the right.							
Note 4	pH is related to the hydroxide ion content by the equation: log [OH(-1)] = pH -14							

The application of these two corrosion criteria to the SSTs reveal that 19 of the unretrieved tanks contain wastes with compositions that are not compliant with the ratio criterion, the DST Corrosion Control Chemistry Limits or both. These 19 SSTs are listed in Table 3. Generally, the hydroxide ion content is adequate, but the nitrite ion content is too low for the amount of nitrate ion in the tanks. 11 of the 19 noncompliant wastes are in tanks assumed to have leaked (Rogers, 2008).

The application of the same criteria to the former contents (Hu, 2007) of the 10 SSTs that have been retrieved implies 9 of these tanks were also noncompliant. However, most of these retrieved wastes contained very low concentrations of nitrate ion and the propensity for corrosion is not well defined by the DST criteria.

4.2.5 Other Contributory Factors

Long term storage of the wastes in the SSTs has created three other problems that deserve attention.

First, the solid layers of some SSTs have become layered and inhomogeneous as a consequence of waste transfer operations that mixed several waste types. Important variations may exist in layer compositions that are not manifest in the average compositions utilized in the analysis.

Second, groundwater might have infiltrated into waste tanks through cracks in the dome or sidewalls. Rain water might have infiltrated into tanks through risers and other dome openings. There are two related concerns. Many SSTs contain very small amounts of liquid. Therefore, the intrusion of water could adversely alter the pH of the surface layers. Also, the addition of dilute condensate solutions to the DSTs sometimes results in the formation of a separate layer with a pH between 10 and 11 that might be vulnerable to corosion of the steel at the LAI.

Third, operations in which commercial grades of sodium hydroxide have been added to the waste tanks simultaneously introduced corrosive chloride ions into the waste tanks.

4.2.6 Future Liner Corrosion Mitigating Factors

Two natural factors will tend to mitigate the propensity for future corrosion of the unretrieved SSTs.

First, the temperatures of the wastes in the 19 SSTs containing noncompliant wastes are less than 25° C. The corrosion rates might be so slow at this temperature that neither new pits or SCC are a credible concern.

Second, ammonia, a common constituent of the SST wastes (Meacham, 2008), might inhibit corrosion at the LAI and on the steel walls in the dome spaces.

Several reports indicating the potential effectiveness of ammonia as an inhibitor of corrosion have appeared in the technical literature. This was noted in an early report from the Hanford Site (Endow, 1954a; Rifaey, 2002, Appendix F). Congdon (Congdon 1986a and 1986b) pointed out that ammonia inhibited corrosion at the LAI and in the vapor above Savannah River waste simulants. Anantatmula (Anantatmula, 1996, Anantatmula, et al., 1996, Anantatmula and Berman, 2003) reported that 100 parts per million (ppm) concentrations of ammonia suppressed vapor phase corrosion at high relative humidity with Hanford Site wastes. Subsequently, Frye, Duncan and Wyrwas (Frye, Duncan and Wyrwas, 2008) demonstrated the addition of 0.3 M ammonia to a dilute waste simulant with 0.48 M nitrate ion and 0.04 M nitrite ion prevented pitting corrosion in solution during CPP testing of another Hanford Site wastes.

4.2.7 Conclusion

There are 19 nitrate ion rich unretrieved SST wastes that presently contain nitrite ion/nitrate ion concentration ratios less than the minimum value (0.1) presumed to protect the DSTs from SCC,

or have compositions not in accord with the DST Corrosion Chemistry Control Limits. Wastes in these tanks have been out of compliance for many years. Given that the SSTs were not heat treated, an even greater propensity for SCC exists in the SSTs than in the DSTs.

Some novel compositional variations may exist because of inhomogeneous solid layers, water infiltration and the inadvertant addition of chloride ion since the last samples were analyzed.

4.2.8 Recommendation LD-2: Avoid inadvertent addition of water and chloride to SSTs

The Panel recommends operational procedures be implemented to prevent the inadvertent addition of water and chloride ion to the SSTs. It is recommended that the impact of water intrusion and the unintended increases in chloride ion concentrations be evaluated on a tank by tank basis and that operational procedures be implemented to prevent their introduction in the future.

4.2.9 Recommendation LD-3: Examine Non-Compliant Wastes at 25° C

The Panel recommends examining selected "non-compliant" SST waste simulants at 25° C to ascertain the propensity for pitting and SCC. The corrosion rates might be so slow at this temperature that examination could eliminate new pits or SCC as credible concerns. Waste simulants should also be tested to determine the propensity for causing corrosion at the LAI and on the steel walls in the vapor space. This testing work should be carefully coordinated with the DST testing program that is already underway.

4.2.10 Recommendation LD-5: Determine Ammonia Corrosion Control Concentration

The Panel recommends that laboratory tests be carried out to assess the effectiveness of ammonia as an inhibitor of corrosion in the liquid phases of the solid and supernatant layers, at the LAI and on the exposed walls in the vapor spaces. A laboratory investigation is needed to establish the relationship between the concentrations of ammonia in the vapor that are needed to control these kinds of corrosion. Again, this testing work should be carefully coordinated with the testing program that is already underway with the DSTs.

4.2.11 Recommendation LD-6: Assess SST Waste Compositional Variation

The Panel recommends determining whether the compositional variation in the solid layers of the SSTs deviates from the general SST and DST programmatic assumptions about composition. If so, testing work may need to be performed to evaluate the propensity for corrosion.

4.3 LEAK INTEGRITY OF STEEL LINERS

4.3.1 Background

Information about liner integrity is important for several reasons. Although the liner does not contribute significantly to the strength of the tank, liner integrity is essential to the prevention of leaks. Identifying the nature of the damage to the liner will contribute to understanding the material degradation mechanisms responsible for the leaks. This information could play an important role in future remediation strategies. Different actions might be taken in a tank known to have minor leaks than in one that is known to have a major tear in its liner. For tanks that are not known to have leaked, information supporting leak integrity would provide critical information in guiding their future use.

The challenges in applying NDE techniques to SST liners also apply also to the NDE of the SST concrete (see Section 3.3).

4.3.2 Guided Wave, Ultrasonic Technology to Assess the Presence of Macroscopic Degradation.

Guided waves are the basis for a form of ultrasonic inspection in which the energy is confined by the surfaces of a part. Ultrasound can propagate in the form of waves with two polarizations, longitudinal and transverse (T). If one thinks of a plate, and imagines these waves propagating at an angle with respect to the surface normal, it is obvious that the waves will be reflected each time they encounter a surface and hence will bounce back and forth down the plate. At each of these reflections, there will generally be two waves coming back, a reflected wave of the same polarization as the incident wave and a wave of the other polarization (known as the mode converted wave). In general, the superposition of these multiple reflections and mode conversions will produce a very complex and difficult to interpret wave pattern. However, for any given plate thickness, at certain combinations of frequency and angles, the multiple reflections and mode conversions form a stable pattern, characterized by a specific variation of dynamic stress and strain across the thickness of the plate that propagates without change (in the absence of attenuation) for long distances. This transverse variation is somewhat analogous to a drumhead mode of a particular shape. The electromagnetic modes of a waveguide (e.g., microwave technology) are a consequence of the same general principles. The fact that one can hear a train coming from a long way off by putting one's ear to the rail is a mechanical example. The rail guides the vibrations created as the train's wheels roll over the rail to the listener's ear with very low loss. Many textbooks describe guided wave propagation, with one of the most recent written by Rose (Rose, 2004).

Guided waves are characterized by three parameters: frequency, phase velocity (rate at which phase fronts move down the plate), and group velocity (rate at which energy moves down the plate), all of which are a function of the plate thickness. Guided wave behavior is relatively simple when the wavelength (ratio of phase velocity to frequency) is larger than the plate thickness, becoming much more complex for shorter wavelength (because of the complicated nature of the interference patterns mentioned above). Accordingly, guided wave inspections are generally performed at lower frequencies than conventional ultrasonic inspections, in which generally the frequency is less than the wall thickness.

The practical advantage of guided waves is they can rapidly obtain information about large structures since the structure is scanned at the speed of sound rather than a mechanical scanning rate. However, less detailed information is obtained since the waves integrate information from the region through which they propagate. For this reason, guided waves are often used as screening tools, with other tests added if a positive indication is obtained.

Over the last decade, the interest in NDE with guided waves has grown rapidly. This is due to pipe inspection needs in chemical plants, below grade, etc. References include the plenary paper by Cawley (Cawley, 2003) and papers presented at a number of special sessions in recent conferences (Thompson and Chimenti, 2009). Commercial application of this technology is underway, but the development of codes and standards is still in its early stages.

A key design decision is the selection of the operational frequency. Several engineering trade-offs must be considered. Low frequency waves generally have a lower attenuation and hence can

propagate greater distances. However, higher frequency waves will be more directional and can obtain more information.

A particularly attractive method to implement guided wave measurements is through the use of electro-magnetic acoustic transducers (EMAT) as is shown in Figure 4 (Thompson, 1990). These devices can excite and detect guided waves without the need for a coupling medium such as fluids that are used with piezoelectric transducers, greatly facilitating measurements on the tank liner. Two strategies for implementation should be considered. In one, a pair of EMATs would be positioned diametrically opposite one another at the top of the liner. One would excite a guided mode that would propagate down one wall of the liner, around the corner, across the bottom, around the next corner and up the other wall to the receiver to identify flaws on the bottom of the tank. The presence of a significant tear to the liner would block this signal path causing a drop in the transmitted signal. In an alternative mode, a single EMAT, positioned near the top of the liner, would be operated in a pulse-echo mode. The measurement would be designed to look for reflections from tears in the liner that have a different signature from that of the reflection from the corner.

In discussions about applications to SSTs with experts in the guided wave community, three potential issues were identified, as described below. These are provided to guide feasibility discussions with potential vendors in the event that implementation is pursued.

- **How much energy will travel around the corners at the bottom of the tank as opposed to being reflected from the geometric discontinuity?** The answer will depend on the mode type, frequency and detailed geometry at the tank bottom.
- **Will the energy stay collimated and reach the bottom of the tank as a beam or will it spread out such that it travels around the tank sidewalls?** Spreading is a consequence of diffraction phenomenon controlled by the transducer aperture, W, and ultrasonic wavelength, λ. The beam will stay collimated for a distance $z = W2/4\ \lambda$ from the transmitter. If the beam were required to stay collimated for a distance of 30 feet (typical of the height of side walls), and the ultrasonic guided wave phase velocity in the steel were 16,000 feet per second, the frequency, f, would then have to satisfy the relationship $f > 1.92 \times 106/W2$, where W is measured in feet. Therefore, for a 1-foot aperture, one would require a frequency greater than 1.92 MHz; whereas for a 10-foot aperture, the frequency would only have to be greater than 19.2 kHz.
- **How much will a pulse be attenuated?** This is a significant unknown. Due to the microstructure, attenuation should not be a problem in a steel plate with free surfaces at low kHz frequencies. It is not clear, however, if increased attenuation will become a problem due to concrete loading the steel and water drawing energy from the guided wave in the steel. Determining how tightly the concrete is bonded to the steel would indicate whether this issue might be a problem.

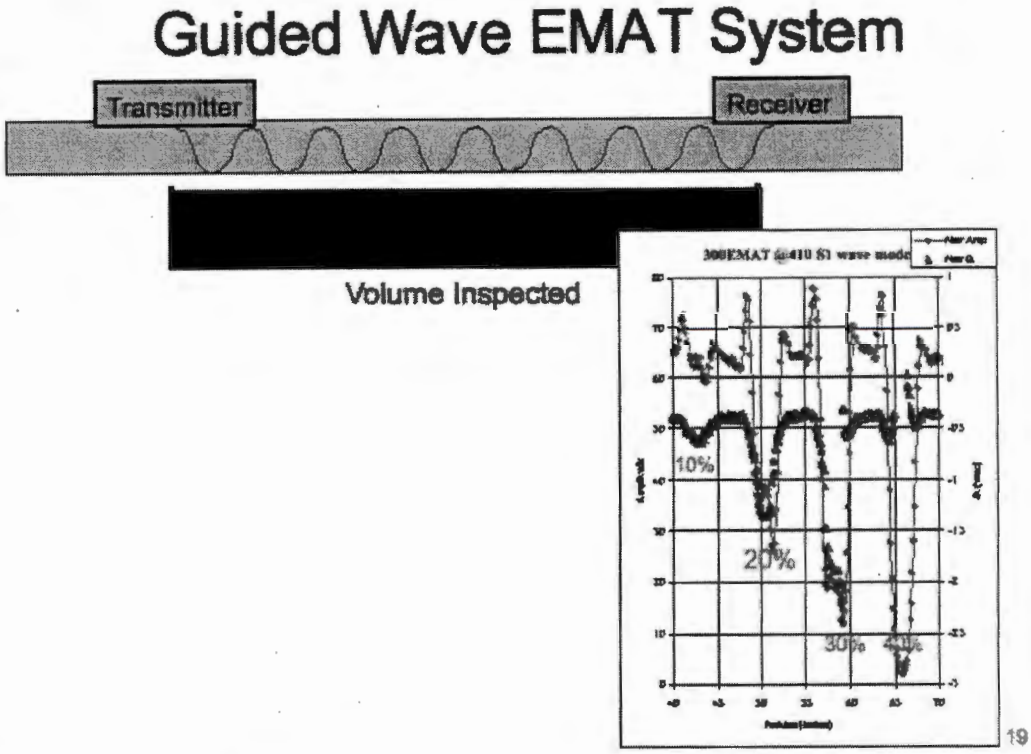

Figure 4: Guided wave EMAT system.

4.3.2.1. Recommendation LD-4: Develop and Deploy Guided Wave Technology

The Panel recommends the development and deployment of guided wave, ultrasonic technology to assess the presence of macroscopic degradation of the steel liner. A design study should be undertaken to determine the optimum parameters of an EMAT system for this application. This should be followed by laboratory feasibility studies and implementation.

Organizations that may be helpful in the development and deployment of this technology include Guided Ultrasonics Limited (U.K.), The Welding Institute (U.K.), Southwest Research Institute, and Sonic Sensors (specializing in the use of EMATs). Peter Cawley at Imperial College (London) leads a strong academic research group specializing in the application of this technology. Guided Ultrasonics Ltd. conducts 1 to 2 day seminars on the use of guided waves. More contact information can be provided upon request.

4.3.3 Direct Current Potential Drop Test

The Direct Current Potential Drop (DCPD) technique is based on injecting current into a metallic component and measuring the resulting voltage (potential) at selected points. For example, if current is injected at one point into a flat metal plate and then extracted at a second point, a distribution of current flowing between these two points can be measured, with the greatest current density occurring along the shortest path between the points. The presence of a crack between the two probes would disrupt the current flow. The change in voltage drop between a pair of electrodes can be measured.

Similar ideas could, in principle, be applied to the tank geometry. Current could be injected on the top of one sidewall and extracted at a diametrically opposed position on the other sidewall. Current will be distributed on the path of least electrical resistance, generally the shortest distance between the two probes. Two paths of particular interest are, (1) around the circumference, a distance of $\pi D/2$ and down one sidewall, and (2) across the bottom and up the other sidewall, a distance of 2H+D. D denotes the diameter of the tank and H denotes the height of the sidewall.

Tearing near the bottom of the tank would be best identified by maximizing the current passing through the bottom of the tank as opposed to that passing around the periphery. This will be easiest for shallow tanks, with the two paths being equal when H/D = 0.285. Since H/D is greater than 0.285 in most tanks, a significant flow around the periphery will occur. Sufficient current might flow through the bottom to allow the detection of a major tear. The situation would be improved if the height of the tank could effectively be reduced by injecting and extracting the current lower on the sidewalls of the tank.

In detecting tears, the voltage would be received by a second set of probes, perhaps placed at 90-degree positions with respect to the injection points.

The Panel is not aware of applications of DCPD to this particular geometry, although such may have occurred. The following action is thus recommended.

4.3.3.1. Recommendation LD-10: Consider Applying Direct Current Potential Drop to SSTs

The Panel recommends the feasibility of applying the DCPD technique to SSTs be studied. One approach could evaluate theoretical models for the current flow in SSTs. A second approach would consist of a simple laboratory experiment. A set of small cylindrical, metal cups containing simulated tears of different length would serve as the samples. Current would be injected at one point and extracted at a diametrically opposed point. Voltage measurements could then be used to evaluate the differences in potential distributions between torn and untorn samples. This data would provide a strong indication of the feasibility of field implementation.

4.3.4 Corrosion Potential Measurements of Liner

The recent DST integrity project studies at ARES/DNV (Brossia, 2008a and 2008b) have found that potential is a critical parameter for determining resistance of tank steel to both SCC and pitting corrosion in waste simulants. Figure 5 shows a summary of the many SSRTs performed in different nitrate-based waste simulants at 50° C. Filled symbols represent conditions where SCC was observed and open symbols represent experiments where no SCC was observed. For simulants with nitrite/nitrate ratio >0.1, a sharp potential boundary exists near -50 millivolts (mV) versus the saturated calomel electrode (SCE), below which the tank steel is immune from SCC and above which SCC is possible. Critical potentials for pitting corrosion also exist.

At present, the aggressiveness of interstitial fluids in SST sludge and saltcake is not fully understood. While SST waste compositions do not differ significantly from DST waste compositions, or from compositions of other simulants that have been tested, some outliers might exist. Therefore, the Panel has recommended an assessment of all the SST waste compositions. Additional laboratory studies might be needed for specific chemistries that have not already been evaluated. If a similar critical potential were observed for tank liner steel in SSTs, knowledge of the tank corrosion potential would be extremely important. If the tank corrosion potential were known to be well below the critical potentials for SCC and pitting corrosion—in particular if

there were a margin of safety of more than about 100 mV—then there is a low probability of these phenomena occurring in the SST.

Probes for measuring potential, corrosion rate and cracking susceptibility have been developed and inserted into selected tanks. A probe that reliably measures the tank corrosion potential was installed in the DST 241-AN-102 in May 2008. Probes have also been installed in DSTs 241-AY-102 and 241-AY-101. The potential of 241-AN-102 has been measured to be in the vicinity of -360 mV SCE. This potential is more than 100 mV more negative than the critical potential for SCC expected for nitrate based waste (approximately -50 mV SCE) and, as a result, provides a strong indication that this tank will not exhibit pitting or SCC in the near term. Such indication of a benign condition is powerful reassurance of the tank status.

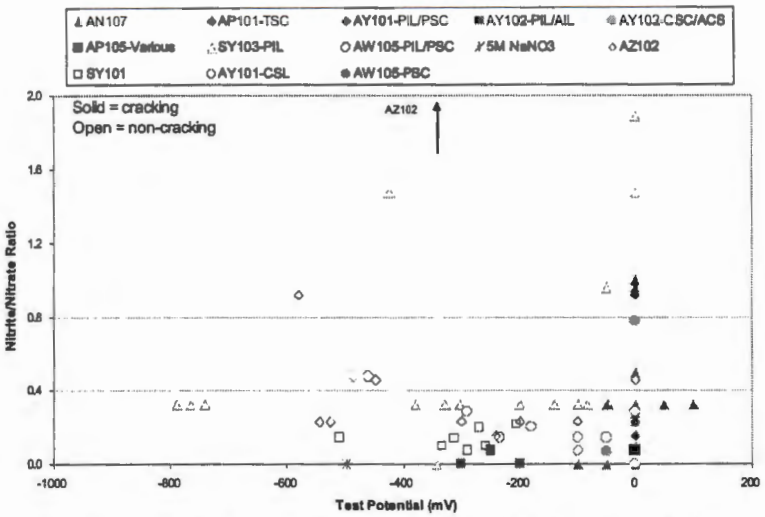

Figure 5: Cracking propensity for nitrate-based solutions as a function of nitrite/nitrate ratio and test potential. Filled symbols indicate cracking, open symbols indicate no cracking (Brossia, 2008a and 2008b).

4.3.4.1. Recommendation LD-8: Consider Installation of Corrosion Potential Probe

The Panel recommends the installation of a potential probe into the sludge or saltcake layer of SSTs that have potentially aggressive interstitial liquids. This would provide critical information regarding pitting or SCC tendencies. Such action is only recommended if SST chemistries are determined, based on analysis or laboratory studies, to be aggressive to corrosion or SCC under tank operating conditions and the chemistries have not been previously addressed in the DST program. The probe could be a simplified version of those employed in the DSTs, or it might be possible to measure with a temporary "dip-stick" approach rather than a permanent probe as is being used in DSTs.

4.3.5 NDE Screening and Characterization Techniques Capable of Assessing Local Wall Damage

Based on the results of the guided wave, DCPD, and corrosion probe measurements (Sections 4.3.2 through 4.3.4) more detailed information about the local condition of particular liner regions might be necessary. If so, two possible alternatives should be considered: (a) using NDE probes as end effectors on a mechanical arm, and (b) inserting a remotely controlled robot to conduct inspections. In either case, wall inspections should be conducted on a sampling basis, motivated

by the same general considerations that are applied to the steel walls of the DSTs and focused on evaluating general wall thinning and weld defects.

A series of techniques should be considered, including the following: visual examination using cameras, fluid coupled ultrasound implemented in a fashion similar to that employed in the DSTs, ultrasonic guided waves implemented using EMAT (of a more localized nature than those discussed in Section 4.3.2), and vibrothermography. The motivations for the first two techniques are based on DST project experiences. The advantage of guided wave techniques is that they can rapidly provide information about defects in a large volume of material as the waves scan the material at the speed of sound. The disadvantage of guided wave techniques is the output is not as quantitative as more traditional techniques. Guided wave techniques, therefore, should be used as a screening tool to determine if further inspection is necessary. To scan more localized areas than those discussed in Section 4.3.2, higher frequencies would be required.

Vibrothermography induces a high amplitude vibration (20-40 kHz) in a local region of the structure. Surfaces of cracks will rub against one another as a result of this vibration, generating friction heat that can be detected by an infrared (IR) camera. Since Vibrothermography is an emerging technique, technical details are still being resolved. Consideration would need to be given to the ability of the IR camera to operate in the hostile environment inside the tank.

4.3.5.1. Recommendation LD-7: Assess Deployment of Local Non-Destructive Evaluation Techniques

The Panel recommends assessing the feasibility of deploying candidate local measurement techniques (such as fluid coupled ultrasound, ultrasonic guided waves implemented using EMATs, and vibrothermography) operated as end effectors on a mechanical arm. Deploying such technologies should be based on the outcomes of other NDE recommendations (e.g. discovery of cracks via visual inspection) and a cost benefit analysis that analyzes the difficulties of employing candidate local measurement techniques.

4.3.6 Low temperature fracture behavior of A285 steel and the ductile-to-brittle-transition temperature

4.3.6.1. Fracture toughness and ductile-brittle-transition temperature

SSTs were constructed from hot-rolled mild steels such as A285, A283 and A201 (RPP-11788). As with all steels, the fracture properties are temperature dependent. The fracture toughness (ductility) drops sharply with temperatures below a critical value. This ductile-to-brittle transition temperature (DBTT) is measured by Charpy or static fracture toughness tests. This temperature is reported as approximately 50° F for the Hanford tanks. As the temperature of some tanks is currently 70° F, it is important to consider the implications of activities (such as gelling the tank waste through cooling) that would further reduce tank temperatures.

Several factors favor a lower DBTT in Hanford tank liner steels. Charpy tests utilize impact loading which tends to decrease the fracture toughness and increase the DBTT relative to static tests. A shift of 100° F has been reported (Rana, 1994) between dynamic tests and static tests for carbon-manganese (C-Mn) steels. Further, the thin tank liners are loaded in plane stress conditions that increases fracture toughness relative to thicker samples or plane strain test conditions.

Above the DBTT the behavior is referred to as upper shelf fracture toughness. It has been reported that the fracture toughness (Jc) and static fracture toughness (K_{Ic}) for welded A285 Grade B steel is 620 inch-lb/inch^2 (110 kJ/m^2) and 143 kips per square inch (ksi) in 1/2 (157 fracture toughness (MPa-m^{½})), respectively (Sindelar, et al, 2000). All tests failed by ductile fracture. These are all very high fracture toughness values supporting the idea that these steels are very resistant to fracture as long as the temperature is above the DBTT.

The lower shelf toughness of tank liners is much lower than the upper shelf fracture toughness but still may be sufficient to resist fracture. Values of 30-50 ksi in 1/2 have been reported for SA 533B-1 and a Cr-Ni-Mo-V steel (Ritchie et al, 1979 and Holzman et al. 1995). If the A285 steel has similar values, cooling the tank might not raise issues. A stress equal to the yield strength, 30,000 psi, the lower shelf toughness values results in a critical flaw size of 0.3 inch. Existing stress corrosion cracks would likely be much larger than 0.3 inches. Rapid crack growth would be expected at the lower shelf temperatures if sufficient stress and stress corrosion cracks were present.

4.3.6.2. Aging effects on fracture toughness

A number of processes can embrittle steels. Most common is grain boundary segregation of species such as phosphorous, sulfur, and antimony that occur at temperatures of 500° C. These temperatures are well above those the SSTs have experienced.

Another process, strain aging, occurs in deformed materials when mobile interstitial atoms such as carbon and nitrogen migrate to dislocations and cause an increase in the yield strength and decrease in the ductility. Deformation occurs in the heat affected zone (HAZ) of welds at temperatures of approximately 25° C. The tanks were warmer than this for most of their lifetime so this embrittlement process is not likely to have occurred.

The third process, carbonitride precipitation, also results in a strength increase and ductility loss. It occurs at moderate temperatures of 200° C to 300° C. Given the lack of information, it is difficult to predict whether carbonitride precipitation has occurred in the SST A285 steel. Small steel samples would assist in determining whether hardening of the steel, and possible thermal embrittlement, has occurred.

4.3.6.3. Recommendation LD-9: Consider Testing Tank Liner Hardness

The feasibility and cost of removing small samples from the tank liner for hardness testing should be evaluated. If feasible and cost effective, samples should be removed from a tank that experienced the highest temperature to determine if hardness increases have occurred.

4.3.7 Effects of wall thinning and temperature on residual stress at welds

4.3.7.1. Stress Relaxation of residual stresses

The tank liners are compression loaded primarily from their own weight and the weight of liquids in the tanks. Tensile stresses necessary for driving SCC result primarily from residual stresses around non-stress-relieved welds and hoop stresses caused by the sludge and saltcake. Knowledge of the extent of 60 years of stress relaxation in the steel liners would help identify future risk for SCC.

Julyk (Julyk, 2002) concluded that no allowance was made for stress relaxation and stress relaxation at 300° F would be insignificant. The standard weld stress relief treatment for carbon steels is 1100° F for 1 hour. A study of steel with similar chemistry to A285 (0.2% carbon and 1% manganese) revealed the through thickness residual stresses in a 2 inch thick welded plate were substantially reduced after the steel was heated to 600° C for 2 hours over a 40-hour period (Smith and Garwood, 1992). The maximum residual stress was 600 MPa in the longitudinal direction. This was reduced to a stress of about 50 MPa. A study of stress relaxation at a temperature more relevant to Hanford Site tanks (300° F), cold worked steel with 0.8 wt% carbon was found to have relaxation between 8% and 16% of the residual stress within 72 hours at 257° F (Zeren and Zeren, 2003). This is a higher carbon steel than that in the SST so one would expect higher relaxation rates in lower carbon steel. Extended time periods are not likely to produce significantly greater relaxations as most relaxation of iron occurs within the first hours after being strained (Medrano and Gillis, 1989). An upper bound stress relief value can be obtained from stress relaxation results during tempering hardened steel (Brown, Rack, and Cohen, 1975). This upper bound value involves relaxation from dislocation movement as well as relaxation contribution from carbide formation. The results show the possibility of only 10% relaxation of residual stresses in 1 hour at 300° F. Thus, the extent of weld stress relaxation in the SST liner welds is at least 10% or 20%. This small stress relaxation would have an equally small effect on the probability of a SCC penetrating the liner since the stress intensity, K, is linearly related to the stress, σ, through the linear elastic stress intensity equation: $K = Y\sigma (\pi a)1/2$ where Y is a geometrical constant, and a is the crack length. Stress intensity is the primary mechanical driving factor for SCC.

Even though the rate of stress relaxation decreases with time, a 50-year period may result in stress relaxation beyond 10-20%. Li (Li, 1967) has shown the relaxation of iron (Fe) has the following relationship: $\sigma - \sigma 1 = K (t + a) -n$ where σ is the starting stress, $\sigma 1$ is the stress after time t and K, a and n are constants. The value given for a is 1 and n is 0.4. Using these values stress relaxation after 50 years, relative to 1 hour, is estimated at 250 times greater. In other words, substantial relaxation could be possible given enough time. However, the relationship developed by Li was at a temperature of 70° F and the a and n values may change with temperature and material. The result obtained with the Li model appears unrealistic and supports the need for experimental measurements of stress relaxation in the A285 material.

4.3.7.2. Potential Effects of Wall Thinning

Uniform corrosion rates will produce general wall thinning at rates of approximately 0.6 mils/year in the lower (waste covered) portion of the tanks and 2 mils/yr in the upper (vapor space) portion of the tank liners (Julyk, 2002, Table 3). It is estimated that, by 2028, liner wall thickness near the bottom of the tank will be 0.2 inch and 0.120 inch near the top of the tank. The original wall thickness was 0.25 inch (Julyk, 2002, Table 3). As is discussed in the following paragraphs, such thinning could produce: (1) a change of the weld residual stresses, (2) an increase in the hoop stresses, (3) a decrease in liner break-through time for cracks, and (4) structural collapse of the tank liner.

Depending on the distribution of the weld residual stress through the tank liner thickness, general corrosion could result in a net reduction of the residual stress by removal of high stress surface material. If the stresses are uniformly distributed or concentrated at the outer diameter, this reduction would be substantially less or could even result in a stress increase. No information is available on the weld residual stress distribution through the liner wall thickness, although estimates could likely be made based on the weld geometry. No conclusion has been reached as to whether general corrosion will reduce, cause no effect, or increase the weld residual stress.

The thinner the wall thickness, the shorter the distance a stress corrosion crack must travel before breaking through the liner. However, crack velocities are sufficiently rapid in the nitrate/high pH environment that reduction in thickness will not have much impact. Given an activation energy for caustic SCC as reported by Singbeil and Tromans (Singbeil and Tromans, 1982a), a SCC velocity in Stage II is estimated at 4×10^{-5} millimeters (mm)/s at 300° F and 3×10^{-6} mm/s at 100° F. Breakthrough times of 1.5×10^{5} seconds and 2.1×10^{6} seconds result for a 0.25 inch thickness liner at 300° F and 100° F, respectively. Given the SSTs mission, a small change in wall thickness from general corrosion will have little effect on the breakthrough time of a SCC.

The self-supporting tank liner walls are aided by friction loading between the liner and the concrete. The hoop stress in the tanks from the sludge and saltcake could contribute to the friction between the liner and the concrete structure. If this frictional loading is ignored, the tank liner can be thought of as a free-standing structure. The lower portion supports the load of the upper portion. Excessive wall thinning, especially in the lower portion, could result in the collapse of the tank liner. Such a collapse would likely result in large cracks and tears in the liner and hence a significant leak rate of sludge and interstitial liquid from the tank. However, the stress in the lower portion of the tank liner is very small so excessive wall thinning would be required to result in such failure.

4.3.7.3. Recommendation LD-11: Analyze Stress Relaxation of Tank Liners

The Panel recommends further analysis or an experimental study to determine if stress relaxation in the tank liner steels could lead to future SCC.

4.4 SUMMARY OF THE PRIORITIZATION OF LINER DEGRADATION RECOMMENDATIONS

Following are the recommendation titles, in order of priority, for the SSTIP future potential for the liner degradation key element.

- Recommendation LD-1: Expand Leak Assessment Reports
- Recommendation LD-2: Avoid inadvertent addition of water and chloride to SSTs
- Recommendation LD-3: Examine Non-Compliant Wastes at 25 C
- Recommendation LD-4: Develop and Deploy Guided Wave Technology
- Recommendation LD-5: Determine Ammonia Corrosion Control Concentration
- Recommendation LD-6: Assess SST Waste Compositional Variation
- Recommendation LD-7: Assess Deployment of Local Non-Destructive Evaluation Techniques
- Recommendation LD-8: Consider Installation of Corrosion Potential Probe
- Recommendation LD-9: Consider Testing Tank Liner Hardness
- Recommendation LD-10: Consider Applying Direct Current Potential Drop to SSTs
- Recommendation LD-11: Analyze Stress Relaxation of Tank Liners

5.0 LEAK IDENTIFICATION AND PREVENTION

5.1 Leak Detection

5.1.1 Leak Detection Systems

Monitoring for leaks in the SSTs is accomplished through in-tank detection systems (Miller, 2008). In-tank systems provide the ability to determine if a leak event has occurred. The SST in-tank leak detection program operates on the assumption that liquid or semi-liquid waste levels will decrease in response to a leak, but solid levels will not. Selection of the leak detection system therefore depends in part upon the type of waste surface. In addition to level decreases, these systems also monitor for liquid intrusion into the tanks.

The ENRAF™ level gauge is the most accurate gauge used in the SSTs. It tracks level changes in tank waste by using a load cell to monitor the buoyancy of a displacer. The displacer is lowered until it encounters an upward force from a solid or liquid surface. It then tracks the position of the displacer, and reports the level of the solid or liquid surface that it has contacted. The gauge is claimed to be accurate within 0.01 inch (equivalent to approximately 27 gallons). For purposes of leak detection, the ENRAF™ gauge needs a free liquid surface below the displacer. Since nearly all of the tanks have been stabilized (i.e., free liquid and most of the interstitial liquid drained), the gauges are typically utilized for liquid intrusion monitoring.

Manual tape (MT) measurements are performed on several tanks. The system consists of a measuring tape and plummet. The tape and plummet form an electrical circuit connected to a continuity meter. The tape and plummet are manually lowered into the tank until they contact a conductive surface. In open air, the circuit remains open and the continuity meter displays no current flow. Contacting the waste surface closes the circuit, as indicated on the continuity meter. The measurement on the tape indicates the level of the waste. Since dry waste surfaces conduct electricity poorly, MTs are typically used to detect liquid intrusion.

Monitoring the level of the interstitial liquid in the SSTs is accomplished via a liquid observation well (LOW). Since 1985, 79 of the SSTs have been equipped with LOWs for the purpose of leak detection and/or intrusion monitoring (Miller, 2008). A LOW is a three-inch diameter hollow tube constructed of fiberglass, steel or TEFZEL™, which is capped at the bottom, and inserted into the solid waste to within approximately two-inches of the tank bottom (Barnes, 1995). The interior of this tube can be opened to the atmosphere via surface risers, but is isolated from the waste, thus providing a surveying environment free from direct contamination. The LOWs are surveyed using wireline-logging techniques that are common to the geophysical and petroleum industries. Thermal neutron and gross gamma ray probes are utilized to survey the waste. The resulting surveys, which are plots of depth vs. count rate, are then evaluated to determine the depth of the liquid. This system is claimed to be accurate within approximately 0.25 inches (which correlates to approximately 690 gallons in a one million gallon tank). Plots of the derived liquid interface against time are utilized to document trends and changes in liquid levels.

5.1.2 Leak Detection Monitoring Requirements and Best Management Practices

Regulatory requirements for leak detection monitoring (LDM) of SSTs are delineated in RPP-9937, Rev. 3 (Miller, 2008) and summarized in Table 4. These regulations address the technical feasibility of LDM. Best Management Practices (BMP) supplements the requirements by, where necessary. These practices are not derived from regulations, but are recommended to provide an assessment of leakage from the tanks.

Table 4: LDM and BMP requirements for SSTs based on Miller (Miller, 2008).

Category	# of SSTs	LDM and BMP requirements
This category includes: (1) Tanks of suspect integrity (see Note 1) for which LDM is technically feasible, meet the interim stabilization criteria, or (2) contain liquid volumes that are not technically feasible to detect.	71	As a BMP, these tanks are monitored annually for liquid intrusion using currently available monitoring systems supplemented by visual photographic inspections on an as needed basis.
This category includes: (1) presumed sound tanks for which LDM is technically feasible, meet the interim stabilization criteria, intrusion prevention has been completed, (2) presumed sound tanks that contain liquid volumes that are not technically feasible to detect, or (3) tanks that have been retrieved.	72	As a BMP, these tanks are monitored annually for liquid intrusion and supplemented by scheduled visual photographic inspections.
This category includes tanks for which LDM is technically feasible; yet do not meet interim stabilization criteria.	6	Presumed sound tanks for which intrusion prevention has been completed require quarterly LDM or intrusion monitoring. Tanks that contain greater than 40,000 gallons of drainable interstitial liquid and do not have complete liquid intrusion prevention require weekly LDM or intrusion monitoring. Tanks in which water intrusion has been detected require weekly monitoring.
This category includes, (1) tanks for which LDM is technically feasible, the interim stabilization criteria have been met, and do not have intrusion prevention completed, (2) presumed sound tanks that do not meet the interim stabilization criteria and have completed intrusion prevention.	0	Tanks that meet interim stabilization criteria yet have not completed intrusion prevention activities would be monitored on a weekly basis using the current level monitoring systems. Presumed sound tanks that do not meet the interim stabilization criteria and have completed intrusion prevention would be monitored on a quarterly basis.
Note 1: A tank is of suspect integrity if it has been declared a known or assumed leaker, has a bulged liner, or stored boiling waste.		

5.1.3 New or Enhanced Monitoring

The vadose zone monitoring system implemented to monitor performance of the 241-T Tank Farm Interim Cover Test (Zhang and Keller, 2006) is an excellent system for tracking infiltrating meteoric water. Expansion of this monitoring system could result in early detection and tracking of leaks. The parameters monitored by this system include: 1) soil water content, 2) soil water pressure, 3) soil temperature, and 4) calculated soil water flux. The technologies used to measure

these parameters meet most criteria for detecting the movement of pore liquids in the vadose zone, are relatively robust, have withstood peer review in the literature for the calculation of flux conditions, and are readily available from commercial sources. These technologies included: neutron moisture monitoring probe, capacitance probe, and heat-dissipation sensors. A datalogger and a meteorological station are also incorporated into the monitoring design.

Early reporting of the results of this monitoring system (Zhang et al., 2008) are promising. However, several items in the performance monitoring system for the T Tank Farm Interim Cover Test are needed to determine if the system is optimized. Evaluation of additional time series data (e.g., monitoring data from fiscal year (FY) 08, Zhang et al., 2008) will provide additional basis for evaluating longer-term operational performance. Several example items, as discussed below, illustrate the need for further consideration of specific monitoring design and installation features.

The backfill in the annulus surrounding the heat dissipation sensors (HDS) was specified as 20/40 sand. Heat dissipation sensors provide an indirect measurement of the matric potential of soil water. The sensor is generally heated for a fixed time period. Since water conducts heat much more readily than air, the rate of heat dissipation is controlled by the water content of the porous matrix. Heat dissipation sensors consist of a heater and a temperature sensor in a porous matrix material that equilibrates with the surrounding soil. The HDS are installed in very fine and wet silica flour slurry surrounded by 20/40 sand (coarse and dry); the native material also appears to be typically coarse and dry. Because of the difference in the nominal pore size distribution and moisture content between the HDS installation and the surrounding coarser sand, the potential for a capillary barrier may exist around the silica flour slurry, thus preventing equilibration of water in the porous matrix of the sensor with water in the surrounding formation native material. If a capillary barrier does exist, the HDS will remain wet (in the range of -0.2 to -0.4 bars) because moisture cannot move freely out of the slurry and dissipate into the surrounding materials, resulting in an erroneously high HDS measurement of the formation soil water content and matric potential. Soil water potentials are between 1 bar and saturation (Zhang et al., 2008), suggesting the potential for significant movement of liquids in the vadose zone. The range of soil water potential reported appears higher than anticipated for the soils commonly encountered on the Hanford Site.

It is not clear if the HDS probes (specifically the ceramic probe tips) were installed in a wet or dry condition. Equilibration of water in the ceramic probes and in the surrounding soil can result in unreliable gradient calculations as monitoring data will appear to show the soil wetting or drying. Other installations have shown significant equilibration time required for probes to match the potential of the surrounding material. This 'equilibration' phenomenon should be taken into account when evaluating future monitoring data.

Soil flux drain gauges (Zhang et al., 2008) did not collect drainage water. Zhang (Zhang et al., 2008) concluded that hydraulic properties of material in the drains were not adequately characterized to determine the proper height of the divergence control tube. Moisture may have been diverted around the drain gauge due to gradients induced by the instrument itself.

5.1.4 Recommendation LIP-1: Continue Leak Detection Monitoring and Best Management Practices and Enhance Monitoring Capabilities

The panel recommends continuing to maintain the current LDM and BMP approach. These practices, coupled with interim stabilization of the waste, provide a means of minimizing the potential for leakage of waste to the environment. The Panel further recommends installing enhanced monitoring based on potential leak risks at each tank farm. The 241-T Tank Farm

Interim Cover Test has proved an excellent system for tracking infiltration of meteoric water. Increasing the depths and expanding the aerial extent of monitoring similar to this test will provide an excellent system for early detection and tracking of leaks.

5.1.5 Recommendation LIP-6: Investigate Leak Detection Technologies for Tanks With Less Than 24 Inches of Waste

DOE has a leak detection plan and is in compliance with Ecology requirements for leak detection. However, for tanks with 24 inches of waste or less, the absence of LOW and a solid surface does not allow for leak detection. Currently there is no technology available for leak detection at these low waste levels. The Panel recommends investigating and developing technologies to address this deficiency.

5.1.6 Ex-tank Monitoring for Leakage During Waste Retrieval

All of the SST farms have five to eight monitoring boreholes installed around each tank. These boreholes, also referred to as dry-wells, were installed and used as part of a tank leak detection monitoring system to detect the presence of gamma-ray-emitting radionuclides in the vadose zone sediments surrounding the tanks. The boreholes are approximately 100 to 200 foot deep and are supported by a carbon steel casing. For many years, gross gamma measurements were made via the dry-wells to determine whether a tank was leaking. However, these were recently discontinued, as they are no longer considered appropriate for the task.

A new leak detection technique, High Resolution Resistivity (HRR), has been effectively demonstrated during recent waste retrieval activities. One major advantage of this technique is that it utilizes existing dry-wells. HRR uses a four-electrode system to measure the soil resistivity surrounding the tank (Schofield, 2007). Measurements are made from dry-well to dry-well, dry-well to surface, and dry-well to tank. HRR can detect a 5,000 to 10,000 gallon leak.

To use HRR effectively, baseline soil resistivity data is acquired. HRR, in conjunction with ground penetrating radar, electromagnetic induction, and differential magnetometry, were utilized to perform Surface Geophysical Exploration (SGE). These techniques identified sub-surface objects or structures that might interfere with the HRR measurements. The SGE produced sub-surface soil resistivity characterization maps. Average baseline resistivity details are contained in RPP-32477 (Schofield, 2007).

During waste retrieval for a particular tank, HRR data is collected on 15-20 minute cycles for a 48-hour period. The average slope is compared to the baseline slope threshold range for a given data pair (e.g., dry-well to tank data pair). If the slope exceeds the threshold range, a value of "1" is assigned to the data pair, while the slope is within the threshold range it is assigned a "0". This calculation is repeated for each data pair. The 48-hour cycle is then repeated with data points older than 48 hours being replaced by the latest set of data. The "1" and "0" are used to calculate a rolling average percentage of how often each data pair exceeded baseline slope threshold ranges in 24 hours. The 24-hour rolling average percentage for all dry-well to tank data is called the Leak Potential. This value is compared to an action level setpoint and is applied only to dry-well to tank data. The action level setpoint percentage is 50%. This action level is based on several mock demonstrations of the system. A Leak Potential that exceeds the setpoint indicates a positive correlation to a physical change. Exceeding the action level triggers data evaluation to explain the cause of the data trend.

5.1.7 Recommendation LIP-3: Continue Use of High Resolution Resistivity

The Panel recommends continuing to utilize the HRR technique for ex-tank leak detection.

5.2 Assessment of Leak Rates Through Tank Liners

Water can penetrate the very tight dimensions of a stress corrosion crack as seen in nuclear reactor piping. It is not clear whether water contained in sludge or as interstitial liquid in saltcake will penetrate these tight cracks because of the forces restraining the water within the sludge.

There is currently no evidence that liquid is leaking from the interim stabilized (retrieved) tanks that contain supernatant, sludge or saltcake. Nor is there evidence that new stress corrosion cracks have developed since the tanks were stabilized. However, continued use of the SSTs requires mitigation efforts be considered to assure SST leak integrity. To determine if such mitigation technologies are necessary, the Panel investigated the issue of whether liquid would leak out of sludge or saltcake through stress corrosion cracks.

Evidence exists that SSTs have cracked in the past (see Section 4.1). Uncertainties exist as to whether the SSTs will continue to crack in the future. There is evidence that SCC will form in carbon steel at stresses of about 80% to 100% of the yield strength (Mazille and Uhlig, 1972; and Bombara and Bernbai, 1981) in caustic solutions. Also, carbon steels have been shown to have stress intensity threshold of 10-15 MPa-m$^{1/2}$ in caustic solutions (Singbeil and Tromans, 1972b). A stress equal to the yield strength of the carbon steel used in the tanks will cause cracking in caustic solutions with a flaw as small as 0.5 mm. This flaw could be the result of pitting or other surface defects.

Carbon steels have also been shown to experience SCC in nitrate solutions. Past SST chemistry included high concentrations of nitrate that were mitigated by additions of nitrite and hydroxide. However, it is possible that cracks formed prior to these additions.

SCC of carbon steels in nitrate solutions was studied extensively forty years ago, in part due to nuclear waste storage tank concerns (as discussed in Section 4.2). The parameters affecting the aggressiveness of nitrate solutions include, temperature, cation type, stress, and the concentration of the aggressive ions and the inhibiting chemicals steel carbon content. Somewhat unique to nitrate stress corrosion cracking is the role of the cation in the mechanism. Extensive tests on Hanford wastes have been conducted and are discussed in Section 4.2.

One evaluation that could prove useful is to determine whether the leak rate through new or future cracks is significant. Leak rates of gases through orifices are supported with experimental data and models (Worden, et al., 1962; Jones, Conn and Schafer, 1985). There have also been efforts to measure leak rates of high temperature water through cracks in nuclear piping. In these models the water is superheated to a vapor in the crack (Friedel and Westphal, 1989). Experimental measurements and predictions of water leakage through cracks have been reported by Grebner and Hofler (Grebner and Hofler, 1992); Yano, et al., (Yano, et al., 1989); and Whitman (Whitman, 1975). Grebner and Hofler report experimentally measured and predicted leak rates ranging from 5 to 10 gallons per minute (gpm) for a water pressure of 10 MPa (1470 psi). No flaw size was given. Yano, et al., (Yano, et al., 1989) predicted leak rates of 5 to 10 gpm through a flaw of 19 x 0.25 mm and a pressure of 6.8 MPa (1000 psi). In an effort to determine leak rates from Savannah River Site waste tanks, Whitman (Whitman, 1975) performed a series of experiments using through-wall stress corrosion cracks and water under a pressure head. The cracks were formed in steel plates by nitrate SCC. For the smallest flaw of 25 x 0.15 mm of crack

opening, Whitman measured a leak rate of less than 0.001 gpm with a pressure head of water of 37 feet.

Several forces drive liquid leak rates from sludge and saltcake. Crack pressure and capillary forces attract the liquid, capillary action in saltcake and sludge repel the liquid. An analysis performed at Savannah River National Laboratory (SRNL) (Mertz, 1999) has predicted a leak rate of 0.09 gpm for a six inch through wall crack. The fluid was assumed to have a viscosity of 5 to 10 centipoises (cP). This is a viscosity approximately 10 times greater than water. However, even this small leak rate results in the leakage of 47,304 gallons/year. Sludge has a viscosity of 20-30 cP so it is likely the leak rate will be less than 47,304 gallons/year. Mertz (Mertz, 1999) also estimated the leak rate for fluid with a viscosity similar to water leaked at 0.36 gpm or approximately 190,000 gallons/year. These results indicate unacceptable leaks could occur if leak mitigation methods are not implemented.

5.2.1 Recommendation LIP-5: Evaluate Sludge and Saltcake Liquid Leak Rates

The Panel recommends evaluating liquid leak rate assessments through sludge and saltcake from the Savannah River Site to determine if the results are applicable to the Hanford Site SSTs.

5.3 Test for ionic conductivity between the inside and outside of tanks.

It is possible that ionic pathways to the ground through liner cracks exist underneath the sludge and saltcake layers. If such a condition exists, new leaks might be generated during sluicing operations.

It might be possible to test for ionic conductivity by inserting a probe into the tank sludge layer and another outside of the tank in the ground and measuring the resistance or impedance between the two. Figures 6 and 7 show schematic illustrations of electrodes in and outside of an SST. Between these electrodes are various phases that provide resistance. To measure a resistance, a small current must be passed. Note that electrical current can be carried either by electrons in an electrical conductor such as metal or by ions in an ionic conductor such as sludge, saltcake, or soil. Current can also change between electronic and ionic conductors as the result of electrochemical reactions at the interface of an electrode and electrolyte.

It is reasonable to assume that a good electrical connection could be made between a metal probe immersed in the tank sludge or saltcake (labeled Metal 1 in Figure 6) and a resistance meter such that the resistance along that connection would be essentially zero.. A resistance exists across the metal/sludge interface. In fact, an equivalent electrical circuit consisting of a parallel resistor and capacitor can represent the electrical response of many electrode/electrolyte interfaces. The resistance, called polarization resistance (Rp), is inversely proportional to the rate of the electrochemical reaction. If the metal electrode is corroding, then the polarization resistance is a measure of the corrosion rate. The capacitance is associated with the electrical double layer that sets up at this interface and is called the double layer capacitance.

Following the electrical path to the right, the ionic current would flow through the sludge or saltcake (indicated in Figure 6 as sludge for simplicity) until reaching the next barrier, the tank liner. Transport resistance through the sludge can be represented by a resistor, the value of which, R_{sludge}, would depend on the resistivity of the sludge and the geometry of the current flow (length and cross-sectional area). Assuming that the tank liner is intact with no ionic pathway connected with a through-crack, the current would have to convert to electronic current at the sludge/liner interface. This interface can be represented by another parallel resistor and capacitor as shown in

Figure 6. The electrochemical reaction at this interface (passive dissolution of the tank metal) would convert the ionic current back to an electronic current, which would flow through the tank metal. The resistance associated with this current, R_{liner}, would be essentially zero. The current would then be converted back to ionic current at the outer surface of the liner.

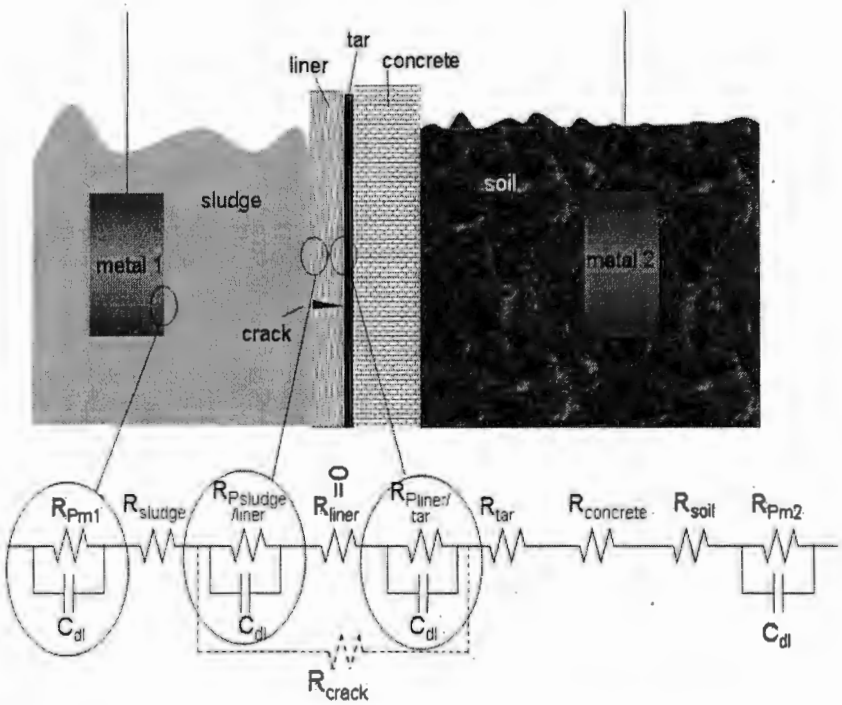

Figure 6: Schematic of a system to measure ionic pathways. Expanded image of the current path segments between a metal electrode in a tank and one in the ground including an equivalent circuit.

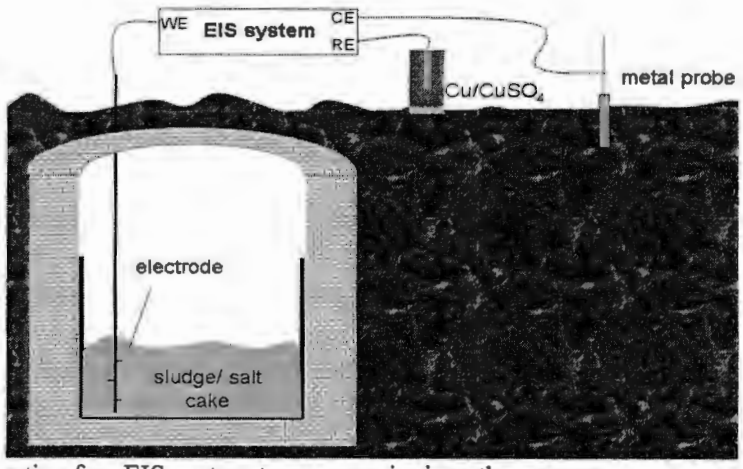

Figure 7: Schematic of an EIS system to measure ionic pathways.

The outer liner surface is covered with tar that acts as a sort of water-proofing. The nature of this phase in terms of its electrical and ionic resistance is not clear. However, it is certainly not a perfect water-proofing or else waste would never leak. There is some conductivity of the tar

phase, R_{tar}. The next phase is the concrete, which has a resistivity associated with the pore water, which reaches equilibrium with the calcium hydroxide in the cement. The conductivity of concrete, and the next phase, which is soil, depends on the amount of water available. Both concrete and soil can be quite conductive if enough water is present, which would allow passage of ionic current until reaching the interface associated with the electrode in the soil, Metal 2.

If the liner is breached by a through crack, then it is possible for part of the equivalent circuit in Figure 6 to be shorted. At a minimum the crack would short the two liner interfaces and it might also short the tar layer. If the resistance of the crack were low compared to the resistances of these interfaces and phases, then the current would flow as ionic current from the sludge to the concrete. A resistance meter operating in DC mode might sense the difference in resistance between a shorted and sound tank. One would have to use a tank thought to be sound as a control case.

Instead of using a DC resistance measurement, it might be possible to be more sensitive to such cracks using an AC measurement, which is called electrochemical impedance spectroscopy (EIS). EIS would require the use of a third electrode, a reference electrode, placed on the ground between the tank and the auxiliary or counter electrode. In brief, EIS works by applying a potential sine wave of varying frequency to an electrode and measuring the current. One can obtain the impedance as a function of the frequency. The impedance is, in general, a complex number owing to any capacitance of the equivalent circuit describing the electrochemical system. The response of a system with an ionic short through the liner would be different than that of a system having a sound liner with electrochemical interfaces on either side. This would be true if the time constants, R x C, of the polarization resistances and double layer capacitances associated with the liner interfaces were vastly different than the time constant of Metal 1 in the sludge. These different time constants would provide an EIS spectrum of very different nature than if there were an ionic path directly from the surface of Metal 1 to the soil.

As a result, the EIS response of an electrode immersed in a tank with reference and counter electrodes placed outside the tank should provide information about the existence of any through-crack in the liner. However, it would only sense cracks below the level of the sludge or saltcake. On the other hand, such a technique might be useful during retrieval operations to sense for leaks through cracks above the sludge top surface layer as liquid is sluiced into the tank. If a change in the impedance response were sensed during retrieval, operations could be shut down to prevent leakage.

EIS is a practical technique that has wide application. However, there are several unknowns and possible artifacts that would complicate the measurement. The values of the circuit elements shown in Figure 6 are unknown so that it is not clear if the resistance or impedance of a cracked liner would be different than that of a sound liner. It should be noted the area normalized resistance associated with the polarization resistance of an electrochemical interface has dimensions of Ω-cm2 and the resistance of the full exposed area is determined by dividing this value by the area. For a large tank, this would result in a low resistance. The stray capacitance associated with long lead wires also can create problems with this measurement.

5.3.1 Recommendation LIP-8: Assess the Feasibility of Testing for Ionic Conductivity between the Inside and Outside of SSTs

The Panel recommends that an assessment of the feasibility of this approach be initiated. Some laboratory-based experiments and analysis would be helpful and straightforward.

5.4 Strategies for Future Leak Prevention

5.4.1 Introduction

The prevention of future leaks in SSTs is a major objective. Wastes have been retrieved from 10 SSTs and other tanks have been interim stabilized by the removal of most of the drainable liquids. Nevertheless, the unretrieved SSTs still contain approximately 30 million gallons of radioactive waste, including more than 2.5 million gallons of drainable liquids (Roger, 2008).

The prevention of future leaks is a complex problem due to uncertainties about the conditions of the steel liners and differences in the behavior of liquids in sludge and saltcake and mixtures of sludge and saltcake. If drainable liquids remain in contact with the present steel liners, there is no assurance that future leaks can be prevented. Consequently, the strategies for future leak prevention are centered on the immobilization or removal of drainable liquids, or the introduction of new internal barriers between the wastes and steel liners.

There are major variations in the amounts of drainable liquids in the SSTs and in the properties of these liquids within the saltcake and the sludge layers of the SSTs. These variations require that liquid removal be considered on a tank-by-tank basis. Special emphasis should be given to methods that serve the interests of the community and worker health and safety, and do not compromise the future retrieval of the wastes.

5.4.2 Liquid Waste Removal

The most efficient method for removal of the drainable liquids is simply to pump them from a SST into a sound DST. Operations of this kind have been underway at the Hanford Site for many years and the interim stabilization program is virtually complete.

This program originated in the work of Handy (Handy, 1975) and was augmented by other technical contributions (Metz, 1976; Kirk, 1980; Flach, 2003a, 2003b; Strohmeier, 2007). In essence, these investigations showed the interstitial liquids drain very slowly from sludge layers, and rather rapidly from saltcake layers. The drainage rates of liquids from salt cakes are directly proportional to the height of the liquid, its density, and its viscosity. Drainage occurs until the height of the liquid column can no longer overcome the capillary forces. Estimates of this height range from approximately 0.5 to 2 feet for Hanford Site saltcake.

Engineering analyses and practical experience indicate major difficulties are encountered when pumping rates decrease to less than 0.05 gallons per minute. For example, approximately 1,000 hours were required for the drainage of approximately 100 gallons of liquid from the saltcake in Tank 25 at the Savannah River Site during the final stages of liquid removal (Strohmeier, 2007). Operational procedures, such as clearing the pumps of solid deposits, often added more water to the waste than could be removed by the continuation of the pumping operation at the limiting rates (Martin and Terry, 2009).

The present protocols permit the abandonment of pumping when the transfer rate is less than 0.05 gallons per minute (72 gallons/day). They also permit the retention of 50,000 gallons of drainable liquid within a single saltcake layer. This amount of liquid does not include the liquid retained by capillary forces, which is assumed to be 0.5 feet. As already mentioned, the SSTs now contain more than 2.5 million gallons of drainable liquids (Roger, 2008).

5.4.2.1. Recommendation LIP-4: Seek Engineering Methods to Increase Water Removal by Pumping From SSTs

The Panel recognizes the problems are challenging, but believes pumping is a safe and potentially efficient and cost effective method for the removal of liquids from the tanks. Consequently, the Panel recommends engineering solutions be sought for the removal of additional liquids from the tanks by pumping.

5.4.2.2. Water Removal

The removal of water from SSTs would decrease both the amount of liquid in the tank and the viscosity of the remaining liquid, therefore, reducing its drainability.

Water has been removed through enhanced dome ventilation and by passing air through the waste. In some circumstances, the rates of evaporation have been accelerated by heating the air, waste or both. Rates of water removal are adversely affected by the slow rates of water transport through sludge, saltcake, and surface crusts. To avoid this difficulty, air has been introduced beneath the waste surface.

The SSTs are now passively ventilated by natural variations in barometric pressure. Modeling suggests that more than 100 years are necessary to materially impact the water content of deep saltcake or sludge layer (Simmons, 1998; Meacham, et al., 1997; Sandgren, 2002). However, modeling indicates that a shallow saltcake waste (10 inches deep) would lose approximately 16 percent of its water in 10 years. In some circumstances, a 16% reduction in the water content might be sufficient to materially impact the mobility of the liquid. Generally, the removal of water by natural ventilation is too slow to accomplish the desired goal.

Water loss rates from actively ventilated tanks are much higher. The models mentioned in the previous paragraph indicate more than 1,000 gallons of water per year per tank can be removed by active ventilation.

The combination of active ventilation and heat considerably accelerate water removal. In one instance, portable air exhausters were used to remove water from the waste in Tank 241-A-104. Approximately 7,000 gallons of water were removed from the tank and photographs show the waste surface is dried and cracked (Johnson and Field, 2008)..

The surface crust presumably decreased the water transport rate through the partially dried solids beneath the surface and through the surface crust. This difficulty has been circumvented by passing heated air in concentric tubes below the solid surfaces.

Steam coils and other methods have been used to heat the wastes and accelerate drying during ITS operations (Rifeay, 2002, Appendix D). For example, a heat exchanger, operated at 115° C, removed water from Tank 241-BY-101. At the end of the operation, the density of the residual liquid was about 1.6 g/mL and the viscosity was 21 cP at 33° C (Brevick, 1996; Dunn, 1986).

Other methods considered for accelerating water removal include microwave heating (Brevick, 1996; White, 1990; Berry, 1990) and wiped film evaporation techniques (Brevick, 1996; DP82-157-2, 1982). Additional rate enhancements could be achieved by the use of drying agents.

The Panel concludes implementation of a water removal strategy would require expensive active ventilation and heating. Heating will increase the risk of pitting corrosion and SCC. In addition,

two concerns central to the interests of community and worker health and safety arise. First, heating increases the rates of decomposition of organic compounds and the attendant risk of unacceptably vigorous exothermic reactions (Meacham, et al., 1997; Sandgren, 2002). Second, heating accelerates the formation and release of hydrogen, inorganic and organic compounds (Mahoney, et al., 1999; Stock, 2001; Stock and Huckaby, 2004). On balance, the Panel does not regard accelerated water removal as an attractive approach for future leak prevention.

5.4.2.2.1. Recommendations LIP-11: Avoid Heating and Active Ventilation Strategies for Removing Additional Water from SSTs

The Panel recommends against pursuing strategies from removing water from tanks that include active ventilation or heating.

5.4.3 Liquid Waste Immobilization

The attempts to immobilize waste by the addition of solid absorbents have not been encouraging. Large amounts of diatomaceous earth (27 to 95 tons) were added to six SSTs in 1972 (241-BX-102, 241-SX-113, 241-TX-116, 241-TX-117, 241-TY-106, and 241-U-104) and Portland cement was added to another SST (241-BY-105). None of these operations were judged successful (Brevick, 1996). The diatomaceous earth clumped during addition and did not spread evenly over the surface. The cement powder initially spread across the liquid surface, but did not mix sufficiently to provide the desired protective barrier (Brevick, 1996). Attempts to remove residual liquid from this tank were unsuccessful because the main underground transfer line was blocked by cement. Even more discouraging, Tank 241-U-104 continued to leak after the addition of 55 tons of diatomaceous earth (Rifaey, 2002).

5.4.3.1. Recommendation LIP-2: Avoid the Addition of Water-Insoluble Absorbents to SSTs

The Panel recommends the addition of water-insoluble solid absorbents be avoided. Such additions do not appear to be especially effective for immobilizing water, will interfere with the future retrieval of wastes, and may adversely impact WTP operations.

5.4.3.2. Addition of Gel Agents

Immobilizing liquids by adding organic and inorganic thickening agents has been considered previously.

Organic compounds including starch, acrylates, methacrylates, carboxymethylcellulose, and polymers grafted to starch are effective because they are naturally slow moving molecules that restrict motion within the liquid phase by interconnecting the aqueous network via numerous hydrogen bonds and other dipolar interactions. Advantages include the maturity of such techniques and the ability to reverse the process by dilution. The disadvantages of the approach include problems associated with mixing gelling reagents with interstitial liquids dispersed through heterogeneous solid layers, relatively high material costs and increased radiolytic and chemical production of hydrogen during storage in SSTs and in future operations of the WTP (Meacham, 2008).

At least two inorganic gelling agents have been identified. One tactic involves adding silica gels that immobilize the drainable liquid, but can be subsequently pumped as liquids. The second involves the use of carbon dioxide to gel aluminum-rich waste through pH adjustment. It has been

reported that, "large quantities of complex aluminum hydroxide gel are produced by passing carbon dioxide through simulated waste solutions equivalent to those found in Tank 241-SY-101" (Alexander, et al., 2006). These gels restrict interstitial liquid mobility by converting saltcake into sludge. Gel formation can be reversed by the adjustment of the pH (Alexander, et al., 2006).

The use of silica gels is also a mature technology, with similar problems associated with dispersal of organic gelling agents in the heterogeneous solids. In addition, it would be necessary to demonstrate that silica gels are compatible with WTP operations. Gelling aluminum rich wastes by adding carbon dioxide is a promising technology. However, two important complications exist. First, the addition of carbon dioxide will likely increase the corrosivity of the waste. Second, the sodium hydroxide used to reconstitute the liquid will adversely impact future operations.

5.4.3.2.1. Recommendation LIP-12: Avoid Strategies to Immobilize Waste Through the Addition of Gelling Agents

As a general programmatic practice, the Panel recommends against the addition of gelling agents. Existing gelling techniques will be difficult to implement, may complicate WTP operations, and may increase the corrosivity of the waste. However, individual tank-by-tank instances may arise in which gelling a tank may be a wise option (e.g. to stop a significant tank leak or if new gelling techniques were developed).

5.4.3.3. Cooling

Cooling the waste would presumably increase the viscosity and reduce the mobility of the interstitial liquid. The temperature required to render the liquids sufficiently immobile does not appear to have been investigated. However, Poloski (Poloski, et al., 2007) formulated an empirical expression for the description of the viscosities of Hanford Site wastes based on densities and temperatures. The expression implies the effect of temperature would be significant. To illustrate, the measured viscosities of two different wastes with densities of approximately 1.5 g/mL are 22cP (25° C) and 27 cP (29° C). The Poloski formulation implies the viscosities at 18° C (the natural ground temperature at the Hanford Site) would be approximately 29 and 35 cP, respectively. For comparison, the viscosities of ethylene glycol (antifreeze) and glycerol are about 22 and 1,400 cP, respectively, at ambient temperature.

The influence of temperature on viscosity is sufficiently large to suggest that cooling, which would also reduce the mobility of the liquids in complex solid matrices in other ways, would materially slow the drainage of liquids from sludge and saltcake wastes. Lowering the temperature has the added advantage of reducing the general corrosion rate and the likelihood of pittiing and SCC. However, carbon steels exhibit a ductile to brittle transition with decreasing temperature and the impact of this transition on tank integrity would need to be assessed.

5.4.3.3.1. Recommendation LIP-7: Evaluate Effect of Lowering SST Waste Temperature

The Panel recommends the effect of lowering the temperature on the drainability of representative waste types be determined during other investigations of drainability (Recommendation LIP-5).

5.4.4 Internal Barriers on Steel Liner

Tank inspections at the Savannah River Site imply numerous small cracks in the steel liners have been sealed by water evaporation and the waste solidification in the cracks (Martin and Terry, 2009 and Martin, 2009). Such findings suggest that the cracks may be sealed by the addition of silicates, sugars, and clays. Technology of this kind has been considered previously (Bamberger, et al., 2001). This approach suffers from the same disadvantages that have been discussed previously for other additives.

An alternative approach involves introducing a synthetic bladder into the tank and transfer of waste into the bladder. This technique has been used successfully in the petroleum industry for the elimination of leaks in storage tanks. The polymer Etheylene-Propylene-Diene Monomer (EPDM) is known to be rather resistant to alkaline waste and simulants. A bladder made of this material could line a complete tank if its reliability were shown to be extremely high.

5.4.4.1. Coating of liner interior with barrier layer

Given the potential for cracks in the liner above the current waste level, concerns of additional leaks during sluicing retrieval exist. Sluicing might raise the liquid level to a crack, resulting in leakage. It would be advantageous to identify a method to seal the tank liner inner wall sufficiently to allow safe retrieval by sluicing.

Thermal spray technology was invented in 1910 and has been applied widely since the 1980's (Davis, 2004). Thermal spray technologies accelerate fine dispersions of particles or molten droplets and impact a surface to form conformal and adherent layers. Each particle or droplet forms a flattened "splat." Many different metals, ceramics, intermetallics and polymers can be thermal sprayed. Typical applications improve wear resistance, corrosion resistance, thermal resistance, or electrical properties. If the inner liner surfaces could be covered with a protective coating prior to retrieval, then leakage concerns would be assuaged.

There are several issues relevant to the application of thermal sprayed layers onto SST liners. A thermal spray deposit typically contains 1-2% porosity and a connecting pathway could allow leakage over time. However, for low pressures and short time periods, even porous coatings might resist leakage. A related technology, cold spraying, can deposit 100% dense coatings. Titanium is a corrosion resistant metal utilized in cold spray applications.

Thermal spray is performed over a distance of inches, not feet. To create an adherent deposit layer, surface layers should be removed by grit blasting before thermal spraying. It is possible to grit blast and simultaneously collect the residue with a vacuum system. It would be necessary to remove hazardous gases such as hydrogen during any such operation.

Another potential application for coating the liner would be the reuse of known sound SSTs. Such tanks might be used to hold low temperature, in-spec waste with low aggressiveness. The first step would be to use NDE methods to assure liner integrity. Leak integrity would be enhanced by coating the liner surface with a material resistant to corrosion and SCC.

5.4.4.1.1. Recommendation LIP-10: Evaluate Coating of Tank Liners and Installation of Polymeric Bladder

The Panel recommends evaluating both the coating of the tank liners with a material resistant to corrosion and SCC; and the deployment of a polymeric bladder to line SSTs. The Panel

acknowledges that difficulties associated with introducing materials into SSTs may reduce the feasibility of implementing this recommendation.

5.4.5 Evaluation of the use of cathodic protection of the SST liners

There is considerable evidence that the SST liners have leaked due to SCC in non-stress relieved welds. It is conceivable that the stresses at the cracks have relaxed during the last 50 years and it is also possible that the sludge and salt cake will not cause SCC. However, a conservative conclusion is that the conditions of the tank are still sufficient to cause SCC (an estimate of stress relaxation is provided in Section 4.3.7.1). Also, since the chemistry of the sludge and salt cake are known, it can be estimated whether the conditions exist to cause SCC.

Cathodic protection (CP) is widely applied to suppress corrosion of thousands of miles of underground pipelines, off-shore structures, and steel reinforcing bar in concrete, bridges and water storage tanks. CP requires a source of direct current, an auxiliary electrode (anode) located at some distance from the protected structure and a conducting medium between the two. The applied voltage is based on the resistance of the ionic medium and the current density required to protect the component. CP works on the principle of protecting a structure from corrosion by the impressed current driving the electrochemical potential of the protected part to lower values. The dissolution rate decreases exponentially with decreasing potential, so the corrosion rate can be greatly decreased by CP. Singbeil and Tromans (Singbeil and Tromans, 1982) have concluded that caustic SCC of carbon steels is an anodic dissolution driven cracking process. Therefore, it is reasonable to expect that suppression of anodic dissolution in the SST tank liners would greatly reduce the potential for SCC. Also, SCC can initiate from pits. Pitting is also an anodic dissolution corrosion process that is suppressed by CP.

The feasibility of applying CP to DSTs was conducted and reported by E.L. Moore (Moore, 1977). It was concluded that such a system would not be necessary because nitrite was added to the liquid waste and CP could cause corrosion based on a study conducted at Battelle Columbus Laboratories (Payer, 1977). The corrosion study suggested the tanks were adequately protected from SCC when nitrite was added to the high pH, nitrate-containing waste. However, there was also evidence that SCC could occur at potentials below the active SCC potentials. This conclusion was based on the presence of a small anodic peak in the potential-current curve at potentials below the primary anodic corrosion peak for iron in these environments. Therefore, CP was deemed not necessary and potentially harmful to the integrity of DSTs.

Most of the SSTs also have nitrite present in the supernatant and solid layer (see Sections 4.1 and 4.2). Therefore, these tanks likely have conditions similar to those which led to the decision to not employ CP for the DSTs. However, several of the non-retrieved SSTs have little or no nitrite and should be examined regarding their potential for SCC.

Another reason that a CP system could be harmful is based on the results of Singbeil and Tromans (Singbeil and Tromans, 1982) who found intergranular SCC in caustic solutions in the active-passive electrochemical potential range but transgranular SCC in caustic solutions at the open circuit potential. Driving the potential lower with a CP system could activate the transgranular SCC form of caustic SCC.

Several practical considerations raise issues for the application of CP in the SSTs: (1) frequent replacement of the reference and anode electrodes, (2) difficulty of penetrating the saltcake with these electrodes, and (3) high CP currents as a result of the large, unprotected surface area of the tanks.

Use of CP for the protection of the exterior of the tank and/or the rebar is a viable option. Waste from overfilled tanks or leaks have contacted the external surface of the tank liner and rebar. Whether this caused corrosion or is continuing to cause corrosion is unknown. The high pH waste should not have caused much corrosion to either the outside diameter of the liner or the rebar. Also, it is possible that ground water has seeped through the concrete and caused corrosion of the rebar and outside diameter of the tank liner.

5.4.5.1. Recommendation LIP-9: Consider Cathodic Protection for Rebar and Exterior of Tank Liner

The Panel recommends that CP not be deployed for use in protecting the interior of SST tanks where supernatant, sludge and/or saltcake is present. The Panel further recommends that CP be considered as an option to protect the exterior of the tank liner and rebar, should evidence arise that either has corroded.

5.5 SUMMARY OF THE PRIORITIZATION OF LEAK IDENTIFICATION AND PREVENTION RECOMMENDATIONS

Following are the recommendation titles, in order of priority, for the SSTIP leak identification and prevention.

- Recommendation LIP-1: Continue Leak Detection Monitoring and Best Management Practices and Enhance Monitoring Capabilities
- Recommendation LIP-2: Avoid the Addition of Water-Insoluble Absorbents to SSTs
- Recommendation LIP-3: Continue Utilization of High Resolution Resistivity
- Recommendation LIP-4: Seek Engineering Methods to Increase Water Removal From SSTs
- Recommendation LIP-5: Evaluate Sludge and Saltcake Liquid Leak Rates
- Recommendation LIP-6: Investigate Leak Detection Technologies for Tanks With Less Than 24 Inches of Waste
- Recommendation LIP-7: Evaluate Effect of Lowering SST Waste Temperature
- Recommendation LIP-8: Assess the Feasibility of Testing for Ionic Conductivity between the Inside and Outside of SSTs
- Recommendation LIP-9: Consider Cathodic Protection for Rebar and Exterior of Tank Liner
- Recommendation LIP-10: Evaluate Coating of Tank Liners and Installation of Polymeric Bladder
- Recommendations LIP-11: Avoid Heating and Active Ventilation Strategies for Removing Additional Water from SSTs
- Recommendation LIP-12: Avoid Strategies to Immobilize Waste Through the Addition of Gelling Agents

6.0 MITIGATION OF CONTAMINANT MIGRATION

6.1 Introduction: Natural and Man-made Recharge: A Driving Force

Groundwater recharge is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone and is often expressed as a flux to the water table surface. Recharge occurs both naturally (e.g., as the result of rainfall) and

anthropologically (e.g., by "artificial groundwater recharge" either intentional or accidental as with pipe leaks), where rainwater and or other sources of water are routed to the subsurface.

SST leak information contains many uncertainties (Zhang and Keller, 2006). Leak dates, leak volumes, leak detection limits (i.e., the minimum size leak that can be detected) and the spatial distribution of wells required to detect leaks in areas deemed at highest risk all contribute to these uncertainties. Historical water migration into the subsurface has been associated with precipitation and leaks from water lines, pumps, sumps, unlined ditches and trenches, surface spills, and run-on from offsite locations.

Though annual precipitation at the site averages less than 180 mm/year, recharge of meteoric precipitation can be significant and is enhanced by the lack of vegetation in the SST farms and the presence of erosion-armoring gravel that constitutes a barrier to evaporation. Gee, et al. (Gee, et al., 2007) reports that recharge averaging more than 60 mm/year has been measured for over 25 years at the Hanford Site. Recharge reported by Gee et al. for bare gravel-covered surfaces, such as exists at the SSTs, ranges from 50 to 100 mm/year. The effective recharge at the SSTs is locally enhanced and concentrated in the subsurface when downward percolating water is diverted by the sloping, low-permeability concrete domes of the SSTs (Khaleel et al., 2007). This mechanism is analogous to the concentration of rainwater dripping off the roof eave of a residence.

6.2 Past SST Leak Detection Methods

SST leak detection has been accomplished using several methods. Inventory systems using tank soundings and remote camera inspections are limited by access difficulties and potentially permeability-limiting salt cake and sludges in the tank interior. Near-tank systems are also used to detect the leaked material in the soil very close to the tanks. These methods have been evaluated using external sensor arrays deployed at a mock-tank that detected changes in the near-surface electrical field related to increased moisture content (Barnett et al., 2003). Also, historic and newer dry wells (approximately 800 wells) extending deeper in the vadose zone have been monitored for gamma radiation.

Performance evaluation testing was performed for two types of Electrical Resistivity Tomography (ERT): Point-Electrode Technique (ERT-PET) and Long-Electrode Technique (ERT-LET). A second method, High-Resolution-Resistivity Steel Casing Resistivity Technique (HRR-SCRT) was also tested (Barnett et al., 2003). Both methods were reported successful in identifying leaks (nine out of 13 leaks were detected) and reasonably estimating the volume of the leak (ERT-LET could not estimate leak volumes; ERT-PET overestimated the leak volumes by a factor of two). Success was dependent on the exceptional performance of the geophysical monitoring equipment and the data acquisition system.

Historically, monitoring of the dry wells has identified the general location of leaked materials within the vadose zone. The monitoring data indicate contaminant movement due to infiltration of meteoric water through relatively high-permeability soil materials surrounding the tanks.

6.3 Surface Barriers to Mitigate Future Leachate Migration

6.3.1 Surface Barrier Effectiveness

The application of interim surface barriers has been successful at reducing infiltration at waste facilities, and is a standard practice at many municipal landfill facilities. Khaleel, et al. (Khaleel,

et al., 2007) modeled a "no-surface barrier" scenario that calculated recharge of 100 mm/year infiltration with no surface barrier. For an interim surface barrier scenario, the model estimated recharge at 0.5 mm/year.

Knepp (Knepp, 2002) conducted a preliminary evaluation of Interim Corrective Measures (ICMs) that have been evaluated as they relate to the waste management area (WMA) S-SX. Knepp (Knepp, 2002) stated that, "ICMs are response actions having the objective of reducing contaminant migration to groundwater to acceptable regulatory levels and which require a balancing of risk, benefits, and costs." The study compared the performance of a surface barrier to a near-surface barrier and to an overhead structure. The only surface barrier evaluated was a 6 cm (2.5 inch) layer of asphalt cement pavement. The near-surface barrier consisted of an impervious, buried geo-fabric (geomembrane liner or geosynthetic clay) system over the entire WMA S-SX to direct surface water to the outer boundaries of the WMA. For both the surface and near-surface barriers, a run-off collection system consisting of ditches and pipes would be required to route collected surface water to existing drainage routes. The overhead structure consisted of an enclosed shelter covering the majority of the surface water control area of the WMA. An asphalt apron would be constructed around the perimeter of the structure to capture surface water and route that water to a run-off collection system.

The ICMs were evaluated using a relative scoring system for the following criteria: safety, regulatory compliance, life cycle cost analysis, tank integrity, future retrieval and processing, schedule, proven technology, maintainability, operability, constructability, decontamination, decommissioning, and disposal. Based on this, implementation of a surface barrier ranked highest among the three. The cost estimate presented to implement the surface barrier in the 241-S and 241-SX tank farm WMAs was $3,373,000 and $3,892,000, respectively.

An interim barrier of spray-on polyurea was applied in 2008 as part of a demonstration project (Badden, 2008) It would be useful to have a little more information. Monitoring instrumentation was installed both under and outside of the interim demonstration barrier. Modeling estimates (Khaleel et al., 2007) and baseline data indicate in the absence of a surface barrier, surface infiltration may further distribute contamination within the vadose zone and continue to impact groundwater in the area.

Data from the FY 2007 monitoring report shows that monitoring instrumentation is working as intended; however, only the sensors outside of the interim cover footprint were gathering data. It is assumed that the sensors beneath the interim cover have been collecting data since the application of the cover in 2008. Review of FY 2008 monitoring data will provide insight as to whether the instrumentation beneath the cover is working properly.

The interim surface barrier demonstration instrumentation was designed to detect and quantify surface infiltration. The instrumentation associated with the demonstration project is limited. The recommended expansion of the surface barrier system should be accompanied by design and expansion of the monitoring system. Despite a lack of current data, the modeling results presented by Khaleel et al. (Khaleel et al., 2007) indicate a significant reduction in recharge.

Surface barriers have proven effective at reducing infiltration. Surface barriers are the most common form of landfill remediation because they are both effective and less expensive than other technologies (FRTR, 2009). The FRTR (2009) states, "The most effective single-layer caps are composed of concrete or bituminous asphalt. It is used to form a surface barrier between landfill and the environment. An asphalt concrete cap would reduce leaching through the landfill into an adjacent aquifer."

6.3.2 Subsurface Techniques to Mitigate Future Leachate Migration

Treat et al. (Treat et al., 1995) published a report that evaluated the feasibility of 13 subsurface barriers deemed viable for application to the SSTs. Additional concepts were discussed but considered less viable. Eleven of the thirteen techniques were standoff in character, meaning the options were to be installed some distance in the subsurface from several tanks or a tank farm. Two of the techniques were characterized as close-coupled, or designed-to-be-installed in contact with individual tanks. The information was subjective and required testing to determine their respective suitability.

The viable options that Treat et al. (Treat et al., 1995) evaluated, along with salient caveats for each concept, are summarized below.

6.3.2.1. Standoff Options

6.3.2.1.1. Chemical Jet Grout Encapsulation using Cementitious Grouts

Chemical jet grout encapsulation isolates waste systems by using high-pressure jet grouting to form columns of grouted soil via directionally-drilled wells. Portland cements, bentonite clays, or more exotic grouts are used. Concerns raised included producing contaminated soils during drilling and installing complete and uniform barrier without extensive overlapping of barrier sections.

6.3.2.1.2. Ice Encapsulation using Freeze Walls

Two freezing methods were considered: (1) slow-rate freezing or closed-loop systems and (2) fast-freezing or open-loop systems (e.g., liquid nitrogen). Directional drill holes with steel casings are used to emplace the desired freezing line. An open system could quickly freeze the soil and then couple with a closed-loop system to maintain the freeze wall barrier. Concerns include whether the system would create sufficiently low permeability within the highly transmissive Hanford Site soils or whether it would be necessary to inject supplemental water. This action could have the undesirable side effect of mobilizing soluble contaminants. Installation could potentially create some stresses on the SSTs due to the expansion of the soil during the freezing process. As an active subsurface barrier concept, freeze walls would likely require a refrigeration plant to maintain the barrier.

6.3.2.1.3. Jet Grout Curtains using Cementitious Grout

Jet-grouted curtains are similar to grout encapsulation except that both vertical and horizontal well drilling, rather than directionally drilled wells, would be used for injection. Concerns similar to those associated with other grouting scenarios were also noted for this methodology. Emplacement of the horizontal component of this solution was deemed problematic.

6.3.2.1.4. Permeation Chemical Grouting using Cementitious Grouts

Permeation chemical grouts would be injected at lower pressures than jet grouts. Both vertical and horizontal barriers would be formed. Horizontal drilling would be utilized for the placement of a horizontal permeated grout barrier beneath a tank farm. This technology raises seismic concerns as joints between grouted zones could separate under tension. Variation in soil texture

and porosity (e.g., silt lenses, clastic dikes, and other soil heterogeneities) will likely prevent uniform permeation of chemicals which may result in ungrouted soil volumes.

6.3.2.1.5. Wax Emulsion Permeation Grouting using Grouts with Thermoviscous Fluids

Wax has a high-melting point and is composed of C-24 to C-32 esters of long-chained acids and alcohols. In this concept, an emulsion of wax, water and a surfactant is injected in the target soil zone. The wax particles move through the soil pores with the fluid. Once inside the soil matrix, the wax particles aggregate and move through void spaces until they bridge an opening and become fixed. Bridging these openings between pores reduces the permeability of the soil. Concerns are the wax may destabilize in the presence of SST leachates with a high pH (> 12.0) and the wax, like other petroleum products, is susceptible to bacterial biodegradation over time.

6.3.2.1.6. Silicate Permeation Grouting using Colloidal Silica, Sodium Silicates

Sodium silicate grout consists of four components: water, an acidic liquid consisting of glyoxal and additives, an alkaline liquid consisting of silicon dioxide and sodium oxide, and an aqueous suspension of non-agglomerated silica particles in an alkaline medium. Colloidal silica, a colloidal suspension with gelling properties, was also considered. When the pH decreases to less than 10, the colloid would polymerize or gel, form a cross-linked network, and reduce soil permeability. As with other grouting methods, predicting the movement of injected grout is difficult due to the anisotropy and heterogeneity of most Hanford Site soils.

6.3.2.1.6.1 Polymer Permeation Grouting using Grouts with Polymer Grouts, Polyacrilates

Polymer permeation grouting employs an injected liquid monomer or resin that is converted to a polymer to form a concrete-like monolithic barrier. Polymer-forming chemicals could be injected into the ground using the same methods for emplacing cement slurry walls. Polymer grout is expensive compared to standard grouts. Some polymer grouts (e.g., furfuryl alcohol) are chemically incompatible with Hanford Site soils.

6.3.2.1.6.2 Formed-In-Place Horizontal Grout Barriers using Rubberized Cements, Clays and Grouts

Horizontal grout barriers could be constructed in-situ in a basin configuration without excavation. A proprietary technology would generate a concrete barrier slab of uniform thickness (0.3 m) between guide wires placed by horizontal drilling methods. Demonstration projects had not been completed at the time of the Treat et al. (Treat et al., 1995) report. As a result, the feasibility of the technology had not been completely demonstrated. Any formation of concrete cold joints may render the barrier prone to leakage over time.

6.3.2.1.7. Radio Frequency Desiccating Subsurface Barriers using Electrodes

A radiofrequency (RF) heating process was considered for the formation of an active desiccating barrier underneath SSTs. RF energy applied to electrodes would heat a 2 to 3 m (7 to 10 ft) thick soil layer to temperatures above 100° C moisture creating a dry barrier. Concerns were that horizontal holes must be drilled to relatively low tolerances to achieve the 1 to 2 m (3.3 to 6.6 ft) spacing required for the RF electrodes. As with the Circulating Air Barrier (CAB), the absence of a physical barrier would complicate recovery of leaked waste (particularly sudden, large volume events).

6.3.2.1.8. Sheet Metal Piling Subsurface Barriers using Sheet Metal w/Grout

Interlocking metal sheet piling in a vertical configuration forms sheet metal piling subsurface barriers. This barrier is coupled with a horizontal barrier to form a complete barrier envelope. Injecting grout where the sheets are joined seals sheets. Concerns are that the approach has typically been limited to vertical sheet piling installations. The technology is not usually applicable to soils containing boulders or large cobbles such as may exist at the Hanford Site.

6.3.2.2. Close-Coupled Options

Close-coupled options, as described below, are designed to be installed in contact with individual SSTs.

6.3.2.2.1. Close-coupled Injected Chemical Barriers using Low-cost Filler and Polymer

This close-coupled subsurface barrier option adapts the concepts of jet and permeation grouting in angled boreholes using directional drilling methods. Injectate chemicals include Portland cement, polymer formers, and aggregating emulsions. The chemical grout would be formed against the sides and bottom of an individual SST. In one version, the close-coupled barrier walls are installed directly against the tank walls using vertical boreholes. The horizontal members of the barrier are installed in two layers using horizontal boreholes. Close-coupled barriers may induce physical stresses on the tank, depending on the emplacement method used. Close-coupled injected chemical barriers are relatively unproven and have undergone little testing. The area between many of the tanks is restricted (nominally 25 feet).

6.3.2.2.2. Induced Liquefaction Barriers using Sheet Metal with Polymer

This close-coupled subsurface barrier option combines sheet metal piling to create a vertical barrier with caisson-drilled horizontal jet grouting. One to three caissons (or a coffered trench) would first be excavated using a 5 to 7 m (15 to 20 foot) diameter clamshell. An overlapping horizontal jet grout curtain would be installed via horizontal wells through the caisson(s) or coffered trenches. Finally, vertical injection wells would be installed between the SST and sheet metal piling/jet grout curtain to inject grout, polymers, or other barrier-forming material, encapsulating the SST. Concerns are that sheet metal pilings may be subject to corrosion without CP. Boulders and large cobbles may cause the sheet metal edges to deflect. The horizontal component of this barrier had not been demonstrated at the time of the study. Potentially contaminated soils could be brought to the surface during the excavation of caissons or trenches.

6.3.3 Leverage Past Work and Recent Technological Developments

Since the Treat et al., (Treat et al., 1995) report was written, advancements have been made in environmental remediation technologies. The knowledge base has increased substantially for nearly all of the remediation technologies considered in 1994. In addition, new remedial technologies have been identified.

6.3.3.1. New Potential SST Leak Mitigation Technology: Injected Apatite Reactive Zone

As an example of recent advances in subsurface remediation, an in-situ remediation technology, has been recently identified that utilizes the placement of apatite [$Ca10(PO_4)6(X)_2$, where X is a monovalent anion such as OH^-, Cl^- or F^-]. Apatite is very resistant to biodegradation, highly stable and remains unaltered for thousands of years. As described by Moore (US Patent No. 6,592,294

B1; July 15, 2003), the proprietary placement process is based on injecting a solution of calcium citrate and sodium phosphate into soil. As the citrate is biodegraded, calcium is gradually released and reacts with the phosphate to form insoluble calcium phosphates that transform into apatite. Apatite is a strong sorbent for radionuclides and heavy metals. Apatite strongly sorbs uranium, plutonium, strontium, lead and other contaminants (Seaman, et al., 2003).

Because citrate forms strong complexes with calcium, it prevents the calcium from immediately reacting with the phosphate before it can be injected into the soil. However once injected, citrate is easily metabolized by microorganisms. As the citrate is biodegraded, calcium is gradually released and reacts with phosphate to form insoluble calcium phosphates. At pH between 7 to 9, and in the presence of fluoride, conditions are favorable for apatite formation.

Hydroxyapatite and apatitic compounds have been demonstrated to irreversibly sorb a variety of constituents including actinides, strontium, and lead. Technetium is also sorbed when a second material is added that reduces the technetium before capture by the apatite (Sandia National Laboratory, undated). Tests conducted in a laboratory setting indicate that, in highly oxidizing conditions, technitium does not desorb from apatite (Sandia National Laboratory, 2001a). The technology appears to have promise for SST application and proposals have been written for demonstration of the technology in bench-scale and field-testing environments (Sandia National Laboratory, 2001b).

In 2008-2009, a series of presentations reported on testing to determine the appropriate rate of Ca-citrate-PO_4 solution injection with the objective of achieving relatively uniform spatial distribution of apatite, and to determine the optimum injection rate to balance Sr-90 adsorption with Sr-90 migration to the aquifer. Effective delivery of the solution to both low- and high-permeability zones involves a slow injection until the low permeability material is nearly saturated, followed by a high injection rate resulting in the wetting of nearby high-permeability zones (Szecsody et al., 2008).

A field study, comprised of three injection tests, was conducted in which 300,000 gallons of solution was injected into a total of 16 wells screened across the Hanford and Ringold Formations. The peak Sr-90 concentration in down-gradient monitoring wells increased 8.3 times at a relatively high stoichiometric ratio of calcium to phosphate and citrate. Subsequent injection tests were conducted with lower calcium and citrate concentrations that reduced Sr-90 in the monitoring wells (Thompson et al., 2009).

6.3.3.2. Potential SST Leak Mitigation Technology: Electrokinetic Remediation

Electrokinetic remediation is a process in which a low-voltage direct-current (DC) is applied across a volume of contaminated soil between electrodes in the soil. Under the influence of a DC field, contaminants can be moved toward an electrode and then recovered. Electrokinetics has been applied to move contaminants to a target zone for extraction. Electrokinetics was eliminated in a previous Hanford Site technology screening study (WMP-27397, 2005) to support remediation of technetium-99 in the deep vadose zone. It is not effective in dry soils and would be difficult to implement in the deep vadose zone. Key problems include uncertainty of consequences induced by concentrating contaminants and water in a small area of the vadose zone, limited zone of influence for the electrodes, and limited applicability in low moisture content soils (USDOE, 2008). Due to these challenges, electrokinetics was not included for treatability testing in the Fluor Hanford Inc. study (WMP-27397, 2005).

6.3.3.3. Potential SST Leak Mitigation Technology: Circulating Air Barrier (CAB)

As previously discussed, the CAB system is a desiccant-type barrier designed to prevent the movement of liquid contaminants toward groundwater. It employs air circulation and a processing system to lower the soil water saturation in a subsurface zone. The concept of CAB was evaluated in a study (USDOE, 1993) of barrier systems that could be installed beneath and around the tank farms with a minimum of excavation. The CAB can be installed using either vertical or horizontal wells to establish a pattern of air injection and extraction wells. The moving air vaporizes water and carries the water vapor to an extraction well. Over time, circulation of the air reduces the water saturation in the swept interval, and continues to remove, by evaporation, liquids that move into the zone. In the event of a leak, the CAB system desiccation zone provides a monitoring point for early leak detection. The desiccation zone also provides a means to withdraw volatile contaminants by vapor extraction or to mitigate aqueous chemical migration by reduction of the saturation level. Identified advantages of the CAB system include non-physical confinement, active monitoring and leak detection, commercially available equipment, a monitored zone for emergency response, and high potential for integration with other remediation technologies. However, the concept needs to be demonstrated to develop data needed for scale-up and regulatory acceptance. Field pilot testing of the CAB system is underway at the Hanford Site, although published results are not currently available.

6.3.3.4. Performance Assessment Monitoring of Subsurface Barriers

SST subsurface leak mitigation strategies will require performance assessment and monitoring programs to demonstrate effectiveness in relation to remedial action objectives. Significant advancements have been made in the areas of subsurface monitoring, remote data acquisition, and data handling and interpretation. The technological capability exists to cost-effectively: place sensors, conduct real time and automatic remote data acquisition, handle and manipulate large datasets, and quickly provide data interpretations (e.g., leak location, leak volume, pore liquid travel velocity).

6.3.3.5. SST Leak Mitigation Combined with SST Closure Strategy

The optimum leachate mitigation strategy should support the objective of final tank closure. For example, Knepp (Knepp, 2002) accounted for life cycle cost analysis, tank integrity, and future retrieval and processing in his evaluation of ICMs.

6.3.3.6. Risk Assessment

Risk assessment methodologies have also advanced since the Treat et al., (Treat et al., 1995) report. SST leak mitigation strategies should be evaluated based on modern risk evaluation methodologies. In the past 15 years, toxicological data that underlies risk calculations has expanded and improved. Exposure information has improved through data collection. The methodologies upon which cancer risk evaluation is based have also improved. These new advancements in the science of risk assessment should be addressed in a modern risk evaluation to provide the risk reduction estimates associated with SST leak mitigation.

6.3.3.7. Limited Benefit of Subsurface Barriers

Treat et al., (Treat et al., 1995) found that capping the tank farm with a surface barrier capable of limiting recharge to 0.05 cm/year (0.02 in/year) may result in acceptable risks for some tanks if collapse of the tank domes could be prevented. Treat, et al., (Treat et al., 1995) also concluded the

use of subsurface barrier concepts would not result in significant additional risk reduction. Except for the clean-closure application, the cost-effectiveness of subsurface barrier technologies is essentially equal and relatively low. The cost-effectiveness of the subsurface barriers, calculated by the method most favorable to subsurface barriers, is about 0.0001 times that of surface barriers, and 0.01 times that of the set of baseline technologies.

6.3.4 Recommendation MCM-1: Install Surface Barrier Over SST Farms

Recommendations for future interim measures (Badden, 2008) related to minimizing surface infiltration are valid and should be accomplished as soon as possible, specifically constructing, maintaining, or upgrading run-off and storm water control structures and constructing interim barriers at other tank farm areas. Design and implementation of a surface barrier to reduce recharge at the SSTs is recommended. Sources of water that could contribute to subsurface water deep percolation should be identified and controlled. New control/barrier measures should be prioritized based on risk associated with past and/or future releases. In a recently published study, Maann (Maann, 2009) presents criteria for prioritizing future SST interim barriers and for evaluating barrier performance. This study should be used as the initial basis for implementing interim surface barriers.

6.3.5 Recommendation MCM-2: Evaluate Subsurface Leak Mitigation Technologies

A number of viable candidate subsurface leak mitigation strategies have been identified in the past. Since the last published Feasibility Study (FS) in 1994, new viable remedial technologies have been identified and developed, and older technologies have matured and improved. Using the previously conducted FS as a selection guide, a program to evaluate the viable leak mitigation technologies should be initiated. This program should consist of bench scale studies (where possible), followed by demonstration in a Hanford Site field setting where appropriate. In some cases, these tests have already been initiated. The above-mentioned injection apatite reactive zone and CAB technologies are examples that have already been implemented. Concurrently, an updated FS should be performed, using updated risk assessment methodologies and modern performance assessment technologies. It is recognized that an updated FS and risk-based selection process may also conclude, as before in the Treat et al., (Treat et al., 1995) study, that only little additional benefit can be derived from implementing a subsurface barrier in addition to implementing a surface barrier.

6.4 SUMMARY OF THE PRIORITIZATION MITIGATION OF CONTAMINANT MIGRATION RECOMMENDATIONS

Following are the recommendation titles, in order of priority, for the mitigation of contaminant migration key element.

- Recommendation MCM-1: Install Surface Barrier Over SST Farms
- Recommendation MCM-2: Evaluate Subsurface Leak Mitigation Technologies

7.0 REUSE OF SSTS

The Panel was tasked with providing recommendations to support development of a robust SSTIP—not developing criteria allowing the reuse of SSTs for routine storage.

Although this issue was clearly outside the Panel's scope, it arose during the Panel's deliberations several times. As a result, the Panel has included this section to reflect its deliberations on this issue.

Generally, the Panel discussed the difficulty of executing activities necessary to demonstrate that an SST was sufficiently sound to be reused. Some initial thoughts on this issue include:

- SST inspection and hydrostatic testing would be necessary. This report outlines many of the difficulties that currently face inspection efforts (e.g. waste characteristics, lack of SST access, and geometry of SSTs). If the inspection goal were SST reuse, the requirements would likely be quite stringent and, as a result, increase the difficulty of inspection.

- SSTs with compositions not in compliance with the Kirsch (See Section 4.2.4) criterion or those that have a nitrite to nitrate ion concentration ratio less than 0.1 should be excluded from consideration for reuse. Most of these tanks fail the compliance test because they have insufficient nitrite ion or low pH.

- SSTs that have boiled waste for long intervals should be excluded.

- SSTs that have contained waste type compositions known to have a high propensity for leaking should be excluded.

- SSTs that contain benign waste types could be considered for reuse.

- SSTs that maintained stagnant waste levels for long periods should be excluded as LAI corrosion would be a concern.

The Panel acknowledges the topic of SST reuse is politically sensitive. Given this, and the technical difficulty of demonstrating whether SSTs are sound, much time and effort would be necessary to develop a process by which a decision to reuse SSTs could be made.

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APPENDIX A

SHORT BIOGRAPHIES FOR SINGLE-SHELL TANK INTEGRITY PANEL

MICHAEL T. TERRY, P.E., PANEL CHAIR
CONSULTANT
Perot Systems Government Services

Mr. Terry is currently providing independent consulting services to clients such as the US Department of Energy and the US Nuclear Regulatory Commission. He earned a Masters Degree in Mechanical Engineering from Washington University and a BS in Mathematics from the University of New Mexico. He has extensive experience in nuclear and process safety; engineering, design, and construction of nuclear and non-nuclear facilities and processes; program and project design and implementation; management systems and organizational development; professional facilitation; and project management and administration.

Recently, Mr. Terry has been assisting the Double-Shell Tank Integrity Project (DSTIP) at CH2M HILL, Hanford Group, Inc. (CH2M HILL). His primary responsibilities include chairing an Expert Panel on tank waste chemistry optimization, oversight of the implementation of the recommendations from the original panel report as chair to an expert panel oversight committee, and providing technical and programmatic guidance on matters related to the DSTIP. He has also chaired and facilitated a workshop with another expert panel assembled to investigate vapor space corrosion in the Hanford double-shell tanks. In addition to these activities for the CH2M HILL, Mr. Terry facilitated a High-Level Liquid Waste Tank Integrity Workshop for the Savannah River National Laboratory, with participation similar to the Hanford double-shell tank integrity workshops.

TODD MARTIN, PANEL CO-CHAIR
CONSULTANT

Todd has worked on Department of Energy Environmental Management issues for nearly 20 years. Todd received his Masters in Environmental Sciences from Bard College and Bachelor of Science in Biology from Whitworth College. Consulting with DOE, contractors, states, and public interest organizations Todd has worked to forge consensus in DOE communities to ensure cleanup protects the health and safety of the public, workers and the environment and is technically sound, publicly accountable and fiscally responsible. Todd is currently leading the river corridor clean up standards working group for DOE-RL.

JOHN A. BEAVERS, PH.D.
CHIEF TECHNOLOGY OFFICER
CC Technologies, A DNV Company

Dr. Beavers is Chief Technology Officer of CC Technologies, a corrosion engineering and research company. Currently, he serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford. He has directed and contributed to numerous research programs on corrosion performance of structural materials. These programs have included failure analyses, critical literature reviews, and laboratory and field evaluations of metallic and non-metallic materials. Dr. Beavers has utilized state-of-the-art electrochemical, surface analytical, and mechanical techniques for evaluation of materials performance for different forms of corrosion.

Electrochemical techniques used include potentiodynamic polarization, polarization resistance, electrochemical impedance spectroscopy, electrochemical noise, and galvanic current measurements. Surface analytical techniques used include Auger electron spectroscopy, x-ray photoelectron spectroscopy, energy dispersive x-ray spectroscopy, scanning electron microscopy, transmission electron microscopy, electron microprobe, and x-ray diffraction. Mechanical techniques used include elastic and plastic fracture mechanics and dynamic mechanical loading techniques such as slow strain rate and low cycle fatigue.

STEPHEN J. CULLEN, PHD.
CONSULTANT
D.B Stephens and Associates

Dr. Cullen is a Principal Hydrogeologist with more than 30 years of experience. Areas of expertise include vadose zone and groundwater flow and transport modeling, hydrocarbon and halocarbon site investigations, contaminant source identification, hazardous and solid waste landfill investigations and monitoring systems, metals and radionuclide investigations, land disposal of biosolids and sewage effluent, land treatment facilities, intrinsic bioremediation as well as active approaches to soil and groundwater remediation. Dr. Cullen has provided expert opinions and testimony for resolution of a wide range of groundwater and vadose zone characterization, monitoring, and remediation problems. Dr. Cullen was co-author of the Handbook of Vadose Zone Characterization and Monitoring published in 1995 by Lewis Publishers.

GERALD FRANKEL, PHD.
PROFESSOR and DIRECTOR
Fontana Corrosion Center at The Ohio State University

Dr. Frankel's primary interests are in the fields of corrosion and electrochemistry. He has focused on localized corrosion, passivation, coatings, inhibition, corrosion of electronic and magnetic materials, X-ray absorption studies of electrochemically-formed films using synchrotron radiation, behavior of anodes used in electrodeposition applictions, and electrode position of magnetic materials. Presently, he serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford. The current activities in Dr. Frankel's group are focused largely on localized corrosion, and primarily on the corrosion and protection of Al and Al alloys. His group is using a number of approaches to study pitting, intergranular corrosion and exfoliation corrosion of Al alloys related to aging aircraft. His group has initiated novel uses of Atomic Force Microscopy-based techniques in the study of corrosion, including Scanning Kelvin Probe Force Microscopy and Atomic Force Microscopy scratching. The mechanism by which chromates inhibit the corrosion of Al alloys has been studied in earlier projects.

Currently his group is studying the inhibition mechanisms of various chromate replacements. Corrosion of welds has been another focus of Dr. Frankel's work. A Cr-free consumable for the welding of stainless steel is currently under development with the goal of minimizing the production of Cr-containing weld fumes. In another study, the susceptibility of oxide dispersion strengthened Ni-based superalloys to hydrogen embrittlement is under study. Dr. Frankel is the author of over 150 publications, primarily in the field of corrosion.

RUSSELL H. JONES, PHD.
CONSULTANT
GT Engineering

Dr. Russell H. Jones has 38 years of experience in materials development, evaluation, and characterization. Dr. Jones has extensive experience in the fields of stress corrosion cracking, radiation effects on materials, corrosion, and high-temperature composites. His work in stress corrosion cracking includes evaluation of the effects of hydrogen, aqueous, high-temperature, and nuclear environments on crack growth behavior of iron, nickel, aluminum, and magnesium alloys, and ceramics and ceramic composites. Dr. Jones was one of the original members of the Expert Panel for Chemistry Optimization for Double-Shell Tanks at Hanford.

Dr. Jones' nuclear experience includes development of materials for advanced nuclear reactors and irradiation assisted stress corrosion cracking for light water reactors. Specific corrosion experience includes evaluation of the effects of interface, grain boundary, and surface chemistry on corrosion of materials including Yucca Mountain waste container materials. Dr. Jones has been instrumental in the development of SiCf/SiC composites for advanced nuclear reactor applications including high-temperature properties, corrosion and radiation stability. Dr. Jones has expertise in fracture toughness testing of metal and ceramic materials.

ROBERT P. KENNEDY, PHD.
STRUCTURAL MECHANICS
RPK Structural Mechanics

Dr. Kennedy has over 30 years of experience in static and dynamic analysis: design of special purpose civil- and mechanical-type structures particularly for the nuclear, petroleum, and defense industries: design of structures to resist extreme loadings including seismic, missile impact, extreme wind, impulsive loads, and nuclear environmental effects; and development of computerized structural analysis methods.

Dr Kennedy has more than 30 years of experience in the seismic design and evaluation of liquid storage tanks. He has co-author or was the prime contributor to

- BNL 52361, Seismic Design and Evaluation Guideline for the Department of Energy High-Level Waste Storage Tanks and Appurtenances
- DOE-STD-1020, natural Phenomena Hazard Design and Evaluation Criteria for Department of Energy Facilities.

Dr. Kennedy chaired the ASCE committee that wrote ASCE Standard 4, Seismic Analysis of Safety-Related Nuclear Structures.

LEON STOCK, PHD.
CHEMIST
Independent Consultant
Professor Emeritus, Department of Chemistry, University of Chicago

Professor Stock has written approximately 210 articles and authored or co-authored numerous papers related to Hanford Site waste. His recent work at the Hanford Site has centered on the rates of hydrogen generation in the tanks and in the Waste Treatment and Immobilization Plant and on the occurrence and chemistry of organic compounds within the waste tanks. Currently, he

serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford.

KARTHIK SUBRAMANIAN
FELLOW TECHNICAL ADVISER
High Level Waste Integration
URS Washington Division

Karthik Subramanian has experience and expertise in basic and applied research, specifically in materials processing and consequent performance. His relevant expertise includes mechanical and environmental testing, hydrogen isotope effects on polymers and structural metals, and aqueous corrosion of structural materials. Karthik's research experience at the Savannah River National Laboratory (SRNL) focused on (1) structural integrity programs for high level waste tanks, including design and implementation of corrosion control; and (2) life-cycle engineering for tritium reservoirs, involving the development of structure, property, performance models for long-term hydrogen/tritium/helium effects on structural materials. Karthik's current focus is on integrating the activities related to high level waste for the URS Washington Division including structural integrity programs and multi-faceted technology development and operational programs.

BRUCE THOMPSON, PHD.
PROFESSOR AND DIRECTOR
Center for Nondestructive Evaluation, Ames Laboratory

Bruce Thompson is the Director of the Center for Nondestructive Evaluation, Director of the Ames Laboratory Applied NDE Program, and a Distinguished Professor in the Department of Materials Science and Engineering and in the Department of Aerospace Engineering and Engineering Mechanics. He received his B.A. in Physics from Rice University (1964), his M.S. in Physics from Stanford University (1965) and his Ph.D. in Applied Physics from Stanford University (1971). From 1970 to 1980 he served as a member of the technical staff and Group leader of Ultrasonic Applications at the Rockwell International Center before coming to Iowa State University.

Thompson's research interests fall in the area of ultrasonic nondestructive evaluation. Specialties include the analysis and development of noncontact sensors, in particular electromagnetic acoustic transducers, modeling the effects of measurement geometry on ultrasonic inspection, studying the uses of ultrasound to characterize a variety of microstructural and material properties such as stress, texture, porosity, grain size, and anisotropy and partially contacting interfaces, and uses of physics-based simulation tools to assist in the determination of probability of detection.

Thompson is the author of 6 major invited review articles in the field of nondestructive evaluation, over 90 articles in archival journals and over 323 papers in edited conference proceedings. He has been awarded 24 U.S. patents and presently serves as the Editor-in-Chief of the Journal of Nondestructive Evaluation. Dr. Thompson was one of the authors of Guidelines for Development of Structural Integrity Programs for DOE High-Level Waste Storage Tanks (BNL-52527).

BRUCE J. WIERSMA, PHD.
FELLOW ENGINEER
Savannah River National Laboratory

Dr. Wiersma has 17 years of experience in the corrosion and structural integrity disciplines at the Savannah River Site. His primary responsibilities have been associated with the structural integrity of high-level waste tanks. He has developed experimental programs to evaluate the corrosion performance of materials utilized on the Savannah River Site, and he led the team that developed the in-service inspection program for the high-level waste tanks. Currently, he serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford.

APPENDIX B

TEMPERATURES AND COMPOSITIONS OF SUPERNATANT AND INTERSTITIAL LIQUIDS OF UNRETRIEVED SSTs

Tank	Layer	Temperature (C)	OH^- (Molar)	OH^- (pH)	NO_2 (Molar)	NO_3 (Molar)
Unretrieved SSTs						
241-A-101	Supernatant		2.51	14.4		
241-A-101	Solid	44.2	2.51	14.4	3.59	3.76
241-A-102	Supernatant	35.5	1.02	14.0	3.76	3.05
241-A-102	Solid	35.5	1.02	14.0	3.74	3.05
241-A-103	Supernatant	35.6	2.88	14.5	2.70	3.90
241-A-103	Solid	40.4	2.88	14.5	2.70	3.90
241-A-104	Supernatant					
241-A-104	Solid	73.9	2.51	14.4	0.78	1.28
241-A-105	Supernatant	59.0				
241-A-105	Solid	59.0				
241-A-106	Supernatant	50.1				
241-A-106	Solid	50.1	2.51	14.4	0.78	1.28
241-AX-101	Supernatant		2.29	14.4		
241-AX-101	Solid	34.5	2.29	14.4	3.76	4.39
241-AX-102	Supernatant					
241-AX-102	Solid	23.5	2.29	14.4	2.33	2.84
241-AX-103	Supernatant					
241-AX-103	Solid	38.7	2.29	14.4	2.65	3.08
241-AX-104	Supernatant					
241-AX-104	Solid	31.6	2.29	14.4	0.78	1.28
241-B-101	Supernatant					
241-B-101	Solid	38.8	1.00	14.0	2.87	5.74
241-B-102	Supernatant	18.1	1.00	14.0	0.18	3.50
241-B-102	Solid	18.1	1.00	14.0	0.19	3.50
241-B-103	Supernatant					
241-B-103	Solid	17.3	1.00	14.0	0.19	3.52
241-B-104	Supernatant					
241-B-104	Solid	21.5	1.00	14.0	0.19	3.48
241-B-105	Supernatant					
241-B-105	Solid	18.6	1.00	14.0	0.19	3.48
241-B-106	Supernatant	17.6	1.00	14.0	0.19	3.50
241-B-106	Solid	22.9	1.00	14.0	0.19	3.50
241-B-107	Supernatant					
241-B-107	Solid	16.0	1.00	14.0	0.14	5.34
241-B-108	Supernatant					
241-B-108	Solid	21.2	1.00	14.0	1.17	6.06
241-B-109	Supernatant					
241-B-109	Solid	20.0	1.00	14.0	0.19	3.50
241-B-110	Supernatant	21.4	1.00	14.0	0.86	1.25
241-B-110	Solid	21.4	1.00	14.0	0.86	1.25
241-B-111	Supernatant	23.6	1.00	14.0	0.86	1.25
241-B-111	Solid	23.9	1.00	14.0	0.86	1.25
241-B-112	Supernatant	24.5	1.00	14.0	2.54	3.50
241-B-112	Solid	24.5	1.00	14.0	2.54	3.50
241-B-201	Supernatant					
241-B-201	Solid	17.6	1.00	14.0	0.78	1.28
241-B-202	Supernatant					
241-B-202	Solid	16.2	1.00	14.0	0.78	1.28
241-B-203	Supernatant	20.2	1.00	14.0	0.03	0.91

Tank	Layer	Temperature (C)	OH^- (Molar)	OH^- (pH)	NO_2 (Molar)	NO_3 (Molar)
241-B-203	Solid	16.5	1.00	14.0	0.03	0.91
241-B-204	Supernatant	19.0	1.00	14.0	0.03	0.56
241-B-204	Solid	16.7	1.00	14.0	0.03	0.56
241-BX-101	Supernatant					
241-BX-101	Solid	22.0	1.00	14.0	1.40	1.95
241-BX-102	Supernatant					
241-BX-102	Solid	20.2	1.00	14.0	0.78	1.28
241-BX-103	Supernatant	23.3	1.00	14.0	0.30	0.72
241-BX-103	Solid	21.2	1.00	14.0	0.30	0.72
241-BX-104	Supernatant	29.5	1.00	14.0	1.38	2.16
241-BX-104	Solid	29.5	1.00	14.0	1.38	2.16
241-BX-105	Supernatant	20.3	1.00	14.0	0.87	1.89
241-BX-105	Solid	19.9	1.00	14.0	0.87	1.89
241-BX-106	Supernatant					
241-BX-106	Solid	20.4	1.00	14.0	2.54	3.50
241-BX-107	Supernatant					
241-BX-107	Solid	21.9	1.00	14.0	0.78	1.28
241-BX-108	Supernatant					
241-BX-108	Solid	19.9	1.00	14.0	0.78	1.28
241-BX-109	Supernatant					
241-BX-109	Solid	21.1	1.00	14.0	0.78	1.28
241-BX-110	Supernatant	19.9	1.00	14.0	1.13	6.64
241-BX-110	Solid	22.0	1.00	14.0	1.13	6.64
241-BX-111	Supernatant					
241-BX-111	Solid	19.8	1.00	14.0	2.30	2.98
241-BX-112	Supernatant	18.9	1.00	14.0	0.77	1.59
241-BX-112	Solid	20.6	1.00	14.0	0.77	1.59
241-BY-101	Supernatant					
241-BY-101	Solid	27.3	2.25	14.4	2.54	3.50
241-BY-102	Supernatant					
241-BY-102	Solid	21.9	2.25	14.4	1.83	2.39
241-BY-103	Supernatant		1.85	14.3		
241-BY-103	Solid	23.7	1.85	14.3	0.98	2.27
241-BY-104	Supernatant					
241-BY-104	Solid	38.5	2.25	14.4	2.41	3.34
241-BY-105	Supernatant		2.25	14.4		
241-BY-105	Solid	34.5	2.25	14.4	1.49	3.21
241-BY-106	Supernatant		2.11	14.3		
241-BY-106	Solid	32.3	2.11	14.3	1.70	1.77
241-BY-107	Supernatant					
241-BY-107	Solid	29.5	2.25	14.4	2.54	2.11
241-BY-108	Supernatant					
241-BY-108	Solid	34.8	2.25	14.4	1.71	4.74
241-BY-109	Supernatant					
241-BY-109	Solid	18.5	2.25	14.4	1.80	3.06
241-BY-110	Supernatant					
241-BY-110	Solid	32.8	2.25	14.4	2.70	2.00
241-BY-111	Supernatant					
241-BY-111	Solid	24.8	2.25	14.4	1.19	3.24
241-BY-112	Supernatant					
241-BY-112	Solid	27.7	2.25	14.4	3.06	3.06
241-C-101	Supernatant					
241-C-101	Solid	32.4	1.00	14.0	0.78	1.28
241-C-102	Supernatant					
241-C-102	Solid	28.0	1.00	14.0	0.78	1.28
241-C-104	Supernatant					
241-C-104	Solid	38.1	1.00	14.0	0.78	1.28

Tank	Layer	Temperature (C)	OH^- (Molar)	OH^- (pH)	NO_2 (Molar)	NO_3 (Molar)
241-C-105	Supernatant					
241-C-105	Solid	48.6	1.00	14.0	0.80	0.53
241-C-107	Supernatant					
241-C-107	Solid	42.9	1.00	14.0	0.78	1.28
241-C-110	Supernatant	20.8	1.00	14.0	0.10	0.97
241-C-110	Solid	23.8	1.00	14.0	0.10	0.97
241-C-111	Supernatant					
241-C-111	Solid	23.1	1.00	14.0	0.78	1.28
241-C-112	Supernatant					
241-C-112	Solid	27.5	1.00	14.0	0.78	1.28
241-S-101	Supernatant		2.80	14.4		
241-S-101	Solid	38.2	2.80	14.4	2.46	3.45
241-S-103	Supernatant	24.8	2.15	14.3	3.19	3.48
241-S-103	Solid	28.7	2.15	14.3	3.19	3.48
241-S-104	Supernatant		0.30	13.5		
241-S-104	Solid	38.4	0.30	13.5	0.83	4.32
241-S-105	Supernatant					
241-S-105	Solid	26.2	4.81	14.7	2.65	3.06
241-S-106	Supernatant		3.26	14.5		
241-S-106	Solid	25.2	3.26	14.5	2.26	3.81
241-S-107	Supernatant					
241-S-107	Solid	32.5	1.76	14.2	1.55	1.84
241-S-108	Supernatant		2.83	14.5		
241-S-108	Solid	28.3	2.83	14.5	2.65	3.06
241-S-109	Supernatant		4.82	14.7		
241-S-109	Solid	25.9	4.82	14.7	1.85	2.13
241-S-110	Supernatant					
241-S-110	Solid	42.1	4.81	14.7	1.86	3.50
241-S-111	Supernatant		3.00	14.5		
241-S-111	Solid	27.4	3.00	14.5	1.82	3.11
241-SX-101	Supernatant		2.86	14.5		
241-SX-101	Solid	50.5	2.86	14.5	1.63	1.74
241-SX-102	Supernatant		2.95	14.5		
241-SX-102	Solid	51.8	2.95	14.5	3.28	2.53
241-SX-103	Supernatant		2.66	14.4		
241-SX-103	Solid	57.6	2.66	14.4	3.41	2.52
241-SX-104	Supernatant		1.79	14.3		
241-SX-104	Solid	56.2	1.79	14.3	2.54	4.68
241-SX-105	Supernatant		2.41	14.4		
241-SX-105	Solid	59.9	2.41	14.4	3.11	2.64
241-SX-106	Supernatant		1.88	14.3		
241-SX-106	Solid	33.2	1.88	14.3	3.24	3.95
241-SX-107	Supernatant					
241-SX-107	Solid	68.7	3.57	14.6	2.14	3.50
241-SX-108	Supernatant					
241-SX-108	Solid	76.1	3.57	14.6	0.78	1.28
241-SX-109	Supernatant					
241-SX-109	Solid	54.6	3.57	14.6	2.33	2.84
241-SX-110	Supernatant					
241-SX-110	Solid	68.5	3.57	14.6	0.78	1.28
241-SX-111	Supernatant					
241-SX-111	Solid	67.4	3.57	14.6	2.15	3.50
241-SX-112	Supernatant					
241-SX-112	Solid	61.2	3.57	14.6	2.15	3.50
241-SX-113	Supernatant					
241-SX-113	Supernatant	27.9				
241-SX-113	Solid		3.57	14.6	0.78	1.28

Tank	Layer	Temperature (C)	OH^- (Molar)	OH^- (pH)	NO_2 (Molar)	NO_3 (Molar)
241-SX-114	Solid	72.3	3.57	14.6	2.15	3.50
241-SX-115	Supernatant					
241-SX-115	Solid	25.4	3.57	14.6	0.78	1.28
241-T-101	Supernatant		2.83	14.5		
241-T-101	Solid	23.1	2.83	14.5	2.65	3.05
241-T-102	Supernatant	17.8	0.00	11.6	0.50	1.76
241-T-102	Solid	17.8	0.00	11.6	0.50	1.76
241-T-103	Supernatant	19.2	1.00	14.0	0.86	1.26
241-T-103	Solid	19.0	1.00	14.0	0.86	1.26
241-T-104	Supernatant					
241-T-104	Solid	19.0	1.00	14.0	0.78	1.28
241-T-105	Supernatant					
241-T-105	Solid	16.6	1.00	14.0	1.18	0.60
241-T-106	Supernatant					
241-T-106	Solid	19.6	1.00	14.0	0.78	1.28
241-T-107	Supernatant					
241-T-107	Solid	18.8	1.00	14.0	0.78	1.28
241-T-108	Supernatant					
241-T-108	Solid	16.2	1.00	14.0	0.19	3.50
241-T-109	Supernatant					
241-T-109	Solid	22.6	1.00	14.0	0.19	3.50
241-T-110	Supernatant	18.6	1.00	14.0	0.00	0.30
241-T-110	Solid	18.0	1.00	14.0	0.00	0.30
241-T-111	Supernatant					
241-T-111	Solid	22.4	1.00	14.0	0.78	1.28
241-T-112	Supernatant	18.9	1.00	14.0	0.84	0.38
241-T-112	Solid	23.0	1.00	14.0	0.84	0.38
241-T-201	Supernatant	19.2	1.00	14.0	0.01	0.74
241-T-201	Solid	20.6	1.00	14.0	0.01	0.74
241-T-202	Supernatant					
241-T-202	Solid	20.6	1.00	14.0	0.73	1.28
241-T-203	Supernatant					
241-T-203	Solid	21.0	1.00	14.0	0.78	1.28
241-T-204	Supernatant					
241-T-204	Solid	20.5	1.00	14.0	0.78	1.28
241-TX-101	Supernatant					
241-TX-101	Solid	25.2	1.00	14.0	2.65	3.06
241-TX-102	Supernatant					
241-TX-102	Solid	26.1	1.00	14.0	2.65	3.06
241-TX-103	Supernatant					
241-TX-103	Solid	22.0	1.00	14.0	2.56	3.08
241-TX-104	Supernatant	20.6	1.00	14.0	2.05	5.71
241-TX-104	Solid	20.6	1.00	14.0	2.05	5.69
241-TX-105	Supernatant					
241-TX-105	Solid	33.3	1.00	14.0	2.65	3.06
241-TX-106	Supernatant					
241-TX-106	Solid	25.4	1.00	14.0	2.65	3.06
241-TX-107	Supernatant					
241-TX-107	Solid	22.3	1.00	14.0	2.52	3.18
241-TX-108	Supernatant					
241-TX-108	Solid	20.8	1.00	14.0	2.65	3.06
241-TX-109	Supernatant					
241-TX-109	Solid	35.4	1.00	14.0	0.78	1.28
241-TX-110	Supernatant					
241-TX-110	Solid	27.5	1.00	14.0	2.65	3.06
241-TX-111	Supernatant					
241-TX-111	Solid	28.5	1.00	14.0	2.65	3.06

Tank	Layer	Temperature (C)	OH^- (Molar)	OH^- (pH)	NO_2 (Molar)	NO_3 (Molar)
241-TX-112	Supernatant		2.83	14.5		
241-TX-112	Solid	27.7	2.83	14.5	2.30	3.13
241-TX-113	Supernatant		2.83	14.5		
241-TX-113	Solid	22.5	2.83	14.5	2.65	3.06
241-TX-114	Supernatant					
241-TX-114	Solid	20.9	1.00	14.0	1.12	3.34
241-TX-115	Supernatant		2.83	14.5		
241-TX-115	Solid	21.8	2.83	14.5	2.65	3.06
241-TX-116	Supernatant		0.15	13.2		
241-TX-116	Solid	21.1	0.15	13.2	0.23	6.11
241-TX-117	Supernatant					
241-TX-117	Solid	21.1	1.00	14.0	0.19	3.50
241-TX-118	Supernatant		2.83	14.5		
241-TX-118	Solid	28.9	2.83	14.5	2.65	3.06
241-TY-101	Supernatant					
241-TY-101	Solid	18.6	1.00	14.0	0.18	3.50
241-TY-102	Supernatant		2.83	14.5		
241-TY-102	Solid	16.0	2.83	14.5	1.52	3.26
241-TY-103	Supernatant		2.83	14.5		
241-TY-103	Solid	25.1	2.83	14.5	2.65	3.06
241-TY-104	Supernatant	15.9	1.00	14.0	0.25	1.60
241-TY-104	Solid	22.3	1.00	14.0	0.25	1.60
241-TY-105	Supernatant					
241-TY-105	Solid	24.7	1.00	14.0	0.78	1.28
241-TY-106	Supernatant					
241-TY-106	Solid	16.0	1.00	14.0	0.78	1.28
241-U-101	Supernatant					
241-U-101	Solid	20.7	2.89	14.5	0.78	1.28
241-U-102	Supernatant	26.7	1.72	14.2	3.17	3.19
241-U-102	Solid	28.7	1.72	14.2	3.17	3.19
241-U-103	Supernatant	28.3	1.81	14.3	2.98	2.45
241-U-103	Solid	29.4	1.81	14.3	2.98	2.45
241-U-104	Supernatant					
241-U-104	Solid	28.0	2.89	14.5	2.28	3.34
241-U-105	Supernatant		1.23	14.1		
241-U-105	Solid	30.8	1.23	14.1	2.35	2.92
241-U-106	Supernatant	24.4	0.30	13.5	2.15	4.00
241-U-106	Solid	29.6	0.30	13.5	2.15	4.02
241-U-107	Supernatant		1.84	14.3		
241-U-107	Solid	24.3	1.84	14.3	2.78	2.29
241-U-108	Supernatant		2.89	14.5		
241-U-108	Solid	27.2	2.89	14.5	2.91	2.97
241-U-109	Supernatant		2.60	14.4		
241-U-109	Solid	26.0	2.60	14.4	2.78	2.98
241-U-110	Supernatant					
241-U-110	Solid	28.6	2.89	14.5	0.78	1.28
241-U-111	Supernatant		1.99	14.3		
241-U-111	Solid	23.0	1.99	14.3	2.61	2.69
241-U-112	Supernatant					
241-U-112	Solid	20.8	2.89	14.5	0.78	1.28
241-U-201	Supernatant	20.7	0.74	13.9	0.45	2.31

Tank	Layer	Temperature (C)	OH^- (Molar)	OH^- (pH)	NO_2 (Molar)	NO_3 (Molar)
Tank	**Layer**	**Temperature (C)**	**OH^- (Molar)**	**OH^- (pH)**	**NO_2 (Molar)**	**NO_3 (Molar)**
241-U-201	Solid	22.8	0.74	13.9	0.45	2.31
241-U-202	Supernatant	18.2	1.05	14.0	0.53	2.45
241-U-202	Solid	19.5	1.05	14.0	0.53	2.45
241-U-203	Supernatant	18.8	0.28	13.4	0.42	2.32
241-U-203	Solid	19.1	0.28	13.4	0.42	2.32
241-U-204	Supernatant	18.0	0.09	13.0	0.15	0.89
241-U-204	Solid	18.0	0.09	13.0	0.15	0.89
Note 1: The temperatures and compositions were obtained from Meacham (2008).						
Note 2: The known and presumed leakers are shown in gray in the Tank column on the left						
Note 3: pH is related to the hydroxide ion content by the equation: log [OH(-1)] = pH -14						

Attachment 2
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(59 Pages)

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"Second Expert Panel Report for Hanford Site Single-Shell Tank Integrity Report"

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SINGLE-SHELL TANK INTEGRITY EXPERT PANEL REPORT

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Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-08RV14800

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Abstract: After release of the Panel's first report, RPP-RPT-43116, "Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project," the Department of Energy Office of River Protection sent a letter to WRPS requesting additional commentary from the Panel. At a January 2010 Workshop, WRPS presented proposals for future use and requested the Panel provide commentary in four areas: evaluation of the existing known conditions of the single-shell tanks (SSTs); evaluation of the proposed future use of the SSTs; recommendations for critical modifications and associated schedule aimed at preventing of minimizing further degradation of SST integrity; and recommendations for additional evaluations and program elements that would improve existing understanding of SST integrity. This report provides a Panel response to these proposals, as well as additional requests found in the Department of Energy letter.

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Single-Shell Tank Integrity Expert Panel Report

M.T. Terry
Dell Perot Systems

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EXECUTIVE SUMMARY

Hanford Site single-shell tank (SST) and double-shell tank (DST) wastes are slated for treatment in a Waste Treatment and Immobilization Plant (WTP) that is currently under construction. Delays to the initiation of operation of the WTP will necessitate extended waste storage in SSTs. These delays provide the impetus for a more robust Single-Shell Tank Integrity Project (SSTIP).

The Single-Shell Tank Integrity Expert Panel (the Panel) was tasked with providing recommendations to Washington River Protection Solutions, LLC (WRPS) to support the development of an enhanced SSTIP. The Panel's recommendations for an SSTIP are documented in the *Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project* (Terry, 2009). The Panel provided recommendations regarding; (1) confirmation of tank structural integrity ("SI"), (2) assessment of the likelihood of future tank liner degradation ("LD"), (3) leak identification and prevention ("LIP"), and (4) mitigation of contaminant migration ("MCM"). These recommendations are summarized in Appendix A.

The Panel participated in a Workshop in January 2010 in which Panel members were informed of ongoing work by WRPS to implement the recommendations of the first report. The Panel is pleased with the significant progress that has already been made in this direction.

Shortly after the release of the Panel's first report, the Department of Energy Office of River Protection (DOE-ORP) sent a letter to WRPS requesting additional commentary from the Panel (Charboneau, 2009). WRPS, in turn, requested the Panel provide such commentary in four areas outlined in the DOE letter: (1) evaluation of the existing known conditions of the SSTs; (2) evaluation of the proposed future use of the SSTs; (3) recommendations for critical modifications and associated schedule aimed at preventing or minimizing further degradation of SST integrity; and (4) recommendations for additional evaluations and program elements that would improve existing understanding of SST integrity.

The Panel was briefed at the January 2010 Workshop on the origin of the future use proposal. This report provides a Panel response to that proposal and the additional requests found in the DOE letter.

Area 1: Evaluation of existing SST conditions. The Panel does not have any additional information since the first report (Terry, 2009) to suggest that the conditions of the SSTs have changed. As a result, the findings from the Panel's first report are summarized in Section 2.

Area 2: Future use of SSTs. The Tri Party Agreement (TPA) between the DOE, the US Environmental Protection Agency (EPA) and the Washington State Department of Ecology requires the retrieval of wastes from SSTs. Currently, SST wastes are pumped from SSTs into DSTs. The future use proposal arose from a programmatic dilemma presented by WRPS—the current baseline schedule will require suspension of SST retrievals due to a lack of DST space in the 2018 timeframe. Further, 200 West Area SST retrievals are limited by cross-site transfer line capacities for delivering waste to the 200 East Area (where the WTP is located). The future use proposal would involve retrieval and transfer of SST wastes into carefully selected SSTs to resolve this programmatic dilemma and enable the retrieval operations to be completed in a more timely fashion.

As with any activity at Hanford, the WRPS proposal carries risks. Risks can fall into a variety of categories including programmatic, political, health, safety, and environmental. For this report, the Panel has only considered the risks of structural failure or a leak from the steel liner in an SST

chosen for future use.

The Panel concluded current data was insufficient to quantify the risk of a leak during the proposed future use of waste in SSTs. Consequently, the Panel's recommendations are focused on conducting risk assessment activities to better understand and reduce the risk of a leak. The Panel offers no assessment of the acceptability of the risk of a leak during operations. WRPS must decide whether SST evaluation and characterization activities have reduced the risk to an acceptable level.

The Panel's commentary on the proposed future use of SSTs is found in Section 3. Following are summaries of the Panels future use recommendations denoted by "ST" for storage.

- Recommendation ST-1: An engineering assessment for the SST candidate tank farm should be prepared.
- Recommendation ST-2: The relative acceptability of SSTs for future use should be evaluated on the basis of the following historical information.
    - Highest preference should be given to SSTs that have not leaked.
    - Highest preference should be given to SSTs without fillet joints.
    - Higher preference should be given to SSTs with liners fabricated from A-283 and A-285 steel rather than A-7 or A-10 steels.
    - Higher preference should be given to SSTs that historically have had a nitrite ion/nitrate ion concentration ratio greater than 0.2, were operated at less than 50° C and have been compliant with DST chemical specifications contained in OSD-T-151-00007 (2010).
    - Higher preference should be given to SSTs that have not stored wastes at the same level for prolonged intervals.
- Recommendation ST-3: Candidate SSTs should be retrieved.
- Recommendation ST-4: The following visual (surface) and ultrasonic (volumetric) Non-Destructive Evaluation (NDE) inspections should be performed.
    - A Probabilistic Risk Assessment (PRA) should be performed to inform decisions on both the extent of visual and ultrasonic inspections required and the appropriate technologies for the inspection. An independent review of the PRA should be obtained.
    - Visual inspection of the steel liners should be performed to identify surface degradation or associated evidence such as water or tar stains, particularly at the former Liquid Air Interface (LAI) or the knuckle.
    - Volumetric inspection utilizing ultrasonic technique(s) should be deployed to detect tight cracks, wall thinning, and pitting from corrosion, particularly at liner welds, the LAI and the knuckle.
- Recommendation ST-5: Improved High Resolution Resistivity (HRR) should be deployed to support future use.
- Recommendation ST-6: Hydrostatic testing should be performed by filling the candidate SST in increments with inhibited water.
- Recommendation ST-7: Adequate emergency tank space and capability to initiate retrieval of staged waste from an SST within 24 hours should be provided.
- Recommendation ST-8: Potential leak volume from a staged SST should be minimized by transferring waste in increments.
- Recommendation ST-9: The waste level should be maintained below the historical LAI.
- Recommendation ST-10: A corrosion potential probe coupon should be installed if recommended by corrosion laboratory studies.

- Recommendation ST-11: Staged SST wastes should have a nitrite ion/nitrate ion concentration ratio greater than 0.2, be maintained at less than 50° C and be compliant with DST chemical specifications contained in OSD-T-151-00007 (2010).
- Recommendation ST-12: New technological advances, including the installation of bladders in future use SSTs, should be considered.

Areas 3 and 4: Understanding of SST Integrity and Preventing or Minimizing Further SST Integrity Degradation. The Panel considered Areas 3 and 4 together and concluded they were best addressed through a combination of several recommendations from the first report and new or expanded recommendations. The new recommendations concern structural integrity (SI-9),corrosion behavior of rebar steel (SI-10), a structural integrity mitigation strategy (SI-11), remediation of SST wastes (LIP-13) and utilization of HRR (LD-12).

Additionally, based on discussions with WRPS at the January 2010 workshop, the Panel has categorized recommendations for three types of SSTs: retrieved, interim stabilized assumed leakers, and interim stabilized assumed sound.

For clarity, the naming and numbering of the recommendations are consistent with the Panel's first report (Terry, 2009). Structural integrity recommendations are denoted by "SI," liner degradation recommendations are denoted by "LD," and leak identification and prevention recommendations are denoted by "LIP." These old and new recommendations are summarized here.

Recommendations from Previous Report:

- Recommendation SI-1: Perform Modern Structural Analyses.
- Recommendation SI-2: Perform Dome Deflection Surveys.
- Recommendation SI-3: Obtain and Test Sidewall Core.
- Recommendation SI-4: Perform NDE of Concrete
- Recommendation SI-5: Test Dome Concrete and Rebar "Plugs."
- Recommendation SI-6: Develop Engineering Mechanics Document.
- Recommendation LD-2: Avoid inadvertent addition of water and chloride to SSTs.
- Recommendation LIP-2: Avoid the Addition of Water-Insoluble Absorbents to SSTs.

New Recommendations:

- Recommendation SI-9: AORs on SSTs should be performed.
- Recommendation SI-10: If waste exposure tests indicate concrete integrity has been degraded; additional, reasonable evaluations should be performed to determine the corrosion behavior of rebar steel exposed to waste simulants.
- Recommendation SI-11: If structural integrity issues are identified the Panel recommends that WRPS develop and implement a mitigation strategy.
- Recommendation LIP-13: The wastes in all of the SSTs (not just those selected for future use) should be brought into conformity with the specifications noted in Recommendation ST-11 unless the SSTs are retrieved or new testing demonstrates that there is an acceptably low propensity for corrosion under the storage conditions.
- Recommendation LD-12: The Panel recommends HRR monitoring be performed on sample SSTs for at least one year.

KEY WORDS

concrete degradation; concrete mechanical properties; corrosion; corrosion chemistry; corrosion limits; corrosion potential; expert panel; guided wave; Hanford Site leak immobilization; leak integrity; leak prevention; non-destructive evaluation; seismic loading; single-shell tank; single-shell tank integrity; stress corrosion cracking; structural integrity; subsurface contaminant; tank chemistry; waste simulants

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LIST OF TERMS

Abbreviations, Initialisms and Acronyms

AOR	analysis of record
DCPD	direct current potential drop
DOE	Department of Energy
DST	double-shell tank
DTR	design target risk
EMAT	electro-magnetic acoustic transducer
EPA	Environmental Protection Agency
EPDM	ethylene-propylene-diene monomer
FAA	Federal Aviation Administration
HRR	high resolution resistivity
ITS	in-tank-solidification
LAI	liquid-air interface
MARS	mobile arm retrieval system
NDE	non-destructive evaluation
ORP	Office of River Protection
POD	probability of detection
PRA	probabilistic risk assessment
SCC	stress-corrosion cracking
SGE	surface geophysical exploration
SST	single-shell tank
SSTIP	Single-Shell Tank Integrity Project
TBP	tri-butyl phosphate
TPA	Tri Party Agreement
TPO	thermoplastic polyolefin
WRPS	Washington River Protection Solutions, LLC
WTP	waste treatment and immobilization plant

Units of Measure

C	Celsius
cP	centipoise
F	Fahrenheit
ft	foot
gc	gravitational constant
gpm	gallons per minute
h	height
Ko	empirical material constant
M	molar
mm	millimeter
psi	pound per square inch

1 INTRODUCTION

Radioactive and hazardous chemical waste is stored in 177 carbon steel tanks at the Hanford Site in southeast Washington State. One hundred forty nine of the tanks are Single-Shell Tanks (SSTs) and 28 are Double-Shell Tanks (DSTs). The DSTs were constructed between 1968 and 1986.

The 149 SSTs were constructed in twelve groupings (known as "farms") between 1943 and 1964. Figure 1 is a photo of an SST farm under construction. The SSTs were built with four different nominal volumes:

- Sixteen 55,000-gallon tanks, which are the 200 Series tanks in 241-B, 241-C, 241-T, and 241-U Farms.
- Sixty 530,000-gallon tanks, which are the 100 Series tanks in 241-B, 241-BX, 241-C, 241-T, and 241-U Farms.
- Forty-eight 758,000-gallon tanks, which are the 100 Series tanks in 241-BY, 241-S, 241-TX, and 241-TY Farms.
- Twenty-five 1,000,000 gallon tanks, which are the 100 Series tanks in 241-A, 241-AX and 241-SX Farms.

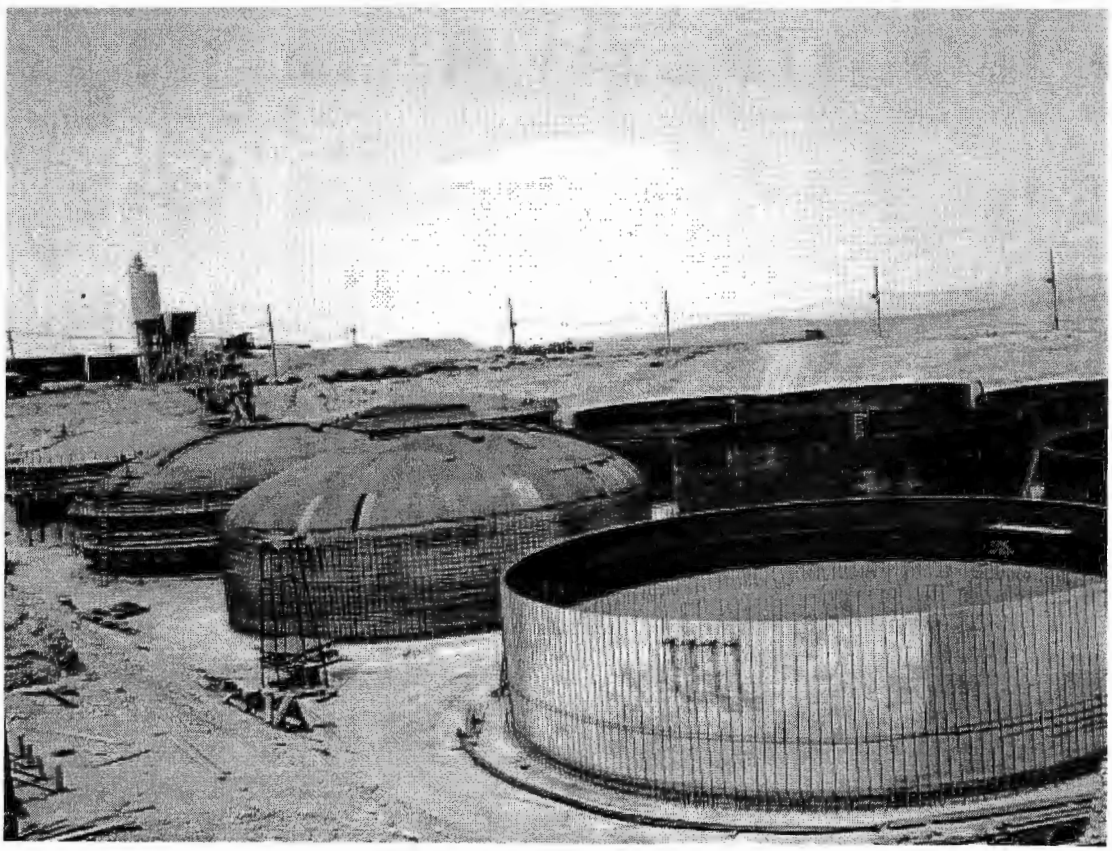


Figure 1: Single-Shell Tank Farm under construction.

The SSTs received alkaline waste from multiple nuclear fuel processing operations, starting in 1944. The initial radioactive wastes were principally derived from three different chemical processing operations, each of which produced several different types of waste. The bismuth phosphate process, the REDOX process, and the PUREX process were designed to recover plutonium from irradiated reactor fuels. The bismuth phosphate wastes that were discharged to the tanks were later processed to recover uranium from the wastes by using the tributyl phosphate (TBP) process. Potassium ferrocyanide was used to scavenge cesium ion from this waste. The oldest tanks (241-B, 241-C, 241-T, and 241-U farms) were constructed to receive the wastes from bismuth phosphate plants. REDOX and PUREX wastes were stored in the 241-S, 241-A, 241-AX and 241-SX farms, which were designed to hold boiling wastes so that water could be removed from the tanks to conserve space for the retention of radioactive materials. Later operations, including the in-tank solidification (ITS) and outside-tank evaporation, were used to remove water and concentrate the wastes.

Waste additions to the SSTs ceased in 1980 and pumpable liquids have been transferred from the SSTs to the DSTs. The SSTs which have had pumpable liquids removed are known as "interim stabilized" SSTs.

The SSTs currently contain ten million gallons of sludge, twenty million gallons of salt cake, and one hundred thousand gallons of drainable liquid. Sixty-seven of the SSTs are assumed to have leaked as much as one million gallons of waste to the vadose zone. These SSTs are known as "assumed leakers" while those that have not exhibited evidence of leaking are known as "assumed sound."

SST wastes are slated for retrieval to DSTs and treatment in a Waste Treatment and Immobilization Plant (WTP) that is currently under construction. Technical issues have delayed the schedule for initiating operations of the WTP. The delays in construction of the WTP will necessitate extended storage in the SSTs—all of which are currently beyond their design life.

The extension of the SST mission has created an incentive for the tank farm contractor, Washington River Protection Solutions, LLC (WRPS) to develop an enhanced Single-Shell Tank Integrity Project (SSTIP). The SSTIP is composed of activities aimed at understanding and ensuring SST integrity during the extended operational period. Such activities include analyses of SST conditions, analyses of the potential for SST corrosion or degradation, and inspection and evaluation of SSTs. In 2009, WRPS created an expert panel on SST integrity (the Panel) to provide recommendations to support the development of such a project.

The Panel's recommendations for an SSTIP are documented in the *Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project* (Terry, 2009). In the report, the Panel provided recommendations in four key areas: (1) confirmation of tank structural integrity; (2) assessment of the likelihood of future tank liner degradation; (3) leak identification and prevention; and (4) mitigation of contaminant migration. The recommendations are summarized in Appendix A of this report.

The Panel participated in a Workshop in January 2010 in which Panel members were informed of the ongoing work by WRPS to implement the recommendations of the first report. The Panel is pleased with the significant progress that has already been made in this direction.

Shortly after the release of the Panel's first report, the Department of Energy Office of River Protection (DOE-ORP) sent a letter to WRPS requesting additional commentary from the Panel (Charboneau, 2009). WRPS, in turn, requested the Panel provide such commentary in four areas

outlined in the DOE letter: (1) evaluation of the existing known conditions of the SSTs; (2) evaluation of the proposed future use of the SSTs; (3) recommendations for critical modifications and associated schedule aimed at preventing or minimizing further degradation of SST integrity; and (4) recommendations for additional evaluations and program elements that would improve existing understanding of SST integrity. Additionally, DOE requested the revision contain a high level schedule associated with critical SST integrity project modifications. Such scheduling will be performed by WRPS with input from ORP and the Panel as necessary.

The Panel was briefed at the January Workshop on the origin of the future use proposal. This report provides a Panel response to that proposal and the additional requests found in the DOE letter. The conditions of the SSTs are discussed in Section 2, the proposal for future use of SSTs is discussed in Section 3 and recommendations aimed at improving understanding of SST integrity and preventing or minimizing further degradation of SST integrity are presented in Section 4.

2 EVALUATION OF THE SSTs CONDITIONS

Presentations at the January 2010 workshop indicated the conditions of the SSTs have not changed since the Panel's first report. Therefore, the Panel includes here a summary of the relevant findings from the first report. The complete set of recommendations from the first report is contained in Appendix A.

2.1 Structural integrity

The Panel reviewed and considered existing documentation related to structural integrity of the SSTs. Following is a summary of the Panel's findings from Terry (2009).

- Dome deflection surveys have been conducted on all of the SSTs, approximately every two years since the early 1980s. A maximum allowable decrease in the dome elevation of 0.24 inches, relative to the baseline measurement, has been specified as the acceptable limit for SSTs. Adequate safety margin exists if dome deflections do not increase more than 0.48 inch.

- While remote visual inspection has not been performed on all tanks, existing inspections of the underside of the SST concrete domes do not indicate signs of concrete cracking, rust stains, or spalling.

- Preliminary indications have shown the concrete and rebar in the tank walls remain in good condition. The current state of knowledge indicates collapse of the concrete dome is not a likely event under in-situ loading unless significant degradation of the concrete or rebar in the dome or haunch area occurred in the future.

- Existing analytical studies indicate an adequate safety margin exists for a major seismic event as long as the material design strengths have not seriously degraded. However, the Panel does not have sufficient data to make a fully definitive statement concerning the structural integrity of the tanks under an unlikely major seismic event. The presence of "Rubbelized" concrete at the bottom of the SST walls would indicate a seismic structural concern.

- Liquid waste that has leaked through the steel liner and the concrete walls could have damaged the concrete and rebar. Studies of the interaction of SST waste with concrete indicate a large range of potential concrete damage depending on the volume and temperature of the liquid waste fluids coming in contact with the concrete. However, crack sizes in the liners of known SST "leakers" have not been measured, making it impossible to estimate the volume of concrete exposed to liquid waste. Rebar corrosion is not considered a significant issue although concrete property reductions will result from waste and elevated temperature exposure.

2.2 Leak integrity of SSTs

The Panel performed a review of SST leak history documentation. This review included SST

construction, operations, waste types, and leak investigations. The Panel's findings were primarily focused on how and why SST steel liners have failed. Following is a summary of the Panel's findings from the first report (Terry, 2009).

- Laboratory and field-work implies several factors contributed to the failure of the steel liners. First, the liners of the SSTs were not heat treated to remove stresses in the weldments and some tanks were constructed without knuckles (the "knuckle" is the curved plate where the liner sidewall meets the liner floor). SSTs without knuckles were constructed with double fillet welds where the sidewall connects with the floor. Second, the wastes were potentially corrosive; some wastes had high nitrate ion concentrations and low nitrite ion concentrations at pH values less than ten, and subsequently, wastes with high hydroxide ion concentrations were stored in the tanks. Third, some tanks were operated at the boiling point of the waste for extended periods of time. These conditions increased corrosion rates, stress corrosion cracking susceptibility and led to thermal excursions in which super heated water trapped beneath the solid layers caused bumping and vigorous steam eruptions. In some cases, water trapped between the SST floor and the concrete structure was superheated resulting in violent upheaval of the tank floor. Collectively, these chemical and physical conditions caused failure of the liners by pitting, stress corrosion cracking (SCC) and mechanical ruptures.

- The solids of some SST wastes have become layered and inhomogeneous as a consequence of waste transfer operations that mixed several waste types. Important variations may exist in layer compositions that are not represented by the existing waste analyses, which only contain average compositions.

- Groundwater might have infiltrated into waste tanks through cracks in the dome or sidewalls. Rainwater might have infiltrated into tanks through risers and other dome openings. The intrusion of water could adversely alter the pH of the waste surface layers. Also, the addition of dilute condensate solutions to the SSTs may result in the formation of a separate layer that might promote corrosion of the steel at the liquid air interface (LAI). Operations in which commercial grades of sodium hydroxide have been added to SSTs simultaneously introduced corrosive chloride ions into the waste tanks. The inadvertent addition of chloride ions will increase the corrosive properties of the waste.

- There are 40 waste layers in unretrieved SST wastes that presently contain either nitrite ion/nitrate ion concentration ratios less than the minimum value (0.1) presumed by the Panel to protect the DSTs from SCC, or have compositions not in accord with the DST Corrosion Chemistry Control Limits. The DST limits are listed in Appendix B and the non-compliant SST layers are listed in Appendix C. Wastes in these SSTs have been out of compliance for many years. Given that the SSTs were not stress relieved, a much greater propensity for SCC exists in the SSTs in comparison with the DSTs.

- Tensile stresses necessary for driving SCC result primarily from residual stresses around non-stress-relieved welds and hoop stresses caused by the sludge and saltcake. Knowledge of the extent of 60 years of stress relaxation in the steel liners would help identify future risk for SCC. Existing data related to stress relaxation is limited and unrealistic, indicating the need for more experimental measurements of stress relaxation in the steel liner material.

- The Panel investigated existing data related to tank liner wall thickness and how it may

have thinned over operational periods. The thinner the wall, the shorter the distance a stress corrosion crack must travel before breaking through the liner. However, given the original thickness of the liner and the high crack velocities in high nitrate ion and high pH environments, reduction in thickness will not have a significant impact on the remaining life of stress corrosion cracks. Given the SSTs mission, a small change in wall thickness from general corrosion will have little effect on the breakthrough time for SCC. Based on experience with the DSTs, pitting in the liquid and saltcake/sludge layers does not appear to be a significant threat to leak integrity in the SSTs. However, LAI corrosion and pitting in the vapor space in the SSTs might affect leak integrity.

2.3 Leak identification and prevention

The Panel reviewed existing technologies and methods being employed to identify and prevent leaks. Following are the findings from the first report (Terry, 2009).

- A surface barrier has been placed over the 241-T tank farm to evaluate barrier performance and the effectiveness of a variety of monitoring technologies. The vadose zone monitoring system implemented to monitor performance of the 241-T Tank Farm Interim Cover is an excellent system for tracking infiltrating meteoric water. Expansion of this monitoring system could result in early detection and tracking of leaks.

- DOE has a leak detection plan and is in compliance with Washington State Department of Ecology requirements for leak detection. However, for tanks with 24 inches of waste or less, the presence of a solid surface and the absence of Liquid Observation Wells does not allow for leak detection. Currently there is no technology available for leak detection at these low waste levels.

- There is currently no evidence that liquid is leaking from the interim stabilized (SSTs that have had pumpable liquids removed) SSTs that contain supernatant, sludge or saltcake. Nor is there evidence that new stress corrosion cracks have developed since the tanks were stabilized. However, if interstitial liquids remain in contact with the present steel liners, there is no assurance that future leaks can be prevented.

3 EVALUATION OF PROPOSED FUTURE USE OF SSTs

3.1 WRPS proposal for future use of SSTs

In January 2010, the Panel received a briefing on the WRPS proposal to evaluate the future use of assumed sound SSTs to support retrieval of other SSTs. This proposal arose from a programmatic dilemma presented by WRPS—the current baseline schedule will require suspension of SST retrievals due to a lack of DST space in the 2018 timeframe. Additionally, 200 West Area SST retrievals rely on a limited capacity cross-site transfer line that must deliver waste to the 200 East Area (where the WTP is located). These two limitations are projected to threaten DOE's ability to meet Tri Party Agreement (TPA) milestones requiring retrieval of waste from the SSTs. As a result, WRPS is considering the use of carefully selected, assumed sound SSTs to receive waste from other SSTs. WRPS projects this approach to speed both SST retrievals and expedite feed to the WTP.

As with any activity at the Hanford Site, the WRPS proposal carries with it some risks, including programmatic, political, health, safety, and environmental. The Panel has limited its deliberations specifically to the risk that an SST for future use will leak or fail structurally.

The Panel considered the options available for WRPS to manage the tank space issue. In these discussions, the Panel identified three reasonable options and discussed the risk of a leak in the context of these options.

A. **Extend the retrieval and closure schedule and make no changes in the way DSTs and SSTs are currently being utilized.** This option increases the likelihood of releases from assumed leaker SSTs that still contain drainable liquid. There is also a finite, albeit very small, increased risk that a DST or assumed sound SST could develop a leak during the extended time period.
B. **Build new DSTs to accommodate the existing retrieval and closure schedule.** In this case, budgetary and logistical barriers could prevent the construction of new DSTs within the time frame of the existing retrieval and closure schedule. Furthermore, there is a finite risk of failure of new equipment. This risk can be minimized but cannot be completely eliminated.
C. **WRPS proposal: Increase available SST space by utilizing sound SSTs to store waste.** The most significant risk is a leak occurring in an SST deemed to be sound. There is also a finite probability that an SST that is currently assumed sound will develop a leak.

Scenario B is considered by the Panel to have the lowest risk of a leak, assuming new DSTs can be built such that the mission stays on schedule. The Panel does not have adequate information to determine the relative risk for the other two scenarios.

The Panel attempted to evaluate the quantity of liquid that might leak from an SST as discussed in Appendix D, but there was not enough reliable information to quantitatively determine the risk of the development of a leak during the proposed future use operations in Scenario C. The Panel offers no assessment of the acceptability of the risk of a leak during operations. Rather, the Panel's recommendations are focused on assessment activities to better understand and reduce the

risk of a leak. WRPS must decide whether these evaluation and characterization activities have reduced the risk to an acceptable level.

3.2 Panel Recommendations on the proposed future use of SSTs

To better understand and reduce the risk of a leak, the Panel offers the following set of recommendations denoted by "ST" for storage. These recommendations are based on the logic that a candidate future use SST is identified, retrieved, characterized by NDE, hydrotested and then, if found acceptable, utilized for storage. Recommendations ST-1 and ST-2 represent activities aimed at identifying a candidate set of SSTs that might be suitable for future use. Recommendations ST-3 through ST-6 represent activities that confirm a candidate SST as acceptable to utilize, including NDE to provide a risk assessment basis for utilizing an SST. Recommendations ST-7 through ST-12 represent activities to minimize risks during operations.

Recommendation ST-1: An engineering assessment for the SST candidate tank farm should be prepared.

This recommendation coincides with both Recommendations LD-1 and SI-1 from the Panel's first report (Terry 2009 or Appendix A). In the first report, the Panel recommended expanding on Leak Assessment Reports that are performed for assumed leaker SSTs. These reports include information about SST construction history, SST operations history, the types of waste stored in the SSTs, and a discussion of the locations and causes of leaks. An assessment including similar factors should be performed for identifying SSTs that might be suitable for future use.

Recommendation SI-1 focused on performing an Analysis of Record (AOR) for SSTs. The Panel is supportive of current WRPS efforts to respond to Recommendation SI-1 by completing such AOR's for each type of SST (see Figure 2 for SST types). It is important to complete the AORs prior to any decision for extended storage in the SSTs.

The location of the candidate SST might also be important in identifying candidate SSTs. For example, whether an SST is in the 200 East Area (where the WTP is located) or the 200 West Area may render it more or less advantageous. Other evaluations of unique location characteristics such as the history of nearby SSTs, the presence of contamination in the soil, or the proximity to other contaminated sites might also render the SST more or less suitable for future use.

Recommendation ST-2: The relative acceptability of SSTs for future use should be evaluated on the basis of the following historical information.

The following preferences are recommended as criteria—not absolute requirements—for developing a list of candidate SSTs for future use.

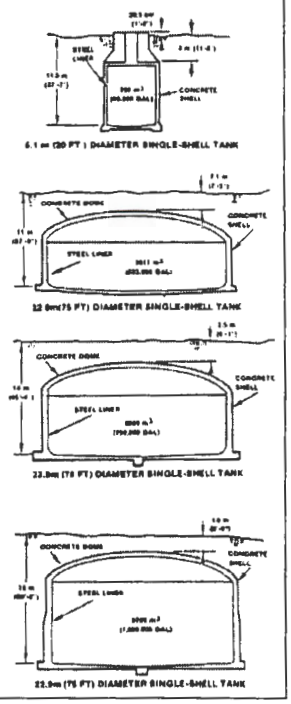
- **Highest preference should be given to SSTs that have not leaked.**

- **Highest preferences should be given to SSTs without fillet joints.** The SST liners were constructed in several different ways as shown in Figure 2. SST Types I, II and III were fabricated with knuckles having a radius of approximately 4 feet between the bottom plates and the lower wall plates. The Type IV-A and IV-B tanks were constructed with fillet welded joints. Historical records indicate that several tanks with fillet welds, especially the ones in the 241-SX farm, failed during usage. Similar failures of fillet

welded joints have occurred at other facilities. Clearly, the tanks without fillet welded joints are more attractive for future use.

Figure 2: Layout and classification of SSTs (Rinker, 2010)

Type	Farms					Tanks Include
	YEAR CONSTRUCTED	TANK FARM	NO. BUILT	NO. DESIGNATED LEAKERS	% OF DESIGNATED LEAKERS	
I	1943-44	B	4	1	25%	200-series, 20-foot diameter, 50,000 gallons
		C	4	0	0%	
		T	4	0	0%	
		U	4	0	0%	
II	1943-44	B	12	1	8%	100-series, 75-foot diameter, 530,000 gallons
		C	12	1	8%	
		T	12	1	8%	
		U	12	4	33%	
	1946-47	BX	12	2	17%	
III	1947-48	TX	18	0	0%	100-series, 75-foot diameter, 750,000 gallons
	1948-49	BY	12	2	17%	
	1950-51	S	12	0	0%	
	1951-52	TY	6	3	50%	
IVA	1953-54	SX	15	7	47%	100-series, 75-foot diameter, 1 million gallons
IVB	1954-55	A	6	2	33%	100-series, 75-foot diameter, 1 million gallons
IVC	1953-54	AX	4	0	0%	100-series, 75-foot diameter, 1 million gallons



- **Higher preference should be given to SSTs with liners fabricated from A-283 and A-285 steel rather than older steels such as A-7 or A-10.** The steel liners provide the only defense against future leaks. The nature of the liner steels and the techniques used in their construction are important considerations in the selection of candidate tanks for future use.

  Many of the early SST liners were fabricated from older steels such as A7 and A-10 steels (as shown in Table 1 based on RPP-RPT-10435). These steels have considerable variations in their properties and corrosion resistances. The liners in the more recently constructed SSTs were fabricated from A-283 and A-285 steels. These steels are more uniform in their compositions and properties than the older steels and are therefore more attractive for future use than the older tanks fabricated from lower quality steels.

Table 1: SST steel liner materials of construction

Tank Farm	ASTM Steel Type
241-B, 241-C, 241-T, 241-U, 241-BX	A7-39
241-TX, 241-BY	285-46
241-S	285-46T Grade B
241-TY	285-49T Grade B
241-SX	A283-52T Grade A or B
241-A	A283-52T
241-AX	A201, Grade A

- **Higher preference should be given to SSTs in which the waste has historically had the following properties:**
    - A composition that is compliant with DST chemical specifications contained in OSD-T-151-00007 (2010).
    - An operating temperature of less than 50° C, and
    - A nitrite ion/nitrate ion concentration ratio greater than 0.2.

  In developing this recommendation, the Panel started with established limits for the DSTs and discussed which variables should be made more conservative for selecting future use of the SSTs. This added conservatism is necessary because the SSTs were not heat treated to relieve residual construction stresses in the steel liner plates or in the welds and are therefore more vulnerable to SCC than the DSTs. The Panel has added conservatism in two areas—temperature and nitrite/nitrate concentration ratio.

  The general chemical specifications for the operation of DSTs should be adopted for the evaluation of the SSTs with the following two adjustments.

  First, preference should be given to SSTs with wastes at temperatures less than 50° C rather than at the 75° C temperature limit of the DST controls. The preference for a lower temperature arises from the present testing programs at 50° C, and the concept that pitting and SCC are generally suppressed at lower temperatures.

  Second, preference should be given to SSTs with nitrite ion/nitrate ion concentration ratios greater than 0.2. The preference for this concentration ratio arises from testing demonstrating that alkaline simulants with ratios greater than 0.1 do not cause cracking of A537 steel at temperatures less than 50° C. The preference for a higher ratio reflects our concerns about the nature of the steels in the SSTs and the lack of heat treatment.

  The adoption of this recommendation will enable a preliminary evaluation of past and present storage conditions and will offer an assessment of the relative corrosion risks associated with candidate SSTs.

- **Higher preference should be given to SSTs that have not stored wastes at the same level for prolonged intervals.** Testing has demonstrated that wastes with high concentrations of nitrate ion or hydroxide ion can cause SCC. The storage of these types of wastes contributed to the failure of some SST steel liners. The historical evidence also implies that major leaks in at least two SSTs, in which the wastes were stored at the same height for years, resulted from corrosion at the LAI. Recent investigations at the Savannah River Site indicate the storage of dilute waste solutions with low concentrations of nitrate ion (less than 1 Molar (M)) at pH 10 can cause pitting corrosion and corrosion at the LAI unless high concentrations of nitrite ion are present (Hoffman and Subramanian, 2008; Hoffman and Edwards, 2009). Consequently, SSTs known to have stored wastes at the same level for prolonged intervals should not be considered as primary candidates for future use.

Recommendation ST-3: Candidate SSTs should be retrieved.

Retrieved SSTs are more attractive for several reasons: (1) the liner knuckle, former vapor spaces,

LAIs, and areas previously in contact with waste (potentially including the SST bottom plate) are easier to inspect; (2) residual wastes have been characterized and the potential for corrosion can be assessed; and, (3) data concerning whether the SST leaked during retrieval is available.

The Panel is not recommending such retrieval be compliant with TPA retrieval requirements. For the purposes of this recommendation, an SST that contains a small amount of waste in a hard heel could be considered "retrieved."

Recommendation ST-4: The following visual (surface) and ultrasonic (volumetric) Non-Destructive Evaluation (NDE) inspections should be performed.

The Panel recommended a hierarchical application of NDE techniques in the first report (Terry, 2009). This approach was based on the logic that relatively simple, straightforward NDE techniques could be applied and, if problems were identified, more complex and extensive techniques could then be pursued. The proposal for future use of SSTs requires a more thorough and rigorous visual and volumetric inspection based NDE application than that recommended in the first report.

The inspection of the steel liners should focus on wall thinning, SCC, wall pitting, tar stains, in-leakage of water and evidence of corrosion. Of particular interest are the former LAIs, the knuckle and, if practical to inspect, the SST bottom. Evidence of SCC or other forms of cracking, or significant pitting or general wall thinning would eliminate the SST from consideration for future use.

- **A Probabilistic Risk Assessment (PRA) should be performed to inform decisions on both the extent of visual and ultrasonic inspections required and the appropriate technologies for the inspection. An independent review of the PRA should be obtained.**

  The Panel's PRA recommendation arises from the difficulty of conducting inspections in the SST environment. Given this difficulty, the PRA will help WRPS with the overall goal of providing a convincing argument that the SST liner is sufficiently sound to proceed with hydrostatic testing. The PRA will also assist WRPS in providing a defensible basis for selecting inspection techniques, selecting areas of inspection and developing inspection program details by better understanding and comparing trade-offs in various approaches.

  A risk assessment approach from the aerospace industry provides a useful example. In the design of rotating components of aircraft engines the Federal Aviation Administration (FAA) calls for a PRA procedure (FAA, 2001; AIAA, 1997). Inputs to that process include:

  - anomaly distributions (defining the expected defect distribution resulting from the manufacturing process),
  - Probability of Detection (POD) of NDE techniques. POD is a measure of inspection effectiveness that quantifies the probability a given condition will be detected, often reported as a function of the size of the flaw. Variables influencing the POD include technological capabilities and variability in the response of nominally identical flaws. Traditionally, POD is determined by empirical analysis of data obtained in experiments designed to reproduce the sources of variability that will be observed in the inspection (Annis, 2007). In an emerging practice, physics-based models of the inspection are being used to

reduce the number of required experiments (Thompson, 2008).
- inspection intervals,
- stress levels (influencing crack propagation life),
- volume (affecting the probability of having a defect in a structure),
- materials data (controlling the rate of growth of cracks),
- propagation life.

The design goal is a Design Target Risk (DTR) of 10^{-9} events per component or 5×10^{-9} events per engine.

The concern with SSTs is leaks rather than fatigue induced structural failure. However, the basic ingredients are similar with inputs including:

- the distribution of inhomogeneities (number per unit volume and size distribution) likely to initiate corrosion (e.g., imperfect welds),
- the stress and/or chemical factors expected to drive the growth of anomalies,
- the volume of material in which anomalies would be expected to occur (e.g., the extent of the weld regions),
- material data controlling the growth of anomalies,
- the period of service,
- the time(s) of inspection,
- inspection coverage (e.g., what fraction of the welds are inspected),
- the POD of the NDE technique(s) used. It should be noted the POD will be influenced by the flaw type of concern, with the POD of stress corrosion cracks generally being lower than for defects with simpler morphologies.

The Panel recognizes that significant uncertainties in estimating these inputs would render this a relative rather than absolute calculation. Indeed, this has been found to be the case in the design of aircraft engines.

The accept/reject decision strategy would be a natural by-product of the above analysis. The PRA methodology would provide a mechanism to assess, for example, the relative importance of increasing the volume of inspection (it may be impractical to inspect all welds) and increasing the sensitivity of inspection (e.g. from 80 to 50 to 10 percent of wall thickness for normal UT measurements of wall thickness or analogous changes from other modes of inspection). Decision makers can then weigh tradeoffs between inspecting a large volume with relatively low sensitivity or a smaller volume with higher sensitivity. The weighing of tradeoffs can be a quantitative or qualitative exercise. If a quantitative risk goal for the PRA is necessary, it should be developed by WRPS.

Given the uncertainties associated with the SST inspections, the PRA will contain significant assumptions, estimates and relative comparisons. As a result, the Panel recommends WRPS obtain independent peer review of the PRA to ensure a sound analysis on which to base future use decisions.

- **Visual inspection of the steel liners should be performed to identify surface degradation or associated evidence such as water or tar stains, particularly at former LAIs or the knuckle.**

The visual examination should focus on identifying signs of water in-leakage or tar stains. The visual examination should focus on the LAI and the lower one-third of the

liner. The PRA should be utilized to assist in making decisions about the overall area of the visual inspection.

- **Volumetric inspection utilizing ultrasonic technique(s) should be deployed to detect tight cracks, wall thinning, and pitting from corrosion, particularly at liner welds, the LAI and the knuckle.**

  DST inspections employ a traditional, water coupled inspection that produces high-resolution maps of wall thickness and detects relatively small defects. However, this approach can take considerable time to implement since it involves scanning a beam, point-by-point, over the region of interest.

  An alternate and attractive approach is the application of Electro Magnetic Acoustic Transducer (EMAT) guided wave technology. EMATs are discussed extensively in the Panel's first report (Terry, 2009). EMATs can quickly assess the condition of a large region, although with less sensitivity than the traditional water coupled approach. EMATs also perform better under less than ideal surface conditions (such as in the presence of a surface scale) and are effective at the selective excitation of particular guided modes. EMATs are less efficient than piezoelectric transducers, but this limitation can often be mitigated by carefully designed electronics. While the Panel favors EMAT, the PRA process will assist WRPS in determining which technology is most appropriate.

  For either type of ultrasonic system, the probe will have to be scanned over the appropriate region of the tank wall. One possible scanning method would employ a remotely controlled, magnetic crawler deployed by the Mobile Arm Retrieval System (MARS). It should be noted that a wireless recovery of the signal information is envisioned, since the use of a tethered coaxial cable would likely complicate the scanning process. The regions to be scanned will likely focus on the welds, the LAI and the knuckle but should be determined based on the PRA.

Recommendation ST-5: Improved HRR should be deployed to support future use. Such deployment should be a two-phase approach. First, HRR should be utilized to obtain a baseline resistivity prior to storing waste. Second, HRR should be applied continuously if waste is stored in an SST.

HRR has been successfully utilized for leak detection purposes during waste retrieval activities. HRR uses a four-electrode system to measure the soil resistivity surrounding a tank (Schofield, 2007). Measurements are made from dry-well to dry-well, dry-well to surface, and dry-well to tank. HRR can detect a 5,000 to 10,000 gallon leak.

To use the HRR system as an effective means of leak detection, baseline soil resistivity data is necessary. Previously, HRR in conjunction with ground penetrating radar, electromagnetic induction, and differential magnetometry were utilized to perform Surface Geophysical Exploration (SGE). These other techniques were useful in identifying sub-surface objects or structures that might interfere with the HRR measurements. The SGE produced sub-surface maps characterizing soil resistivity. At the January workshop, information on the improved HRR system was presented. The improvement allows the system to evaluate soil resistivity at greater depths and eliminate the interference due to sub-surface objects.

Recommendation ST-6: Hydrostatic testing should be performed by filling the candidate SST in increments with inhibited water.

The Panel discussed the advantages and disadvantages of performing a hydrostatic test with inhibited water, DST supernate, or SST waste. The Panel believes inhibited water is the most appropriate fluid for this test. The Panel assumes a disposition path for the water could be readily identified. For example, if multiple SSTs were needed for use in the same time frame, inhibited water could be reused efficiently as each successive SST is tested and wastes effectively transferred. Additionally, the water could be used to support sluicing operations. On the other hand, inhibited water could have disadvantages if the SST space necessary were minimal, mandating significant evaporator operations to remove the water from the system. Further, water could potentially mobilize existing contamination if pre-existing leaks are present in an SST. If timing, environmental, regulatory and logistical issues associated with inhibited water render it impractical, WRPS should assess utilizing DST supernate for this test.

Regardless of the test fluid, the SST should be filled in increments in order to identify leaks early and allow for actions to minimize the magnitude of the leak.

Recommendation ST-7: Adequate emergency tank space and capability to initiate retrieval of stored waste from an SST within 24 hours should be provided.

Application of stringent criteria for future use of the SSTs will not eliminate the possibility of a leak. A leak could occur through existing cracks or the development of a crack during an extended storage period. Consequently, rigorous leak response measures must be in place throughout the storage process.

Recommendation ST-8: Potential leak volume from an SST should be minimized by transferring waste in increments.

After completion of the PRA and inspections, the risk of a leak will be reduced but will still exist. If WRPS pursues future use, it is recommended that the tanks be filled in increments to minimize the potential quantity of liquid leakage.

Recommendation ST-9: The waste level should be maintained below the historical LAI.

The LAI is a likely location for localized corrosion and previously undetected stress corrosion cracks might be present in the vapor space above the LAI in some SSTs. The concern with LAI corrosion is highest for those SSTs that maintained a constant liquid waste level for long periods of time (in some cases, decades) prior to retrieval.

A secondary LAI concern exists with SSTs in which pumpable liquids were removed and the SST remained stagnant for a period of time prior to retrieval. Generally, this concern is lessened because these LAIs existed for a relatively short period of time.

The Panel noted a higher preference for selecting SSTs that have not maintained a consistent waste level over extended periods of time (Recommendation ST-2). Recommendation ST-9 acknowledges that, given the operations history of the SSTs, it will be difficult to identify SSTs that have not stored waste at a consistent level over long time periods. If WRPS maintains the waste level in an SST below the LAI, it will reduce both the risk of a leak and the reliance on NDE to ensure the SST is sound.

Recommendation ST-10: A corrosion potential probe coupon should be installed if recommended by corrosion laboratory studies.

In the first report, the Panel recommended WRPS consider installation of corrosion potential probes if recommended laboratory studies indicate SST chemistries aggressively foster corrosion or SCC under SST operating conditions (Recommendation LD-8).

Given the increased risk of a leak with the proposed future use of SSTs, the Panel strengthens this recommendation. Potential monitoring will be required if recommended laboratory studies indicate SST chemistries associated with the proposed future use of the SSTs are sufficiently aggressive to foster corrosion or SCC under tank operating conditions. In the DSTs, electrical connection to the tanks can be readily made and the potential of the tank wall is monitored using several types of reference electrodes located at different levels. In the SSTs, it might be difficult or impossible to obtain electrical connection to the tank liners. Therefore, it will likely be necessary to include coupons of the tank steel (or a similar alloy) on the probe and monitor the potential of the coupons, as an indirect indicator of the tank wall potential. Additional analysis and laboratory testing might be required to relate these measurements with the tank wall potential.

Recommendation ST-11: SST wastes selected for the future use proposal should have a nitrite ion/nitrate ion concentration ratio greater than 0.2, be maintained at less than 50° C and be compliant with DST chemical specifications contained in OSD-T-151-00007 (2010).

ST-2 recommends giving higher priority in the selection process for candidate future use SSTs on the basis of the following three criteria: a nitrite ion/nitrate ion concentration ratio greater than 0.2; operating temperatures of less than 50° C and compliance with DST chemical specifications contained in OSD-T-151-00007 (2010). The Panel also recommends these criteria be adopted for the operation of the SSTs until technical work establishes a basis for relaxing these criteria, for example because the waste is stored at low temperatures. The Panel also recommends that any heel left in the SST be compliant with these criteria.

Recommendation ST-12: Installation of bladders in SSTs selected for future use should be considered.

In its first report (Terry, 2009), the Panel recommended WRPS evaluate either coating of SST liners with a material resistant to corrosion and cracking or deployment of a polymeric bladder to line SSTs (Recommendation LIP-10). The quality and protectiveness of any liner coating would depend strongly on the pretreatment of the liner surface prior to coating application. Owing to the lack of access to SST interiors, high quality surface preparation is problematic. Therefore, liner coatings should be a low priority.

On the other hand, the use of polymeric bladders should be investigated further. Polymeric bladders have been used successfully in the chemical process and petroleum industries. The polymer Etheylene-Propylene-Diene Monomer (EPDM) is known to be rather resistant to alkaline waste and simulants. Another polymer that has been used for similar applications is thermoplastic polyolefin (TPO). A bladder made of these materials could line an entire SST if its reliability were shown to be extremely high. This reliability includes stability of the polymeric bladder material in the radiation fields emanating from the waste.

The Panel acknowledges the existence of significant logistical, technical and regulatory

challenges to deploying liners in SSTs. However, maintaining a project open to consideration of options that initially appear unrealistic has been important at Hanford and other sites for identifying unique, innovative solutions for unique, intractable challenges. In other words, while considering liners, other better and more implementable solutions could arise. Therefore, while the deployment of liners may not prove practical, they should continue to be considered as an option.

4 RECOMMENDATIONS AIMED AT IMPROVING UNDERSTANDING OF SST INTEGRITY AND PREVENTING OR MINIMIZING FURTHER SST INTEGRITY DEGRADATION

The Panel offers this section as a combined response to Areas 3 (preventing and minimizing further SST integrity degradation) and 4 (improving understanding of SST integrity) of the DOE-ORP letter (Charboneau, 2009).

This section includes both priority recommendations from the Panel's first report responsive to DOE's letter and new or expanded recommendations the Panel has developed. New recommendations cover issues such as corrosion behavior of rebar steel (SI-10), a structural integrity mitigation strategy (SI-11), remediation of SST wastes (LIP-13) and utilization of HRR (LD-12). Additionally, based on discussions with WRPS at the January 2010 workshop, the Panel has categorized recommendations for three types of SSTs: retrieved, interim stabilized assumed leakers, and interim stabilized assumed sound. The recommendations are presented in these categories in both the text and Table 2.

The naming and numbering of the recommendations are consistent with the Panel's first report (Terry, 2009). Structural integrity recommendations are denoted by "SI," liner degradation recommendations are denoted by "LD," and leak identification and prevention recommendations are denoted by "LIP."

Table 2: SST integrity activities for retrieved, interim stabilized assumed sound and interim stabilized assumed leaker SSTs.

Recommendation	Retrieved	Interim stabilized assumed sound	Interim stabilized assumed leaker
SI-1: Perform Modern Structural Analyses	X	X	X
SI-2: Perform Dome Deflection Surveys	X	X	X
SI-3: Obtain and Test Sidewall Core		X	X
SI-4: Perform NDE of Concrete		X	X
SI-5: Test Dome Concrete and Rebar "Plugs"		X	X
SI-6: Develop Engineering Mechanics Document	X	X	X
SI-9: AORs on SSTs should be performed.	X	X	X
SI-10: If waste exposure tests indicate concrete integrity has been degraded, additional evaluations should be performed to determine the corrosion behavior of rebar steel exposed to waste.			X
SI-11: If structural integrity issues are identified, the Panel recommends WRPS develop and implement a mitigation strategy.			X
LD-2: Avoid inadvertent addition of water and chloride to SSTs:	X	X	X
LD-12: Perform HRR monitoring on sample SSTs for at least one year.		X	X

Recommendation	Retrieved	Interim stabilized assumed sound	Interim stabilized assumed leaker
LIP-2: Avoid the Addition of Water-Insoluble Absorbents to SSTs:	X	X	X
LIP-13: The wastes in all of the SSTs (not just those selected for future use) should be brought into conformity with the specifications noted in Recommendation ST-11 unless the SSTs are retrieved or new testing demonstrates that there is an acceptably low propensity for corrosion under the storage conditions.		X	

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 NDE 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 NDE 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-9: AORs on SSTs should be performed. Performing modern structural analyses was the focus of Recommendation SI-1. This recommendation expands on SI-1 by providing specific guidance for structural AOR activities. The Panel recommends performing AORs on SSTs prior to any decision for extended storage in the SSTs.

The AOR should analyze varying levels of rebar corrosion for both the lower third of the sidewalls and the dowel steel connecting the sidewalls to the foundation. If rebar corrosion has occurred, this is the most likely area due to contact with waste.

For both the normal load case, and the seismic load case, the AOR should model and analyze varying levels of rebar corrosion for the lower third of the sidewalls and the dowel steel connecting the sidewalls to the foundation. These two areas are the most likely to have been exposed to waste and therefore most likely to have damaged concrete and/or rebar.

The first case should assume the rebar cross sectional area is 100 percent intact and therefore available for structural support. Subsequent modeling cases should assume 75, 50, 25, and 0 percent of the rebar cross-sectional area of each individual piece of rebar is available for structural support. The goal of these analyses is to determine how much rebar is necessary to maintain SST structural integrity.

Recommendation SI-10: If waste exposure tests indicate concrete integrity has been degraded, additional evaluations should be performed to determine the corrosion behavior of rebar steel exposed to waste and/or simulants.

In the first report the Panel recommended WRPS test the effects of waste exposure on the integrity of the concrete (Recommendation SI-7). The Panel recommended measuring the physical and mechanical properties of concrete cured for more than 28 days exposed to simulated waste. 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.

If concrete has been degraded and exposed to waste, rebar might have also been exposed to waste. It is unlikely that rebar has been impacted by exposure to waste or water that has infiltrated into the SST concrete. Still, if the rebar has corroded, it could impact SST structural integrity. As a result, the Panel recommends additional, reasonable steps be taken to evaluate the corrosion behavior of the rebar steel in contact with waste simulants. This evaluation likely would consist of a combination of analysis of existing data, screening electrochemical tests and extended exposure tests of rebar samples for waste chemistries where data are not available.

Based on these measurements, the effects of waste/concrete/rebar reactions on the structural integrity of the tank walls should be estimated.

Recommendation SI-11: If structural integrity issues are identified, the Panel recommends WRPS develop and implement a mitigation strategy. The Panel's structural integrity recommendations are designed to provide fair warning of SST structural integrity problems. If

structural integrity issues (e.g. AOR, evaluation of corrosion) are identified, the Panel recommends that WRPS develop and implement a mitigation strategy. Actions will depend on the severity of risk for structural failure of the SSTs. A severe immediate threat could potentially require structural reinforcement of the affected SSTs. For less severe threats, it might be necessary to accelerate retrieval from the affected SSTs. Accelerated or more extensive integrity monitoring might be appropriate for cases where the immediate threat is minimal but a potential long-term threat exists.

The types of monitoring required will depend on the nature of the threat. For example, Recommendation SI-8 would be appropriate where evidence exists from testing and analysis that the leaked waste is capable of promoting accelerated corrosion of the rebar steel. Recommendation SI-8 consists of 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 and assess the extent of the integrity problem on the affected tanks.

Other integrity assessments such as Recommendation SI-2 (Perform Dome Deflection Surveys), Recommendation SI-3 (Sidewall Coring and Testing), Recommendation SI-4 (Non-Destructive Evaluation of Concrete), and Recommendation SI-5 (Testing of Dome Concrete and Rebar Plugs) could be accelerated or expanded if integrity issues are identified.

Recommendation LD-2, Avoid inadvertent addition of water and chloride to SSTs: To avoid creating conditions that could lead to liner corrosion, the Panel recommends operational procedures be implemented to prevent the inadvertent addition of water and chloride ion to the SSTs. The impact of water intrusion and unintended increases in chloride ion concentrations should be evaluated on a tank-by-tank basis.

Recommendation LD-12: High Resolution Resistivity (HRR) monitoring should be performed on sample SSTs for at least one year. Currently the HRR system is utilized for waste retrieval activities only. However, the Panel cannot quantify the risk of continued storage in interim stabilized SSTs. As a result, the Panel recommends acquiring additional leak monitoring data using the improved HRR system. Sample SSTs should be selected and monitored for at least one year to determine if changes in the baseline resistivity occur. This approach would provide information on how effective interim stabilization is at reducing the risk of further leakage.

Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs: The Panel considered the addition of absorbents to the SSTs to further immobilize liquids. However, the Panel recommends avoiding the addition of water-insoluble solid absorbents to the SSTs as such additives do not appear effective in immobilizing water and will interfere with the future retrieval of wastes, and may adversely impact WTP operations.

Recommendation LIP-13: The wastes in all of the SSTs (not just those selected for future use) should be brought into conformity with the specifications noted in Recommendation ST-11 unless the SSTs are retrieved or new testing demonstrates that there is an acceptably low propensity for corrosion under the storage conditions.

If the criteria in Recommendation ST-11 were applied to the present storage conditions of the wastes in the SSTs, the tanks can be divided into three distinct groups.

The first group consists of the wastes that are now stored under conditions that are compliant with the new specifications in ST-11. Most SST wastes fall into this category.

The second group consists of approximately 45 waste layers that are almost entirely stored at temperatures less than 25° C and are not in compliance with the ST-11 specifications because the nitrite ion/nitrate ion ratios are too low. Simulants of these wastes are presently under investigation, as recommended in the first Panel report, to establish whether the low storage temperatures compensate for their undesirable compositions. The concern may be relieved if these investigations demonstrate the propensities for pitting and SCC are greatly diminished at this lower temperature. If these concerns are not relieved, the Panel recommends sodium hydroxide and/or sodium nitrite be added to the wastes to protect against future corrosive damage to SSTs.

The third group consists of about 15 wastes that are not compliant only because they are stored at temperatures greater than 51° C. These wastes are in the A and SX farms that presumably are not going to be selected for future use because of their fillet joints, or because they are known or assumed to have leaked. These tanks were constructed with A283 and A285 steels and have substantial hydroxide ion and nitrite ion contents that should inhibit pitting. The lowest nitrite ion/nitrate ion concentration ratio among this group is 0.61. The propensity for SCC of stimulants with similar compositions has been investigated with the same steels at the Savannah River Site. Unfortunately, only a limited number of tests were performed at temperatures below 75° C, and the body of work may be insufficient to gauge the SCC hazard. The Panel therefore recommends the results of previous work on pitting and SCC be critically reviewed and that, if necessary, additional work be undertaken to determine whether the current high hydroxide and nitrite ion contents protect these steels. If these concerns are not relieved, then the Panel recommends sodium hydroxide and/or sodium nitrite be added to the wastes to protect against future corrosive damage to SSTs. The Panel recognizes that mixing remediating solutions with essentially solid, interim-stabilized wastes will be slow and that special operations may be required to ensure that the wastes in the tank are brought into compliance. However, the risk of future leaks in aging tanks that have not been heat treated to relieve stress is too great to be ignored.

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APPENDIX A

SUMMARY OF FIRST SINGLE-SHELL TANK INTEGRITY PANEL REPORT RECOMMENDATIONS

Based on the Panel's investigations, deliberations and findings outlined in Section 2, the Panel provided 33 recommendations categorized in four key elements: (1) confirmation of tank structural integrity (denoted by "SI"); (2) assessment of the likelihood of future tank liner degradation (denoted by "LD"); (3) leak identification and prevention (denoted by "LIP"); and (4) mitigation of contaminant migration (denoted by "CM").

This section summarizes the recommendations presented within the four key elements from the Panel's first report aimed at supporting development of an SSTIP (Terry, 2009).

Confirmation of tank structural integrity

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 cured for more than 28 days and exposed 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.

Assessment of the likelihood of future tank liner degradation

Recommendation LD-1, Expand Leak Assessment Reports: The Panel recommends continuing the preparation of Leak Assessment Reports for each tank farm. The Panel found the Leak Assessment Report for 241-A and 241-AX tank farms to be very helpful in understanding the status of data and information about both known and assumed leaker tanks. The discussion for each tank should include an operations summary, an operations history, an analysis of the leak location and cause, a waste loss estimate, the nature and extent of ground contamination, and a conclusion.

Recommendation LD-2, Avoid inadvertent addition of water and chloride to SSTs: To avoid creating conditions that could lead to liner corrosion, the Panel recommends operational procedures be implemented to prevent the inadvertent addition of water and chloride ion to the SSTs. The impact of water intrusion and unintended increases in chloride ion concentrations should be evaluated on a tank-by-tank basis.

Recommendation LD-3, Examine "non-compliant" wastes at 25° Celsius (C): The Panel recommends selected "non-compliant" SST waste simulants be examined at 25° C. "Non-compliant" wastes are those that fail to meet specific temperature, nitrite, nitrate, and hydroxide concentration criteria. The examinations will provide information on the propensity for pitting, cracking, and corrosion at the LAI or corrosion of the liner in the vapor space. This testing should be coordinated with the DST testing program.

Recommendation LD-4, Develop and Deploy Guided Wave Technology: The Panel recommends the development and deployment of guided wave, ultrasonic technology to assess the presence of macroscopic degradation of the steel liner. A design study should be undertaken to determine the optimum parameters and feasibility of an Electro-Magnetic Acoustic Transducer (EMAT) system for this application. If shown feasible, and other SSTIP activities raise concerns

about liner integrity, the EMAT system should be deployed.

Recommendation LD-5, Determine Ammonia Corrosion Control Concentration: Ammonia in sufficient concentrations has the potential to inhibit liner corrosion. The Panel recommends laboratory testing to determine the concentration of ammonia required to control corrosion in the liquid phases of the solid and supernatant layers, at the LAI and on the exposed liner in the vapor spaces. This testing should be coordinated with the DST testing program.

Recommendation LD-6, Assess SST Waste Compositional Variation: The Panel recommends determining whether compositional variations in the solid layers of the SSTs deviates from general SST and DST programmatic assumptions about composition. If so, testing work may need to be performed to evaluate the propensity for SCC and corrosion.

Three factors may have given rise to novel compositions in the SSTs. First, the wastes might have become layered and inhomogeneous as a consequence of waste transfer operations that mixed several waste types. Second, groundwater and rainwater might have infiltrated into waste tanks through cracks in the dome or sidewalls. Third, corrosive chloride ions have been introduced to the SSTs through operational additions of sodium hydroxide.

Recommendation LD-7, Assess Deployment of Local Non-Destructive Evaluation Techniques: The Panel recommends assessing the feasibility of deploying candidate local measurement techniques (such as fluid coupled ultrasound, ultrasonic guided waves implemented using EMATs, and vibrothermography) operated as end effectors on a mechanical apparatus (such as robotic arms) deployed in the SSTs. Deploying such technologies should be based on the outcomes of other non-destructive evaluation (NDE) recommendations (e.g., discovery of cracks via visual inspection) and a cost benefit analysis that analyzes the difficulties of employing candidate local measurement techniques.

Recommendation LD-8, Consider Installation of Corrosion Potential Probe: If recommended laboratory studies indicate SST chemistries aggressively foster corrosion or SCC under tank operating conditions, the Panel recommends installing a probe similar to that employed in the DSTs to measure corrosion potential. This information can be used to further assess the likelihood for corrosion or SCC.

Recommendation LD-9, Consider Testing Tank Liner Hardness: The feasibility and cost of removing small samples from the tank liner for hardness testing should be evaluated. If feasible and cost effective, samples should be removed from a tank that experienced high temperatures to determine if hardness increases, which could impact structural integrity, have occurred.

Recommendation LD-10, Consider Applying Direct Current Potential Drop to SSTs: The Panel recommends studying the feasibility of applying Direct Current Potential Drop (DCPD) to the SSTs for the purpose of locating tears and cracks in the liner. The DCPD technique is based on injecting current into a metallic component and measuring the resulting voltage (potential) at selected points. Such study could include both theoretical modeling as well as simple laboratory experiments. Once feasibility is established, a DCPD system should be developed for implementation.

This recommendation, along with consideration of local NDE techniques (Recommendation LD-8), provide a suite of techniques to assess liner degradation based on the outcome of other tests and observations, as well as the feasibility of deployment.

Recommendation LD-11, Analyze Stress Relaxation of Tank Liners: The Panel recommends analysis or experimental study of stress relaxation in tank liner steels to determine whether SCC is a possibility in the future.

Leak identification and prevention

Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced SST Monitoring: The Panel recommends continuing current Leak Detection Monitoring and Best Management Practices to monitor for leaks. Further, the Panel recommends installing enhanced monitoring based on potential leak risks at each tank farm. The 241-T Tank Farm Interim Cover Test has proved an excellent system for tracking infiltration of meteoric water. Increasing the depths and expanding the aerial extent of monitoring similar to this test will provide an excellent system for early detection and tracking of leaks.

Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs: The Panel considered the addition of absorbents to the SSTs to further immobilize liquids. However, the Panel recommends avoiding the addition of water-insoluble solid absorbents to the SSTs as such additives do not appear effective in immobilizing water and will interfere with the future retrieval of wastes, and may adversely impact WTP operations.

Recommendation LIP-3, Continue Use of High Resolution Resistivity (HRR): The Panel recommends continuing utilization of HRR for leak detection outside of tanks. HRR can detect a 5,000 to 10,000 gallon leak by utilizing existing dry-wells to measure soil resistivity. The technique has been effectively demonstrated during recent waste retrieval activities.

Recommendation LIP-4, Seek Engineering Methods to Increase Water Removal by Pumping From SSTs: The Panel recommends seeking engineering solutions for the removal of additional tank liquids by pumping. While the Panel acknowledges further removal of liquids by pumping will be challenging, it is a safe and potentially efficient and cost effective method for the removal of liquids from the tanks.

Recommendation LIP-5, Evaluate Sludge and Saltcake Liquid Leak Rates: The Panel recommends evaluating liquid leak rate assessments of sludge and saltcake from the Savannah River Site to determine if the results are applicable to SSTs.

There is currently no evidence that liquid is leaking from the interim stabilized (retrieved) tanks that contain supernatant, sludge or saltcake. Nor is there evidence that new stress corrosion cracks have developed since the tanks were stabilized. Information as to whether liquid would leak out of sludge or saltcake through stress corrosion cracks is important when considering continued use of the SSTs.

Recommendation LIP-6, Investigate Leak Detection Technologies for Tanks With Less Than 24 Inches of Waste: The Panel recommends investigating and developing technologies to allow for leak detection in tanks with waste levels of less than 24 inches. Limitations of current leak detection technologies (Liquid Observation Wells and ENRAF™) do not allow for leak detection in these SSTs below 24 inches.

Recommendation LIP-7, Evaluate Effect of Lowering SST Waste Temperature: The Panel recommends evaluating the effect of lowering the temperature of representative waste types to determine its practical impact on drainage rates.

Recommendation LIP-8, Assess the Feasibility of Testing for Ionic Conductivity Between Inside and Outside of SSTs: The Panel recommends performing experiments to assess the viability of testing ionic conductivity between the inside and outside of SSTs. An ionic path between the inside and outside of SSTs could be indicative of cracks through the liner and concrete. If techniques can reliably measure such ionic conductivity, it would be useful in demonstrating whether breaches exist in SSTs.

Recommendation LIP-9, Consider Cathodic Protection (CP) for Rebar and Exterior of Tank Liner: The Panel recommends that CP not be deployed for use in protecting the interior of SSTs where supernatant, sludge and/or saltcake is present. The Panel further recommends that CP be considered as an option to protect the exterior of the tank liner and rebar, should evidence arise that either has corroded.

CP has the potential to suppress corrosion in the SSTs. CP has not been applied to the DSTs due to concerns that waste chemistry may lead to SCC. These issues, as well as difficulties associated with frequent replacement of electrodes, inserting electrodes into the saltcake and high CP currents have led the Panel to recommend against applying CP to the interior of the SSTs. This recommendation is tempered by the possibility of applying CP to the interior of SSTs with little or no nitrite.

Recommendation LIP-10, Evaluate Coating of Tank Liners and Installation of Polymeric Bladder: The Panel recommends evaluating both the coating of the tank liners with a material resistant to corrosion and cracking; and the deployment of a polymeric bladder to line SSTs. Many different metals, ceramics, intermetallics and polymers have the potential to be thermally sprayed onto the tank liners to reduce leakage concerns during retrieval.

Storing waste in polymeric bladders has been used successfully in the petroleum industry for the elimination of leaks in storage tanks. A bladder made of this material could line a tank if its reliability were shown to be extremely high. The Panel acknowledges that difficulties associated with introducing materials into SSTs may reduce the feasibility of implementing this recommendation.

Recommendations LIP-11, Avoid Heating and Active Ventilation Strategies for Removing Additional Water from SSTs: The Panel recommends against pursuing strategies for removing water from tanks that include active ventilation or heating. Such strategies would be expensive, heating will increase the risk of pitting corrosion and SCC, and heating could increase the risk of unacceptably vigorous exothermic reactions.

Recommendation LIP-12, Avoid Strategies to Immobilize Waste Through the Addition of Gelling Agents: As a general programmatic practice, the Panel recommends against the addition of gelling agents. Existing gelling techniques will be difficult to implement, may complicate WTP operations, and may increase the corrosivity of the waste. However, individual tank-by-tank instances may arise in which gelling a tank may be a wise option (e.g. to stop a significant tank leak or if new gelling techniques were developed).

Mitigation of contaminant migration

Recommendation MCM-1, Install Surface Barrier Over SST Farms: The Panel recommends design and implementation of a surface barrier to reduce recharge at the SSTs. Sources of water (leaking pipes, vaults, etc.) that could contribute to deep subsurface percolation should also be identified and controlled. New control/barrier measures should be prioritized based on the risk

associated with past and/or future releases at each tank farm.

Recommendation MCM-2, Evaluate Subsurface Leak Mitigation Technologies: A number of viable candidate subsurface leak mitigation strategies were identified in a 1994 Feasibility Study (FS). The Panel recommends evaluating leak mitigation technologies utilizing this FS as a selection guide.

- Bench scale studies on candidate technologies should be conducted.
- Demonstration in a Hanford Site field setting should be performed where appropriate.
- Currently ongoing tests, such as the injection apatite reactive zone, should be considered for application at the SST farms.
- An updated FS should be performed, using updated risk assessment methodologies and modern performance assessment technologies, with the objective of selecting an SST leak mitigation strategy and potentially a final SST closure strategy.
- It is recognized that an updated FS and risk-based selection process may also conclude that little additional benefit can be derived from implementing a subsurface barrier in addition to implementing a surface barrier.

The Panel also prioritized a subset of these recommendations as its "top ten" primary recommendations that should form the initial foundation of a robust SSTIP. The primary recommendations are as follows.

Recommendation SI-1, Perform Modern Structural Analyses
Recommendation SI-2, Perform Dome Deflection Surveys
Recommendation SI-3, Obtain and Test Sidewall Core
Recommendation SI-4: Perform Non-Destructive Evaluation of Concrete
Recommendation LD-1, Expand Leak Assessment Reports
Recommendation LD-2, Avoid Inadvertent Addition of Water and Chloride to SSTs
Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced External SST Monitoring
Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs
Recommendation LIP-3, Continue Use of High Resolution Resistivity
Recommendation MCM-1, Install Surface Barrier Over SST Farms

APPENDIX B

CHEMISTRY CONTROL LIMITS APPLICABLE TO DOUBLE SHELL WASTE TANKS FOR WASTE TEMPERATURES < 167° F (75° C)[a] (Wywras, 2010)

For $[NO_3^-]$ Range[b]	Variable	Limits[c]
$[NO_3^-] \leq 1.0\underline{M}$	$[OH^-]$	$0.010\underline{M} \leq [OH^-] \leq 8.0\underline{M}$
	$[NO_2^-]$	$0.011\underline{M} \leq [NO_2^-] \leq 5.5\underline{M}$
	$[NO_3^-] / ([OH^-] + [NO_2^-])$	< 2.5
$1.0\underline{M} < [NO_3^-] \leq 3.0\underline{M}$	$[OH^-]$	$0.1\ ([NO_3^-]) \leq [OH^-] < 10\underline{M}$
	$[OH^-] + [NO_2^-]$	$\geq 0.4\ ([NO_3^-])$
$[NO_3^-] > 3.0\underline{M}$	$[OH^-]$	$0.3\underline{M} \leq [OH^-] < 10\underline{M}$
	$[OH^-] + [NO_2^-]$	$\geq 1.2\underline{M}$
	$[NO_3^-]$	$\leq 5.5\underline{M}$

a. Except for Tanks 241-AN-107 and 241-AN-102 for temperature <122° F (50° C).

b. The brackets [ ] denote concentration in M (molarity or moles/L).

c. These limits apply to waste temperature that is less than 167 °F.

APPENDIX C

TABLE OF TEMPERATURES AND COMPOSITIONS OF NON-COMPLIANT SST SUPERNATANT AND INTERSTITIAL LIQUIDS OF UNRETRIEVED SST WASTES (Wyrwas, 2010)

SST	Steel	Layer	Temp. C	OH^- Molar	OH - pH	NO_2^- Molar	NO_3^- Molar	Compliance Test Ratio	Compliance Test DST Limits
Unretrieved Wastes									
241-BX-110	A7-39	Solid	22.0	1.00	14.0	1.13	6.64	0.17	Not compliant
241-BX-110	A7-39	Supernatant	19.9	1.00	14.0	1.13	6.64	0.17	Not compliant
241-TX-116	285-46	Solid	21.1	0.15	13.2	0.23	6.11	0.04	Not compliant
241-TX-116	285-46	Solid	21.1	0.15	13.2	0.23	6.11	0.04	Not compliant
241-B-108	A7-39	Solid	21.2	1.00	14.0	1.17	6.06	0.19	Not compliant
241-B-101	A7-39	Solid	38.8	1.00	14.0	2.87	5.74	0.50	Not compliant
241-TX-104	285-46	Supernatant	20.6	1.00	14.0	2.05	5.71	0.36	Not compliant
241-TX-104	285-46	Solid	20.6	1.00	14.0	2.05	5.69	0.36	Not compliant
241-B-107	A7-39	Solid	16.0	1.00	14.0	0.14	5.34	0.03	Not compliant
241-S-104	285-46T (grade B)	Solid	38.4	0.30	13.5	0.83	4.32	0.19	Not compliant
241-U-106	A7-39	Solid	29.6	0.30	13.5	2.15	4.02	0.53	Not compliant
241-U-106	A7-39	Supernatant	24.4	0.30	13.5	2.15	4.02	0.53	Not compliant
241-B-103	A7-39	Solid	17.3	1.00	14.0	0.19	3.52	0.05	Not compliant
241-B-102	A7-39	Solid	18.1	1.00	14.0	0.19	3.50	0.05	Not compliant
241-B-106	A7-39	Solid	22.9	1.00	14.0	0.19	3.50	0.05	Not compliant
241-B-109	A7-39	Solid	20.0	1.00	14.0	0.19	3.50	0.05	Not compliant
241-T-108	A7-39	Solid	16.2	1.00	14.0	0.19	3.50	0.05	Not compliant
241-T-109	A7-39	Solid	22.6	1.00	14.0	0.19	3.50	0.05	Not compliant
241-TX-117	285-46	Solid	21.1	1.00	14.0	0.19	3.50	0.05	Not compliant
241-TY-103	285-46	Solid	18.6	1.00	14.0	0.18	3.50	0.05	Not compliant
241-B-102	A7-39	Supernatant	18.1	1.00	14.0	0.18	3.50	0.05	Not

SST	Steel	Layer	Temp. C	OH^- Molar	OH^- pH	NO_2^- Molar	NO_3^- Molar	Compliance Test Ratio	Compliance Test DST Limits
									compliant
241-B-106	A7-39	Supernatant	17.6	1.00	14.0	0.19	3.50	0.05	Not compliant
241-B-104	A7-39	Solid	21.5	1.00	14.0	0.19	3.48	0.05	Not compliant
241-B-105	A7-39	Solid	18.6	1.00	14.0	0.19	3.48	0.05	Not compliant
241-U-203	A7-39	Solid	19.1	0.28	13.4	0.42	2.32	0.18	Not compliant
241-U-203	A7-39	Supernatant	18.8	0.28	13.4	0.42	2.32	0.18	Not compliant
241-T-102	A7-39	Solid	17.8	0.00	11.6	0.50	1.76	0.28	Not compliant
241-T-102	A7-39	Supernatant	17.8	0.00	11.6	0.50	1.76	0.28	Not compliant
241-C-110	A7-39	Solid	23.8	1.00	14.0	0.10	0.97	0.10	Not compliant
241-C-110	A7-39	Supernatant	20.8	1.00	14.0	0.10	0.97	0.10	Not compliant
241-B-203	A7-39	Solid	16.5	1.00	14.0	0.03	0.91	0.04	Compliant
241-B-203	A7-39	Supernatant	20.2	1.00	14.0	0.03	0.91	0.04	Compliant
241-U-204	A7-39	Solid	18.0	0.09	13.0	0.15	0.89	0.17	Compliant
241-U-204	A7-39	Supernatant	18.0	0.09	13.0	0.15	0.89	0.17	Compliant
241-T-201	A7-39	Solid	20.6	1.00	14.0	0.01	0.74	0.01	Not compliant
241-T-201	A7-39	Supernatant	19.2	1.00	14.0	0.01	0.74	0.01	Not compliant
241-B-204	A7-39	Solid	16.7	1.00	14.0	0.03	0.56	0.05	Compliant
241-B-204	A7-39	Supernatant	19.0	1.00	14.0	0.03	0.56	0.05	Compliant
241-T-110	A7-39	Solid	18.0	1.00	14.0	0.00	0.30	0.00	Not compliant
241-T-110	A7-39	Supernatant	18.6	1.00	14.0	0.00	0.30	0.00	Not compliant

Note 1: The temperatures and compositions were obtained from Meacham (2008).

Note 2: The assumed leakers are shown in gray on the left

Note 3: Ratios that are less than 0.11 and wastes that are not compositionally compliant are shown in gray on the right.

Note 4: pH is related to the hydroxide ion content by the equation: log [OH(-1)] = pH -14

Note 5: Compliance Ratio: Wastes were regarded as compliant if the ratio was greater than 0.11

Note 6: The DST Chemistry Control Limits are shown in Appendix B.

Note 7: Compliance SR Limits: The chemistry Control Limits of WSRC-STI-2007-00712 were employed

Note 8: The construction steels are reported in RPP-10435

APPENDIX D

PANEL DISCUSSION OF LEAK RATE ESTIMATES

To develop a general understanding of the consequences of a leak during future use, the Panel estimated potential leak rates. Given the following uncertainties, potential leak rates are very difficult to estimate and it is therefore best to develop upper bound estimates.

- The size and location of stress corrosion cracks or penetrations from pitting corrosion are unknown (other than information about large tears in the bottom of some tanks). Determining the size and location of SCC or pitting perforations is difficult due to the lack of access to the tank liner and the small dimensions of stress corrosion cracks. While these cracks might be centimeters or meters long, the crack width is typically 10^{-3} mm or less.

- The flow rates through small orifices such as cracks are poorly understood. Well-established equations are utilized to calculate the flow of liquids and gases through orifices. Data and equations describing two-phase flow associated with leakage of high-temperature water under pressure through flaws have been developed for the nuclear power industry. However, the application of these equations to single-phase flow through very small orifice dimensions, such as cracks, is not well established. The flow can be laminar or become turbulent as the crack opening decreases and the crack walls are sufficiently rough to cause turbulence. This has been demonstrated in work at the Savannah River Site by Whitman (1975), Mertz (1999) and Wiersma (2010).

  Equations for flow through cracks generated by SCC or fatigue are as follows:

  1. Flow rate = $C_o (2g\ \Delta P/\rho)^{1/2}$ where C_o is an orifice coefficient, g is the gravitational constant, ΔP is the pressure differential between the inside and outside of the crack (the pressure head in the SSTs), ρ is the fluid density (Whitman, 1975).

  2. Flow rate (turbulent flow, small crack opening) = $(1/k_o d)^{1/2}$ ghbc where g is the gravitational constant, h is the height of liquid above the leak, k_o is an empirical material constant, d is the grain size of the material, b is the crack opening displacement and c is crack length (Clarke, 1997).

  3. Flow rate (laminar flow) = $\rho g L b^3/12\mu$ where the symbols have the same meaning as above, L is the crack length and μ is the fluid viscosity. The pressure was constant at 12.6 pounds per square inch (psi). (Clarke, 1997)

  Equations 2 and 3 give a linear pressure dependence (from gravity but height not given in Equations 2 and 3) while Equation 1 gives a square root pressure dependence. Equation 3 gives an inverse dependence on the fluid viscosity while Equations 1 and 2 show no dependence on liquid viscosity. By comparison, the flow of high-temperature high-pressure water through cracks, where the water converts to gas or steam (two phase flow) is given by an expression where the flow rate is a function of the square root of the density and pressure, but the inverse square root of the liquid density as given in Equation 1 (Yano, et al, 1989).

- The extent to which salt waste might plug cracks is unknown. At low solution flow rates with high dissolved salt content, salt crystals might form within the crack as drying occurs. These salt crystals could lead to a reduction in flow rate and perhaps total plugging of cracks. Salt plugging of leaks in Savannah River waste tanks has been documented (Wiersma, 2010).

- The magnitude of opposing capillary forces attracting the liquid towards the concrete and attracting the liquid towards the salt cake are unknown. Capillary attraction toward the concrete will increase the leak rate while capillary attraction toward the saltcake will decrease the leak rate. In SSTs containing liquid waste, the negative capillary forces of the salt cake would be absent.

Given these uncertainties, the Panel estimated the upper bound leak rate expected from a stress corrosion crack. Three leak rates reported for water flowing through stress corrosion cracks or fatigue cracks are useful for this estimate. The values are:

- 0.16 gallons per minute (gpm) at a pressure of 12.6 psi through fatigue cracks (5 millimeters (mm) in length) (Clarke, 1997).
- 0.09 gpm of liquid with a viscosity of 5 to 10 centipoise (cp) through stress corrosion cracks (150 mm in length) (Mertz, 1999) with a pressure from an unspecified water head.
- 3.5 gpm for water through approximately 60 mm in length and a pressure head of 35 feet (ft) (Whitman, 1975).

The estimated viscosity of Hanford sludge is 20 cp (water viscosity is 1 cp). The above leak rates result in a leakage of between 130 to 5,000 gallons per day over the range of pressures and viscosities reported.

APPENDIX E

SINGLE-SHELL TANK INTEGRITY PROJECT EXPERT PANEL WORKSHOP NOTES

January 19-20, 2010
Pacific Northwest National Laboratory (PNNL)
Richland, WA

Attendees

Rob Davis, BNI	Jeff Rambo, ORP	Herbert S. Berman, WRPS
		Kayle Boomer, WRPS
John Beavers, CCT/DNV	Dirk Dunning, State of Oregon	Chris Burke, WRPS
		Tom Crawford, WRPS
Bruce Thompson, CNDE, Iowa State	Jerry Frankel, OSU	Jim Duncan, WRPS
		Susan Eberlein, WRPS
Nancy Uziemblo, Ecology	Kenneth Johnson, PNNL	Jason Engeman, WRPS
	Al Pardini, PNNL	Les Fort, WRPS
Russ Jones, GT-Engineering	Mike Rinker, PNNL	Rick Rast, WRPS
		Jennie Reynolds, WRPS
Susan Leckband, HAB	Robert Kennedy, RPK	Mark Scott, WRPS
Keith Smith, HAB		Erik Shallman, WRPS
	Bruce Wiersma, SRNL	
Kitty Bryant, MSA		Matt Maryak, WSRC
	Leon Stock, self	Karthik Subramanian, WSRC/URS
Stacy Charboneau, ORP		
Jeff Cheadle, ORP	Steve Wiegman, WRPS	Wade Riggsbee, YN
Jeremy Johnson, ORP	Felix Miera, WRPS	
Randy Nielsen, ORP	Gretchen Reeploeg, WRPS	Mike Terry, Dell Perot Systems
		Todd Martin, Self

These notes are intended to generally capture discussion and items *not* included in presentations given at the workshop. For a more complete review of the workshop, one should also review the presentations available at: http://www.wrpstoc.com/resources/entry/sstintegrity.

Introduction, Welcome and Administrivia

Mike Terry began the workshop with a safety topic, review of the evacuation plan and instructions on internet access in the building. Each participant was introduced and Mike reviewed the agenda and general groundrules for the meeting.

Third Expert Panel Workshop on Hanford Single-Shell Waste Tank Integrity (Mike Terry)

Mike outlined the four issues that ORP presented to WRPS for the Panel to address. Mike outlined the aggressiveness of the schedule in responding to the request as well as the aggressiveness of the agenda for this workshop.

Welcoming Remarks (Stacey Charboneau, Herb Berman)

Stacey outlined ORP's need to better understand the proposed future uses of the SST given the new TPA commitments and initiatives. Stacey thanked the Panel for its recommendations to date and stated that they have been incorporated into the work ORP is performing.

Herb is looking forward to the Panel's input on what will be required to allow interim storage in SSTs. Herb pointed out that he is retiring and will miss the implementation of these initiatives.

SSTIP Implementation Plan (Erik Shallman)

Erik summarized WRPS' activities aimed at addressing the top ten SSTIP recommendations from its report as well as three other recommendations WRPS has chosen to pursue.

Update of Current Structural Conditions of SSTs (Rick Rast)

Rick reviewed the plans and analyses associated with cutting a penetration in C-107 and deployment of MARS.

Karthik asked if there is currently a 55-inch penetration at the riser location. Rick said no. Karthik asked if a core sample will be taken when the 55 inch plug is removed. Herb answered, yes, forensics would be performed on the plug.

Dirk asked if seismic analysis has been performed on the SST in which the penetration will be taken. Rick said yes.

Russ asked if safety factors are included in the analyses. Rick said safety factors are included in the ACI-349. Jerry said it translates to essentially a safety factor of 2. Jerry asked what would be considered "insufficient". Rick said 1 would be insufficient. Bob said it satisfies load factor requirements.

Kayle asked the Panel for more specificity on what tests were expected of the plug— should the entire 55-inch core be tested or can it be cut into sections and tested. Bob answered that several cores should first be taken and then the plug can be cut up into reasonable sizes to access the rebar. Rick pointed out the testing will not be funded until the specific approach is decided upon.

Rick outlined the process that is planned for cutting the hole.

Matt asked if the analyses of the tanks was essentially a modification of the DST analyses. Rick said yes, this is an evaluation on DSTs and is not the Analysis of Record; the AOR will occur this summer. Matt asked if the AOR will include seismic and the 55 inch hole. Rick said it will include seismic but not the penetration.

Matt asked if degraded properties were analyzed to determine the lower limit on structural strength of the concrete. Rick said no.

Karthik asked what happens to the hole after the MARS and the core are removed. Herb said, theoretically, MARS will be removed and deployed in another tank and a seal plug installed.

Structural Analysis of Record (Mike Rinker)

Mike reviewed the schedule, approach, methodology and evaluation criteria associated with the AOR.

Herb added that, if the large riser works out in 241-C-107, they would add analysis of the large riser to the AOR since they would expect to add the large riser to the other SSTs as a routine piece of the retrieval puzzle.

Bruce T. asked about assumptions made in the bounding analysis. Does it assume an average corrosion? Mike said they assumed 1 mm per year as the liner corrosion allowance in the DST AOR. Mike added that, since the liner is not a structural member for the SSTs, it is not of particular interest to the AOR. Jerry asked about rebar corrosion assumptions. Mike said the analysis does not assume corrosion of the rebar but simply removes it from certain parts of the tank to determine impacts.

Bob said the evaluation criteria document states that rebar will be degraded in the lower part of the tank to determine how much rebar is required to maintain structural integrity in seismic conditions. Mike said some level of degradation of the rebar will be analyzed.

Bob asked whether lower bound (95 percent confidence) properties or best estimate properties would be utilized in the analysis. Ken said a combination of concrete strength and stiffness will be utilized to determine the most conservative cracking and degradation combination (this is the same approach used for the DSTs).

Susan L. asked when the report will be released to the public. Mike said when PNNL finishes it will go to WRPS and then WRPS will issue it to the public. Kayle said June time frame for the report.

Susan L. asked when the report from the work that goes through 2011 will be released. Mike said he is hoping to release the Type II tanks report this year, the Type III report in 2011 and does not yet have a schedule for the Type I and II tank report. Kayle added the meeting based on these reports will be open to the public.

Susan L. asked why leak integrity is not considered in this analysis. Mike said leaking is not a structural issue. Mike said whether the tanks can carry their loads (soil, etc.) is not impacted by whether they have leaked or not.

Michelle M. asked whether the analyses will start with the original properties and degrade those over time and whether cumulative impacts will be considered. Mike said changes based on temperature and resultant impacts to the concrete will be analyzed and that the model takes into account the cumulative impacts over time, including how tension loads impact the concrete. Michelle M. asked if cracking is analyzed at the same time as temperature and corrosion. Mike said corrosion is not being analyzed.

Pam L. said it appears that separate panels are looking at separate issues and questioned whether integration was occurring. Mike said others are analyzing issues related to leaks. Pam asked about

the panel identifying SSTs for future use. Mike said staging is not being analyzed since it is not currently in the baseline. If it does become part of the baseline, WRPS would have to perform an AOR. Chris B. said a similar situation occurred with the DST program where additional analyses had to be performed as the baseline evolved.

Dirk asked if additional moisture attacking the anchoring rebar would be analyzed as this may have been a failure mechanism for much of the concrete and should be a key part of the analysis. Mike said it currently isn't part of the analysis.

Dirk pointed out the confusion around the definition of a "tank". The integrity of the tank system is separate from the tank liner. Most would consider the liner the tank. Dirk pointed out the waste that might be trapped between the liner and the concrete is considered a leaking tank under the Resource Conservation and Recovery Act (RCRA). It is a third category of waste other than waste in the vadose zone and waste inside the tank.

Rob D. asked what assumptions will be included in the analysis for the level of waste in the SSTs. Mike said historical records will be used to determine actual levels for the analyses—as a result, both full and empty tanks will be analyzed. In terms of whether full or empty tanks represent the worst case, the DST analysis demonstrated that empty tanks can be worse than full. Rob asked if this analysis could be used to support additional cleaning techniques in the tanks that haven't been considered to date due to structural integrity concerns. Herb said retrieval is based on whether the tank is assumed sound or an assumed leaker, not based on structural integrity concerns. Rob said that MARS utilization is driven by structural integrity. Mike said this analysis will not consider MARS (unless it becomes part of the baseline), it is currently only a comparative analysis based on DST analysis.

Matt commented that this analytical task is daunting and therefore a document that clearly communicates the scope and objectives of the anlaysis is important. Mike said the preliminary analysis should do exactly that. Mike also acknowledged that baseline changes will impact the program over time.

Leon asked about feedback between testing programs and the modeling for the purpose of validating the models. Mike said they have those kinds of discussions with WRPS.

Michelle M. asked if erosion from the outside to the inside might be included in the analysis. Mike said external conditions and/or external soil impacts have not been considered yet but if information is available, it would be considered. Michelle asked about vapor pressures from inside. Mike said no, although they used it for DSTs. Michelle asked if an IQRPE will be used at the end of the analysis. Kayle said that decision hasn't been made yet but it was utilized for the DSTs.

Karthik asked if the evaluation criteria will be sufficiently robust to include activities that are not currently in the baseline. Mike said installation of a large riser and utilizing SSTs to stage waste would not change evaluation criteria.

Dirk asked whether thermal shock loadings due to thermal expansion will be considered. Mike said that it would be included in the analysis.

Kayle pointed out that much of the discussion has been about the overall integrity of the system but this presentation was just about the concrete. Kayle added that retrieval line leaks should not be a concern as they install all new lines for retrieval operations.

Dirk said differential temperatures and shock loadings of 500° F could cause leaks. Additionally, the shock loading of the steel could cause severe strains from severe expansion and contraction. Mike agreed with Dirk but reiterated the focus of his work is on the concrete that wouldn't be impacted although the liner would be affected greatly.

Evaluation of Future Use of SSTs (Tom Crawford)

Tom summarized the system planning process, process flow diagram, key issues, technology needs, and projected DST use.

Rob said the aluminum removal facility (ARF) is not in the baseline. Tom agreed saying the ARF is being funded for development work but the goal is to blend waste sufficiently in the pretreatment facility so the ARF will not be necessary.

Karthik asked what tank space impact would result if all assumed leaker SSTs were transferred to sound SSTs. Tom said SST retrieval overall would be expedited and waste would be staged for WTP earlier, thereby easing retrieval pressure after WTP starts. Additionally, it would allow more time to deal with the risks associated with retrieving assumed leakers.

Bruce T. asked to what extent the individual SSTs are specified. Tom said assumed sound or leaker, type of waste, chemical composition of tank, relative location of specific tank, and location of the tank farms, are included.

Rob D. said the reason SSTs are being retrieved is to prevent additional leaks, not to stage for WTP. How many SSTs would be evaluated and needed to provide sufficient space? Pam L. answered that Ecology has calculated that 12 million gallons are required between 2018-2025. Tom said the prime benefit in terms of risk to environment is based on placing a barrier over the farm after retrieval—especially for those farms that have lots of contamination in the soil. Herb said it would be very worthwhile to look at this just from the point of risk reduction to better understand what the benefits are independent of WTP.

Jerry asked if the assumption is that waste transferred out of suspect SSTs will be easily retrieved from the sound SST. Tom said saltcakes remain in solution in the receiver tank. Generally, the insoluble particles are reduced in size so waste is more retrievable. Jerry asked about the increase in volume from retrieval. Karthik said the evaporator would mitigate the increase.

Michelle asked if nuclear safety folks have considered the implications of retrieving and handling Contact Handled Transuranic waste (CH-TRU) over a period of five years. She also noted that this waste is really HLW. Tom said the issue is whether this waste can go to the Waste Isolation Pilot Project (WIPP) given the limited operational period of WIPP. Michelle said, based on TPA Milestone M-91 with rejections out to 2054 for TRU, one can assume WIPP will remain open. Given the difficulty of disposing of the waste intended for WIPP, disposing of tank waste will be very difficult and expensive

Dirk asked how criticality will be avoided during this process? Tom said waste compatibility criteria would screen out potential criticality problems.

Single-Shell Tank Leak Integrity (Kayle Boomer)

Kayle reviewed the leak assessment process, leak assessments to date, tanks recommended for formal review, recommendation LD-1 (Expand Leak Assessment Reports), and the proposed approach for assessing SST leak integrity.

Jerry asked what qualifies as "clear evidence" of a leak in BY-103. Kayle said the tank experienced a two-foot decrease in the waste level and a dry well reading was detected. Les F. said assumed leakers are generally due to dry well hits due to overflows.

Kayle asked if the Panel is recommending that all SSTs should be included in expanded reports or just those that address the vadose zone (which is how they do it now). He also asked about the rigor of the leak location and leak cause entries in the reports. Both are currently investigated but reliable information is rarely found to support this aspect of the reports.

Bruce T. asked what procedure D-42 requires. Kayle said it requires gathering of information about the history of a tank. Subsequently, knowledgeable individuals determine whether they believe with 95 percent confidence that evidence does not indicate a leak. Bruce T. said the absence of heat treatment would make you think many would leak but the evidence is now showing that they did not.

Jerry said the ENRAF™ data presented in the slide is compelling evidence at least to about 60 inches. Kayle said the Tank 241-S-112 liquid level was maintained at 120 inches for decades, so he assumes the tank is sound to 120 inches. Kayle pointed out that waste would be added incrementally to ensure minimization of any potential leaks. Les said historical records show 241-S-112 held solids up to the 120 inch level. The tank has never shown any liquid loss. Kayle said the temperature limit was 140° F.

Jeff L. questioned the change in purpose from interim stabilization to staging in SSTs. Kayle acknowledged the change and reemphasized the concept of moving waste from leakers into non-leakers. Jeff asked if additional emergency capacity is considered. Kayle said that emergency space will be required to support any reuse of SSTs.

After a break, Kayle and Chris B. provided some comments intended to clarify how baseline assumptions drive analyses and how those analyses might change as the baseline evolves.

Chemical Testing of Simulated Non-Compliant Waste (Rich Wyrwas)

Rich outlined the testing objectives, panel recommendations, and testing plan.

Jerry asked about SCC and slow strain rate testing or stressed C-Rings. Rich said he was not certain but thinks stressed C-rings will be included in the testing.

Russ asked how much duplication will occur in each test. Rich said that decision has not been made yet but duplication will be driven by statistical needs. Russ suggested Jerry or John should review the plan.

Keith questioned whether using ammonia as a corrosion inhibitor could present worker exposure hazards. Rich said ammonia additions are not planned—only whether it makes sense to take credit for existing SST ammonia as an inhibitor.

Rob D. asked about the testing schedule and what base material will be used. Rich said vintage 285 steel that was obtained from Savannah River will be utilized. Rob encouraged Rick to perform full reverse polarization.

Leon asked if A10 and A7 steels from 1939 will be analyzed. Bob added that A7 steel had very loose specifications with great variability.

Jerry asked if there is overlap with the statistical matrix in the DST and, if so, an interesting comparison could be made. Rich said that overlaps do exist.

Non-Destructive Evaluation (Jason Engeman)

Jason reviewed recommendation SI-4, SST implementation sequence, SST inspection selection, and SST inspection system.

Bob pointed out the recommendation doesn't require 100 percent haunch examination but rather a sample type approach. Jason would like to know how to quantify how much constitutes a reasonable sample.

Bruce T. asked whether issues have arisen with the thumper truck. Kayle said they are having difficulty with determining how good a model is required to gauge the response of the thumper truck.

Dirk asked about other techniques such as a dipenetrant to aid identifying cracks. Jason said PNNL has reviewed some technologies but not in detail. Rob asked about laser topography and Jason said PNNL did review laser topography as it is very costly. Dirk asked if interferometry has been considered. Dirk thinks it would work. Jason said they haven't considered it.

Matt followed up on Bob's comment about this process being focused on leakers and unless a problem is identified, extensive examination should not be required. Bob says visual examination should be focused on areas that are relatively easy to reach as he is concerned about this project taking significant sums of money from other projects

SST Sidewall Coring (Rick Rast)

Rick outlined recommendations SI-4, historical structural integrity activities, and planned concrete testing.

Bob asked whether the footing would be cored. Rick said that decision has not been made yet. Bob said the lower part of the tank and the footing are the most likely trouble spots and therefore the most important place to obtain information.

Bob said the diameter of the core will have to be quite small to avoid cutting too many hoop bars. It is desirable to have 2x the aggregate size.

Russ asked how much contamination is found near the bottom of the tank. Herb said the tank will contain a low level of waste.

Keith also wants to know how much the waste has impacted the concrete.

Hoop steel is most critical in the haunch. How far above the tank bottom did they stop during the

last coring? Rick said eight inches.

Bob said the old core seemed to be of lesser strength near the bottom but this may have had to do with lifts or thermal degradation. It wasn't dramatic enough to provide a clear understanding. Information is necessary on more than one tank to understand the condition of the concrete.

Bruce T. asked when you do the coring, what size pieces come out? Rick said it depends on the drilling but can be as much as a few feet or small chunks.

Jeff L. assumes some risk analysis will occur to figure risk to tanks, workers, etc. if drilling doesn't go right. Have you considered what would happen to the tank? Rick said we will have to consider those items but it is too preliminary at this point. Chris B. said the plan isn't complete until those items are considered.

Dirk how much waste is in this tank? Kayle said it is essentially empty and it will be retrieved after C farm retrievals are completed.

Bob said this is costly but extremely important. Should be able to bring out several feet long sections of core unless there are major cracks. Definitely need to map and do more tests to get more information than they did for the core in the 1980s.

Vadose Zone and Barriers (Susan Eberlein)

Susan reviewed the monitoring instruments and logging results for the T Barrier. She also discussed the status of TY barrier and prioritization for future barriers. Susan also presented the results of deep electrode tests in Waste Management Area (WMA-C).

Bruce T., in T Farm, why did the barrier not cover all the tanks? Susan said the intent is to prevent movement of contamination in the soil in the short term so the barrier is covering the contamination plume. Bruce T. commented that the 25-year flood for Benton County and wonders if this is the correct number. Susan said it is the right number but it may take additional action but wouldn't cause failure.

Keith is glad the Panel is talking about interim barriers but things at Hanford that are interim often become permanent. Is there monitoring in the runoff catch basin for the barriers? Susan said currently there isn't. Are there efforts to identify sources of contaminants that aren't from tank farms? Susan said, yes, the chemical profile will usually show characteristics that will help you distinguish between sources, but sometimes you can't distinguish.

Dirk stated that moisture content is changing significantly under the barrier which questions the lateral movement under barrier. Are you going to put flux meters under the TY barrier? Susan said they don't plan to install such meters but it is worthwhile to figure out a way to determine lateral flow. Dirk said the conceptual model for BX farm shows clear lateral movement and without emphasis on boundary layers causing the lateral movement may cause us to miss important contaminant movement.

Jerry asked what is the estimated lifetime of the barriers? Susan said 25 years for both T and TY. Jerry asked if inspection and maintenance will be required. Susan said yes and they repair holes in the plastic. These are both evaluation barriers. Jerry said you may have unintended consequences if water is funneled into a defect. Susan said that is part of the inspection regime for fast snow melts.

APPENDIX F

SHORT BIOGRAPHIES FOR SINGLE-SHELL TANK INTEGRITY PANEL

MICHAEL T. TERRY, P.E., PANEL CHAIR
CONSULTANT
Dell Perot Systems

Mr. Terry is currently providing independent consulting services to clients such as the US Department of Energy and the US Nuclear Regulatory Commission. He earned a Masters Degree in Mechanical Engineering from Washington University and a BS in Mathematics from the University of New Mexico. He has extensive experience in nuclear and process safety; engineering, design, and construction of nuclear and non-nuclear facilities and processes; program and project design and implementation; management systems and organizational development; professional facilitation; and project management and administration.

Recently, Mr. Terry has been assisting the Double-Shell Tank Integrity Project (DSTIP) and the Single-Shell Integrity Project (SSTIP) at Washington River Protection Solutions, LLC (WRPS). His primary responsibilities include: chairing an Expert Panel on single-shell tank structural and leak integrity; chairing an Expert Panel on tank waste chemistry optimization, oversight of the implementation of the recommendations from the original DSTIP panel report as chair to an expert panel oversight committee; and providing technical and programmatic guidance on matters related to the DSTIP and SSTIP. He has also chaired and facilitated an expert panel workshop with another expert panel assembled to investigate vapor space corrosion in the Hanford double-shell tanks. In addition to these activities for WRPS, Mr. Terry also facilitated and chaired two workshops for the Savannah River National Laboratory; a High-Level Liquid Waste Tank Integrity Workshop and one on Non-destructive Evaluation. Participation on all panels consisted of individuals from sites, industry, and academia.

TODD MARTIN, PANEL CO-CHAIR
INDEPENDENT CONSULTANT

Todd has worked on Department of Energy Environmental Management issues for nearly 20 years. Todd received his Masters in Environmental Sciences from Bard College and Bachelor of Science in Biology from Whitworth College. Consulting with DOE, contractors, states, and public interest organizations Todd has worked to forge consensus in DOE communities to ensure cleanup protects the health and safety of the public, workers and the environment and is technically sound, publicly accountable and fiscally responsible. Todd is currently leading the river corridor clean up standards working group for DOE-RL.

JOHN A. BEAVERS, PH.D.
CHIEF SCIENTIST
CC Technologies, A DNV Company

Dr. Beavers is Chief Scientist of DNV Columbus, a company that specializes in asset risk management. Currently, he serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford. He has directed and contributed to numerous research programs on corrosion performance of structural materials. These programs have included failure analyses, critical literature reviews, and laboratory and field evaluations of metallic and non-metallic materials. Dr. Beavers has utilized state-of-the-art electrochemical,

surface analytical, and mechanical techniques for evaluation of materials performance for different forms of corrosion.

Electrochemical techniques used include potentiodynamic polarization, polarization resistance, electrochemical impedance spectroscopy, electrochemical noise, and galvanic current measurements. Surface analytical techniques used include Auger electron spectroscopy, x-ray photoelectron spectroscopy, energy dispersive x-ray spectroscopy, scanning electron microscopy, transmission electron microscopy, electron microprobe, and x-ray diffraction. Mechanical techniques used include elastic and plastic fracture mechanics and dynamic mechanical loading techniques such as slow strain rate and low cycle fatigue.

GERALD FRANKEL, PHD.
PROFESSOR and DIRECTOR
Fontana Corrosion Center at The Ohio State University

Dr. Frankel's primary interests are in the fields of corrosion and electrochemistry. He has focused on localized corrosion, passivation, coatings, inhibition, corrosion of electronic and magnetic materials, X-ray absorption studies of electrochemically-formed films using synchrotron radiation, behavior of anodes used in electrodeposition applications, and electrode position of magnetic materials. Presently, he serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford. The current activities in Dr. Frankel's group are focused largely on localized corrosion, and primarily on the corrosion and protection of Al and Al alloys. His group is using a number of approaches to study pitting, intergranular corrosion and exfoliation corrosion of Al alloys related to aging aircraft. His group has initiated novel uses of Atomic Force Microscopy-based techniques in the study of corrosion, including Scanning Kelvin Probe Force Microscopy and Atomic Force Microscopy scratching. The mechanism by which chromates inhibit the corrosion of Al alloys has been studied in earlier projects.

Currently his group is studying the inhibition mechanisms of various chromate replacements. Corrosion of welds has been another focus of Dr. Frankel's work. A Cr-free consumable for the welding of stainless steel is currently under development with the goal of minimizing the production of Cr-containing weld fumes. In another study, the susceptibility of oxide dispersion strengthened Ni-based superalloys to hydrogen embrittlement is under study. Dr. Frankel is the author of over 150 publications, primarily in the field of corrosion.

RUSSELL H. JONES, PHD.
CONSULTANT
GT Engineering

Dr. Russell H. Jones has 38 years of experience in materials development, evaluation, and characterization. Dr. Jones has extensive experience in the fields of stress corrosion cracking, radiation effects on materials, corrosion, and high-temperature composites. His work in stress corrosion cracking includes evaluation of the effects of hydrogen, aqueous, high-temperature, and nuclear environments on crack growth behavior of iron, nickel, aluminum, and magnesium alloys, and ceramics and ceramic composites. Dr. Jones was one of the original members of the Expert Panel for Chemistry Optimization for Double-Shell Tanks at Hanford.

Dr. Jones' nuclear experience includes development of materials for advanced nuclear reactors and irradiation assisted stress corrosion cracking for light water reactors. Specific corrosion experience includes evaluation of the effects of interface, grain boundary, and surface chemistry

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RPK Structural Mechanics

Dr. Kennedy has over 30 years of experience in static and dynamic analysis: design of special purpose civil- and mechanical-type structures particularly for the nuclear, petroleum, and defense industries: design of structures to resist extreme loadings including seismic, missile impact, extreme wind, impulsive loads, and nuclear environmental effects; and development of computerized structural analysis methods.

Dr Kennedy has more than 30 years of experience in the seismic design and evaluation of liquid storage tanks. He has co-author or was the prime contributor to

- BNL 52361, Seismic Design and Evaluation Guideline for the Department of Energy High-Level Waste Storage Tanks and Appurtenances
- DOE-STD-1020, natural Phenomena Hazard Design and Evaluation Criteria for Department of Energy Facilities.

Dr. Kennedy chaired the ASCE committee that wrote ASCE Standard 4, Seismic Analysis of Safety-Related Nuclear Structures.

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Independent Consultant
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Professor Stock has written approximately 210 articles and authored or co-authored numerous papers related to Hanford Site waste. His recent work at the Hanford Site has centered on the rates of hydrogen generation in the tanks and in the Waste Treatment and Immobilization Plant and on the occurrence and chemistry of organic compounds within the waste tanks. Currently, he serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford.

KARTHIK SUBRAMANIAN
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URS - Global Management and Operations Service

Karthik Subramanian has experience and expertise in basic and applied research, specifically in materials processing and consequent performance. His relevant expertise includes mechanical and environmental testing, hydrogen isotope effects on polymers and structural metals, and aqueous corrosion of structural materials. Karthik's research experience at the Savannah River National Laboratory (SRNL) focused on (1) structural integrity programs for high level waste tanks, including design and implementation of corrosion control; and (2) life-cycle engineering for tritium reservoirs, involving the development of structure, property, performance models for long-term hydrogen/tritium/helium effects on structural materials. Karthik's current focus is on

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BRUCE THOMPSON, PHD.
PROFESSOR AND DIRECTOR
Center for Nondestructive Evaluation, Ames Laboratory

Bruce Thompson is the Director of the Center for Nondestructive Evaluation, Director of the Ames Laboratory Applied NDE Program, and a Distinguished Professor in the Department of Materials Science and Engineering and in the Department of Aerospace Engineering and Engineering Mechanics. He received his B.A. in Physics from Rice University (1964), his M.S. in Physics from Stanford University (1965) and his Ph.D. in Applied Physics from Stanford University (1971). From 1970 to 1980 he served as a member of the technical staff and Group leader of Ultrasonic Applications at the Rockwell International Center before coming to Iowa State University.

Thompson's research interests fall in the area of ultrasonic nondestructive evaluation. Specialties include the analysis and development of noncontact sensors, in particular electromagnetic acoustic transducers, modeling the effects of measurement geometry on ultrasonic inspection, studying the uses of ultrasound to characterize a variety of microstructural and material properties such as stress, texture, porosity, grain size, and anisotropy and partially contacting interfaces, and uses of physics-based simulation tools to assist in the determination of probability of detection.

Thompson is the author of six major invited review articles in the field of nondestructive evaluation, over 90 articles in archival journals and over 323 papers in edited conference proceedings. He has been awarded 24 U.S. patents and presently serves as the Editor-in-Chief of the Journal of Nondestructive Evaluation. Dr. Thompson was one of the authors of Guidelines for Development of Structural Integrity Programs for DOE High-Level Waste Storage Tanks (BNL-52527).

BRUCE J. WIERSMA, PHD.
FELLOW ENGINEER
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Dr. Wiersma has 17 years of experience in the corrosion and structural integrity disciplines at the Savannah River Site. His primary responsibilities have been associated with the structural integrity of high-level waste tanks. He has developed experimental programs to evaluate the corrosion performance of materials utilized on the Savannah River Site, and he led the team that developed the in-service inspection program for the high-level waste tanks. Currently, he serves on the Expert Panel Oversight Committee for Chemistry Optimization for Double-Shell Tanks at Hanford.

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"Implementation Plan for the Single-Shell Tank Integrity Project"

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Implementation Plan for the Single-Shell Tank Integrity Project

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Abstract: The Hanford Site Tank Operations Contractor, Washington River Protection Solutions, LLC (WRPS), has initiated a project to ensure the integrity of the single shell tanks until the waste can be retrieved from the tanks for treatment. As part of the Single Shell Tank Integrity Project, WRPS has commissioned a Single Shell Tank Integrity Expert Panel to provide advice on the formation of the project. The Panel has developed 33 recommendations based on the proceedings of two workshops in Fiscal Year 2009. This implementation plan addresses the primary recommendations as well as six additional secondary recommendations, identifying the scope, work plan, and work schedule to complete each recommendation. Some of the implementations will require the preparation of a baseline change request to the WRPS baseline to add the scope of work covered by the implementation plan.

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Executive Summary

The Hanford Site Tank Operations Contractor (TOC), Washington River Protection Solutions, LLC (WRPS), has initiated a project to ensure the integrity of the single-shell tanks (SSTs) until the waste can be retrieved from the tanks for treatment. As part of the Single-Shell Tank Integrity Project (SSTIP), WRPS has commissioned a Single-Shell Tank Integrity Expert Panel (Panel) to provide advice on the formation of the project. The Panel has developed 33 recommendations based on the proceedings of two workshops in Fiscal Year (FY) 2009. The Panel further identified ten of the 33 as primary recommendations, which provide the basis for a robust SSTIP. WRPS has already initiated some of the primary recommendations (e.g., development of a modern structural analysis of record for the SSTs) and the SSTIP is developing plans that will encompass the primary recommendations and six of the secondary recommendations.

The Panel met a third time to revise their findings against the requirements contained in the draft Tri-Party Agreement Milestone M-45-91 of *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989). WRPS presented its plans for the SSTIP to the Panel and the Panel concurred with the approach taken. The Panel issued RPP-RPT-45921, *Single-Shell Tank Integrity Expert Panel Report*, which presented a series of further recommendations based on their review of the Tri-Party Agreement draft milestone. The recommendations were related to transferring and/or storing SST wastes in other SSTs, and are briefly summarized in Appendix D. These recommendations will not be actively pursued unless transferring and/or storing SST wastes in other SSTs is accepted and integrated into the baseline schedule.

The Panel identified the original recommendations within four key elements of the SSTIP: (1) confirmation of tank structural integrity (denoted by SI), (2) assessment of the likelihood of future tank liner degradation (denoted by LD), (3) leak identification and prevention (denoted by LIP), and (4) mitigation of contamination migration (denoted by MCM). The Panel prioritized its recommendations in two ways: (1) overall prioritization, and (2) prioritization within the four key elements.

As noted, the primary recommendations represent the panel's top ten priorities, which form a robust foundation for the SSTIP. This implementation plan addresses the primary recommendations as well as six additional secondary recommendations. Five of the six secondary recommendations apply to the assessment of the likelihood of future tank liner degradation while the sixth applies to the development of a living document to contain the current best understanding of the engineering mechanical properties of the SSTs. The implementation plan identifies the scope, work plan, and work schedule to complete each recommendation. As identified in this plan some of the recommendations will require the preparation of a baseline change request (BCR) to the WRPS baseline to add the scope of work covered by the recommendations.

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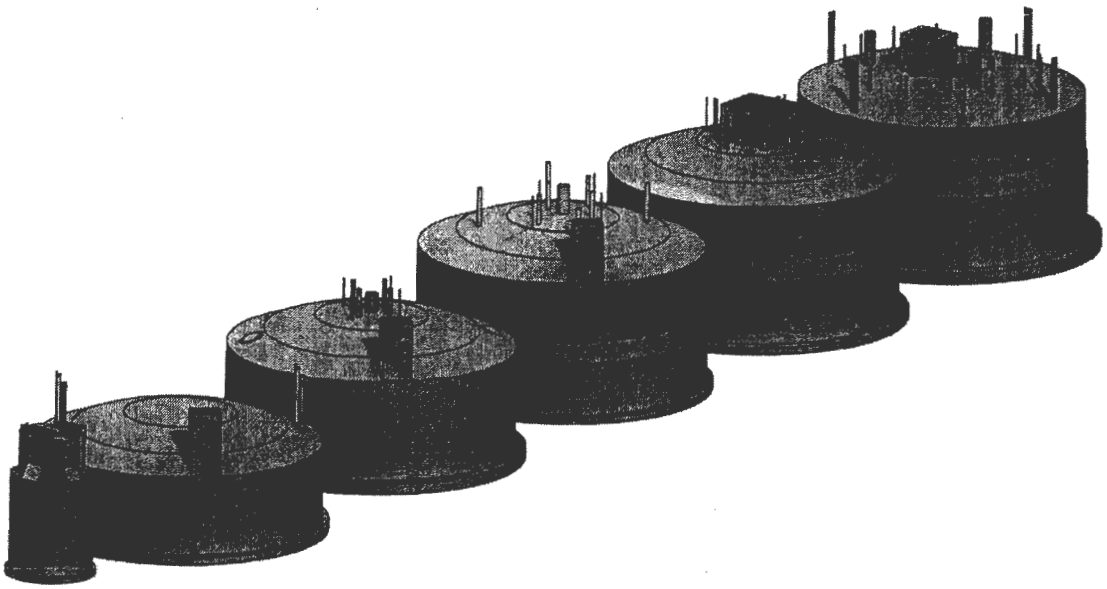
List of Terms

ACI	American Concrete Institute
AOR	Analysis of record
ASTM	American Society for Testing and Materials
BCR	Baseline correction request
BMP	Best management practices
CP	Cathodic protection
CPP	Cyclic potentiodynamic polarization
CY	Calendar year
DOE-ORP	Department of Energy Office of River Protection
DST	Double-shell tank
ECN	Engineering change notice
EIS	Electrochemical impedance spectroscopy
F&Rs	Functions and requirements
FS	Feasibility study
FY	Fiscal year
HRR	High resolution resistivity
ISB	Interim surface barrier
LAI	Liquid-air interface
LD	Liner degradation
LDM	Leak detection and monitoring
LIP	Leak identification and prevention
M&D	M&D Professional Services
MARS	Mobile arm retrieval system
MCM	Mitigation of contamination migration
NDE	Non-destructive evaluation
OSD	Operating specifications document
Panel	Single-Shell Tank Integrity Expert Panel
PER	Problem evaluation request
PNNL	Pacific Northwest National Laboratory
PRA	Probabilistic Risk Assessment
REDOX Plant	Reduction and Oxidation Plant
RFI	Request for information
SCC	Stress corrosion cracking
SI	Structural integrity
SST	Single-shell tank
SSTIP	Single-Shell Tank Integrity Project
TOC	Tank operations contractor
WRPS	Washington River Protection Solutions
WTP	Waste Treatment and Immobilization Plant

1.0 Introduction

The Hanford Site's single-shell tank (SST) wastes are slated for retrieval and treatment in the Waste Treatment and Immobilization Plant (WTP) that is currently under construction. Figure 1-1 shows a comparison of the SSTs present at Hanford. Technical issues have delayed the schedule for initiating operations of the WTP. The delays to the WTP will necessitate extended waste storage in the SSTs, all of which are currently beyond their design life.

Figure 1-1. Comparison of Hanford's Single-Shell Tanks



The extension of the SST mission has created an incentive for the Tank Operations Contractor (TOC), Washington River Protection Solutions, LLC (WRPS), to develop an enhanced Single-Shell Tank Integrity Project (SSTIP). WRPS created an expert panel on SST integrity (Panel) to provide recommendations to support the development of such a project.

1.1 Single-Shell Tank Integrity Panel

To date, the Panel has met three times. Table 1-1 shows the dates of these meetings and the corresponding documents produced. The Panel developed recommendations based on the proceedings of two workshops, and the research and deliberation of the Panel members. Of the 33 recommendations developed by the Panel, ten were deemed as primary recommendations for the SSTIP.

Table 1-1. Meetings of the Single-Shell Tank Integrity Panel

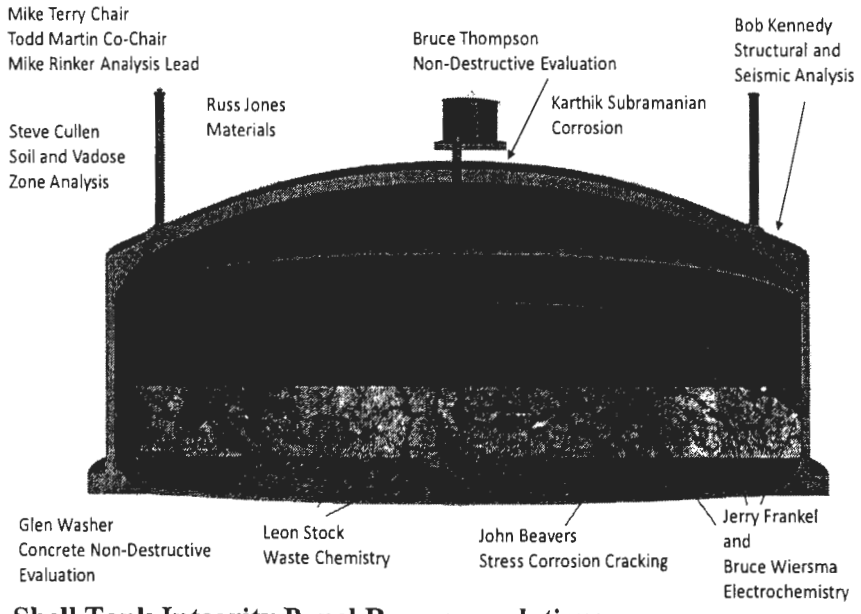
Meeting	Dates	Purpose	Documentation
First	January 26-28, 2009	Provide information to the Panel about SSTs.	WRPS-40656, *Summary of First Single-Shell Tank Integrity Expert Panel Workshop - January 2009*
Second	April 29-May 1, 2009	Respond to questions from Panel and for Panel members to present information based on assignments from the first meeting.	WRPS-42005, *Summary of Second Single-Shell Tank Integrity Expert Panel Workshop - April 2009* RPP-RPT-43116, *Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project*
Third	January 20-21, 2010	New report to reflect new guidance.	RPP-RPT-45921, *Single-Shell Tank Integrity Expert Panel Report*

In the first workshop, the Panel considered a broad range of issues including:

- Current status
- Chemistry
- Retrieval technologies
- Structural integrity requirements and status
- Corrosion
- Stress corrosion cracking (SCC)
- Design impacts at the Savannah River Site
- Vadose zone characterization
- Leak detection, monitoring, and mitigation
- Non-destructive evaluation (NDE)

At this workshop the Panel developed individual work assignments to research specific areas of interest (WRPS-40656, *Summary of First Single-Shell Tank Integrity Expert Panel Workshop – January 2009*). Based on this research and subsequent requests for more information from WRPS, the Panel held a second workshop to develop recommendations. The personnel on the Panel were adjusted after the second workshop, removing the soil and vadose zone expert and adding a concrete NDE expert, Dr. Glen Washer. Figure 1-2 shows the current members of the panel.

Figure 1-2. Single-Shell Tank Integrity Panel



1.1.1 Single-Shell Tank Integrity Panel Recommendations

In developing its recommendations, the Panel agreed on three overarching values that should guide the SSTIP.

- Project activities should be strategically focused on programmatic needs. This value acknowledges the pitfall of developing an SSTIP that includes activities that may be of interest scientifically, but offer little prospect for directly supporting programmatic requirements.
- Project activities should not adversely impact final disposition of tank waste. Such disposition of SST wastes requires retrieval from the tanks and treatment in the WTP. The waste must have certain physical and chemical characteristics for successful retrieval and treatment, and this must be considered when designing the SSTIP.
- Integrity project activities should protect public and worker health and safety.

The Panel's recommendations focused on the following four key elements that form the foundation of the SSTIP:

- Confirmation of tank structural integrity, denoted by SI
- Assessment of the likelihood of future tank liner degradation, denoted by LD
- Leak identification and prevention, denoted by LIP
- Mitigation of contaminant migration, denoted by MCM

The Panel then issued report RPP-RPT-43116, *Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project,* outlining the results of workshop discussions and Panel

deliberations, including the rationale and prioritization of the Panel's recommendations. The Panel developed ten primary recommendations, which the Panel stated in RPP-RPT-43116:

> "...form the foundation of a robust SSTIP. As is outlined in Section 2, these primary recommendations should be pursued at the initiation of the SSTIP.
>
> Recommendation SI-1, Perform Modern Structural Analyses
> Recommendation SI-2, Perform Dome Deflection Surveys
> Recommendation SI-3, Obtain and Test Sidewall Core
> Recommendation SI-4: Perform Non-Destructive Evaluation of Concrete
> Recommendation LD-1, Expand Leak Assessment Reports
> Recommendation LD-2, Avoid Inadvertent Addition of Water and Chloride to SSTs
> Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced External SST Monitoring
> Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs
> Recommendation LIP-3, Continue Use of High Resolution Resistivity
> Recommendation MCM-1, Install Surface Barrier over SST Farms

This implementation plan addresses the Panel's primary recommendations, six secondary recommendations, and identifies an intended path forward. The basic elements of developing the plan were presented, in draft form, to the Panel on January 19, 2009, and the Panel comments and concerns have been incorporated into this plan.

2.0 Prioritization and Summary of Recommendations in Implementation Plan

The Panel provided primary recommendations to be pursued as activities critical to a robust SSTIP, refer to RPP-RPT-43116. Secondary recommendations were also identified. A sub-set of the secondary recommendations will be included as part of the implementation plan. This plan will be to address scope, work plan, and schedule for the primary recommendations and included secondary recommendations.

2.1 Summary of Primary Recommendations

Table 2-1 lists the ten primary recommendations as prioritized by the Panel. The comments indicate if the recommendation is included in the SSTIP baseline schedule, another baseline schedule, or if a Baseline Change Request (BCR) will be required to add funding for the recommendation.

Table 2-1. Single-Shell Tank Integrity Panel Primary Recommendations (4 Sheets)

Number	Recommendation	Comment
1.	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?*	Included in WRPS baseline (FY 2009 –FY 2011).
2.	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.*	BCR required to add dome surveys, evaluation of additional benchmarks, repair of existing benchmarks, and monuments to the SSTIP baseline.

Table 2-1. Single-Shell Tank Integrity Panel Primary Recommendations (4 Sheets)

Number	Recommendation	Comment
3.	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.*	Included in WRPS baseline. Develop plan by 9/30/10. Complete first core by 9/30/11. If deemed necessary, prepare BCR to acquire a subsequent core.
4.	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, and vertical core results) indicate potential concrete degradation.*	Visual inspections included in WRPS baseline. Proceed with procurement of new camera system. Twelve tanks will be video inspected in FY 10. Use of a "thumper truck" is not being considered at this time.
5.	LD-1, Expand Leak Assessment Reports *The Panel recommends continuation of the preparation of Leak Assessment Reports for each tank farm. The Panel found the Leak Assessment Report for 241-A and 241-AX Tank Farms to be very helpful in understanding the status of data and information about both known and assumed leaker tanks. The discussion for each tank should include an operating summary, an operating history, an analysis of the leak location and cause, a waste loss estimate, commentary on the nature and extent of the ground contamination, and a conclusion.*	BCR required. Add review and update of existing leak assessment reports.

Table 2-1. Single-Shell Tank Integrity Panel Primary Recommendations (4 Sheets)

Number	Recommendation	Comment
6.	LD-2, Avoid Inadvertent Addition of Water and Chloride to SSTs *To avoid creating conditions that could lead to liner corrosion, the Panel recommends that operational procedures are implemented to prevent the inadvertent addition of water and chloride ion to the SSTs. The impact of water intrusion and unintended increases in chloride ion concentrations should be evaluated on a tank-by-tank basis.*	Operation specifications document (OSD) revision required. Review existing WRPS procedures and revise procedures as required.
7.	LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced External SST Monitoring *The Panel recommends continuing current LDM and Best Management Practices to monitor for leaks. Further, the Panel recommends installing enhanced monitoring based on potential leak risks at each tank farm. The 241-T Tank Farm Interim Cover Test has proved an excellent system for tracking infiltration of meteoric water. Increasing the depths and expanding the aerial extent of monitoring similar to this test will provide an excellent system for early detection and tracking of leaks.*	Included in the WRPS baseline under SST Retrieval and Closure Projects.
8.	LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs *The Panel considered the addition of absorbents to the SSTs to further immobilize liquids. However, the Panel recommends avoiding the addition of water-insoluble solid absorbents to the SSTs, as such additives do not appear effective in immobilizing water, will interfere with the future retrieval of wastes, and may adversely impact WTP operations.*	Operation specifications document (OSD) revision required. Review existing WRPS procedures and revise procedures as required.
9.	LIP-3, Continue Use of High Resolution Resistivity *The Panel recommends continuing utilization of high resolution resistivity for leak detection outside of tanks. High resolution resistivity can detect a 5,000 to 10,000 gallon leak by utilizing existing dry-wells to measure soil resistivity. The technique has proved effective during recent waste retrieval activities.*	The use of high resolution resistivity (HRR) is included in the WRPS baseline under SST Retrieval and Closure Projects.

Table 2-1. Single-Shell Tank Integrity Panel Primary Recommendations (4 Sheets)

Number	Recommendation	Comment
10.	MCM-1, Install Surface Barrier Over SST Farms *The Panel recommends design and implementation of a surface barrier to reduce recharge at the SSTs. Sources of water (leaking pipes, vaults, etc.) that could contribute to subsurface water deep percolation should also be identified and controlled. New control/barrier measures should be prioritized based on the risk associated with past and/or future releases at each tank farm.*	Included in current WRPS baseline. Vadose Zone Project to install interim surface barriers at a rate of 1 tank farm per year (see baseline for specifics).

2.2 Summary of Secondary Recommendations

At this time WRPS has identified six of the 23 secondary recommendations for further investigation; see Table 2-2.

Table 2-2. Single-Shell Tank Integrity Panel Secondary Recommendations Included in the WRPS Implementation Plan (2 Sheets)

Number	Recommendation	Comment
1.	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.*	BCR required. Add development of forensics plan, actual forensics testing and report generation. To be coordinated with C-107 Waste Retrieval Project.
2.	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.*	Included in WRPS baseline (FY 2009 – FY 2011), integrated with SI-1.

Table 2-2. Single-Shell Tank Integrity Panel Secondary Recommendations Included in the WRPS Implementation Plan (2 Sheets)

Number	Recommendation	Comment
3.	LD-3, Examine "non-compliant" wastes at 25°C *The Panel recommends selected "non-compliant" SST waste simulants be examined at 25°C. "Non-compliant" wastes are those that fail to meet specific temperature, nitrite, nitrate, and hydroxide concentration criteria. The examinations will provide information on the propensity for pitting, cracking, and corrosion at the liquid-air interface (LAI) or corrosion of the liner in the vapor space. This testing should be coordinated with the double-shell tank (DST) testing program.*	Test plan development included in current WRPS baseline. A BCR will be generated to add the execution of the test plan to the baseline.
4.	LD-5, Determine Ammonia Corrosion Control Concentration *Ammonia in sufficient concentrations has the potential to inhibit liner corrosion. The Panel recommends laboratory testing to determine the concentration of ammonia required to control corrosion in the liquid phases of the solid and supernatant layers, at the LAI, and on the exposed liner in the vapor spaces. This testing should be coordinated with the DST testing program.*	Test plan development included in current WRPS baseline. A BCR will be generated to add the execution of the test plan to the baseline.
5.	LD-6, Assess SST Waste Compositional Variation *The Panel recommends determining whether the compositional variation in the solid layers of the SSTs deviates from the general SST and DST programmatic assumptions about composition. If so, testing work may need to be performed to evaluate the propensity for stress corrosion cracking (SCC) and corrosion.*	Test plan development included in current WRPS baseline. A BCR will be generated to add the execution of the test plan to the baseline.
6.	LIP-8, Assess the Feasibility of Testing for Ionic Conductivity Between Inside and Outside of SSTs *The Panel recommends performing experiments to assess the viability of testing ionic conductivity between the inside and outside of the SSTs. An ionic path between the inside and outside of the SSTs could be indicative of cracks through the liner and concrete. If techniques can reliably measure such ionic conductivity, it would be useful in demonstrating whether breaches exist in SSTs.*	Test plan development included in current WRPS baseline.

2.3 Implementation Schedule

The implementation schedule for each recommendation is detailed in the following sections. Table 2-3 depicts a nominal high level schedule for all items that are included in the SSTIP baseline or are already funded by another WRPS baseline.

Table 2-3. Schedule for Currently Funded Activities

Activity	FY2010												FY2011											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Analysis of Record																								
Type I, II, III, IV SST Preliminary																								
Type II Detailed Analysis Final																								
Type III Detailed Analysis Draft																								
Type III Detailed Analysis Final																								
Type IV Detailed Analysis Final																								
Type I Detailed Analysis Final																								
Engineering Mechanics Document																								
SST Sidewall Coring																								
Plan Development																								
Obtain & Test Sidewall Core																								
NDE of Concrete (12 Tanks per Year)																								
Chemical Testing Test Plan																								
SST Statistical Grouping Study																								
Leak Detection Monitoring	Scheduled in Other Baseline																							
High Resolution Resistivity	Scheduled in Other Baseline																							
Develop Ionic Conductivity Test Plan																								
TY Surface Barrier Construction																								

All other recommendations will require a BCR in order to add scope and funding to the baseline. Once a BCR is approved, a schedule will be formulated for each activity included in the BCR.

3.0 Single-Shell Tank Structural Integrity

The Panel has developed a series of recommendations for WRPS to confirm and maintain the structural integrity of the Hanford SSTs. Recommendations discussed in Section 3.0 of RPP-RPT-43116 are denoted by SI-#, where # is an integer, relating to Structural Integrity (SI).

3.1 Analysis of Record for the Single-Shell Tanks

The discussion with the Panel through the first two meetings led to the conclusion that structural failure under static loading conditions of the SSTs is highly unlikely. The Panel felt seismic events would also not lead to the collapse of the SSTs, but further analysis was required. Thus the Panel recommends performing modern structural analyses (including seismic) on representative samples of SSTs. They also recommend the development of a living engineering mechanics document. WRPS agrees with the Panel's conclusion and has initiated work to prepare an analysis of record (AOR) and a living document containing the engineering mechanics properties based on the following recommendations:

Recommendation SI-1, Perform Modern Structural Analysis

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-6, Develop Engineering Mechanics Document

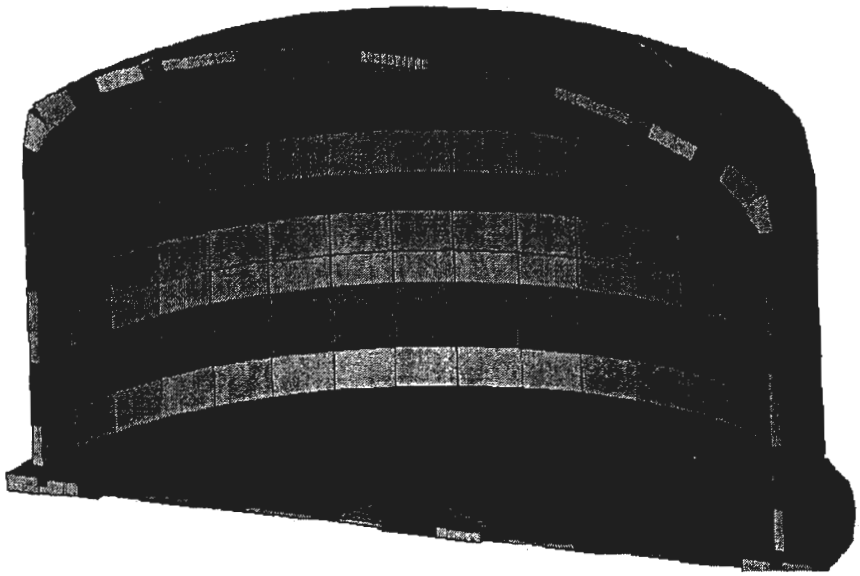
The Panel recommends the development and up-to-date maintenance of a living document containing the best current understanding of engineering mechanics properties of each tank. Such a document is an important reference in understanding both the current and future structural integrity of the SSTs and will be useful in defining input information for future tank evaluations.

3.1.1 Analysis of Record Implementation Scope

Structural analysis of the SSTs is currently in the WRPS baseline. At this time WRPS believes execution of the baseline activities will fully implement these Panel recommendations.

A modern finite element structural analysis is being performed for all four types of Hanford SSTs. Figure 3-1 depicts a finite element model to be used in a modern structural analysis. The analysis considers the effects of creep and dead, live, operating, thermal, and seismic loading. The analysis incorporates the use of temperature dependent mechanical properties of concrete and reinforcing steel.

Figure 3-1. Finite Element Model of a Concrete Single-Shell Tank



The analysis of the SSTs is being conducted in two phases. The first phase is a preliminary analysis. The preliminary analysis will address the variation in tank designs, concrete properties, reinforcing steel properties, and operating histories. The preliminary analysis will also investigate appurtenances and their impact on structural integrity. Benchmarking studies included in the preliminary analysis will address varying soil conditions within the SST tank farms, waste properties for seismic modeling, SST seismic response spectra, acceleration time-histories, and other parameters as necessary. The preliminary analysis will provide recommendations as to the number and size of finite element models required for analysis of each of the SST types.

The second phase will be a detailed AOR. The detailed analysis will be based on agreed upon detailed models and loading conditions (including dead loads, live loads, thermal loads, seismic loads and creep). The resulting demands on the tanks will be assessed in various load combinations and compared to the capacities at various locations on the tanks to determine the overall structural integrity.

The living engineering mechanics document will be prepared and maintained by WRPS to contain the current best understanding of engineering mechanics properties of each tank.

3.1.2 Analysis of Record Implementation Work Plan

WRPS has secured the services of Pacific Northwest National Laboratory (PNNL) and its subcontractor, M&D Professional Services (M&D), to perform the work necessary to implement recommendation SI-1. PNNL and M&D will generate the necessary finite element models to perform preliminary and detailed analyses.

The work plan currently includes the development of an SST structural evaluation criteria document, and preliminary and detailed analyses. All documentation will be subject to review by the Department of Energy Office of River Protection, the Panel, and WRPS subcontracted independent expert reviewers.

3.1.3 Analysis of Record Implementation Schedule

Per the PNNL Project Management Plan (*Project 57926, Rev. 1, SST AOR PMP, December 15, 2009*) the following are to be delivered to WRPS in fiscal year (FY) 2010:

- Type I, II, III, and IV SST Preliminary Analysis Documentation: models, analyses, results, and recommendations for detailed analyses by July 31, 2010.
- Type II SST Detailed Analysis of Record Final Documentation: models, analyses, results, and conclusions delivered to WRPS by September 30, 2010.
- Type III SST Detailed Analysis of Record Draft Documentation: models, analyses, results, and conclusions delivered as draft copy to WRPS by September 30, 2010.

The following are anticipated to be delivered to WRPS in FY 2011:

- Type III SST Detailed Analysis of Record Final Documentation: models, analyses, results, and conclusions delivered to WRPS by November 30, 2010.
- Type IV SST Detailed Analysis of Record Final Documentation: models, analyses, results, and conclusions delivered to WRPS by August 31, 2011.
- Type I SST Detailed Analysis of Record Final Documentation: models, analyses, results, and conclusions delivered to WRPS by September 30, 2011.
- Engineering Mechanics document prepared by WRPS by September 30, 2011

3.2 Dome Deflection Surveys

WRPS has performed dome deflection surveys since the initiation of interim isolation and stabilization of the SSTs in support of loads placed on the tanks during salt well pumping. Enhancements to the dome survey work have been identified. These activities will satisfy the Panel's concerns put forth by:

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.

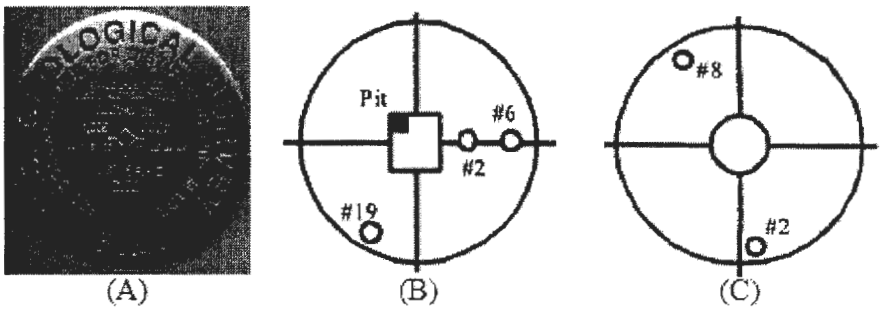
3.2.1 Dome Survey Implementation Scope

A dome survey of the SSTs is contained within the current WRPS baseline. WRPS will propose the addition of the following activities to the SSTIP baseline. The addition will allow WRPS to fully evaluate and implement this recommendation.

The addition of benchmarks "near the haunch" is to be evaluated by Engineering. This effort will take into account existing benchmarks that could be used and identify new benchmark locations that may be required.

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." Figure 3-2 shows typical benchmark type and placement.

Figure 3-2. (A) Typical Survey Benchmark, (B) Typical Benchmark Placement with Pit (from RPP-20444, *241-A Tank Farm Historic Dome Load Record Data*), (C) Typical Benchmark Placement without Pit (from RPP-20449, *241-C Tank Farm Historic Dome Load Record Data*)



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.

3.2.2 Dome Survey Implementation Work Plan

Prepare a baseline change request (BCR) to:

- Move performance of annual SST dome surveys from the SST maintenance to the SSTIP baseline.
- Add the performance of an engineering study to identify the requirements for the addition of benchmarks near the haunch. This study will also address the cost of installing new benchmarks.

- Add the repair and replacement of existing benchmarks and monuments.

3.2.3 Dome Survey Implementation Schedule

The implementation schedule will be per WRPS approved baseline.

3.3 Single-Shell Tank Sidewall Core

WRPS has obtained core samples in the past from the dome, sidewall, and footing of the SSTs. The Panel concluded that additional sidewall core samples from selected SSTs would improve the knowledge of the SST structural integrity. As such, WRPS has initiated work to obtain and test concrete from at least one additional SST to satisfy:

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.

3.3.1 Single-Shell Tank Sidewall Core Implementation Scope

The SSTIP baseline includes the development of a work plan and actual tank wall coring of one SST. In 1981 a concrete core sample was obtained from 241-SX-115, which was a leaker that saw relatively high heat during its operation. 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. Once the condition of the concrete in the sidewalls of a high-heat tank is assessed, a decision can be made as to whether a subsequent sidewall core sample is required. If the decision is made to acquire a subsequent core, WRPS technical staff has determined that a sample from a low-heat leaker could provide a valuable comparison to the data already acquired, although this determination is subject to change pending the results of the first sidewall core sample.

It is expected that the activities for concrete sidewall coring will be executed during FY 2010 and FY 2011. WRPS will require compliance with all applicable standards, procedures, policies, and quality assurance programs.

SST sidewall coring activities will include planning and executing the necessary tasks to have work completed to the satisfaction of WRPS. It is important to emphasize that the intent of the SST sidewall coring activities is to obtain valuable information regarding the condition of SST concrete. Concrete samples will be removed by core drilling through the haunch, down the full depth of the sidewall, and into, but not through the footing. It is not the intent of SST sidewall coring to drill through or cut any rebar in the SST sidewall, particularly horizontal (hoop) rebar.

As much care as practically allowed will be taken to avoid drilling through or cutting rebar while performing SST sidewall coring.

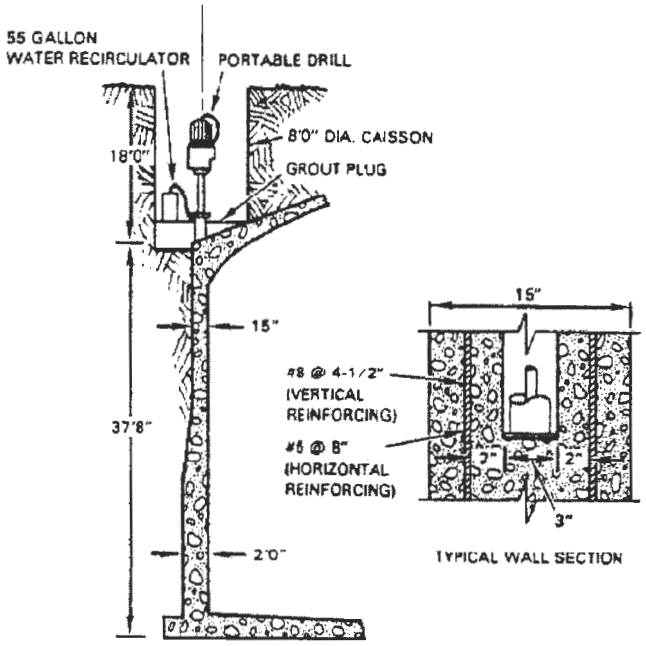
SST sidewall coring activities will result in the determination of desired mechanical properties of the SST concrete. Currently the desired mechanical properties for the concrete include compressive strength, elastic modulus, and Poisson's ratio. In addition to testing for mechanical properties, WRPS will require careful NDE of the removed samples before and after destructive testing. NDE of the samples will include, but not be limited to, visual inspection. Details on the mechanical testing and NDE of concrete samples will be included in a detailed work plan.

Preliminary sidewall coring activities will include, but are not limited to:

- Identification of the desired location of the SST for sidewall coring. This will include consideration of tank operating history, location within the farm, and crane access for equipment installation and material handling.
- Identification of core size (diameter) to be removed from the SST. Core size is of the utmost importance. The size of the sample will have to comply with ASTM C 42 and restrictions resulting from concrete wall thickness and the spacing and location of the rebar.
- Selection of drilling technique used for removing the concrete core samples. This will include considerations for desired specimen size (diameter), controls for drilling angle, control of water, and capability to perform drilling within a confined area, which is to be determined.
- Determination of appropriate access needed to perform SST sidewall coring. This will be dependent on the drilling equipment used and the desired coring location on the tank wall.
- Determination of all necessary personnel to complete sidewall coring activities. This will include all WRPS and non-WRPS staff required.
- Preliminary cost estimates for completion of SST sidewall activities.
- Schedule for detailed sidewall coring activities.

Figure 3-3 shows the general method for obtaining a sidewall core.

Figure 3-3. 241-SX-115 Sidewall Coring Detail (from RHO-CD-981, *Waste Tank Core Drilling Test Plan*)



Detailed sidewall coring activities will include, but are not limited to:

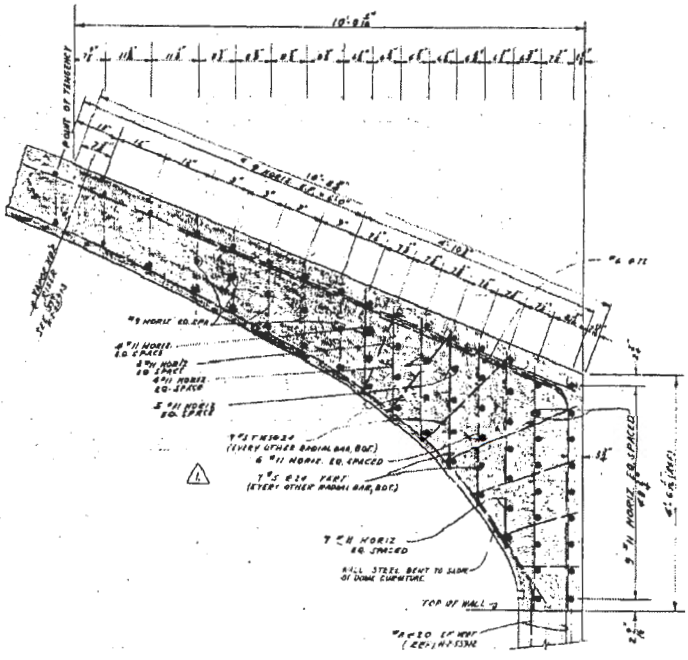
- Construction drawings for excavation and drilling activities. Drawings will convey construction sequence for excavation down to tank sidewall, installation of engineered barriers, structures, and supports, identification of drilling location on tank, installation of all drilling equipment and supports, removal of all removable equipment, grouting of the drilled hole, and resolution of the excavated area. Drawings will include design drawings and as-built drawings.
- Construction specifications for sidewall coring activities. All necessary information to accompany drawings for construction will be included. Specifications will also include methodology for tracking core samples with respect to depth of sidewall. Consideration will be given to proper handling of possibly contaminated samples. Specifications will consider stop work conditions and resolutions for multiple conditions adverse to safety and quality. This will include consideration of the inadvertent cutting of sidewall rebar.
- Detailed reporting on all construction activities. The report will include a data log for all construction activities. Pictures associated with as-built construction drawings will be provided. Proper documentation of all issues encountered during construction and drilling will be provided.
- Detailed specifications on concrete core testing. All applicable ASTM and ACI standards for performing NDE and mechanical testing will apply. Direction for visual inspection of concrete cores and associated documentation of findings will be included.

Specifications will include desired specimen sizes. Specifications will include testing procedures in accordance with ASTM and ACI standards. As-built specimen sizes will be documented. Direction for documenting test results, including testing conditions, will be provided. Specifications will also provide direction for necessary photographs to be taken before, during, and after inspection and testing.

3.3.2 Single-Shell Tank Sidewall Core Implementation Work Plan

A concrete core sample was obtained from 241-SX-115 in 1981. The current plan is to obtain and test a core sample from the sidewall of 241-A-106 because it has the highest recorded tank temperature identified from historical records. Figure 3-4 shows the rebar reinforcement of 241-A-106 at the haunch and top of the sidewall. Once the core sample data has been acquired, a determination will be made as to whether a subsequent core sample is required. If it is determined necessary, a BCR will be prepared to obtain and test another core sample from the sidewall of an SST, likely one with a lower temperature history than 241-SX-115. The data set obtained from these core samples will provide insight as to how temperature has affected the concrete strength.

Figure 3-4. Reinforcement of 241-A-106 Haunch and Top of Sidewall (from H-2-55913, *Waste Storage Tanks Dome Reinforcing Purex Waste Disposal Facility*)



3.3.3 Single-Shell Tank Sidewall Core Implementation Schedule

WRPS will develop a plan to obtain a full height core sample from 241-A-106 sidewall (start 4/5/10, complete 9/30/10).

In FY 2011, a sidewall core sample will be obtained from 241-A-106 (start 10/1/10, complete 9/30/11). Once the sample data has been acquired, the necessity of obtaining a subsequent core sample will be determined. If necessary, a BCR to obtain and test a core sample from another tank will be prepared.

If the BCR is approved, a core sample will be taken from a low temperature tank per WRPS baseline.

3.4 Non-Destructive Evaluation of Concrete

The Panel emphasized the importance of the hierarchical aspects of this recommendation. The relatively simple technologies of visual examination should be pursued first. Additional development and deployment of technologies should occur in the event SSTIP activities (e.g. visual inspection, modeling, and vertical core results) indicate potential concrete degradation.

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, and vertical core results) indicate potential concrete degradation.

3.4.1 Non-Destructive Evaluation of Concrete Implementation Scope

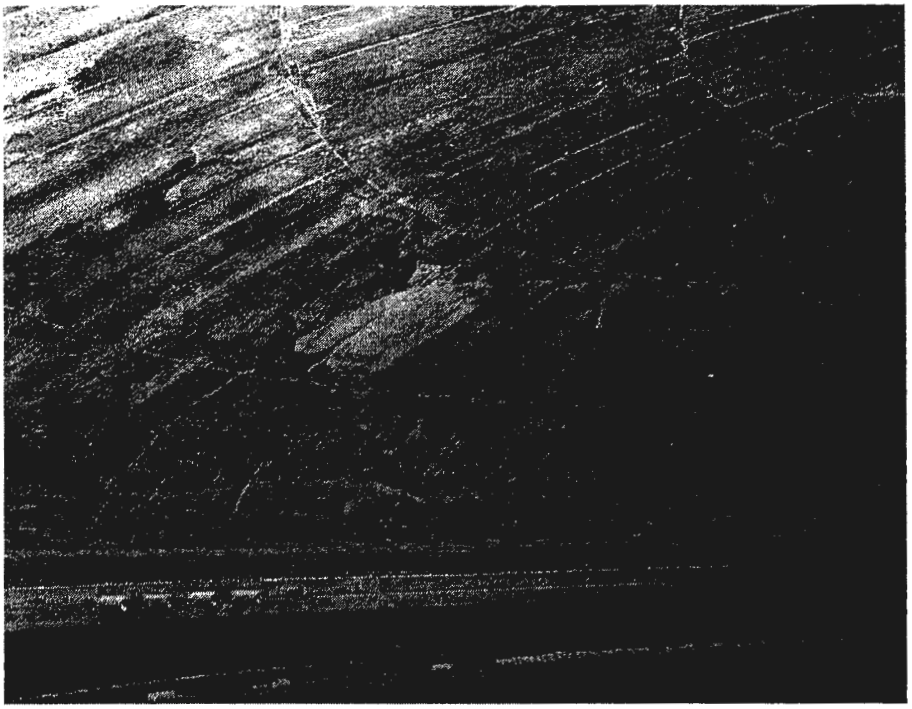
The SSTIP baseline includes the development of an SST visual inspection plan, development of camera technology for the SST visual inspections, and performance of visual inspections of 12 SSTs per year from 2010 – 2043.

3.4.1.1 Visual Inspection of SST domes

The initial visual inspection of the SST's interior concrete dome condition will primarily focus on the haunch or upper knuckle region (see Figure 3-5 for an example). The goal of these inspections is to identify cracks, spalling, or rust stains in the concrete, which would indicate signs of distress. This cracking, in combination with other factors such as past high heat conditions or increased dome load, would be anticipated along this region prior to showing

elsewhere. Supplemental information related to visual inspection expectations provided by the Panel recommended an inspection of the entire dome, with a focus on the haunch region, the center of the dome if feasible, and an inspection of the haunch regions near risers otherwise. This area of the dome is the section most likely to indicate problems, if any exist. The Panel suggested a search radius of approximately 25-ft about the selected inspection riser as being sufficient to provide a good representative sample region on each tank. Due to the limited access to the SST headspace the selected remote inspection system shall provide adequate resolution and illumination to view both the tank haunch and peak of the dome regions from a single access riser.

Figure 3-5. Interior View of an SST Haunch Region



As a part of the selection process for the first year of SST inspections, WRPS has determined the initial 12 tanks to be inspected during FY 2010. These tanks will be a representative sample of the 149 SSTs, taking into consideration various in-tank characteristics, conditions, and anomalies, including but not limited to:

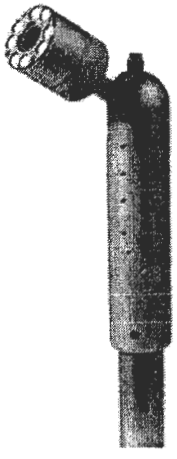
- Suspected integrity (sound or assumed leaker)
- Tank type (geometry and construction)
- Waste types
- Exposed sidewall available for inspection
- Riser accessibility
- Head space visibility
- Historic dome loading

- Waste and dome temperatures
- Temperature durations
- Tar rings
- Chemical additions

By using the selected criteria, SSTs chosen to cover different combinations of in-tank conditions will help determine the priority of future inspections if degradation is noted.

Currently utilized visual inspection equipment has the capability to inspect the SST concrete dome for 1/16-in wide anomalies at distances up to 14-ft based on vendor-supplied camera testing and resolution data. Vendor-supplied camera head modules have a range of lens capabilities and lighting configurations. Additional camera head modules will be procured for use in SST inspections to meet the recommendation of a 25-ft inspection radius. Figure 3-6 is an example of a remote visual inspection camera head.

Figure 3-6. Remote Visual Inspection Camera Head



While the SST headspace accessibility is limited due to installed equipment, a single riser penetration in the central section of the tank will allow the necessary inspection detail of the haunch and central dome region. This capability reduces the number of tank penetrations necessary to inspect the applicable regions listed by the Panel. In cases where only one tank riser is available for use, that being in the haunch region, the haunch will be inspected for cracks, spalling, and rust stains while the center section of the dome will be inspected to the extent possible by the limits of the camera equipment capabilities.

The remote camera system will be paired with additional lighting if the built-in system lighting is deemed inadequate. The use of the additional lighting will be based on the degree of visibility between the camera and the concrete dome. During the inspection, the camera system will record all inspection footage for review.

Based on the results of the initial SST inspections, WRPS will evaluate the need for development of additional inspection systems. Inspection system development will focus on enhanced camera resolution and alternatives to the current in-tank illumination.

3.4.1.2 "Thumper" Truck Utilization

WRPS agrees with the Panel on the importance of determining the elastic modulus of the reinforced concrete tank dome. Activities that are planned include performing concrete sidewall coring (Section 3.3.1) of a particular SST. This activity will provide WRPS with valuable information regarding the strength and modulus of the haunch, sidewall, and foundation concrete. In addition, planned retrieval activities consider removal of a concrete plug at the center of the tank dome (241-C-107). The plug will be available to the SSTIP for inspection. Direct inspection of dome concrete and rebar is preferred. Details related to plug testing are covered in Section 3.5 Test Dome Concrete and Rebar, Recommendation SI-5.

Use of a "thumper" truck is not being considered for implementation by WRPS. Vibration studies for Hanford underground waste storage tanks are not on-going. It is unknown as to the merit of applying this NDE technique to Hanford SSTs. WRPS recognizes that the in-situ modulus of a reinforced concrete structure is not the same as the elastic modulus that is determined from testing concrete core specimens alone. However, results from mechanical testing of tank dome rebar and concrete can be used in engineering formulas to determine transformed section properties including elastic modulus. The dynamic response of the dome can be predicted using the calculated modulus, section properties, and known soil properties.

3.4.2 Non-Destructive Evaluation of Concrete Implementation Work Plan

An evaluation team will determine the necessary sequence for in-tank inspections of the 149 SSTs over the life of the inspections, assuming 12 inspections per year, until each tank has completed one inspection. The team will take into consideration the items identified in the scope in their selection process. A lifecycle schedule will be prepared and approved by the evaluation team to incorporate all 149 SSTs.

WRPS will submit a request for interest (RFI) on an in-tank visual inspection system to meet the criteria set by the SSTIP in Recommendation SI-4. Responses to the RFI shall be evaluated by SSTIP personnel followed by additional discussion with eligible vendors, if necessary. After completion of the evaluation, the selection of a vendor or a separate path forward for procurement of a camera system shall be identified and initiated. Procured equipment will be verified to meet the criteria established by the Panel through testing by either the vendor or WRPS.

See Appendix B for further details on the evaluation and selection process of the SST inspections.

3.4.3 Non-Destructive Evaluation of Concrete Implementation Schedule

The implementation schedule will be per WRPS approved baseline.

3.5 Test Dome Concrete and Rebar

The Panel suggested that WRPS take advantage of the section of the concrete dome removal in support of installation of waste retrieval equipment for additional concrete and rebar testing. Concrete cores should be obtained from the intact removed concrete.

The installation of WRPS retrieval technologies will include the removal of a 55-in diameter section at the center of the SST domes. The removal of these plugs will provide WRPS with the ability to perform non-destructive and destructive evaluation of the dome concrete and rebar. It is in the interest of WRPS to maximize the amount of samples produced from the plugs. Currently, the plan is to install concrete anchors to provide support at lifting points to remove the plug intact. Once the plug is removed, it will be stored for future use.

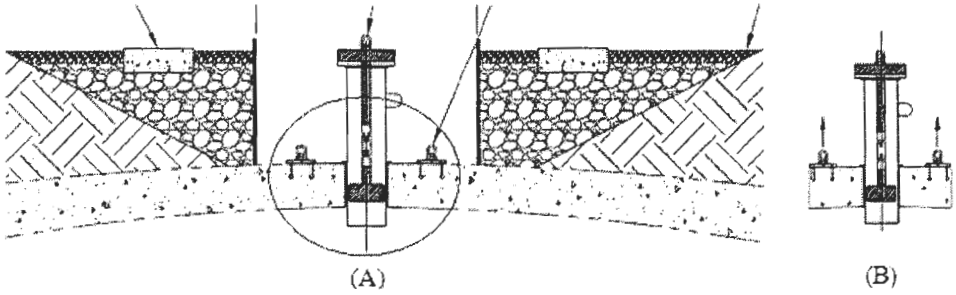
Recommendation SI-5, Test Dome Concrete and Rebar 'Plugs'

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.

3.5.1 Test Dome Concrete and Rebar Implementation Scope

The WRPS SSTIP will inherit the concrete plugs from Tank 241-C-107 for the purpose of gaining further insight into the current structural conditions of SSTs. Figure 3-7 displays the excavation and removal of the concrete plug. In addition to performing mechanical testing of the dome concrete, WRPS will conduct inspection and testing of the rebar. The investigation of the condition of the rebar will include measuring of the rebar diameter, visual inspection of rebar cross-section and longitudinal surface, and mechanical testing. Mechanical testing will include tests for tensile strength, elastic modulus, and Poisson's ratio. The experimental results will then be compared to the predicted rebar mechanical properties and dimensions used for structural analysis. The concrete mechanical tests performed will be the same as those for sidewall coring, discussed in Section 3.4 of this report.

Figure 3-7. (A) Excavation for Plug Removal, (B) Removed Concrete Plug (from H-14-107697, *Large Riser Installation Sequence*)



The SSTIP will prepare a BCR to propose adding the development of a forensics plan, actual forensics, and forensics report generation to the baseline.

3.5.2 Test Dome Concrete and Rebar Implementation Work Plan

It is expected that the activities for removal of the plug by the SST Retrieval and Closure (SST RC) organization will be performed during the current fiscal year, FY 2010. The SSTIP will receive the intact concrete plug from the SST RC. The SSTIP will develop a concrete plug test plan with the guidance of the Panel. The plan will consider both non-destructive and destructive testing techniques. Once the plan is approved, WRPS will place necessary contracts to have construction drawings and specifications developed. Subsequent testing and results will be incorporated into the knowledge base of current structural conditions of SSTs.

A BCR will be prepared to add this scope of work to the SSTIP baseline.

3.5.3 Test Dome Concrete and Rebar Implementation Schedule

If approved, this scope will be performed per the WRPS baseline.

Planning for the testing of the concrete plug will take place during FY 2011. Subsequent testing and reporting will occur during FY 2012. Performance of this work will be integrated with the C-107 Waste Retrieval Project.

4.0 Single-Shell Tank Liner Integrity

The Panel has developed a series of recommendations for WRPS to provide additional assessment of tank liner degradation. Recommendations discussed in Section 4.0 of RPP-RPT-43116 are denoted by LD-#, where # is an integer, relating to Liner Degradation (LD).

4.1 Leak Assessment Reports

The Panel reviewed the ongoing leak assessments. This work is conducted in two phases in which the vadose inventory is assessed and then individual tanks are assessed as to whether they have leaked or not.

For additional information regarding the history of past leak assessment investigations see Appendix C.

Recommendation LD-1, Expand Leak Assessment Reports

The Panel recommends continuation of the preparation of Leak Assessment Reports for each tank farm. The Panel found the Leak Assessment Report for 241-A and 241-AX Tank Farms to be very helpful in understanding the status of data and information about both known and assumed leaker tanks. The discussion for each tank should include an operating summary, an operating history, an analysis of the leak location and cause, a waste loss estimate, commentary on the nature and extent of the ground contamination, and a conclusion.

4.1.1 Leak Assessment Implementation Scope

In 2006, the U.S. Department of Energy committed to work collaboratively with the Washington State Department of Ecology to establish a process to update tank farm leak volume estimates, data interpretations, and the conclusions presented in earlier vadose zone contamination estimates. Pursuant to that commitment a new process was established to develop estimates of tank farm leak loss inventories. The process is described in RPP-32681, *Process to Assess Tank Farm Leaks in Support of Retrieval and Closure Planning.*

The RPP-32681 process assesses leaks from tanks, pipelines, and other in-tank farm events, such as spills, on a tank farm by tank farm basis. By the end of FY 2009, assessments were completed for the 241-A, 241-AX, 241-C, 241-S, 241-SX, and 241-TY Tank Farms. The 241-A, 241-AX, and 241-C Tank Farm assessments were published and the 241-BY Tank Farm assessment was in progress.

The actions recommended in LD-1, Expand Leak Assessment Reports, are addressed in the completed RPP-32681 assessment reports, except for identification of the leak location and the cause of the leak. Identification of the leak location is complicated by the presence of multiple leak paths, including waste transfer lines, ventilation piping, etc. An example of these alternate leak paths is shown in Figure 4-1.

Figure 4-1. Additional Pipelines in BX Tank Farm

The performance of Leak Assessment Reports per current WRPS procedures is in the current WRPS baseline.

4.1.2 Leak Assessment Implementation Work Plan

The SSTIP will prepare a BCR to propose adding a comprehensive review of published leak assessment reports for the 67 assumed leaking tanks as the primary objective of the work. This will be performed by reviewing the existing leak assessment reports. If practical, simple correlations will be made relating the leak sites to tank type.

If it is possible to identify the most likely cause of the leak from the data available in the leak assessment reports, the second objective may be partially fulfilled as well.

The results will be published at the end of the review. The review will be performed independent of the ongoing RPP-32681 work, which is developing estimates of tank farm leak losses for use in SST retrieval and closure planning.

4.1.3 Leak Assessment Implementation Schedule

If approved, the leak assessment activities will be conducted per the WRPS baseline.

4.2 Water and Chloride Control

Many SSTs contain small amounts of liquid. It is therefore prudent for WRPS to control the intrusion of water into the tanks, which could adversely alter the pH of the surface layers.

Recommendation LD-2, Avoid Inadvertent Additions of Water and Chloride to SSTs

To avoid creating conditions that could lead to liner corrosion, the Panel recommends that operational procedures are implemented to prevent the inadvertent addition of water and chloride ion to the SSTs. The impact of water intrusion and unintended increases in chloride ion concentrations should be evaluated on a tank by tank basis.

4.2.1 Water and Chloride Control Implementation Scope

Currently, the addition of water and chloride is not well controlled. The SSTIP will revise OSD-T-151-00013, *Operating Specifications for Single-Shell Waste Storage Tanks*, to include controls which will limit addition of water and chloride to the SSTs.

4.2.2 Water and Chloride Control Implementation Work Plan

The SSTIP will prepare the revision to OSD-T-151-00013, the scope of which will also include reviewing and changing existing operation controls and WRPS procedures as necessary.

4.2.3 Water and Chloride Control Implementation Schedule

The OSD revision including controls for water and chloride addition will be completed and released by the end of FY 2010.

4.3 Chemical Testing

The Panel made recommendations with respect to chemical testing to better understand the degradation of the liners. The SSTs have seen a variety of chemistries in the past, but now have a relatively uniform liquid composition. WRPS has initiated a testing plan that encompasses two of the recommendations:

Recommendation LD-3, Examine Non-Compliant Wastes at 25 °C

The Panel recommends selected "non-compliant" SST waste simulants be examined at 25° C. "Non-compliant" wastes are those that fail to meet specific temperature, nitrite, nitrate, and hydroxide concentration criteria. The examinations will provide information on the propensity for pitting, cracking, and corrosion at the liquid-air interface (LAI) or corrosion of the liner in the vapor space. This testing should be coordinated with the double-shell tank (DST) testing program.

Recommendation LD-5, Determine Ammonia Corrosion Control Concentration

Ammonia in sufficient concentrations has the potential to inhibit liner corrosion. The Panel recommends laboratory testing to determine the concentration of ammonia required to control corrosion in the liquid phases of the solid and supernatant layers, at the LAI, and on the exposed liner in the vapor spaces. This testing should be coordinated with the DST testing program.

4.3.1 Chemical Testing Implementation Scope

The SSTIP baseline currently includes the development of a test plan, or plans, to address SST chemistry concerns. The plan(s) will detail any laboratory investigations.

The investigation of the effect and threshold of the ammonia concentration will be carried out using weight loss coupons, U-bend coupons (stress corrosion cracking), and electrochemistry. It must be realized that hydroxide corrosion is a slow process and the weight loss and U-bend (or C-ring stress) coupons will be exposed for a long period of time, (e.g., 6 to 18 months). The electrochemistry investigation will involve chronoamperometry to delineate the effect of ammonia on the double layer and hence corrosion. Also, Raman spectroscopy will be used in an attempt to determine the mechanism of ammonia passivation. Currently, PNNL has a test bed that could be used for this investigation. Using PNNL would necessitate a sub-contract.

4.3.2 Chemical Testing Implementation Work Plan

The implementation work plan is to prepare and issue the test plan. After the test plan has been reviewed and issued, a BCR will be prepared to propose adding the execution of the test plan to the SSTIP baseline. If the BCR is approved and accepted, the work will be implemented in the following manner:

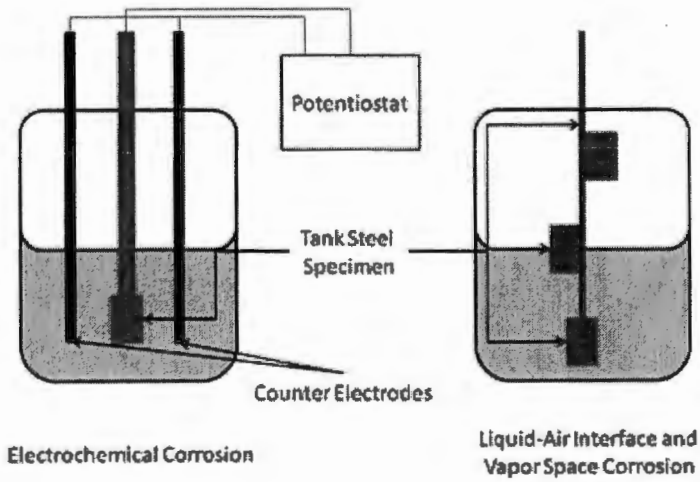
- Identification and procurement of the materials of construction, such as A283 steel. If the steel formulations cannot be procured either commercially or within Hanford inventory, the Panel will be consulted for a path forward.
- The following is for each steel formulation tested:
  - Prior ammonia work will be used to determine a starting point for ammonia passivation concentrations.
  - A cyclic potentiodynamic polarization (CPP) will be performed on the corrosive formulation(s). The formulation(s) will be determined in consultation with the Panel.
  - Using the midpoint of the passive section of the CPP curve, chronoamperometry scans will be carried out using varying concentrations of ammonia against a control.

Once a passivating ammonia concentration is determined, the following will be carried out at concentrations bracketing the passive concentration:

- Weight loss coupons will be subjected to headspace, liquid-air interface (LAI), and submersion in a corrosive solution(s).
- U-bend (or C-ring stress) coupons will be submerged separately, but in the same corrosive formulation(s).

Figure 4-2 depicts the general laboratory setup for such chemical testing experiments.

Figure 4-2. Chemistry Corrosion Experiments



4.3.3 Chemical Testing Implementation Schedule

Preparation of the test plan will be carried out per the SSTIP baseline schedule. If the BCR to execute the test plan is accepted, the test plan will also be executed per the SSTIP baseline schedule.

4.4 Waste Compositional Variation

Due to the range of process and operational experiences of the SSTs, individual tanks have varying properties making it difficult to evaluate all tanks concurrently. As such, WRPS is looking for common features among the SSTs based on:

Recommendation LD-6, Assess SST Waste Compositional Variation

The Panel recommends determining whether the compositional variation in the solid layers of the SSTs deviates from the general SST and DST programmatic assumptions about composition. If so, testing work may need to be performed to evaluate the propensity for stress corrosion cracking (SCC) and corrosion.

4.4.1 Waste Compositional Variation Implementation Scope

The recommendation was to study historical reports to determine whether there are novel and potentially corrosive compositions among the SSTs. The intent is to perform this work and use the results to determine if further laboratory testing is required beyond the testing performed per Section 4.3.

Statistical discussion with the Panel also led to the concept of grouping the SSTs based on common parameters. Because historical reports will already be studied to determine novel waste compositions, it will be simple to expand the studies to include other statistical parameters in an SST grouping activity. This activity will consist of an investigation of the feasibility of grouping SSTs to potentially and defensibly minimize SST inspection efforts, in particular, the number of SSTs requiring inspection for particular features, such as novel waste compositions. In the first phase a representative data matrix of pertinent SST historical information will be established. Statistical analysis will then generate groupings of tanks based on similarities in the historical information.

4.4.2 Waste Compositional Variation Implementation Work Plan

At this time, the only authorized work is the development of a feasibility study and plan. Developing the plan will include an initial series of meetings with key personnel during which inspection objectives and requirements will be better defined, pertinent historical information identified that could impact tank integrity regarding those objectives and requirements, and the path forward for accumulating that historical information established. If the outcome of these meetings is favorable, a BCR will be prepared to implement the plan, and given completion of a reasonable data matrix, the statistical analysis would be performed.

Later actions related to such groupings would be to obtain a more complete data matrix, to establish a more adequate grouping from the more complete data, and then to conduct inspections of some tanks in the various groups to determine if the grouping does have impact on tank inspection results. Depending on the outcome, sampling approaches for tank inspections could potentially be proposed. These later actions would be addressed based on the outcome of the initial feasibility study.

4.4.3 Waste Compositional Variation Implementation Schedule

The plan development for the SST grouping study is to be executed per the SSTIP baseline schedule. Should the BCR to implement the plan be accepted and approved, the execution of the plan will also be governed by the SSTIP baseline schedule.

5.0 Leak Identification and Prevention

The Panel has developed a series of recommendations for WRPS to provide additional assessment of tank leak identification and prevention (LIP). Recommendations discussed in Section 5.0 of RPP-RPT-43116 are denoted by LIP-#, where # is an integer, relating to LIP.

5.1 Leak Detection

WRPS has developed a Leak Detection and Monitoring (LDM) system to support retrievals and to identify the extent of leaks and contamination in the soil at Hanford. High resolution resistivity (HRR) was developed to support detection of leaks during retrieval of waste from the SSTs. The system was deployed during the retrieval of 241-S-102. For soil contamination, a similar system is used in which shallow electrodes are placed in the proximity of a potentially contaminated zone and the soil resistivity is mapped, which indicates areas of higher moisture and conductivity from species such as nitrate.

Recommendation LIP-1, Continue Leak Detection Monitoring and Best Management Practices and Install Enhanced External SST Monitoring

The Panel recommends continuing current Leak Detection Monitoring and Best Management Practices to monitor for leaks. Further, the Panel recommends installing enhanced monitoring based on potential leak risks at each tank farm. The 241-T Tank Farm Interim Cover Test has proved an excellent system for tracking infiltration of meteoric water. Increasing the depths and expanding the aerial extent of monitoring similar to this test will provide an excellent system for early detection and tracking of leaks.

(See Recommendation MCM-1 for surface barrier and monitoring implementation.)

5.1.1 Leak Detection Implementation Scope

The current SST LDM and best management practices (BMP) are specified by RPP-9937, *Single-Shell Tank System Leak Detection and Monitoring Functions and Requirements Document*. This functions and requirements (F&Rs) document establishes leak detection and monitoring for the SST system during pre-retrieval and post-retrieval storage of waste as required by *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989) in Milestone M-23-23, *"Submit Single-Shell Tank System Leak Detection and Monitoring Functions and Requirements Document for Ecology Approval."* The F&Rs come from an analysis of applicable regulations, the current physical condition of system components, and the current LDM program. In addition, BMPs that go beyond the LDM F&Rs define how tanks will be monitored for leak detection and liquid intrusion purposes by processes other than direct in-tank liquid level detection. The implementation of these requirements is enacted by OSD-T-151-00031, *Operating Specifications for Tank Farm Leak Detection and Single-Shell Tank Intrusion Detection.*

Enhanced external monitoring will be employed during the SST retrieval operation. The enhanced monitoring system will meet the requirements as set forth in TFC-OPS-OPER-C-48, "Single-Shell Tank Leak Detection during Waste Retrieval Activities."

5.1.2 Leak Detection Implementation Work Plan

This scope is contained within the WRPS baseline. The responsibility for maintenance and operation of the SST LDM system is with WRPS. The SSTIP has no responsibility for the maintenance and operation of the existing SST LDM system.

5.1.3 Leak Detection Implementation Schedule

Operation and maintenance of the existing LDM system is covered in the current WRPS baseline schedule.

5.2 Limit Addition of Water Insoluble Absorbents

Drying a tank in the past was accomplished sometimes by adding solid absorbents. The results of this have not been favorable. Therefore, addition of absorbents should be avoided in the future.

Recommendation LIP-2, Avoid the Addition of Water-Insoluble Absorbents to SSTs

The Panel considered the addition of absorbents to the SSTs to further immobilize liquids. However, the Panel recommends avoiding the addition of water-insoluble solid absorbents to the SSTs as such additives do not appear effective in immobilizing water, and will interfere with the future retrieval of wastes, and may adversely impact WTP operations.

5.2.1 Limit Addition of Water Insoluble Absorbents Implementation Scope

Currently, the addition of water insoluble absorbents is not controlled. The SSTIP will revise the SST OSD, OSD-T-151-00013, to include controls which will limit addition of water insoluble absorbents to the SSTs.

5.2.2 Limit Addition of Water Insoluble Absorbents Implementation Work Plan

The SSTIP will prepare the revision to OSD-T-151-00013, the scope of which will also include reviewing and changing existing operation controls and WRPS procedures as necessary.

5.2.3 Limit Addition of Water Insoluble Absorbents Implementation Schedule

The OSD revision including controls for addition of water insoluble absorbents will be completed and released by the end of FY 2010.

5.3 High Resolution Resistivity

The Hanford site has developed the HRR leak detection technique and it has effectively been demonstrated during recent SST waste retrieval activities. It has been estimated that the HRR system can detect a 5,000 to 10,000 gallon leak.

Recommendation LIP-3, Continue Use of High Resolution Resistivity

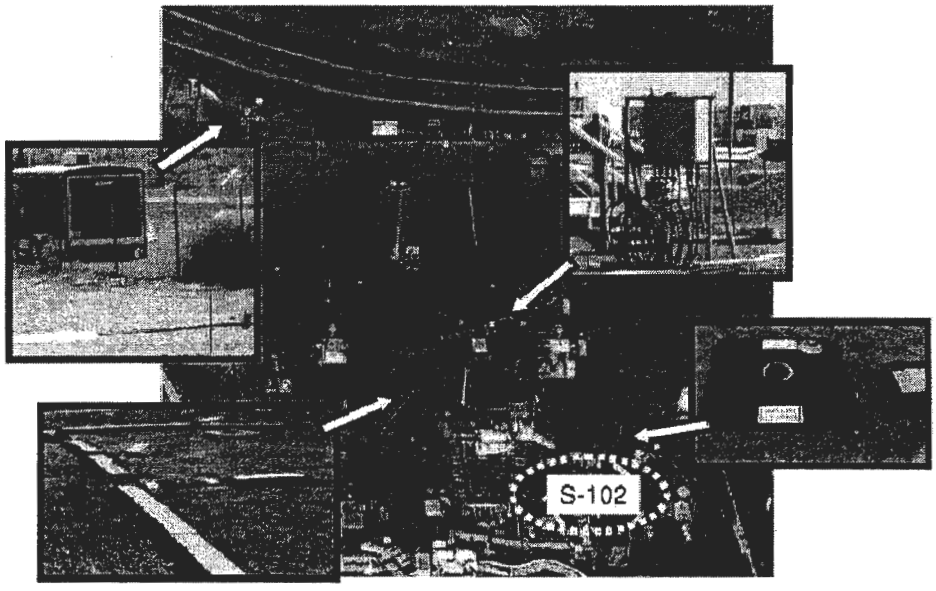
The Panel recommends continuing utilization of High Resolution Resistivity for leak detection outside of tanks. High Resolution Resistivity can detect a 5,000 to 10,000 gallon leak by utilizing existing dry-wells to measure soil resistivity. The technique has been effectively demonstrated during recent waste retrieval activities.

5.3.1 High Resolution Resistivity Implementation Scope

The use of HRR for SST retrievals will be conducted in accordance with individual tank waste retrieval work plans. Enhanced monitoring is presently not within the baselines of Base Operations, Retrieval and Closure Operations, or the Vadose Zone Project.

A typical HRR LDM system, as applied in the 241-C and 241-S Tank Farms, consists of a limited number of shallow (< 3 ft penetration) surface electrodes and all available drywells (50-150 ft penetration) that are hard-wired, connected to an automated system that energizes at a preselected frequency. Figure 5-1 shows an HRR LDM system installed on 241-S-102. The data thus collected are reviewed daily to assess whether or not a release has been detected.

Figure 5-1. HRR LDM System Installed on 241-S-102 (from RPP-30121, *Tank 241-S-201 High-Resolution Resistivity Leak Detection and Monitoring Test Report*)



The Vadose Zone Project performs a similar activity on a farm-wide basis to provide information on the status of resistivity-impacting substances. The physics that are applied are equivalent; however, interpretation is drastically different. Whereas the HRR LDM system uses repeated measurements of resistivity to identify changes that would be caused by a waste release, the Vadose Zone Project approach is analyzed by numerical modeling to provide a snapshot-in-time, 2-dimensional analysis that identifies anomalies in resistivity distribution. Surface electrodes are left in place, but all other equipment is removed. Recent developments have resulted in permanent, multi-depth electrodes being placed as part of the Vadose Zone Project characterization efforts.

Existing drywells, multi-depth electrodes, and permanent surface electrodes could provide the basis for an enhanced monitoring system. This on-ground portion of the system would have to be connected to a multi-channel data collection system, an appropriate power source, and a suite of remote electrodes. Data could then be collected at almost any selected frequency. If multiple SST farms were being monitored, it is likely that only one in each of the 200W and 200E Areas could be monitored simultaneously. Analysis of the data could be implemented at an appropriate frequency.

5.3.2 High Resolution Resistivity Implementation Work Plan

At this time, there are no plans to implement this technology farm-wide as a monitoring approach for SSTs that have been interim stabilized. The Vadose Zone Project is investigating the SST farms using both resistivity and direct soil sampling. The resistivity measurements provide a snapshot-in-time of the resistivity environment; however, plans for revisiting the farms are limited and the expense of performing and analyzing complete resistivity surveys is prohibitive as a means of monitoring. Shallow surface-based electrodes have been left in place and remain available for use. In addition, as characterization (sampling) holes are decommissioned, electrodes are being placed at depth. These electrodes are available should a decision be made to conduct resistivity-based monitoring. Documentation of the location and configuration of the electrodes is maintained through the engineering change notice (ECN) system. Depth electrodes are currently present in C, B, BX, SX, and TY Tank Farms.

Tank waste retrieval work plans have been prepared and approved for the retrieval of SSTs listed in Section 1 of TFC-OPS-OPER-C-48. The respective plans are:

- RPP-21895, *241-C-103 and 241-C-109 Tank Waste Retrieval Work Plan*
- RPP-22393, *241-C-102, 241-C-104, 241-C-107, 241-C-108, and 241-C-112 Tanks Waste Retrieval Work Plan*

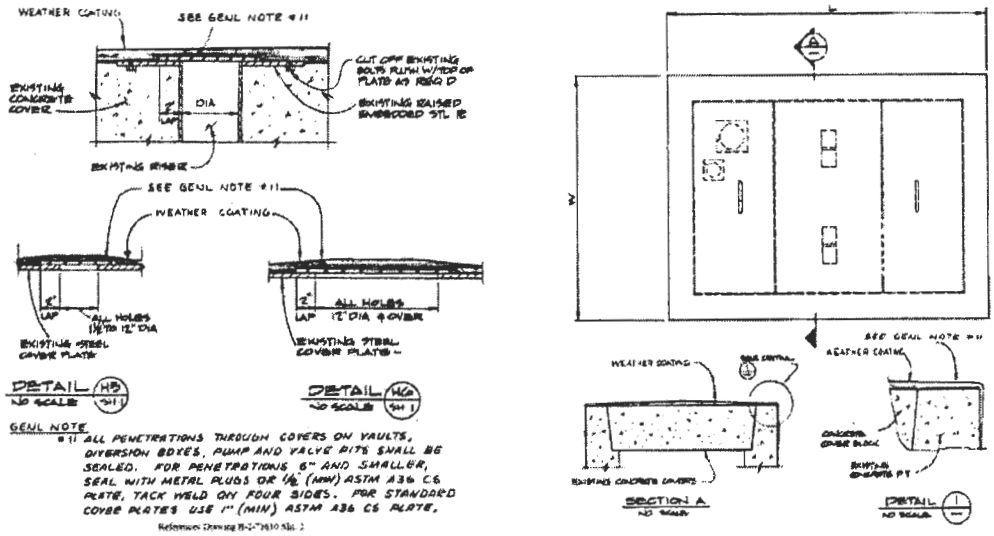
These plans include specific HRR requirements to be followed during retrieval operations on a tank by tank basis.

Deployment of the HRR technology for the current SST LDM program is not required at this time. The justification for this determination is:

- All SSTs have been interim stabilized.

- All SSTs have had the risers and process pits weather covered. Typical details for weather covers of process pits and risers can be found on H-14 and H-2 drawings for each SST tank farm; see Figure 5-2 for typical details.
- Intrusion monitoring is in place and maintained.

Figure 5-2. Typical Weather Covers (from H-2-73630, *Waste Tank Isolation Typical Details Pit Weather Covers*)



Annual System Health Reports, (e.g., *RPP-RPT-25720, Rev. 17, System Health Report For A, AX, B, BX, and BY Waste Tank Structures Mixing & Monitoring for the Fourth Quarter CY 2009*) are published for all SST farms. Deficiencies are identified and repairs are to be made as required. Additionally the system engineers, during the performance of the Single-Shell Tank Farm Quarterly Rounds, examine the condition of "weather covers" that have been installed on process pits and risers; refer to TF-OR-QR-01, "Quarterly Rounds." The aforementioned activities are the responsibility of WRPS Base Operations.

5.3.3 High Resolution Resistivity Implementation Schedule

HRR will be used by the SST RC and as required by individual tank waste retrieval work plans or TFC-OPS-OPER-C-48

5.4 Leak Path Evaluation

It is possible that ionic pathways to the ground through tank liner cracks exist underneath the sludge and salt cake layers. If such a condition exists, new leaks might be generated as the waste is mobilized during sluicing and waste retrieval operations.

Recommendation LIP-8, Assess the Feasibility of Testing for Ionic Conductivity between Inside and Outside of SSTs

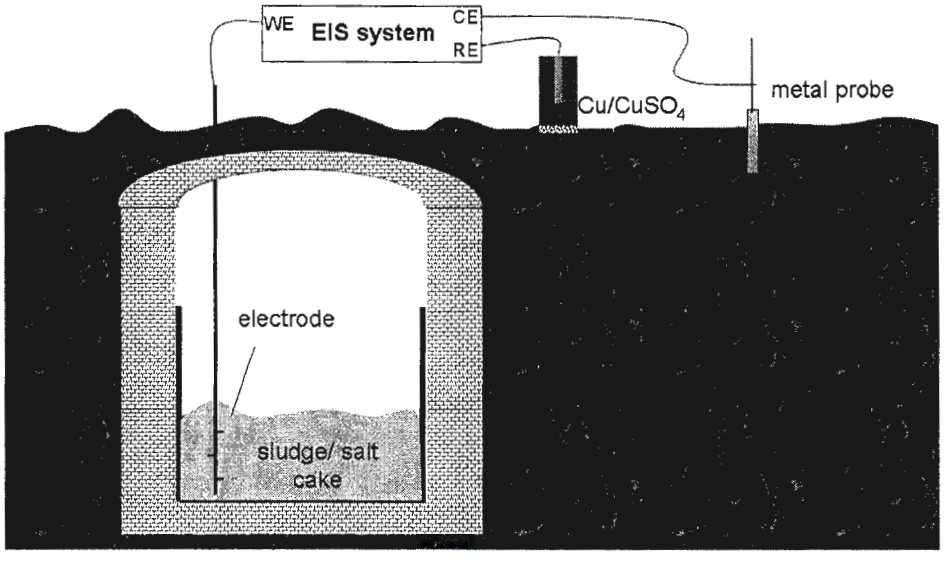
The Panel recommends performing experiments to assess the viability of testing ionic conductivity between the inside and outside of the SSTs. An ionic path between the inside and outside of the SSTs could be indicative of cracks through the liner and concrete. If techniques can reliably measure such ionic conductivity, it would be useful in demonstrating whether breaches exist in SSTs.

5.4.1 Leak Path Evaluation Implementation Scope

The Panel recommendation is to assess the feasibility of using ionic conductivity tests to identify any leak paths between the inside and outside of the SSTs, which would indicate a loss of liner integrity. The SSTIP baseline currently includes the development of a test plan for this effort, which will include laboratory-based experiments and analysis.

The test plan will evaluate the use of both direct current resistance measurements as well as alternating current resistance measurements, called electrochemical impedance spectroscopy (EIS). EIS is a more complicated method of characterizing electrochemical systems, but has been proven as a practical technique that can be used in many applications. Figure 5-3 shows a schematic of the EIS concept.

Figure 5-3. EIS System Schematic (from RPP-RPT-43116, *Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project*)



The test plan will also include provisions for testing the effects of "unknowns and possible artifacts" that can affect ionic conductivity tests. Several of these unknowns and artifacts include the natural resistances and capacitances associated with the various parts of the tank system (waste, liner, tar, concrete, etc.). Other artifacts are presented by the system design, such as the length of lead wires or the size of electrodes. The test plan will at least address these items.

In order to execute the test plan, a BCR will be prepared and submitted.

5.4.2 Leak Path Evaluation Implementation Work Plan

The initial implementation work plan for this scope is to prepare and issue the test plan. Once the test plan has been reviewed and issued, a BCR will be prepared to propose adding the execution of the test plan to the SSTIP baseline. If the BCR is accepted and approved, the test plan will be carried out and a path forward evaluated.

5.4.3 Leak Path Evaluation Implementation Schedule

The test plan is to be prepared per the SSTIP baseline schedule. If the BCR to execute the test plan is approved, the execution of the plan will also be performed per the SSTIP baseline schedule.

6.0 Mitigation of Contaminant Migration

The Panel has developed a series of recommendations for WRPS to provide additional assessment of mitigation activities to preclude migration of water into the tanks and mitigate surface water from reaching the groundwater. Recommendations discussed in RPP-RPT-43116, Section 6.0, are denoted by MCM-#, where # is an integer, relating to Mitigation of Contaminant Migration (MCM).

6.1 Surface Barrier Installation

The Panel reviewed the work conducted to mitigate migration of past leaks. The material presented included both surface and sub-surface barriers. The Panel concluded that the barrier installed over the 241-T Tank Farm was the most promising technology, retarding the movement of contaminants through the vadose zone.

Recommendation MCM-1, Install Surface Barrier Over SST Farms

The Panel recommends design and implementation of a surface barrier to reduce recharge at the SSTs. Sources of water (leaking pipes, vaults, etc.) that could contribute to subsurface water deep percolation should also be identified and controlled. New control/barrier measures should be prioritized based on the risk associated with past and/or future releases at each tank farm.

6.1.1 Surface Barrier Installation Implementation Scope

WRPS is scheduled to complete installation of an interim surface barrier (ISB) at 241-TY Tank Farm in FY 2010. The design for the 241-TY ISB was completed in FY 2009 and is shown in Figure 6-1; reference 09-TPD-116, "Transmittal of the TY Farm Interim Barrier Design and Monitoring Plan to the Washington State Department of Ecology (Ecology) for Approval." The 241-TY ISB design is based on lessons learned from the ISB installed at 241-T. The design differs from the 241-T ISB in the choice of barrier material, the conveyance system for transfer of collected water from the surface barrier to the water disposal location, and the means of water disposal, refer to RPP-39785, *Surface Barrier Project Value Engineering Workshop,* and RPP-RPT-38323, *Tank Farm Interim Surface Barrier Materials and Runoff Alternatives Study.*

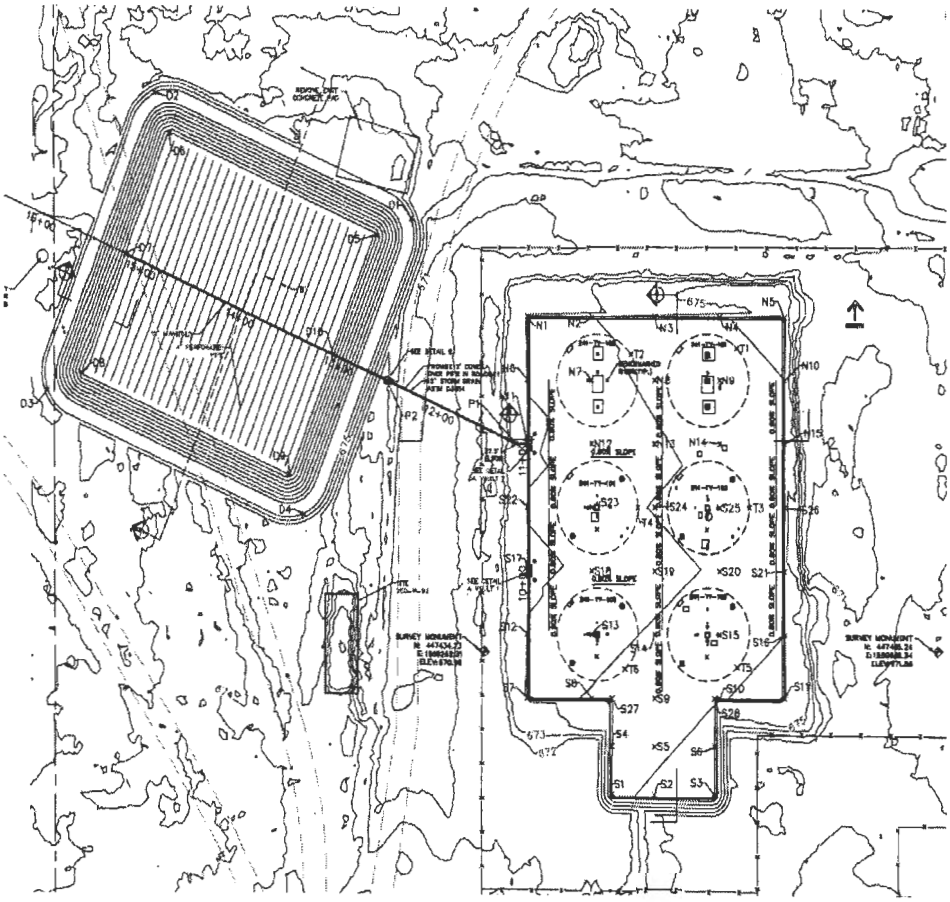
- The 241-TY ISB will be constructed of modified asphalt, rather than the polyurea used at 241-T.
- The 241-TY ISB will use an underground pipe to convey collected water to the water disposal area, rather than a covered ditch as at 241-T.
- The 241-TY ISB will use an evapotranspiration basin to dispose of collected water, rather than an infiltration basin as was used at 241-T.

Certain Tri-Party Agreement milestones are currently under negotiation in parallel with proposed Consent Decree 08-5085-FVS. Specifically, Milestone M-045-92 addresses ISB placement at 241-TY Tank Farm and four additional locations at a rate of one per year.

In addition, criteria for the prioritization of SST tank farms for application of ISBs was developed and performed in FY 2009 (RPP-ENV-41309, *Criteria for Prioritizing Hanford Site Tank Farm Interim Surface Barriers and for Evaluating Their Performance*).

Also, initial characterization of the SX Tank Farm for application of a surface barrier was completed in FY 2009; follow-up work is currently (as of January 2010) ongoing.

Figure 6-1. TY Farm Barrier Design (from H-14-107713, *241 TY Tank Farm Interim Surface Barrier Cover Sheet*)



6.1.2 Surface Barrier Installation Implementation Work Plan

Vadose Zone Program/Project baseline includes the scope to implement this recommendation.

6.1.3 Surface Barrier Installation Implementation Schedule

The installation of surface barriers will be performed per the WRPS baseline schedule. The construction of the TY Interim Barrier began on January 11, 2010.

7.0 Proposed Future Use of the Single-Shell Tanks

Shortly after the release of the Panel's first report, RPP-RPT-43116, the Department of Energy Office of River Protection (DOE-ORP) sent a letter to WRPS requesting additional input from the Panel (09-TF-032, "Contract No. DE-AC27-08RV14800--U.S. Department of Energy (DOE), Office of River Protection (ORP) RPP-RPT-43116, 'Expert Panel Report for Hanford Single-Shell Tank Integrity Project' Revision Request"). WRPS requested the Panel provide additional input in the four areas outlined in the DOE letter, including the Panel's evaluation of the proposed future use of the SSTs.

The Panel participated in a workshop in January 2010 where WRPS presented its proposal for future use of SSTs. This proposal arose from a programmatic dilemma presented by WRPS - the current baseline schedule will require suspension of SST retrievals due to a lack of DST space. Additionally, 200 West Area SST retrievals are limited by the cross-site transfer line capacities for delivering waste to the 200 East Area (where the WTP is located).

The Panel presented a new report, RPP-RPT-45921, *Single-Shell Tank Integrity Expert Panel Report*, to WRPS in May 2010, which included recommendations related to transferring and/or storing single shell tank waste in other single shell tanks. In the event that transferring and storing SST wastes into other SSTs is accepted and integrated into the baseline schedule, the Panel recommendations will be implemented as indicated in Appendix D.

8.0 References

1. 09-TF-032, 2009, "Contract No. DE-AC27-08RV14800--U.S. Department Of Energy (DOE), Office of River Protection (ORP) RPP-RPT-43116, 'Expert Panel Report for Hanford Single-Shell Tank Integrity Project' Revision Request," (letter from Stacy Charboneau to Mr. Abel B. Dunning, October), U.S. Department of Energy Office of River Protection, Richland, Washington.

2. 09-TPD-116, 2009, "Transmittal of the TY Farm Interim Barrier Design and Monitoring Plan to the Washington State Department of Ecology (Ecology) for Approval," (letter from Shirley Olinger to Ms. Jane A. Hedges, October 22), U.S. Department of Energy Office of River Protection, Richland, Washington.

3. 12710-89-042, 1989, "Estimation of Single Shell Tank Leak Volumes," (internal letter from L. Jensen and J.A. Merril to R.E. Raymond, March 28), Westinghouse Hanford Company, Richland, Washington.

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Appendix A Unaddressed Secondary Recommendations

This appendix provides the disposition of the SST Integrity Panel (Panel) secondary recommendations not included in the implementation plan. These secondary recommendations would require additional development prior to application to the SSTs, require no action, or the work is similar to past work on the SSTs. As the SST Integrity Project (SSTIP) progresses, additional secondary recommendations may be initiated.

A.1 Confirmation of Tank Structural Integrity

The Panel developed a set of recommendations to further enhance the knowledge of the structural integrity of the SSTs. Of the eight recommendations made by the Panel for structural integrity, six are being pursued as part of this implementation plan and are discussed in Section 3. The two remaining secondary recommendations are shown below.

Table A-1. Confirmation of Tank Stucutral Integrity Recommendations (2 Sheets)

Recommendation	Status
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.*	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.
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.*	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.
SI-9, AORs on SSTs Should Be Performed *Performing modern structural analyses was the focus of Recommendation SI-1. This recommendation expands on SI-1 by providing specific guidance for structural AOR activities. The Panel recommends performing an AOR on SSTs prior to any decision for extended storage in the SSTs.*	This recommendation will be incorporated as a consideration in decision-making regarding any extended waste storage in the SSTs.

Table A-1. Confirmation of Tank Stucutral Integrity Recommendations (2 Sheets)

Recommendation	Status
SI-10, If waste exposure tests indicate concrete integrity has been degraded, additional evaluations should be performed to determine the corrosion behavior of rebar steel exposed to waste and/or stimulants *...the Panel recommends additional, reasonable steps be taken to evaluate the corrosion behavior of the rebar steel in contact with waste simulants. This evaluation likely would consist of a combination of analysis of existing data, screening electrochemical tests and extended exposure tests of rebar samples for waste chemistries where data are not available.*	This recommendation will be implemented by WRPS at such time as any issues are identified.
SI-11, If structural integrity issues are identified the Panel recommends WRPS develop and implement a mitigation strategy *If structural integrity issues (e.g. AOR, evaluation of corrosion) are identified, the Panel recommends that WRPS develop and implement a mitigation strategy. Actions will depend on the severity of risk for structural failure of the SSTs. A severe immediate threat could potentially require structural reinforcement of the affected SSTs. For less severe threats, it might be necessary to accelerate retrieval from the affected SSTs. Accelerated or more extensive integrity monitoring might be appropriate for cases where the immediate threat is minimal but a potential long-term threat exists.*	This recommendation will be implemented by WRPS at such time as any issues are identified.

A.2 Assessment of the Likelihood of Future Tank Liner Degradation

Of the eleven recommendations made by the Panel to assess the likelihood of future liner degradation, five are being pursued as part of this implementation plan and are discussed in Section 4. The remaining six secondary recommendations are show below.

Table A-2. Assessment of the Likelihood of Future Tank Liner Degradation Recommendations (2 Sheets)

Recommendation	Status
LD-4 Develop and Deploy Guided Wave Technology: *The Panel recommends the development and deployment of guided wave, ultrasonic technology to assess the presence of macroscopic degradation of the steel liner. A design study should be undertaken to determine the optimum parameters and feasibility of an Electro-Magnetic Acoustic Transducer (EMAT) system for this application. If shown feasible, and other SSTIP activities raise concerns about liner integrity, the EMAT system should be deployed.*	The activities associated with non-destructive evaluation have been referred to the technology development group for WRPS. WRPS may fund these activities as a separate initiative. The SSTIP will re-evaluate implementation of these activities should technical or programmatic needs arise.
LD-7, Assess Deployment of Local Non-Destructive Evaluation Techniques *The Panel recommends assessing the feasibility of deploying candidate local measurement techniques (such as fluid coupled ultrasound, ultrasonic guided waves implemented using EMATs, and vibrothermography) operated as end effectors on a mechanical apparatus (such as robotic arms) deployed in the SSTs. Deploying such technologies should be based on the outcomes of other NDE recommendations (e.g. discovery of cracks via visual inspection) and a cost benefit analysis that analyzes the difficulties of employing candidate local measurement techniques.*	The activities associated with non-destructive evaluation have been referred to the technology development group for WRPS. WRPS may fund these activities as a separate initiative. The SSTIP will re-evaluate implementation of these activities should technical or programmatic needs arise.
LD-8, Consider Installation of Corrosion Potential Probe *If recommended laboratory studies indicate SST chemistries aggressively foster corrosion or SCC under tank operating conditions, the Panel recommends installing a probe similar to that employed in the DSTs to measure corrosion potential. This information can be used to further assess the likelihood for corrosion or SCC.*	This recommendation is not being pursued at this time. To deploy this system would require additional development. Corrosion probes would be developed on an as-needed basis and will not be deployed routinely. The need for the use of a corrosion probe would be established through chemical testing or other threat analysis.

Table A-2. Assessment of the Likelihood of Future Tank Liner Degradation Recommendations (2 Sheets)

Recommendation	Status
LD-9, Consider Testing Tank Liner Hardness *The feasibility and cost of removing small samples from the tank liner for hardness testing should be evaluated. If feasible and cost effective, samples should be removed from a tank that experienced high temperatures to determine if hardness increases, which could impact structural integrity, have occurred.*	This recommendation is not being pursued at this time. To deploy this system would require additional development. The chemical testing (LD-3 and LD-4) will show the propensity for SCC to occur in the SSTs. If there is a threat from SCC to the SSTs, testing of the liners may be required to further address this risk.
LD-10, Consider Applying Direct Current Potential Drop to SSTs: *The Panel recommends studying the feasibility of applying Direct Current Potential Drop (DCPD) to the SSTs for the purpose of locating tears in the liner. The DCPD technique is based on injecting current into a metallic component and measuring the resulting voltage (potential) at selected points. Such study could include both theoretical modeling as well as simple laboratory experiments. Once feasibility is established, a DCPD system should be developed for implementation.* *This recommendation, along with consideration of local NDE techniques (Recommendation LIP- 8), provide a suite of techniques to assess liner degradation based on the outcome of other tests and observations, as well as the feasibility of deployment.*	This recommendation is not being pursued at this time. To deploy this system would require additional development. If this recommendation is to be pursued, it would be as improvement to the electrochemical impedance spectroscopy, LIP-8. This similar technology is being funded as part of the implementation plan.
LD-11, Analyze Stress Relaxation of Tank Liners: *The Panel recommends analysis or experimental study of stress relaxation in tank liner steels to determine whether SCC is a possibility in the future.*	This recommendation is not being pursued at this time. To deploy this system, WRPS would require additional development. The chemical testing (LD-3 and LD-4) will show the propensity for SCC to occur in the SSTs. If there is a threat from SCC to the SSTs, testing of the liners may be required to further address this risk.
LD-12: High Resolution Resistivity (HRR) monitoring should be performed on sample SSTs for at least one year *Currently the HRR system is utilized for waste retrieval activities only. However, the Panel cannot quantify the risk of continued storage in interim stabilized SSTs. As a result, the Panel recommends acquiring additional leak monitoring data using the improved HRR system. Sample SSTs should be selected and monitored for at least one year to determine if changes in the baseline resistivity occur. This approach would provide information on how effective interim stabilization is at reducing the risk of further leakage.*	This recommendation will not be implemented. The use of HRR for SST retrievals will be conducted in accordance with individual tank waste retrieval work plans.

A.3 Leak Identification and Prevention

Of the 12 recommendations for leak identification and prevention, four are being evaluated in this implementation plan. The remaining eight could be part of the SSTIP at a future date. The disposition of those eight secondary recommendations is shown below.

Table A-3. Leak Identification and Prevention Recommendations (3 Sheets)

Recommendation	Status
LIP-4, Seek Engineering Methods to Increase Water Removal by Pumping from SSTs *The Panel recommends seeking engineering solutions for the removal of additional tank liquids by pumping. While the Panel acknowledges further removal of liquids by pumping will be challenging, it is a safe and potentially efficient and cost effective method for the removal of liquids from the tanks.*	This recommendation is not being pursued at this time. Though the interim stabilization program has left some liquids, further removal would require deployment of new technologies. The removal of additional liquids from the SSTs would require a major development and construction activities.
LIP-5, Evaluate Sludge and Saltcake Liquid Leak Rates *The Panel recommends evaluating liquid leak rate assessments of sludge and saltcake from the Savannah River Site to determine if the results are applicable to SSTs. There is currently no evidence that liquid is leaking from the interim stabilized (retrieved) tanks that contain supernatant, sludge or salt cake. Nor is there evidence that new stress corrosion cracks have developed since the tanks were stabilized. Information as to whether liquid would leak out of sludge or salt cake through stress corrosion cracks is important when considering continued use of the SSTs.*	This recommendation is not being pursued at this time. Though not included in the recommendation plan at this time, personnel will work with the SRS to collect this data. If further action is required, it would be included in the SSTIP at a future date.
LIP-6, Investigate Leak Detection Technologies for Tanks With Less Than 24 Inches of Waste: *The Panel recommends investigating and developing technologies to allow for leak detection in tanks with waste levels of less than 24 inches. Limitations of current leak detection technologies (Liquid Observation Wells and ENRAF™) do not allow for leak detection in these SSTs below 24 inches.*	This recommendation is not being pursued at this time because the work done in support of salt well pumping is deemed adequate. If further water removal is necessary, this work would be a prerequisite.
LIP-7, Evaluate Effect of Lowering SST Waste Temperature *The Panel recommends evaluating the effect of lowering the temperature of representative waste types to determine its practical impact on drainage rates.*	This recommendation is not being pursued at this time because the completion of the interim stabilization program provides adequate control of the liquid in the tanks.

Table A-3. Leak Identification and Prevention Recommendations (3 Sheets)

Recommendation	Status
LIP-9, Consider Cathodic Protection for Rebar and Exterior of Tank Liner *The Panel recommends that cathodic protection (CP) not be deployed for use in protecting the interior of SSTs where supernatant, sludge and/or salt cake is present. The Panel further recommends that CP be considered as an option to protect the exterior of the tank liner and rebar, should evidence arise that either has corroded.* *CP has the potential to suppress corrosion in the SSTs. CP has not been applied to the DSTs due to concerns that waste chemistry may lead to SCC. These issues, as well as difficulties associated with frequent replacement of electrodes, inserting electrodes into the saltcake and high CP currents have led the Panel to recommend against applying CP to the interior of the SSTs. This recommendation is tempered by the possibility of applying CP to the interior of SSTs with little or no nitrite.*	WRPS is in agreement with the application of CP to the SSTs. This recommendation is not being pursued at this time. For the DSTs the DOE evaluated CP as part of the 1980 EIS for the construction of new DSTs (DOE/EIS-0063, *Final Environmental Impact Statement, Supplement to ERDA 1538, December 1975, Double-Shell Tanks for Defense High-Level Radioactive Waste Storage*). The DOE concluded that stray currents from the CP system could lead to accelerated corrosion.
LIP-10, Evaluate Coating of Tank Liners and Installation of Polymeric Bladder *The Panel recommends evaluating both the coating of the tank liners with a material resistant to corrosion and cracking; and the deployment of a polymeric bladder to line SSTs. Many different metals, ceramics, intermetallics and polymers have the potential to be thermally sprayed onto the tank liners to reduce leakage concerns during retrieval.* *Storing waste in polymeric bladders has been used successfully in the petroleum industry for the elimination of leaks in storage tanks. A bladder made of this material could line a tank if its reliability were shown to be extremely high. The Panel acknowledges that difficulties associated with introducing materials into SSTs may reduce the feasibility of implementing this recommendation.*	This recommendation is not being pursued at this time. The use of a bladder would be in support of the SSTs for special purpose applications on a case-by-case basis.
LIP-11, Avoid Heating and Active Ventilation Strategies for Removing Additional Water from SSTs *The Panel recommends against pursuing strategies for removing water from tanks that include active ventilation or heating. Such strategies would be expensive, heating will increase the risk of pitting corrosion and SCC, and heating could increase the risk of unacceptably vigorous exothermic reactions.*	No implementation required, as the WRPS approach to date has been limited to the removal of standing liquids.

Table A-3. Leak Identification and Prevention Recommendations (3 Sheets)

Recommendation	Status
LIP-12, Avoid Strategies to Immobilize Waste Through the Addition of Gelling Agents: *As a general programmatic practice, the Panel recommends against the addition of gelling agents. Existing gelling techniques will be difficult to implement, may complicate WTP operations, and may increase the corrosivity of the waste. However, individual tank-by-tank instances may arise in which gelling a tank may be a wise option (e.g. to stop a significant tank leak or if new gelling techniques were developed).*	WRPS has no current plans to add gelling agents to the SSTs. As such, this recommendation is not being pursued at this time, and there are no plans to pursue this technology.
LIP-13, The wastes in all of the SSTs (not just those selected for future use) should be brought into conformity with the specifications contained in OSD-T-151-00007 unless the SSTs are retrieved or new testing demonstrates that there is an acceptably low propensity for corrosion under the storage conditions. *If the specifications in OSD-T-151-00007 are not met...the Panel recommends sodium hydroxide and/or sodium nitrite be added to the wastes to protect against future corrosive damage to SSTs.*	This recommendation will not be implemented. The work scopes associated with completion of recommendations LD-3 and LD-5 will quantify the propensity for corrosion in these tanks. This information will be used in the management of the tanks. WRPS will not add liquids to interim stabilized SSTs. In addition, mixing studies have shown that the mixing of sodium hydroxide and solids is prohibitively complicated.

A.4 Mitigation of Contaminant Migration

The Panel made one primary recommendation and one secondary recommendation with respect to the mitigation of contamination migration. The SSTIP looked at this interface as part of the Panel's activities and has noted the importance of surface barriers as identified by the Panel in minimizing the spread of contaminants. Though the mitigation of contamination migration is an important activity at the Hanford Site, it is not covered by the scope of the SSTIP.

Table A-4. Mitigation of Contaminant Migration

Recommendation	Status
MCM-2, Evaluate Subsurface Leak Mitigation Technologies: *A number of viable candidate subsurface leak mitigation strategies were identified in a 1994 Feasibility Study (FS). The Panel recommends evaluating leak mitigation technologies utilizing this FS as a selection guide.* • *Bench scale studies on candidate technologies should be conducted.* • *Demonstration in a Hanford Site field setting should be performed where appropriate.* • *Currently ongoing tests, such as the injection apatite reactive zone, should be considered for application at the SST farms.* • *An updated FS should be performed, using updated risk assessment methodologies and modern performance assessment technologies, with the objective of selecting an SST leak mitigation strategy and potentially a final SST closure strategy.* • *It is recognized that an updated FS and risk-based selection process may also conclude that little additional benefit can be derived from implementing a subsurface barrier in addition to implementing a surface barrier.*	This recommendation is not being pursued at this time as part of the SSTIP scope. If WRPS were to pursue this activity, it would be included as part of the Vadose Zone Project.

Appendix B Single-Shell Tank Selection for Visual Inspection

The Panel made a recommendation, SI-4: Perform Non-Destructive Evaluation of Concrete, documented in RPP-RPT-43116, *Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project*, which identifies the need to perform a one-time remote visual inspection of the underside of the concrete domes for all SSTs. These inspections would focus primarily on the concrete dome to identify any cracks in excess of 1/16-inch wide as well as rust stains and spalling of the concrete, indicating signs of structural distress.

As a part of the selection process for the first year of SST inspections, Washington River Protection Solutions (WRPS) determined that the initial 12 tanks to be inspected during FY 2010 should be a representative sample of the 149 SSTs located on the Hanford site. The tanks would represent structures subjected to various in-tank characteristics, conditions, and anomalies, including but not limited to:

- Suspected Tank Integrity – Confirmed leaking SSTs typically were subjected to harsh conditions such as high temperatures and thermal cycles. These conditions could have potential effects on the concrete dome condition.
- Tank Type – SST geometry varies by tank type, with differences in concrete reinforcement, wall thickness, and riser penetrations. Tank type will be considered when selecting a representative sample.
- Waste Types – SSTs received various types of waste while in operation. Temperatures, pressures, and vapor space environments associated with these waste types imposed a wide range of loads and conditions on the steel liners and concrete structures.
- Exposed Sidewall – Tanks with large areas of exposed steel liner present a greater opportunity to inspect a larger percentage of the steel liner, thus increasing the ability to determine the current condition of the steel itself.
- Accessibility –Tanks with current riser availability are preferred in order to allow inspections to occur more quickly and at a cost savings versus the cost of removing aged, contaminated equipment.
- Dome Loading – While no excessive dome loading has been noted during the required benchmark surveys, historic in-tank inspections have identified areas of relatively higher dome loads. Such inspections include historic images after SST interim stabilization showing large amounts of salt cake crystals adhered to equipment.
- Concrete Dome and Waste Temperatures – Large fluctuations in tank waste and concrete temperatures, in excess of 200° F, can contribute to degradation in the mechanical properties of the concrete.
- Other Physical Anomalies – These would include the addition of various other materials (resin, Portland Cement, acids), the discovery of tar rings, bulged liners, etc.

SSTs were selected to cover as many combinations of conditions as possible. By visually inspecting these tanks, future inspections can be prioritized to focus first on tanks that have similar characteristics to tanks that have showed signs of degradation. The following sections

document the SSTs selected to receive visual inspection in FY 2010, including a brief description of the rationale for selection. Table B-1 details tanks to be inspected in FY 2010 and FY 2011. Table B-2 provides a lifecycle schedule of SST visual inspections for all 149 SSTs.

Type II Tanks (500,000 Gallon):

241-B-102 – Represents a tank that is anticipated to show good overall condition, and has no documented history of high heat or dome loads. There is a large area of steel liner visible. The tank currently contains 32 kgal of waste and no history of leakage.

241-C-107 – This SST is the tank selected for installation of the mobile arm retrieval system (MARS). To support MARS installation, a 55-inch diameter hole must be cut in the center of the tank dome. A visual inspection of the concrete dome in 241-C-107 will assist in providing a baseline of the condition of the dome prior to the installation of the MARS.

241-BX-102 – Represents a tank that is an assumed leaker containing Tributyl Phosphate Process Waste as a primary waste type and cladding waste as a secondary waste type. It is known that diatomaceous earth was added to the tank. There is no documented high thermal history in 241-BX-102. There is a large area of steel liner visible in 241-BX-102. The tank currently contains 79 kgal of waste.

241-T-106 – This SST is known to have had the largest leak of any of the Hanford site SSTs. Tank 241-T-106 currently contains 22 kgal of waste, resulting in a large area of exposed steel liner.

241-U-104 – This SST is known to have had the second largest leak of any of the Hanford site SSTs. Tank 241-U-104 currently contains 54 kgal of waste, resulting in a large area of exposed steel liner.

Type III Tanks (758,000 Gallon):

241-BY-110 – Represents a sound tank with black material suspected to be tar rings that are located circumferentially along the steel liner. Visual inspection of these regions may provide insight as to the actual origin of the black material. The suspected tar rings are located at the 180-inch, 246-inch, and above the 266-inch historic waste levels. Tank 241-BY-110 contains 366 kgal of waste and has no documented high thermal history.

241-S-104 – This SST has a high thermal history with the dome headspace being above 200° F for three years and above 250° F for one year. Tank 241-S-104 is an assumed leaker which currently contains 288 kgal of High-Level REDOX process waste.

241-TX-117 – Represents an assumed leaker with a history of high dome loads. This SST is documented to show signs of a radial crack along the concrete dome. There is currently approximately 480 kgal of waste in the tank, making the primary focus of this tank along the concrete dome and top viewable sections of the steel liner.

241-TY-106 – This SST is an assumed leaker with only 16 kgal of waste currently remaining. This SST was chosen above the remaining TY Tank Farm SSTs due to the large amount of visible sidewall in addition to the presence of 30 tons of diatomaceous earth that have been added.

Type IV A Tanks (1 Million Gallon/Dished Bottom/No Curved Knuckle) :

241-SX-109 – This SST is the only documented tank that meets three key criteria for inspection. There is a high thermal history, eight years above 200° F and five years above 250° F in the tank

headspace. This tank is also an assumed leaker with a high dome load history. Tank 241-SX-109 currently contains 241 kgal of High-Level REDOX process waste.

Type IV B Tanks(1 Million Gallon/Flat Bottom/No Curved Knuckle) :
241-A-106 – Represents a high heat SST that contained waste above 280° F for seven years. These waste temperatures also generated a high thermal history for the tank dome headspace and concrete dome. It is planned to obtain and test a vertical sidewall core from this tank to document any potential effects of high temperatures in the waste and dome space on the concrete and internal rebar properties.

Type IV C Tanks (1 Million Gallon/Flat Bottom/ Curved Knuckle) :
241-AX-102 – This SST is a sound tank with large amounts of exposed steel liner. Only 30 kgal of waste currently remain in 241-AX-102. An inspection of 241-AX-102 will provide a baseline for future inspections in AX Tank Farm.

Table B-1. FY 2010 and FY 2011 Single-Shell Tank Inspections (2 Sheets)

Type I Tanks				
Sound	High Heat	High Dome Load	FY 2010 Inspections	FY 2011 Inspections
x			-	-
x	x		-	-
x		x	-	-
x	x	x	-	-
			-	1 - C-200 Series Tank
	x		-	-
		x	-	-
	x	x	-	-
Type II Tanks				
Sound	High Heat	High Dome Load	FY 2010 Inspections	FY 2011 Inspections
x			B-102 & C-107	-
x	x		-	C-106
x		x	-	-
x	x	x	-	-
			BX-102, T-106, U-104	BX-108
	x		-	-
		x	-	-
	x	x	-	-
Type III Tanks				
Sound	High Heat	High Dome Load	FY 2010 Inspections	FY 2011 Inspections
x			BY-110	S-108 & TX-104
x	x		-	-
x		x	-	BY-102
x	x	x	-	-
			TY-106	-
	x		S-104	-
		x	TX-117	-
	x	x	-	-
Type IV A Tanks				
Sound	High Heat	High Dome Load	FY 2010 Inspections	FY 2011 Inspections
x			-	-
x	x		-	SX-101
x		x	-	-
x	x	x	-	-
			-	-
	x		-	SX-107
		x	-	-
	x	x	SX-109	-

Table B-1. FY 2010 and FY 2011 Single-Shell Tank Inspections (2 Sheets)

Type IV B Tanks				
Sound	High Heat	High Dome Load	FY 2010 Inspections	FY 2011 Inspections
x			-	-
x	x		A-106	-
x		x	-	-
x	x	x	-	-
			-	-
	x		-	A-105
		x	-	-
	x	x	-	-
Type IV C Tanks				
Sound	High Heat	High Dome Load	FY 2010 Inspections	FY 2011 Inspections
x			AX-102	-
x	x		-	-
x		x	-	-
x	x	x	-	-
			-	-
	x		-	AX-104
		x	-	-
	x	x	-	-

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
A-101			X										
A-102				X									
A-103			X										
A-104				X									
A-105		X											
A-106	X												
AX-101			X										
AX-102	X												
AX-103			X										
AX-104		X											
B-101									X				
B-102	X												
B-103									X				
B-104									X				
B-105										X			
B-106										X			
B-107											X		
B-108											X		

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
B-109											X		
B-110												X	
B-111												X	
B-112												X	
B-201													X
B-202													X
B-203												X	
B-204												X	
BX-101											X		
BX-102	X												
BX-103												X	
BX-104												X	
BX-105												X	
BX-106												X	
BX-107												X	
BX-108		X											
BX-109													X
BX-110											X		

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
BX-111													X
BX-112													X
BY-101								X					
BY-102		X											
BY-103								X					
BY-104								X					
BY-105									X				
BY-106									X				
BY-107									X				
BY-108										X			
BY-109										X			
BY-110	X												
BY-111										X			
BY-112										X			
C-101					X								
C-102						X							
C-103						X							
C-104						X							

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
C-105					X								
C-106		X											
C-107	X												
C-108					X								
C-109			X										
C-110				X									
C-111			X										
C-112				X									
C-201		X											
C-202			X										
C-203				X									
C-204						X							
S-101			X										
S-102			X										
S-103			X										
S-104	X												
S-105				X									
S-106				X									

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
S-107				X									
S-108		X											
S-109					X								
S-110					X								
S-111					X								
S-112						X							
SX-101		X											
SX-102				X									
SX-103				X									
SX-104					X								
SX-105					X								
SX-106						X							
SX-107		X											
SX-108						X							
SX-109	X												
SX-110						X							
SX-111							X						
SX-112			X										

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
SX-113			X										
SX-114							X						
SX-115							X						
T-101				X									
T-102				X									
T-103					X								
T-104					X								
T-105					X								
T-106	X												
T-107						X							
T-108						X							
T-109						X							
T-110							X						
T-111							X						
T-112								X					
T-201					X								
T-202						X							
T-203							X						

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
T-204							X						
TX-101								X					
TX-102								X					
TX-103								X					
TX-104		X											
TX-105									X				
TX-106									X				
TX-107									X				
TX-108										X			
TX-109										X			
TX-110							X						
TX-111							X						
TX-112							X						
TX-113											X		
TX-114											X		
TX-115											X		
TX-116												X	
TX-117	X												

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
TX-118												X	
TY-101		X											
TY-102							X						
TY-103							X						
TY-104								X					
TY-105								X					
TY-106	X												
U-101								X					
U-102								X					
U-103								X					
U-104	X												
U-105									X				
U-106									X				
U-107		X											
U-108									X				
U-109										X			
U-110										X			
U-111										X			

Table B-2. Single-Shell Tank In-Tank Inspection Lifecycle Schedule (9 Sheets)

Tank	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
U-112										X			
U-201											X		
U-202											X		
U-203											X		
U-204											X		
# OF TANKS	12	12	12	12	12	12	12	12	12	12	12	12	5

Appendix C Single-Shell Tank Leak Assessment Information

History of Single-Shell Tank Leak Assessment

Historically, the existence of a possible leak from a single-shell tank (SST) was signaled by violation of a tank surveillance leak detection limit. Tank limits were established for the most commonly collected in-tank and ex-tank data: in-tank surface levels, and ex-tank drywell radiation profile logs. When a measurement exceeded the limit, an investigation was initiated to determine whether or not the tank was leaking.

The leak determinations were frequently not straightforward and frequently had to be based on circumstantial evidence. For example, in 1979, 38 tanks were classified as "questionable integrity" tanks. A questionable integrity tank was defined in RHO-CD-213, Volume 1, *Waste Storage Tank Status and Leak Detection Criteria 200 East Area Volume 1,* 1977, as:

> "A tank for which an observed change in one or more surveillance parameters exceed(s) the stated criteria limit(s), and cannot be technically justified as being due to an explainable cause (therefore sound) or to a tank leak (therefore a confirmed leaker) at a confidence level of 95 percent."

Between 1979 and October, 1984, enough additional surveillance data had been collected to declare 7 of the 38 tanks "assumed leakers." The other 31 tanks remained classified as questionable integrity tanks.

In October, 1984, 30 of the remaining 31 tanks were categorically reclassified as assumed leakers. This mass reclassification resulted from two circumstances: (1) all of the SSTs had been deactivated before the beginning of CY 1981 and were no longer needed for active storage of waste, and (2) intense external political pressure was being applied to make a final decision on the leak status of each of these 31 tanks. Some tanks had been in leak classification limbo for as long as 17 years. The decision to re-categorize the tanks as assumed leakers appeared to be a no-cost decision.

A leak volume estimate was not made at the time of the 1984 re-categorization because most of the tanks lacked sufficient leak information with which to develop an estimate. This was the reason they had been previously classified as questionable integrity tanks. It was not until 1989 that leak assignments were made for the final group of 19 re-categorized tanks. A standard leak volume of 8,000 gallons was assigned to each of the 19 tanks. The volume was based on a review of the leaks from 18 other tanks believed to be similar to the group of 19; this similar group had an aggregated leak loss estimated to be ~150,000 gallons of waste, or approximately 8,000 gallons/tank (internal letters 8901832B R1 and 12710-89-042).

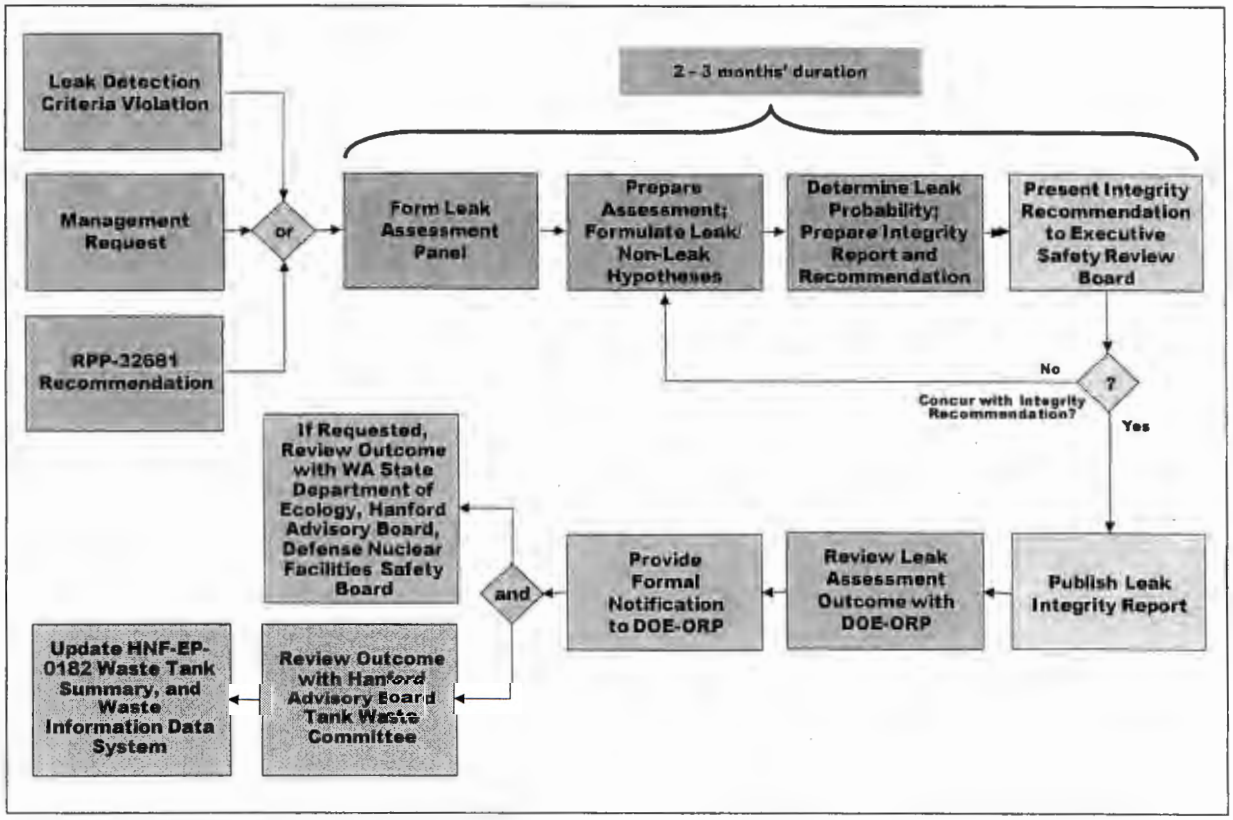
Status of Present Day Single-Shell Tank Formal Leak Assessments

The formal leak assessment process is the method used to formally change the published leak integrity status of SSTs in the Hanford tank farms. This is the key difference between it and the RPP-32681 process described earlier (refer to paragraph 4.1.1, page 25 of this report). The method of analysis used for the formal leak assessment process is

Engineering Procedure TFC-ENG-CHEM-D-42, "Tank Leak Assessment Process" (D-42 process). The D-42 process is based on a probabilistic analysis that assesses the mathematical likelihood (probability) that a tank is leaking or has leaked. The technical basis for the D-42 process, and additional details and examples of the methodology for implementing the process, can be found in HNF-3747, *Tank Leak Assessment Process Technical Background.*

The process, illustrated in Figure C-1, is designed to guide the leak assessment inquiry so that independent groups of knowledgeable reviewers would reach the same leak integrity conclusion if presented with the same data. The leak assessment result is expressed as a probability of the tank leaking, based on the available data.

Figure C-1. Formal Leak Assessment Process Used to Determine Radioactive Waste Tank Leak Integrity



The key attribute of the process is that conclusions can be reached about the likelihood of a tank leak using incomplete knowledge. This is beneficial because there is typically not enough information to conclusively show the existence or absence of a tank leak, as the large population of questionable integrity tanks prior to 1984 illustrates. The formal leak assessment looks at the available in-tank and ex-tank surveillance data, and poses the following question for each surveillance parameter:

"If the tank were leaking, what is the likelihood that the parameter would behave in the manner observed?"

Determining the Location of a Single-Shell Tank Leak and Its Cause

Historically, tank leak detection threshold limits have focused solely on leak determination. The immediate action after determining that an SST was leaking was to pump its contents to a sound tank and deactivate it. With the few notable exceptions discussed later, there has never been a purposeful effort to collect data needed to identify the leak site, or the cause of the leak. In-tank and ex-tank surveillance data used to determine leak integrity have not typically provided information needed to identify leak sites and causes, as the following leak response table indicates (Table C-1).

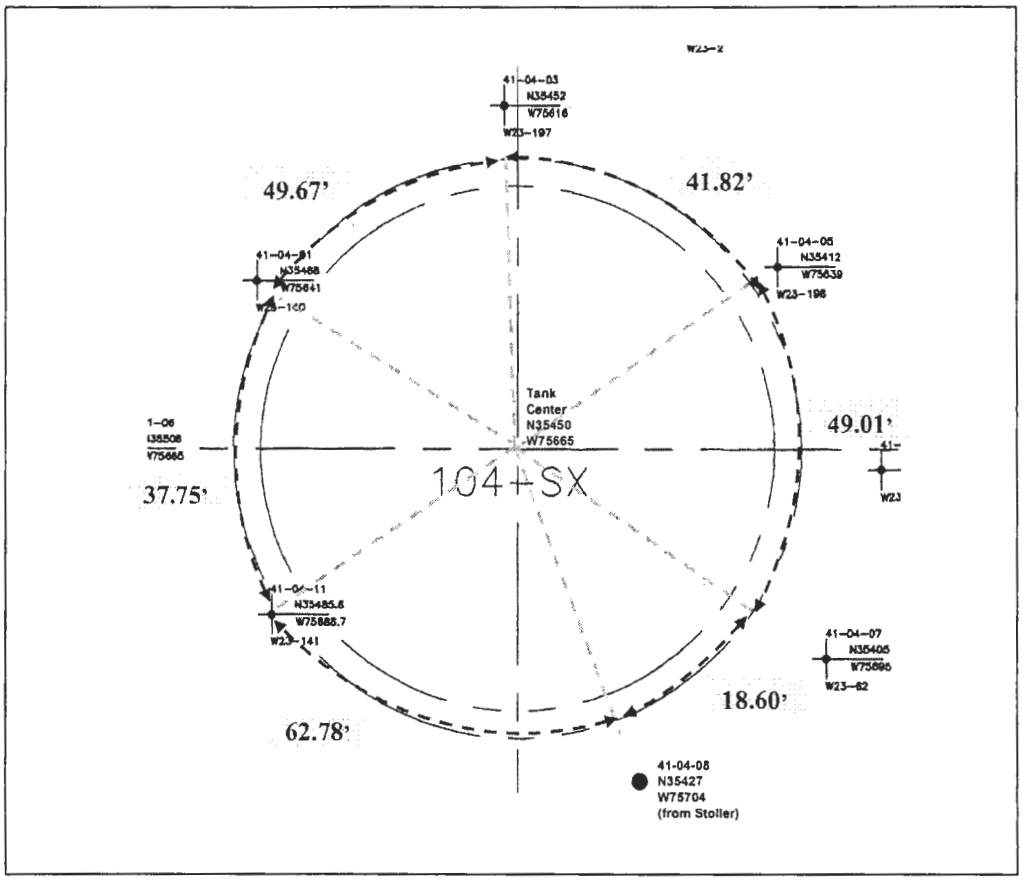
Table C-1. Comparison of Historical Leak Response with Hypothetical Leak Response Necessary to Identify Leak Sites and Leak Causes for a Single Shell Tank

In-tank Surveillance Data	Evidence of Leak	Historical Response to Tank Leak	Required Response to Tank Leak Needed to Determine Leak Location
Waste Surface Level	Decrease in surface level not attributable to other phenomena, such as thermal contraction, evaporation, release of retained gas, or floating crust measurement interference.	Tank contents pumped from tank.	Waste allowed to leak from tank until waste level stabilized, indicating elevation of leak site.
Ex-tank Surveillance Data	**Evidence of Leakage**	**Historical Response to Tank Leak**	**Required Response to Tank Leak Needed to Determine Leak Location**
Drywell Radiation Logs	Appearance of or increase in soil contamination surrounding drywell adjacent to tank.	Tank contents pumped from tank.	Waste allowed to leak from tank until leakage pattern established. Soil contamination increase tracked; additional drywells installed to identify location and elevation of leak site.
Lateral Radiation Logs	Appearance of or increase in soil contamination surrounding lateral beneath tank foundation.	Tank contents pumped from tank.	Waste allowed to leak from tank until leakage pattern established. Soil contamination increase tracked to identify location of leak site.

As an illustration of how difficult identifying an SST leak site can be using ex-tank data, consider the case of tank SX-104, at one time classified as an assumed leaker. In December, 2006, a new liquid observation well was installed in the tank to replace the old, failed well. Neutron moisture measurements of the interstitial liquid level using the new well showed the predictable increase in interstitial liquid level from the installation water. This was followed by a natural decline and re-stabilization of the level by January, 2008, as the free water dissipated through the waste. However, the May 1, 2008, reading showed an interstitial liquid level decrease that exceeded the allowable 1.2-in leak detection limit. Further decreases were measured on May 6, and May 12, 2008. On May 19, 2008, a formal leak assessment was initiated to determine if the tank was re-leaking.

The waste surface level remained stable. During the investigation, the seven drywells surrounding the tank showed no changes in soil contamination levels and no new soil contamination peaks. However, as Figure C-2 shows, the circumferential drywell-to-drywell separation distance varies from 18.6-ft to 62.8-ft. Even if a soil contamination change was detected in one of the drywells, pinpointing the leak radially beyond the likely tank quadrant would have been impossible. Detecting its elevation on the tank sidewall would be complicated as the plume either wicked down the sidewall and flowed outwards upon reaching the footing, or moved down-slope into the soil as it left the leak site.

Figure C-2. Tank 241-SX Drywell Locations and Circumferential Separation Distances (from RPP-ASMT-38450, *Tank 241- SX-104 Leak Assessment Report*)



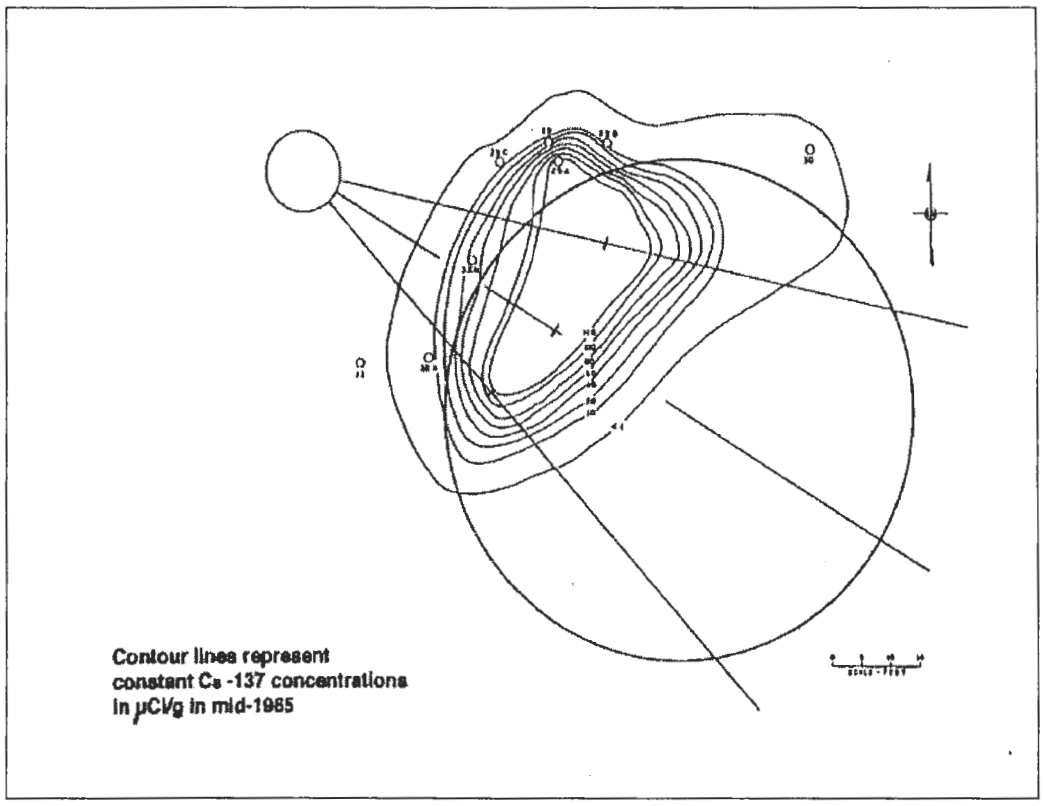
Tanks with Known Leak Site Locations

In some cases SST leaks were so significant that purposeful efforts were made to identify the leak sites. These included:

- Tank A-105: Tank A-105 suffered a steam explosion in January, 1965 that separated the tank bottom liner from the sidewall liner for three-fourths of the circumference of the tank. The liner failure was substantially mapped and results widely reported in documents, such as RHO-CD-625, *Elimination of Water Addition to Tank 105-A 241-A Tank Farm Process Test Plan 781 (Part 1).*
- 241-SX Tank Farm Self-Boiling Waste Tanks SX-107 thru SX-115: Within 13 years of initial operation, five of the nine waste tanks in the 241-SX Tank Farm that stored self-boiling 202-S REDOX Plant first cycle waste failed, including four tanks with bulged floor liners (RHO-R-39, *Boiling Waste Tank Farm Operational History*). Tank SX-113 failed after only eight days of operation in February, 1958.

These nine tanks were each retrofitted with three pipe laterals placed about ten feet beneath the tanks' concrete foundations in 1963 (Drawing H-2-31881 *241-SX Tank Farm Leak Detection System Plan + Section*). On a frequent interval, a radiation rabbit was blown to the end of each lateral, and then slowly withdrawn to map the soil contamination beneath the tank foundation. Two-dimensional isopleths soil contamination maps, prepared from the lateral logs, exist for several of these tanks (Figure C-3).

Figure C-3. Tanks SX-108 Cs-137 Soil Contamination Beneath Tank Foundation (from WHC-MR-300, *Tank 241-SX-108 Leak Assessment*)

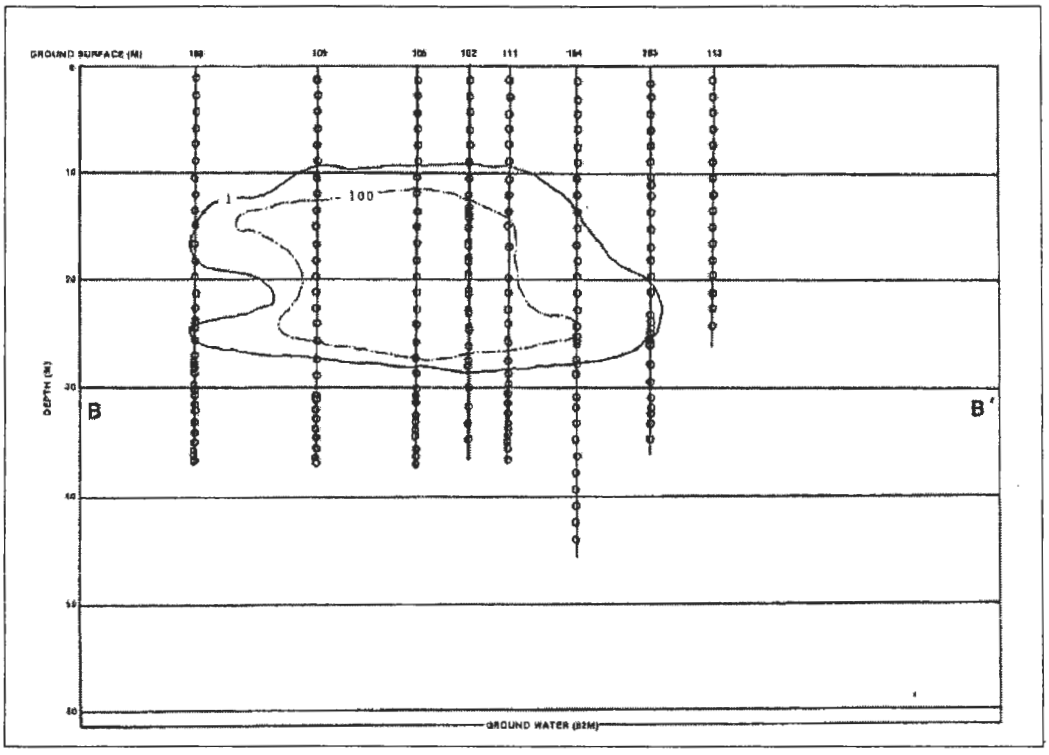


- Tank T-106: On, or about, April 20, 1973, the waste level in tank T-106 began decreasing. The decrease was not recognized as a possible leak until June 7, 1973. During this period, about 115,000 gallons of waste leaked from the tank. Between April 24, 1973, and May 7, 1973, the surface level decreased from 183.7-in to 174-in, indicating the tank was leaking at a rate of ~ 1.4-gallons per minute (RHO-ST-14, *High-Level Waste Leakage from the 241-T-106 Tank at Hanford*).

  Figure C-4; shows the soil contamination isopleths from a vertical section of the vadose zone located immediately south of tank T-106. The contamination plume appears to begin about 9 meters below grade. The dished center of the tank floor

liner is located about 38.5-ft (11.8-meters) below grade. Therefore, it is likely that the leak location was ~9-ft above the tank floor (RHO-ST-14, *High-Level Waste Leakage from the 241-T-106 Tank at Hanford,* H-2-1741, *Tank Farm Riser & Nozzle Elev.*, H-2-73055, *Piping Waste Tank Isolation 241-T-106).*

Figure C-4. Tank T-106 Cs-137 Soil Contamination Vertical Section Adjacent to South Tank Wall (from RHO-ST-14, *High-Level Waste Leakage from the 241-T-106 Tank at Hanford*)



Historical data useful for leak site identification are limited, as previously demonstrated. In some cases it is impractical to do more than assign the leak to a tank quadrant because there are no usable historical data to extend the analysis beyond that simple derivation. The D-42 formal leak assessment process is solely focused on two objectives: (1) determine if the leak integrity status of the tank changed as the result of new data or reinterpreted data; and (2) if the assessment concludes that a leak has occurred, determine the size of the leak and the source term associated with it. There are no provisions in the D-42 process to identify either the leak site or the cause of the leak. These are both out-of-context issues that do not influence the leak integrity determination. Additionally, the requirement to identify the leak site and leak cause would only apply to new leak assessments. New leak assessments became infrequent occurrences once the free liquids were removed from the SSTs.

An equally effective means of addressing Recommendation LD-1 would be to perform a comprehensive review of published leak assessment reports for the 67 assumed leaking

tanks, and derive from these reports the most likely location(s) of the leak site(s). The second, and more problematic, objective would be identification of the leak cause from the published reports. This second objective is not likely to be met by the comprehensive review, based on similar, previous, unsuccessful attempts to understand tank liner failure mechanisms:

In March, 1980, the U. S. Department of Energy Office of Compliance and Overview completed and published a detailed interrogation of Hanford's single-shell tank surveillance program and tank failures. At that time 24 single-shell tanks had leaked. In spite of detailed correlations using service age, temperature, and other common sense variables that would seem to be leak predictors, there was no obvious cause and effect between any of the variables and the tank leaks (RPT-032780, *Assessment of the Surveillance Program of the High-Level Waste Storage Tanks at Hanford*).

Appendix D Expert Panel Recommendations Regarding Single-Shell Tank Future Use

Table D-1. Expert Panel Recommendations Regarding Single-Shell Tank Future Use (6 Sheets)

Specific Recommendation	Implementation Plan	Comments
Recommendation ST-1: An engineering assessment for the SST candidate tank farm should be prepared.		
In the first report, the Panel recommended expanding on Leak Assessment Reports that are performed for assumed leaker SSTs. These reports include information about SST construction history, SST operations history, the types of waste stored in the SST, and a discussion of the locations and causes of leaks. An assessment including similar factors should be performed for identifying SSTs that might be suitable for future use.	This recommendation will be incorporated for all tanks selected for future use.	
Recommendation ST-2: The relative acceptability of SSTs for staging waste should be evaluated on the basis of the following historical information.		
Highest preference should be given to SSTs that have not leaked.	This recommendation will be incorporated as a consideration in selecting tanks for future use.	WRPS will not accept assumed leaking tanks as candidates for waste receiver and storage tanks. Tanks to be retrieved will be selected per individual Tank Waste Retrieval Work Plans and agreements with the State.
Highest preferences should be given to SSTs without fillet joints.	This recommendation will be incorporated as a consideration in selecting tanks for future use.	WRPS will not rule out utilizing SSTs with filet joints for future use. A strategic plan would be developed to allow the correct data to be collected to make a risk based decision on future

Table D-1. Expert Panel Recommendations Regarding Single-Shell Tank Future Use (6 Sheets)

Specific Recommendation	Implementation Plan	Comments
		use of the tank.
Higher preference should be given to SSTs with liners fabricated from A-283 and A-285 steel rather than older steels such as A-7 or A-10.	This recommendation will be incorporated as a consideration in selecting tanks for future use.	WRPS will not rule out utilizing SSTs fabricated form A-7 or A-10 steel. A strategic plan would be developed to allow the correct data to be collected to make a risk based decision on future use of the tank. It may also be noted that AX Tank Farm is constructed of A-201 steel.
Higher preference should be given to SSTs in which the waste has historically been compliant with the DST specifications contained in OSD-T-151-00007, operated at temperatures less than 50°C, and had a nitrite ion/nitrate ion concentration ratio greater than 0.2.	This recommendation will be incorporated as a consideration in selecting tanks for future use.	WRPS will prioritize tanks based on whether they are compliant with the current DST specifications contained in OSD-T-151-00007. No actions will be taken to bring out-of-compliance SSTs into compliance.
Higher preference should be given to SSTs that have not stored wastes at the same level for prolonged intervals.	WRPS will not accept this recommendation as written. There are no SSTs that have not stored waste at the same level for prolonged intervals.	

Table D-1. Expert Panel Recommendations Regarding Single-Shell Tank Future Use (6 Sheets)

Specific Recommendation	Implementation Plan	Comments
Recommendation ST-3: Candidate SSTs should be retrieved.		
Retrieved SSTs are more attractive for several reasons: (1) the liner knuckle, former vapor spaces, liquid air interfaces, and areas previously in contact with waste (potentially including the SST bottom plate) are easier to inspect; (2) residual wastes have been characterized and the potential for corrosion can be assessed; and, (3) data concerning whether the SST leaked during retrieval is available.	This recommendation will be incorporated as a consideration in selecting tanks for future use.	
Recommendation ST-4: The following visual (surface) and ultrasonic (volumetric) Non-Destructive Evaluation (NDE) inspections should be performed.		
A Probabilistic Risk Assessment (PRA) should be performed to inform decisions on both the extent of visual and ultrasonic inspections required and the appropriate technologies for the inspection. An independent review of the PRA should be obtained.	WRPS will not accept this recommendation. WRPS will perform a hydrostatic test of the tank prior to future use of an SST.	Other standard risk assessment tools will be utilized, but WRPS does not propose to conduct a formal PRA.
Visual inspection of the steel liners should be performed to identify surface degradations or associated evidence such as water or tar stains, particularly at former Liquid Air Interface (LAI) or the knuckle.	This recommendation will be incorporated as an activity to be performed as part of the execution of any project for future use of an SST.	It is important to note that visual inspections of the knuckle will be performed to the extent practicable. The knuckle regions of any tank selected for future use are likely to contain waste whether the tank has been previously retrieved or not.

Table D-1. Expert Panel Recommendations Regarding Single-Shell Tank Future Use (6 Sheets)

Specific Recommendation	Implementation Plan	Comments
Volumetric inspection utilizing ultrasonic technique(s) should be deployed to detect tight cracks, wall thinning, and pitting from corrosion, particularly at liner welds and the knuckle.	WRPS will not accept this recommendation. WRPS will perform a hydrostatic test of the tank prior to future use of an SST.	As a risk mitigation activity WRPS intends to commence the development of NDE technologies for the SST steel liners. The WRPS Technology Development organization will work with EM-30 to obtain funding for this effort.
Recommendation ST-5: Improved HRR should be deployed to support future use.		
Improved HRR should be deployed to support future use.	WRPS will deploy and use HRR LDM as required by the anticipated Tank Waste Retrieval Work Plans for each tank.	When receiver tanks have been interim stabilized again, HRR will be removed.
Recommendation ST-6: Hydrostatic testing should be performed by filling the candidate SST in increments with inhibited water.		
Hydrostatic testing should be performed by filling the candidate SST in increments with inhibited water.	WRPS will implement the intent of the recommendation by performing a hydrostatic test with a liquid prior to future use of an SST. If a hydrostatic test cannot be performed WRPS will consider NDE of the steel liner.	
Recommendation ST-7: Adequate emergency tank space and capability to initiate retrieval of staged waste from an SST within 24 hours should be provided.		
Adequate emergency tank space and capability to initiate retrieval of staged waste from an SST within 24 hours should be provided.	WRPS will implement this recommendation via selection of tanks for future use and by including a transfer route to a DST.	

Table D-1. Expert Panel Recommendations Regarding Single-Shell Tank Future Use (6 Sheets)

Specific Recommendation	Implementation Plan	Comments
Recommendation ST-8: Potential leak volume from a staged SST should be minimized by transferring waste in increments.		
Potential leak volume from a staged SST should be minimized by transferring waste in increments	WRPS will implement this recommendation by performing several lifts of liquid into the tank. Between each lift, the tank liquid level will be monitored, the data evaluated and a decision will be made to increase the waste height or cease plans to stage into the tank.	
Recommendation ST-9: The waste level should be maintained below the historical Liquid Air Interface (LAI).		
The waste level should be maintained below the historical Liquid Air Interface (LAI).	WRPS will accept this recommendation and implement via development and implementation of a process control plan for each retrieval into a tank selected for future use.	
Recommendation ST-10: A corrosion potential probe coupon should be installed if recommended by corrosion laboratory studies.		
A corrosion potential probe coupon should be installed if recommended by corrosion laboratory studies.	WRPS will accept this recommendation via a graded approach. Through implementation of other recommendations in RPP-RPT-43116 and RPP-RPT-45921 it is believed that the tank waste will not threaten the steel liner of the tank.	The current proposal requires a corrosion probe to be installed in any SST used as a receiver tank.

Table D-1. Expert Panel Recommendations Regarding Single-Shell Tank Future Use (6 Sheets)

Specific Recommendation	Implementation Plan	Comments
Recommendation ST-11: SST wastes selected for the future use proposal should have a nitrite ion/nitrate ion concentration ratio greater than 0.2, be maintained at less than 50° C and be compliant with DST chemical specifications contained in OSD-T-151-00007 (2010).		
The Panel recommends the criteria from OSD-T-151-00007 be adopted for the operation of the SSTs until technical work establishes a basis for relaxing these criteria, for example because the waste is stored at low temperatures. The Panel also recommends that any heel left in the SST be compliant with these criteria.	This recommendation will be incorporated for all tanks.	
Recommendation ST-12: Installation of bladders in SSTs selected for future use should be considered.		
Installation of bladders in staged SSTs should be considered.	WRPS will accept this recommendation by performing an evaluation of the viability and applicability of deploying polymeric bladders. The deployment evaluation will consider the overall technical decision making process for selecting an SST for future use.	

Attachment 4
10-ESQ-286
(5 Pages)

Change Form M-45-10-01

Change Number M-45-10-01	Federal Facility Agreement and Consent Order Change Control Form Do not use blue ink. Type or print using black ink.	Date September 1, 2010

Originator
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Class of Change

[ ] I - Signatories [X] II - Executive Manager [ ] III - Project Manager

Change Title
Establish new M-045-91 Interim Milestones and Target Dates for SSTs implementing the expert panel's recommendations.

Description/Justification of Change

Hanford Federal Facility Agreement and Consent Order (HFFACO), Milestone M-045-91, requires that the U.S. Department of Energy (DOE), Office of River Protection (ORP) accomplish the following:

- Establish a panel to review available data from retrieved single-shell tanks (SSTs) to (1) evaluate their existing known condition, (2) evaluate proposed future uses, (3) recommend critical modifications and associated schedule to prevent or mitigate degradation, and (4) recommend additional evaluations and program elements that would improve understanding of SST integrity

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Impact of Change

This change implements the requirement of interim milestone M-045-91 and establishes actions to improve the Tri-Parties understanding of Single Shell Tank integrity.

Affected Documents

The HFFACO as amended and Hanford Site internal planning, management, and budget documents (e.g., River Protection Project System Plan, Baseline Control documents, and related work authorizations and directives).

Approvals

_____ _____ _____Approved_____Disapproved
DOE Date

N/A _____ _____ _____Approved_____Disapproved
EPA Date

_____ _____ _____ Approved_____Disapproved
Ecology Date

Description/Justification of Change (continued)

- Provide a report on SST integrity assurance review
- Submit to the Washington State Department of Ecology (Ecology) an agreement change package with interim HFFACO milestones as necessary to implement the panel's recommendations within 90 days of the report.

The first bulleted action was completed by assembling a panel of technical and nationally recognized experts in 2009 and 2010 to review available data from retrieved SSTs and report their findings and recommendations. The second bulleted action was completed by issuing RPP-RPT-43116, "Expert Panel Report for Hanford Single-Shell Tank Integrity Project," and RPP-RPT-45921, "Second Expert Panel Report for Hanford Site Single-Shell Tank Integrity Project".

This change package completes the third bulleted action by establishing two interim milestones and ten target dates in the HFFACO to implement recommendations from RPP-RPT-43116 and RPP-RPT-45921.

Panel reports RPP-RPT-43116 and RPP-RPT-45921 provided recommendations for actions that the Panel "binned" into the following four categories:

1. Confirmation of tank structural integrity (SI)
2. Assessment of the likelihood of future tank liner degradation (LD)
3. Leak identification and prevention (LIP)
4. Mitigation of contaminant migration (MCM)

The table below identifies the recommendations adopted for implementation from the Panel's reports and cross-walks the recommendations to the twelve proposed Target Dates/Interim Milestones. All of the Target Dates and one of the proposed Interim Milestones implement the recommendations from RPP-RPT-43116 and RPP-RPT-45921. One of the proposed Interim Milestones (M-045-91C) requires the assessment of the data obtained from the other actions and (if necessary) the establishment of new milestones.

(NOTE: A milestone is not proposed for the continued use of High Resolution Resistivity, identified in Panel Category 3 [LIP], as this is an ongoing activity. Additionally, milestones are not proposed for Panel Category 4 [MCM] as a number of the Panel's recommendations in this category are met by existing projects or activities [Example: placing barriers over SST Farms].These projects and activities will be continued under the existing administrative mechanisms for each.)

TABLE

Panel Recommendation Summary (Panel Category)	Reference	Proposed Interim Milestone (Summary)
Examine "Non-Compliant" Wastes at 25 °C (LD)	RPP-RPT-43116	M-045-91B, Provide a report on the Chemistries of the SSTs Including "Non-Compliant" Wastes at 25 °C; Ammonia Concentrations for Corrosion Control, and an Assessment of SST Waste Compositional Variation.
Determine Ammonia Corrosion Control Concentration (LD)	RPP-RPT-43116	M-045-91B, Provide a report on the Chemistries of the SSTs Including "Non-Compliant" Wastes at 25 °C; Ammonia Concentrations for Corrosion Control, and an Assessment of SST Waste Compositional Variation.
Assess SST Waste Compositional Variation (LD)	RPP-RPT-43116	M-045-91B, Provide a report on the Chemistries of the SSTs Including "Non-Compliant" Wastes at 25 °C; Ammonia Concentrations for Corrosion Control, and an Assessment of SST Waste Compositional Variation.
NA	NA	M-045-91C, Assess the Adequacy of Information Obtained to Date from the Actions in the M-045-91 Series Milestones and Target Dates and the Need to Establish Additional Interim Milestones.
Perform Modern Structural Analysis and Perform AORs on SSTs (SI)	RPP-RPT-43116 and -45921	M-045-91-T01, Provide Structural Analyses for SSTs in B, BX, C, T and U Farms in FY 2011.
		M-045-91-T02, Provide Structural Analyses for SSTs in BY, S, TX and TY Farms in FY 2012.
		M-045-91-T03, Provide Structural Analyses for SSTs in A, AX and SX Farms in FY 2012.
		M-045-91-T04, Provide Structural Analyses for 200 Series SSTs in B, C, T and U Farms in FY 2013.
Perform Non-Destructive Evaluation of Concrete (SI)	RPP-RPT-43116 and -45921	M-045-91-T05, Provide a Report Documenting the Visual Inspection of 12 SSTs in FY 2010.
		M-045-91-T06, Provide a Report Documenting the Visual Inspection of 12 SSTs in FY 2011.
Expand Leak Assessment Reports (LD)	RPP-RPT-43116	M-045-91-T07 Provide a report on the results of a comprehensive review of published leak assessment reports for all "assumed leaker" tanks in FY 2012.

Obtain and Test Sidewall Core (SI)	RPP-RPT-43116 and -45921	M-045-91-T08 Provide results of testing performed on concrete core obtained from SST Sidewall in FY 2013.
Test Dome Concrete and Rebar "Plugs" (SI)	RPP-RPT-43116 and -45921	M-045-91-T09 Provide results of testing performed on C-107 concrete removed from dome in FY 2013.
Assess Feasibility of Testing for Ionic Conductivity Between Inside and Outside of SSTs (LIP)	RPP-RPT-43116	M-045-91-T10 Provide a report on the feasibility of this technology in FY 2013.

Specific changes to Tri-Party Agreement Appendix D are displayed with double underline to indicate addition of text and by ~~strikeout~~ to indicate deletion of text.

M-045-91B	Provide to Ecology an analysis that documents the technical approach to evaluate the chemistries of the SSTs to determine if those chemistries are outside the understood acceptable limits of the DST chemistries. The report will discuss wastes at 25^0C; ammonia concentrations for corrosion control of waste in the liquid and solid phases; and an assessment of SST waste compositional variation in the solid layers as that variation may create a propensity for stress corrosion.	September 30, 2011
M-045-91C	Ecology and DOE shall meet for the purpose of assessing the adequacy of information obtained from the actions in the M-045-91 series milestones and target dates to determine if additional actions are required for SST integrity assurance.	July 31, 2013
M-045-91C-T01	Provide to Ecology structural analysis of record final documentation (models, analyses, results, and conclusions) for SSTs in B, BX, C, T and U Farms.	September 30, 2011
M-045-91C-T02	Provide to Ecology structural analysis of record final documentation (models, analyses, results, and conclusions) for SSTS in BY, S, TX and TY Farms.	January 31, 2012
M-045-91C-T03	Provide to Ecology structural analysis of record final documentation (models, analyses, results, and conclusions) for SSTs in A, AX, and SX Farms.	September 30, 2012
M-045-91C-T04	Provide to Ecology structural analysis of record final documentation (models, analyses, results, and conclusions) for 200 series SSTs in B, C, T, and U Farms.	October 31, 2012
M-045-91C-T05	Provide a report to Ecology documenting the visual inspection of 12 SSTs.	May 31, 2011
M-045-91C-T06	Provide a report to Ecology documenting the visual inspection of 12 SSTs.	May 31, 2012
M-045-91C-T07	Provide Ecology a report containing the outcome of a comprehensive review of all published leak assessment for "assumed leaker" tanks.	September 30, 2012
M-045-91C-T08	Provide Ecology a report containing the results of testing performed on the concrete core obtained from Tank A-106	May 31, 2013
M-045-91C-T09	Provide Ecology a report containing the results of testing performed on the concrete removed from the dome of Tank C-107.	May 31, 2013
M-045-91C-T10	Provide Ecology a report assessing the feasibility of testing for ionic conductivity between the inside and outside of SSTs.	May 31, 2013