PNNL-13571

Pacific Northwest National Laboratory

Operated by Battelle for the U.S. Department of Energy

Expert Panel Recommendations for Hanford Double-Shell Tank Life Extension

C.W. Stewart, Editor

S.H. Bush, Chair
H.S. Berman
C.J. Czajkowski
J.R. Divine
G.J. Posakony
A.B. Johnson
M.R. Elmore
D.A. Reynolds
R.P. Anantatmula
R.L. Sindelar
P.E. Zapp

June 2001

Prepared for the U.S. Department of Energy
Under Contract DE-AC06-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RL01830

Expert Panel Recommendations for Hanford Double-Shell Tank Life Extension

CW Stewart, Editor

Panel:
SH Bush[a] (Chair) ________________________

HS Berman[b]
CJ Czajkowski[c]
JR Divine[d]
GJ Posakony[e]
AB Johnson[e]
MR Elmore[e]
DA Reynolds[f]
RP Anantatmula[f]
RL Sindelar[g]
PE Zapp[g]

June 2001

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RL01830

Pacific Northwest National Laboratory
Richland, Washington

(a) Review & Synthesis Associates
(b) ADI Technology Corporation
(c) Brookhaven National Laboratory
(d) ChemMet, Ltd., PC
(e) Pacific Northwest National Laboratory
(f) CH2M HILL Hanford Group, Inc.
(g) Westinghouse Savannah River Company

Abstract

An expert workshop was held in Richland, Washington, May 1–4, 2001 to review the Hanford Double-Shell Tank Integrity Project and make recommendations to extend the life of the double-shell tanks. The scope of the workshop was limited to corrosion of the primary tank liner, and the main areas for review were waste chemistry control, headspace and annulus humidity control, tank inspection, and corrosion monitoring.

Participants included corrosion experts from Hanford, the Savannah River Site, Brookhaven National Laboratory, Pacific Northwest National Laboratory, and several experts from industry. The workshop developed 73 specific recommendations to improve the tank integrity program. A senior review committee selected from the initial workshop participants later grouped and sorted this list into 27 high-priority recommendations. This report describes the current state of the program, the final recommendations of the workshop, and the rationale for their selection.

Executive Summary

The purpose of the Double-Shell Tank (DST) Life Extension Workshop and the subsequent Senior Review Committee (SRC) meeting was to perform a comprehensive, expert review and assessment of all pertinent technical information associated with DST operations and inspections for the Hanford DST Integrity Project. Additionally, the experts brought together for these assessments were tasked to provide pertinent, prioritized recommendations that, if implemented, would ensure that the DSTs perform their mission past 2028.

Background

The Hanford DST resource consists of 28 tanks, each of more than one-million-gallon capacity, organized into six tank farms. The DSTs presently contain over 21 million gallons of high-level waste with about 80 million curies of radioactivity. The DSTs have been in service for 15–30 years and were originally designed to provide a 20- to 50-year service life. To meet Hanford programmatic requirements, all the DSTs need to meet or exceed their design life before the mission is completed.

The Hanford Double-Shell Tank Integrity Project (TIP) was established in January 2001 based on the need to ensure DST integrity past an operational horizon of 2028 and in recognition that the waste in four DSTs had remained outside established chemistry controls for years and annulus ventilation systems in several tanks had been out of service for long periods. The objectives of the TIP are to correct out-of-specification waste chemistry conditions, restore inoperable vital support systems (e.g., the tank annulus ventilation), baseline the existing DST conditions, and develop conservative controls and effective surveillance programs to minimize further DST degradation and assess future corrosion concerns.

The DST Life Extension Workshop was chartered to support the TIP objectives. It consisted of two assessment phases, the workshop and the Senior Review Committee (SRC) meeting. The workshop was held May 1–4, 2001, gathering 24 experts from industry, national laboratory, and DOE Hanford and Savannah River sites (see Section 2 for the names and affiliations and Appendix A for biographical sketches). Based on technical presentations of pertinent information, the workshop performed a detailed review of DST design and support systems issues, the chemistry control program, corrosion monitoring and mitigation, and the DST inspection program (visual and ultrasonic methods and results). The review was facilitated by a series of questions designed to elucidate pertinent DST issues and concerns (see Appendix D for this question set and notes on the discussions). The workshop reviews generated 73 individual recommendations (see Appendix E for descriptions and rationale) to enhance the achievement of DST life extension and to resolve uncertainties in DST technical issues.

The Senior Review Committee, which met May 21–22, 2001, was a smaller, multidisciplined, expert body (see Section 3 for SRC membership). The SRC was tasked to analyze, consolidate, balance, and prioritize the original recommendations to ensure that they directed a coherent and achievable program for DST life extension. The SRC reviewed in detail all the items in these groupings to ensure that the recommendations provided a balance between detection and prevention of DST problems and covered all the needs of the DST Integrity Project. The team maintained a focus on what is most important for DST life extension. The SRC assigned priority categories to each recommendation set, which should be interpreted as follows:

Very High Priority:	Action is **mandatory** on an **aggressive schedule** to protect tanks from immediate damage.
High Priority:	Action is **mandatory** to ensure tanks can be operated beyond their design life.
Nominal Priority:	Action is **recommended** for possible improvement of tank lifetime, as resources permit.
Low Priority:	Action is **not recommended**.

Only Very High Priority and High Priority recommendations are listed in this summary. See Section 3.0 for those of lower priority.

Very High Priority and High Priority Recommendations

Three **Very High Priority** overarching management action recommendations stand out as absolutely necessary and require immediate accomplishment:

- Establish a top management priority to provide sufficient consistent funding for the TIP to perform the immediate and long-term actions required to protect the DST resources.
- Establish a top management priority to provide funding to 1) correct the waste chemistry on the four tanks that are now out of specification as soon as possible and 2) consistently maintain all tanks within specifications.
- Establish a top management priority to provide funding to return the inoperative annulus ventilation systems on AZ-101 and 102 to service and to maintain all DST annulus ventilation and other vital support systems in operational condition.

These recommendations for management priority and focus must be accomplished to maintain and extend the DST lifetime and to prevent loss of vital DST capacity due to failure by corrosion. Without such long-term management commitment, the DST mission cannot succeed.

Other **Very High Priority** recommendations are associated with necessary improvements to chemistry and corrosion controls (additional detail on the basis for these recommendations is summarized in Section 3). They are

- Perform frequent, regular sampling and analysis of the waste instead of depending on caustic depletion models to schedule sampling. Sample and analyze all tank layers to establish existing conditions, including vertical and radial waste uniformity and analytical uncertainty, and to generate a coherent database.
- Establish corrosion chemistry data quality objective (DQO) to ensure that consistent, high-quality corrosion data will be obtained. Archived waste samples should be re-analyzed under the new DQO, as appropriate.

- Through laboratory testing with simulants and waste samples and through improved waste sampling, establish the appropriate chemical limits for each layer to prevent or minimize the potential for stress corrosion cracking (SCC) in the knuckle or pitting and excessive thinning of the tank wall.
- Complete the measurement and analysis of natural mixing dynamics so timely decisions can be made on the need for installing mixing pumps for tank life-extension purposes.
- Evaluate the benefits and feasibility of adding nitrite corrosion inhibitor directly, along with the caustic additions for chemistry control.
- Benchmark the Savannah River Site tank farm operations for tank sampling and analysis efficiencies and effectiveness.

Next, the Workshop/SRC established a series of **High Priority** recommendations associated with maintaining the tanks in specification, minimizing corrosion, and operating vital safety systems effectively, as follows:

- Add corrosion chemistry conditions to the waste compatibility criteria to ensure that the rate or volume of dilute waste or raw water additions do not move the waste out of specification.
- Develop a layup and sampling procedure for tanks left with a waste heel after being pumped out.
- Consider increasing the margin between waste chemistry and the chemistry corrosion limits (i.e., pH >12), based on corrosion studies and information from the Savannah River Site.
- Fully characterize the tank waste simulants originally used to determine tank chemistry controls. Determine free hydroxide, nitrate/nitrite, pH, corrosion potential, etc., in the simulant to compare with actual waste composition data.
- Conduct an optimum experimental test program, possibly including low-strain rate tests, to establish chemical conditions to reach stress corrosion cracking (SCC) thresholds for the most vulnerable tank regions. Analysis of sediment and supernatant composition and analysis of more recent SCC data will guide the experiments.
- Plan and perform cold corrosion tests for bulk corrosion, pitting initiation and inhibition, and waterline corrosion on an appropriate range of conditions, to determine safety margin on present chemistry controls and possibly extend their range.
- Systematically and periodically vary waste levels in DSTs equipped for transfers to minimize the effects of waterline corrosion. Maintain this administrative control unless and until chemistry limits are developed that ensure no waterline corrosion.
- Administratively control DST waste levels to avoid maintaining levels in the minimum calculated wall margin regions (100- to 150-inch range) until reassessment with probabilistic mechanical stress analysis determines the accuracy of and need for the control.

- Provide heating or dehumidification for the annulus ventilation system if relative humidity reaches or exceeds 30% for extended periods. Monitor the humidity in some selected DST annuli or review meteorological records to assess the need.
- Eliminate the potential for rain and snow melt intrusion and groundwater or process water invasion of the annulus.

Next, the Workshop/SRC generated several **High Priority** recommendations for tank corrosion condition inspections and tank repair options.

- Complete the visual inspections for all DSTs to establish a corrosion baseline in two years (not to exceed three years) and increase the frequency of scheduled visual inspections thereafter. Let these results guide the priority and locations of ultrasonic testing (UT) (including UT examination of waterline areas).
- Perform volumetric nondestructive examination (NDE) (UT, eddy current [ET]) on all tanks at least every five years, including a vertical strip to cover changing waterlines. Focus priority efforts on tanks known to be out of specification or with known corrosion.
- Continue to support T-SAFT (tandem-synthetic aperture focusing technique) development to achieve a viable UT inspection of the tank knuckle regions.
- Evaluate the use of pulsed ET techniques to supplement UT inspections.
- Complete the DQO for UT inspections to ensure the consistency and quality of UT measurements.
- Complete the procurement and use of a gas (or other) tracer technology to determine whether tank AY-101 has a perforation. Maintain the technology for other potential tank evaluations.
- Benchmark the Savannah River Site NDE equipment and methodology for potential efficiencies and application to the Hanford DSTs.
- Develop a contingency plan for weld repair of DST defects (e.g., perforation, wall thinning, etc.). Include specifications and procedures, stray current corrosion considerations, and qualification of suppliers. Also, perform an assessment of the potential use of mechanical plugs or sealants (e.g., epoxy) to seal potential tank leaks.

Conclusions

The DSTs represent a vital resource that is the cornerstone of the Hanford Site remediation program. These DSTs were built to last 20–50 years, and with careful operational controls and management attention, their service life can be extended. Conversely, if appropriate conservative chemistry controls are not routinely maintained, and vital support systems become inoperative, DSTs may not achieve their original design life.

The Workshop and SRC reviews of the technology bases, areas of technical uncertainty, and the necessary actions to maintain and extend the DST useable lifetime to support the Hanford mission resulted in a well-considered set of recommendations to achieve that goal. The

Workshop/SRC's set of "Very High Priority" and "High Priority" recommendations (as described briefly above and in more detail in the report) needs to receive full management and budgetary support for programmatic success.

Acknowledgments

The committee acknowledges the excellent contribution and hard work of the participants and presenters at the initial workshop that performed the review of the Hanford Tank Integrity Project and developed the original set of recommendations. The participants include

Susan W. Borenstein, APTECH
Glenn L. Edgemon, HiLine Engineering
Ed A. Fredenburg, CHG
Larry J. Julyk, CHG
Nick W. Kirch, CHG
Mark A. Knight, CHG
Steve Krahn, ADI Technology Corp.
John Mickalonis, Westinghouse Savannah River Company
EC Gar Norman, CHG
Stan G. Pitman, PNNL
Dave H. Shuford, CHG

Thanks to Jack Lentsch, CHG project manager, for supporting and guiding the workshops. The efforts of workshop facilitators, Chuck Stewart and Joe Brothers, PNNL, are also acknowledged. A special tanks to Karen Mercer for her assistance in the logistics of setting up and running the workshop.

Sections of the report were written by the following staff:
Judi Cuta, PNNL
Monte Elmore, PNNL
Karen Mercer, PNNL
Chuck Stewart, PNNL
Ed Fredenburg, CHG
Herb Berman, ADI
Steve Krahn, ADI

Sheila Bennett, PNNL, edited the report, and Denny Damschen, PNNL, provided tank data and produced the CD containing workshop presentations.

Contents

Figures

Tables

Acronyms

AB	authorization basis
BNL	Brookhaven National Laboratory
CCTV	closed circuit television
CHG	CH2M HILL Hanford Group, Inc.
DQO	Data Quality Objective
DST	double-shell tank
DWPF	Defense Waste Processing Facility
EN	electrochemical noise
ET	eddy current testing
FGWL	Flammable Gas Watch List
FSAR	Final Safety Analysis Report
HAZ	heat-affected zone
HLW	high-level waste
LPR	linear polarization resistance (probe)
NCL	nonconvective layer (aka "sludge")
NDE	nondestructive examination
MIC	microbiologically induced corrosion
PFP	Plutonium Finishing Plant
PNNL	Pacific Northwest National Laboratory
PUREX	Plutonium-Uranium Extraction plant
SCC	stress corrosion cracking
SRC	Senior Review Committee
SRS	Savannah River Site
SST	single-shell tank
TPA	Tri-Party Agreement
T-SAFT	tandem-synthetic aperture focusing technique (NDE technology)
TSIP	Tank Structural Integrity Panel
TWINS	Tank Waste Information Network System
UT	Ultrasonic testing (ultrasonic examination)
WHC	Westinghouse Hanford Corp.

1.0 Introduction

This report documents an assessment of the Hanford Double-Shell Tank (DST) Integrity Project performed during an expert workshop and review held in Richland, Washington, in May 2001. The purpose of this effort was to review the Hanford Tank Integrity Project and recommend specific changes to extend DST life. These recommendations and their rationale provide a technical basis for Hanford DST life extension to ensure that the DSTs remain a viable resource through the balance of the Hanford mission.

The 28 Hanford DSTs contain over 21 Mgal of waste including about 80 MCi of ^{90}Sr and ^{137}Cs. The tanks are 15–30 years old and have a service life of 20–50 years. Some tanks will exceed their design life before their mission to support single-shell tank (SST) retrieval and waste vitrification is complete. No leaks have been detected in any DST to date; however, significant corrosion has been observed in one tank. The waste chemistry in four tanks is outside the corrosion limits, and the annulus ventilation systems in several tanks have been inoperative for several years.

The Hanford Tank Integrity Project was established in January 2001 (Staehr 2001) with the mission to ensure that the DSTs can be operated until 2028 and beyond. The objectives of the project are to correct out-of-specification waste chemistry, restore the annulus ventilation systems to full operation, develop controls and surveillance programs to prevent and detect corrosion in the future, and inspect and assess the structural integrity of the DSTs and ancillary facilities.

This introduction provides the background summarizing the history and design of the DSTs, the tank integrity program and its makeup, the organization of the workshops, and a summary of important corrosion mechanisms. The rest of the report is arranged to portray the review process accurately so that the background and rationale for the final recommendations are clear. Section 2 presents the deliberations of the initial workshop, including summaries of the presentations, description of needs and problem areas identified in the reviews, and a distillation of recommendations and lessons learned in each of the three program elements reviewed. The method and criteria for ranking the specific recommendations are also described. Section 3 is the report of the Senior Review Committee and the final recommendations. Section 4 lists the references cited. Detailed lists of data and information are contained in appendixes.

1.1 History and Design of the Hanford DSTs

This section presents a brief overview of the history of the Hanford DSTs. Section 1.1.1 describes the construction history of the tanks and their physical design parameters. Section 1.1.2 summarizes the waste transfers to and from the tanks over time in terms of the waste level histories. Section 1.1.3 summarizes the thermal characteristics of the waste and describes the primary and annulus ventilation systems. Section 1.1.4 summarizes the current status of each tank, including the composition of the waste it contains.

1.1.1 Design and Construction of the Hanford DSTs

At Hanford, radioactive waste is stored in 177 carbon steel tanks with capacities of 50 to 1,200 kgal. Of these, 149 are SSTs built in the 1940s, 1950s, and early 1960s, and 28 are DSTs constructed from 1968 through 1986. Figure 1.1 is an aerial photograph of a tank farm under construction, showing tanks in various stages of completion. The SSTs were removed from active use in 1980, and since then, much of their pumpable liquid has been transferred to the DSTs, which entered service from 1971 through 1986. The liquid transferred to the DSTs was typically concentrated by evaporation, so in many of the tanks, the waste separated into a supernatant liquid layer over a relatively deep layer of sediment formed by precipitation as the waste cooled.

Figure 1.2 shows a typical simplified diagram of the DST structure, which is, in effect, two tanks in one, comprising an inner primary tank and a secondary outer tank with a reinforced concrete shell. The primary and secondary tanks are carbon steel from 3/8 to 7/8 inches thick. The wall thickness of the concrete is nominally 18 inches. The entire tank structure is buried at a depth of 6 to 8 feet, measured from the top of the tank dome (Han 1996). Table 1.1 summarizes the structural design parameters of the DSTs by tank farm.

The DSTs were constructed over a period of about 18 years (from 1968 to 1986), with a design life of 20 to 50 years. Table 1.2 summarizes the service date, expected life span, and current age of the Hanford DSTs. The two AZ tanks have exceeded their design lives, and the AY tanks have about 10 years left. The remaining tanks are about halfway through their design lives, with 20 to 30 years remaining. It is not anticipated that any of the tanks will be taken out of service unless absolutely necessary. The current pace of consolidation and final immobilization of the

Figure 1.1. Double-Shell Tank Farm under Construction, circa 1980

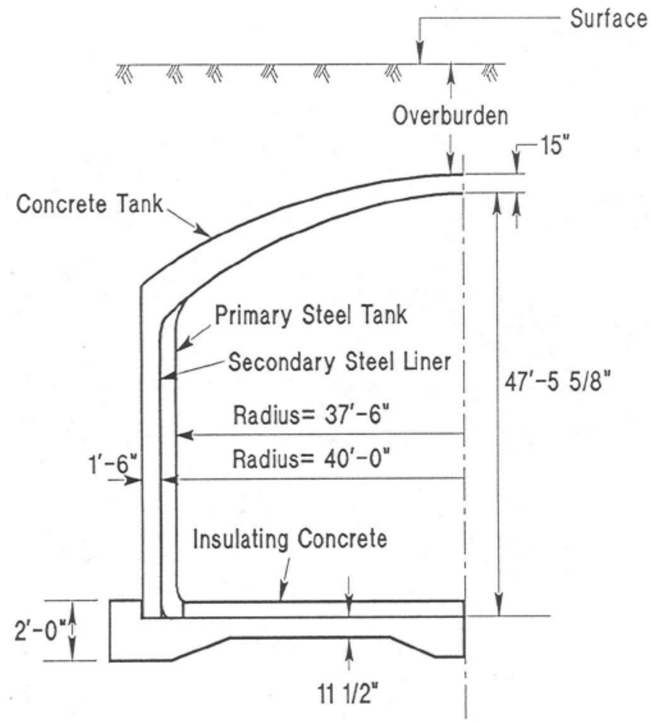


Figure 1.2. Cross-Section of a Typical Double-Shell Tank

waste will require the DSTs to remain in service until at least 2028, beyond the design life of the tanks in the AY, AZ, and SY farms.

Table 1.1. Summary of Material Design Specifications for Double-Shell Tanks

	Primary and Secondary Tanks			Reinforced Concrete Outer Tank					
				Specified compressive strength (ksi)				Reinforcement	
Tank Farm	Carbon steel	Min. yield (ksi)	Min. ult. (ksi)	Dome	Wall	Foundation	Insulating	Rebar	Ties
AN	A537 Class 1	50	70	5	5	4.5	0.130	A615 Gr. 60	A615 Gr. 40
AP	A537 Class 1	50	70	5	5	4.5	0.130	A615 Gr. 60	A615 Gr. 40
AW	A537 Class 1	50	70	5	5	4.5	0.130	A615 Gr. 60	A615 Gr. 40
AY	A515 Gr. 60	32	60	3	3	3	0.200	A432 Gr. 60	A432 Gr. 60
AZ	A515 Gr. 60	32	60	3	3	3	0.200	A432 Gr. 60	A432 Gr. 60
SY	A516 Gr. 65	35	65	4.5	4.5	3	0.130	A615 Gr. 60	A615 Gr. 40

Table 1.2. DST Age and Design Life Summary

Farm	Construction Dates	Service Date	Service Life (yr)[(a)]	Years in Service
AN (7 tanks)	1980–81	1981	50	20
AP (8 tanks)	1983–86	1986	50	15
AW (6 tanks)	1974–76	1980	50	21
AY (2 tanks)	1968–70	1971	40	30
AZ (2 tanks)	1971–77	1976	20	25
SY (3 tanks)	1974–76	1977	50	24
(a) Service life is from Han (1996).				

The diagram of the DST structure in Figure 1.2 gives the impression of two seamless barriers between the tank contents and the external earth. However, where the primary liner meets the secondary shell at the dome, the two plates merely overlap, as shown in Figure 1.3 (from AZ-Farm drawing H-2-67245). Though the figure does not show the flashing that is tack-welded over the joint, this is a location where water inleakage (e.g., from around risers, drains, etc.) could invade the annulus.

Figure 1.4 (detail from SY-Farm drawing H-2-37753) shows the lower knuckle region where stress corrosion cracking is of particular concern due to high mechanical stress and contact with waste (see Sections 1.3 and 2.0). The ultrasonic examination equipment has been unable to reach beyond the upper three inches of the lower knuckle due to the curvature of the lower knuckle. The most highly stressed region of the lower knuckle, where stress-corrosion cracking (SCC) would be most likely, is at the point of tangency between the flat bottom and the curved portion of the knuckle. Access to this region with nondestructive examination (NDE) equipment is restricted by the concrete insulating slab that extends radially into the annulus beyond the bottom of the lower knuckle. The only access to this region is through a series of small radial ventilation slots (not shown).

1.1.2 DST Waste Level History

The waste level data for the 28 DSTs show that some tanks have been used more actively than others. Some tanks were filled in a series of transfers over their first few years in service, and the waste level has remained essentially constant to the present. Other tanks have been emptied and filled repeatedly in transfers consisting of SST saltwell liquor and waste from miscellaneous sources including B-Plant, S-Plant, T-plant processes, Plutonium-Uranium Extraction (PUREX) plant, Plutonium Finishing Plant (PFP), and 300 and 400 Area cleanup. Figures 1.5 through 1.9 plot the level history for all tanks in the six DST farms.

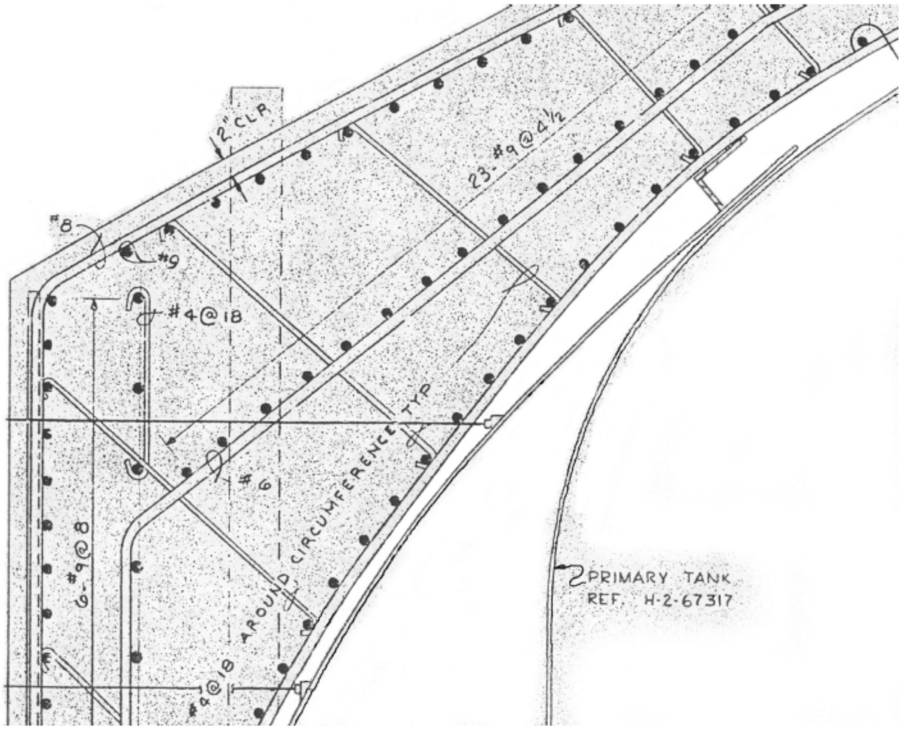


Figure 1.3. Interface of Primary and Secondary Liner in Haunch Region

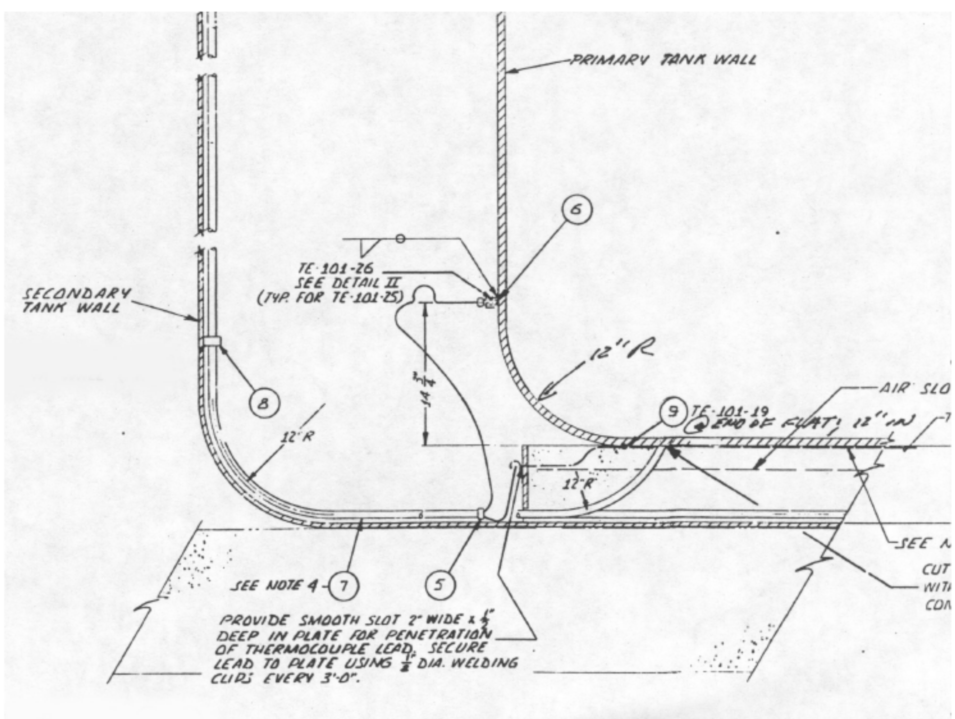


Figure 1.4. DST Cross-Section in Lower Knuckle Region

Figure 1.5 shows that the waste level has been essentially static in all but two of the tanks in the AN farm. Tanks AN-102, AN-103, AN-104, AN-105, and AN-107 show essentially no level change since 1986 or before except for small additions of flush water and normal evaporation. (AN-103, AN-104 and AN-105 have been on the Flammable Gas Watch List [FGWL], which precludes waste additions.) The most operationally active tank in this farm is AN-101, which has seen multiple transfers of SST waste since 1994. Transfers in AN-106 have been mainly DST waste to and from AP and AW farm tanks. AN-106 has been essentially empty since 1997.

Figure 1.6 shows that there has been almost continual transfer activity to and from all the tanks in AP farm since it initially came into service in 1986. Some tanks have seen more activity than others, however. Four of the eight tanks in the farm are nearly full (94 to 98%). AP-101 has been full most of the time, having been completely filled by about 1990, then emptied out once in 1994 and refilled by 1996. AP-102 was initially filled in 1987, emptied out in a series of transfers in 1989, and then remained nearly empty until being filled again in 1993. Although it has been full since January 2000, AP-104 has been empty most of the time, with only two intervals of about a year or so duration (in 1987–88 and 1994) when it contained a significant amount of waste. AP-105 was initially filled by 1989 and remained stable until about 1995, when it was emptied and then refilled in a series of transfers. It was filled to its current level in mid-2000 and has remained stable since then.

The other four tanks in the AP farm show multiple transfers. AP-103 was emptied out in 1994, and since then has received only one major transfer, in early 1999, which filled it to about 24% of capacity. AP-108 shows a similar history except that it was again emptied in 1999 and has not been refilled since then. AP-106 and AP-107 show the most activity of all tanks in the AP farm,

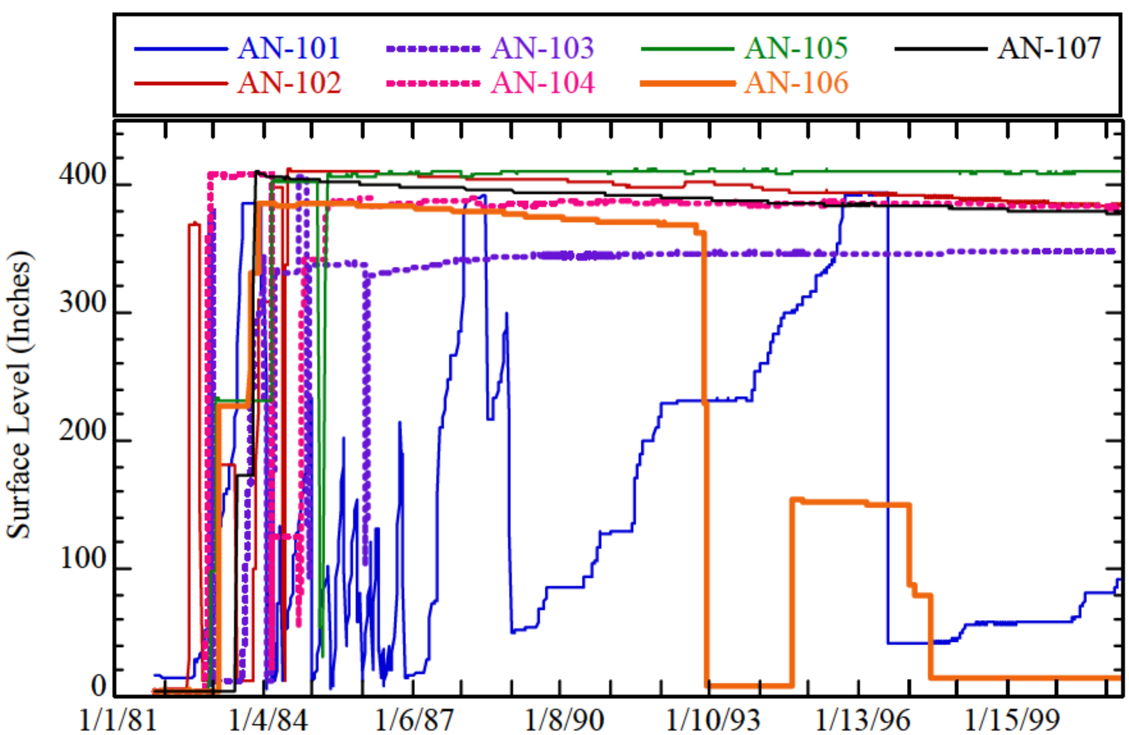


Figure 1.5. Level History of Tanks in the AN Farm

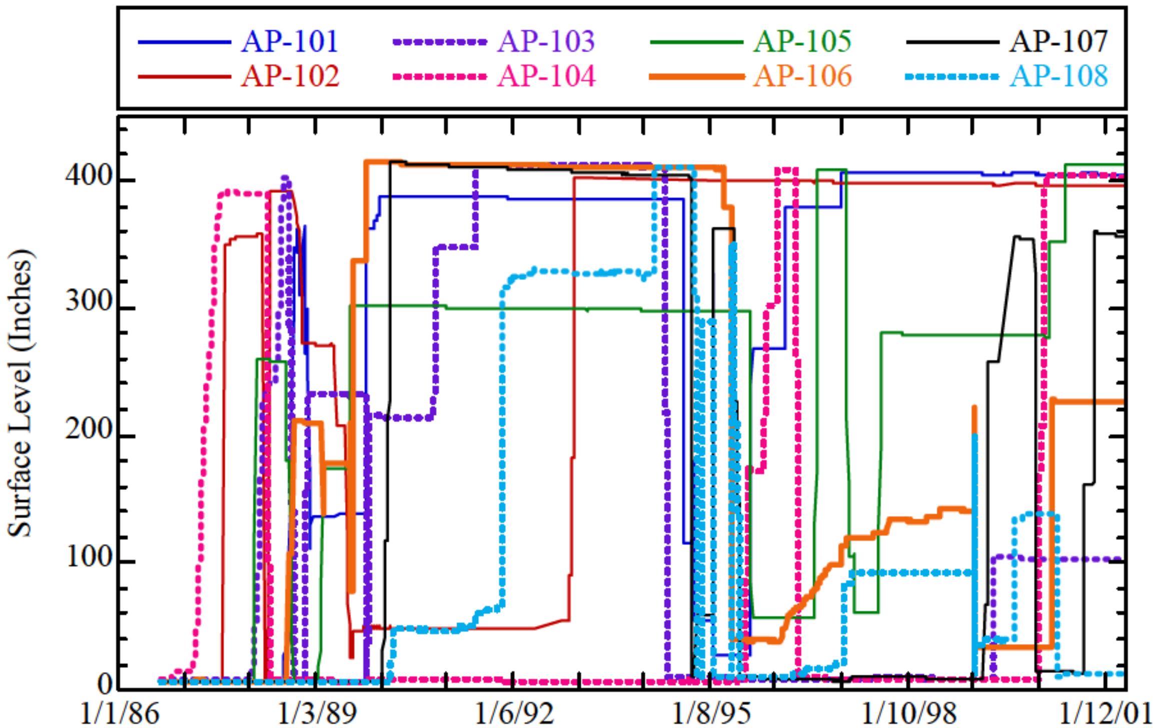


Figure 1.6. Level History of Tanks in the AP Farm

with many small transfers of waste from miscellaneous sources, including B-Plant, S-Plant, and T-Plant, and 300 and 400 Area waste, as well as transfers to and from other DSTs.

Figure 1.7 shows that many of the tanks in the AW farm have seen considerable transfer activity over their service life. AW-101 is the exception. It was filled nearly to capacity (97%) in 1986 and has remained stable ever since. (It is on the FGWL, which prevents waste addition.) AW-103 has also been relatively stable over the past 10 years after initially seeing repeated transfers in the early years of service until 1989. From 1989 to 2001, only one major transfer was made, when waste was removed in 1995. AW-103 was then filled nearly to capacity by a transfer of double-shell slurry waste from AW-106 in January 2001. AW-104 has also been very stable. After being filled nearly to capacity in 1991, the level did not change significantly until nearly three-fourths of its contents were transferred to AW-102 in January 2001.

There was a relatively large number of transfers to and from AW-105 up until 1995, after which it was emptied to approximately 37% of its capacity in a series of transfers completed by the end of 1996. Since then, there have been no significant level changes in this tank. In contrast, AW-102 and AW-106 have seen almost continual transfer activities throughout their service life, experiencing level changes of over 50% on at least a yearly basis. AW-102 is nearly empty, and AW-106 is filled only to about 26% of capacity.

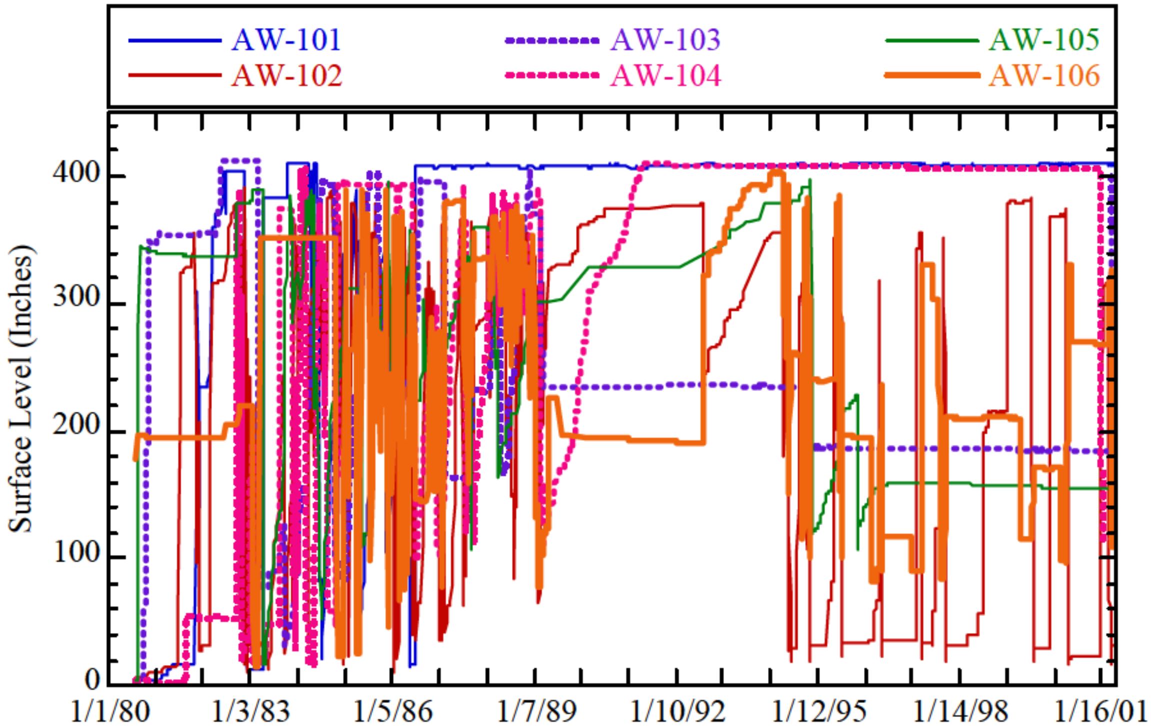


Figure 1.7. Level History of Tanks in the AW Farm

Figure 1.8 shows the level history for the four tanks in the AY and AZ farms. Until late 1988, AY-101 was receiving saltwell liquor from the SSTs. It has been relatively stable since then, with only small caustic and water additions. A large volume of AY-101 waste was transferred to AW-101 in 1997. There have been no big changes since then. Activity in AY-102 has been almost continuous throughout its service life, with many small transfers, including B-Plant, S-Plant, and 300 and 400 Area waste. In 1998–99, the waste in C-106 was transferred to AY-102 in a series of sluicing operations (Cuta et al. 2000), bringing the waste to its present level. The two AZ farm tanks were filled nearly to capacity by 1987 and have been relatively stable ever since. The level increases from 1994 on are due mainly to flush water additions. All decreases in waste level since 1989 in Tanks AZ-101 and AZ-102 are ascribed to evaporation or instrumentation changes.

Figure 1.9 shows the level history of the three tanks in the SY farm. The level history of SY-101 shows oscillations of 6 to 12 inches starting shortly after it was first filled in 1981 and resulting from buoyant displacement gas release events (BD GREs) that were mitigated by the installation of a mixer pump in 1993. The level rise due to uncontrolled crust growth, which became a safety issue in 1997, is shown to be remediated finally by the series of transfers and back-dilutions with water in late 1999 and early 2000 (Mahoney et al. 2000). The level history of SY-103 also appears very stable, with only two noticeable additions (in 1985 and 1988) since initially being filled in 1981. There has been no significant level change in this tank since 1989 except for smaller peaks from BD GREs that still occur. In contrast, SY-102 served as a staging tank for cross-site transfers to the DSTs in the 200-East area. It has also received waste from many other sources, including saltwell liquor from the 200-West area SSTs, PFP labs, S-Plant, 222-S Laboratory, and double-contained receiver tanks, as well as SY-101 waste.

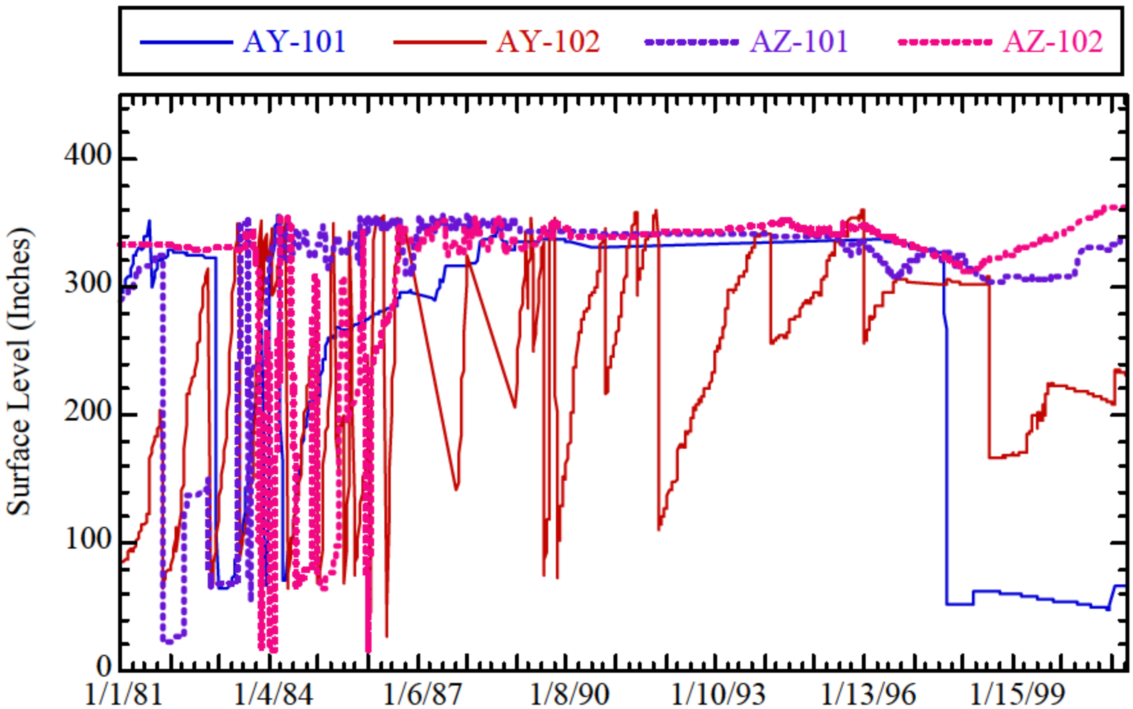


Figure 1.8. Level History of Tanks in the AY and AZ Farms

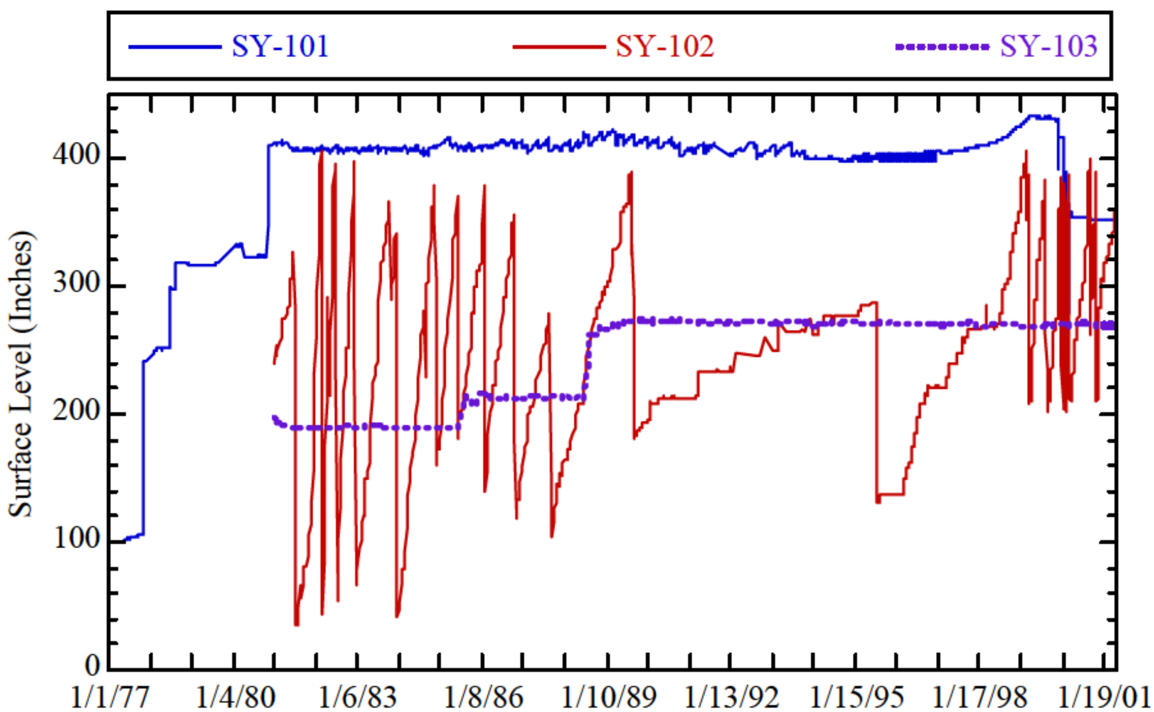


Figure 1.9. Level History of Tanks in the SY Farm

1.1.3 DST Waste Cooling and Ventilation

The waste in the DSTs is cooled primarily by convection to the headspace air with headspace ventilation the main mechanism for heat removal. A significant fraction of the heat load is also conducted through the primary tank wall to the air in the annulus by forced convection in the vent channels in the concrete pad beneath the primary steel tank. Because of this heat transfer path, the peak temperature occurs in the sediment layer (if one is present) at about mid-depth. If there is little or no sediment, the temperature of the liquid waste is essentially uniform due to continuous mixing by convection.

In addition to convection heat transfer, headspace ventilation also allows evaporative cooling of the waste surface. The ambient air at Hanford is generally dry (exceedingly so in the winter) with relative humidity in the range of 20 to 30% during the day. Evaporation removes heat at a rate of approximately 2,400 kJ/kg of water evaporated. However, the high concentration of dissolved salt in the liquid waste, along with the presence of a covering crust layer in the DSTs on the FGWL, all but prevent evaporation.

The waste in most of the DSTs is relatively cool, with peak temperatures typically less than 100°F. The waste in the AY and AZ farm tanks is somewhat hotter, with recent peak temperatures as high as 163°F. The tanks are cooled primarily by headspace and annulus ventilation, and are therefore sensitive to the incoming ambient air temperature. Seasonal variation at Hanford ranges from highs up to 110°F in summer (with temperatures near 100°F for extended periods), to typical lows around 20°–30°F for most of the winter with occasional swings near or below 0°F. The heat capacity of the soil and waste causes the waste temperature to lag behind the seasonal cycle by about three months. The lowest temperatures in the waste occur in March with peak waste temperatures in October. The amplitude of the cycle can be 10°–20°F.

Waste temperatures are decreasing slowly with time in the DSTs due to decay of their radioactive heat load. However, the cooling trend has been accelerated in AN-103, AN-104, AN-105 and AW-101 due to increased ventilation flow rates. In mid-1995, the AN farm annulus ventilation rates were increased to about 200 cfm. The tank headspace ventilation flow rates were increased from about 20 to 30 cfm to around 100 cfm in AW-101 in mid-1996, and in AN-103, AN-104, and AN-105 in early 1997. Since then, peak waste temperatures have decreased by as much as 15°F. The waste temperature in AY-102 increased significantly from 1999 to 2000 with the transfer of hot waste from C-106. The heat load in this tank is so high that the annulus and primary ventilation systems must be operated to keep the waste temperature within limits.

The headspace ventilation systems within each DST farm are manifolded together and driven by single induced draft fan that serves the entire farm. The headspace ventilation fans in the AN and AW farms are nominally capable of about 600 scfm total flow that is distributed among the tanks in the farm by adjusting dampers in the tank inlet ducts. The SY farm fan is capable of 800 scfm. The primary ventilation system is required to be operational to keep the tank headspace at a negative pressure and for flammable gas dissipation; except for relatively short outages for repairs, they have been operating continuously.

The headspace ventilation system draws ambient air into the tank through inlet filters. The headspace exhaust is then drawn through high-efficiency particulate air (HEPA) filters into a manifold and discharged to the atmosphere through the tank farm stack. The induced draft creates a vacuum of 2 to 5 inches of water in the headspace. The nominal flow rate is maintained at about 100 scfm in AN-103, AN-104, AN-105, and AW-101 by inlet flow controllers. Primary ventilation flow rates in the other tanks are in the range 50 to 300 cfm.

All DSTs have active systems in place for ventilation of the annulus space, but these have not always been maintained in continuous operation. In the AY and AZ farms, the systems have been available only about 50% of the time since the service date of the tanks. The system in the AZ farm has been off-line for the past five years. Prior to sluicing activities, which transferred hot C-106 waste to AY-102, the annulus ventilation systems for the AY Farm tanks experienced similar years-long outages (Anantatmula et al. 2001).

The annulus ventilation systems for DSTs are designed to perform three functions. 1) they provide primary tank leak detection through continuous radiation monitoring of the annulus exhaust air; 2) the system instrumentation and filtering of the exhaust air provides secondary containment in the event of a primary tank leak; 3) ventilation removes heat and moisture from the annulus space (Staehr 2001). Typical airflow rates in the annulus ventilation system range from a low of 200 cfm to a high of 1075 cfm in AY-102 (increased as a special provision for storing the high-heat waste from C-106). Typical passive ventilation flow rates are about 10 cfm.

There are separate annulus ventilation systems for each tank farm. Each exhaust equipment train consists typically of a demister, heater, prefilter, two testable HEPA filters in series, and an exhaust fan. The exhaust fan draws outside air through an inlet damper, pre-filter, and high-efficiency filter and distributes it to the annulus through an air distribution chamber in the concrete pad beneath the primary tank. (For AY-102, the incoming air is distributed only to the central distribution chamber beneath the center of the primary tank to obtain the maximum amount of cooling from forced convection to the annulus airflow.) AY-101 and AY-102 each have their own annulus exhaust train. AZ-101 and AZ-102 share a single train.

The design of the annulus ventilation systems in the AN, AP, and AW tank farms are similar to those used in the AY and AZ farms but have redundant equipment trains that provide greater operational flexibility. Eacj annulus ventilation system in the AN and AW farms is driven by two fans with a combined capacity of 800 scfm (5,600 scfm total for the seven AN tanks and 4,800 for the six AW tanks). The AP farm annulus ventilation system also has redundant equipment trains that operate one at a time for a flow of 1,050 scfm per tank. The annulus ventilation system in the SY farm has a single exhaust train driven by one fan rated at 750 scfm, or 250 scfm for each of the three tanks. The side-to-bottom flow in the SY farm can be adjusted external to the tank. The flow through the bottom slots in SY-101 and SY-103 is estimated to be 200 scfm.

Operational availability of the annulus ventilation systems has usually been much lower than that of the primary tank ventilation systems. Requirements for system operation do not demand continuous active ventilation of the annulus (except for AY-102 since 1999), and, as a result, extended operation with only passive ventilation of the annulus has not been unusual in many of the DSTs, including the AY and AZ farm tanks. Annulus ventilation in the AY and AZ farms must be shut down if the liquid in a tank drops below 64 inches (Bergman 2000) because there is a drain path from the annulus pit to the primary tank at this level, which, if uncovered, could allow contaminated vapor to be drawn into the annulus by the annulus ventilation system.

1.1.4 Summary of Current DST Status and Contents

Sampling data that reflect the current contents are available for 21 of the 28 DSTs. For the other seven, transfers have added waste from another tank since the last waste samples were taken. However, data from the donor tank supply an estimate of the composition in five of the seven. The most current determination of the waste composition is documented as the Best Basis Inventory (BBI) in the TWINS database (http://twins.pnl.gov). Table 1.3 gives the concentrations (mol/L) of major anions important to corrosion (OH, NO_2, and NO_3) and the pH value based on BBI data. Tanks with waste that is out of specification are identified by gray shading.

Table 1.3. Concentration (Molar) of Selected Anions and pH in DST Waste

Tank	Date	Sample (calc/tank)	pH	[OH]	[NO_3]	[NO_2]
AN-101	4/8/98	Supernate	14.1	1.170	1.10	0.83
AN-102	2/1/98	Supernate	13.2	0.156	3.82	2.05
AN-103	9/1/96	Supernate	14.7	4.920	2.69	3.56
AN-104	8/1/96	Supernate	14.6	4.210	2.77	2.44
AN-105	6/10/96	Supernate	14.5	3.404	2.60	2.63
AN-106	4/1/95	Supernate	13.9	0.85	1.14	0.41
AN-107	4/17/98	Supernate (pH)	11.0	0.00105	3.86	1.44
AP-101	2/8/00	Supernate	14.4	2.429	2.13	0.91
AP-102	4/30/93	Supernate	13.7	0.539	1.27	0.83
AP-103	8/12/99	Supernate	13.8	0.567	2.21	2.34
AP-104	1/10/00	Supernate (SY-102)	13.9	0.747	1.68	1.29
AP-105	5/24/00	Supernate (AW-106)	13.8	0.700	3.85	2.22
AP-106	2/25/00	Supernate (SY-102)	13.9	0.757	1.47	1.28
AP-107	10/2/00	Supernate (SY-102)	13.9	0.811	1.59	1.31
AP-108	3/1/00	Supernate	13.9	0.731	1.29	0.62
AW-101	4/22/98	Supernate	14.8	5.640	2.74	2.61
AW-102	8/30/99	Supernate (AP-107)	13.6	0.414	0.99	0.41
AW-103	8/29/99	Supernate	13.8	0.566	0.07	0.04
AW-104	8/23/00	Supernate	13.0	0.109	0.14	0.04
AW-105	5/9/97	Supernate	13.6	0.396	0.55	0.05
AW-106	5/24/00	Supernate	13.8	0.698	3.09	1.38
AY-101	1/1/00	Liquid (pH)	9.7	0.00005	0.19	1.17
AY-102	1/6/00	Supernate (pH)	11.9	0.00856	0.01	0.17
AZ-101	11/10/99	Core Comp	13.8	0.623	1.06	1.45
AZ-102	8/1/99	Core Comp (pH)	12.6	0.041	0.28	0.72
SY-101	4/1/00	Supernate	14.2	1.549	2.27	1.91
SY-102	10/2/00	Supernate	13.9	0.811	1.49	1.39
SY-103	8/1/94	Supernate	14.2	1.700	2.84	3.06

Core Comp — Composite from core sample.
Supernate — Supernatant liquid from core or grab sample.
Liquid — Drainable liquid from core sample.
(Tank ID) — Based on sample from identified donor tank.
(pH) — OH concentration calculated from pH measurement of (<12.5).

Table 1.4 summarizes what is known about the status of all 28 DSTs. The waste surface level and waste temperatures are monitored continuously. The depth of the sediment is inferred from the temperature profile ,as is the thickness of the crust layer. The table also summarizes the sampling status and visual and ultrasonic inspections that have been performed. Visual inspections were performed in the annuli of all 28 tanks in 1991 through 1993, and no significant corrosion was found. More recent, limited visual inspections of several tanks turned up extensive corrosion evidence in AY-101 (see Section 2.3). The dome was inspected visually in only two tanks in 1997. Ultrasonic inspections have been carried out in the annuli of 11 tanks in 1998–2001.

1.2 Hanford Double-Shell Tank Integrity Program

The stated purpose of the DST Integrity Program is to ensure DST system integrity throughout the DOE River Protection Project mission (Staehr 2001). The program includes the following principal elements:

- Assessment of DST system integrity and supporting tank equipment examinations
- Restoration of corrosion controls including compliance with chemical limits
- Engineering studies and analyses and development of corrosion monitoring technology supporting waste chemistry control and programmatic decisions on double-shell tank replacement.

The first element depends on the original DST design which includes a generous corrosion allowance and factors of safety as well as support systems (e.g., ventilation system, temperature and level monitoring, etc.) to help protect the tank structure. The third item includes updating structural analyses based on observed wall thinning, pitting or cracking due to corrosion, and tank lifetime prediction. The relationship of the various components of the program is illustrated in Figure 1.10. The DST Life Extension Workshop scope included the items in the solid boxes.

The DST Integrity Program generally follows the guidelines for structural integrity programs for tank systems (Bandyopadhyay et al. 1997), which were developed from 1994–1997 by a committee of experts who have become known as the Tank Structural Integrity Panel (TSIP). The TSIP guidelines advocate a structured approach to assessing structural integrity as a basis for identifying necessary management options to ensure leak tightness and structural adequacy over the life of the tanks' mission.

The main driver for the DST Integrity Program is the need for the existing tanks to be used far beyond their design life for SST waste retrieval and vitrification. However, the current situation challenges this need. The waste in Tanks AN-102, AN-107, AY-101 and AY-102 is below the chemistry corrosion limits for free hydroxide. While ultrasonic inspections of AN-107 and AY-102 indicate that these tanks are sound, significant corrosion was observed visually on the outside of the primary liner in AY-101. This was attributed to the annulus ventilation system being out of service and to water intrusion into the annulus from above.

Table 1.4. Summary of Current Knowledge of Status of All Double-Shell Tanks

Tank	Waste Data[a, b]				Waste Sampling			Waste Transfer History [c]	Visual Inspection [d]		UT Inspection
	Level (in.)	Sediment depth (in.)	Crust (in.)	Liquid Temp (°F)	Core	SN Grab Sample	Current?		Dome	Annulus	
AN-101	91	12	n/a	63	n/a	1995, 1998	no	multiple transfers from SSTs since 1995	No	1992	No
AN-102	383	32	n/a	82	n/a	1994, 1995, 1998, 2000	yes	none since mid. 1984	No	1992	No
AN-103	347	149	35	98	1996	n/a	yes	none since 1986	No	1992	No
AN-104	382	162	16	90	1996	n/a	yes	none since 1985	No	1992	No
AN-105	410	117	18	87	1996	n/a	yes	none since 1985	No	1992	1998-9
AN-106	14	6	n/a	60	n/a	1995	yes	essentially empty since 1997	No	1992	1999
AN-107	378	76	n/a	82	n/a	1996, 1998	yes	none since 1985	No	1992	1998
AP-101	405	n/a	n/a	68	n/a	1993, 1995, 2000	yes	none since 1996	No	1992	No
AP-102	396	n/a	n/a	69	n/a	1993	yes	none since 1993	No	1992	No
AP-103	102	n/a	n/a	67	n/a	1991, 1997, 1998, 1999	yes	essentially emptied in 1994, last add in 1999	No	1992	No
AP-104	403	n/a	n/a	74	n/a	1996, 1997	no	essentially emptied in 1996, filled early 2000	1997	1992	No
AP-105	412	32	n/a	69	1997	1993, 1996	no	transfers to and from other DSTs since 1994	No	1992	No
AP-106	226	n/a	n/a	67	n/a	1993, 1994, 1996, 1997, 1998	no	transfers to and from other DSTs since 1994	No	1992	No
AP-107	356	n/a	n/a	67	n/a	1993, 1995, 1997, 1999	no	transfers to and from other DSTs since 1994	1997	1992	1999
AP-108	13	n/a	n/a	56	n/a	1994, 1996, 1997, 1999, 2000	yes	essentially emptied in 2000	No	1992	1999
AW-101	409	111	31	90	1996	1990, 1995, 1998, 2000	yes	none since 1986	No	1991	2000-2001
AW-102	32	15	n/a	63	n/a	1991, 1995, 1996, 1998, 1999	no	transfers since 1994	No	1991	No
AW-103	401	126	n/a	74	1997, 1999	1994	no	2 transfers since 1994, last March 2001	No	1991	1996

Table 1.4. Summary of Current Knowledge of Status of All Double-Shell Tanks

Tank	Waste Data[a, b]				Waste Sampling			Waste Transfer History [c]	Visual Inspection [d]		UT Inspection
	Level (in.)	Sediment depth (in.)	Crust (in.)	Liquid Temp (°F)	Core	SN Grab Sample	Current?		Dome	Annulus	
AW-104	115	84	n/a	61	1997	1994, 1999, 2000	yes	none 1991 to Jan 2001	No	1991	No
AW-105	155	102	n/a	56	1986, 1990, 1997	1995, 1996	yes	none since 1996	No	1991	2001
AW-106	108	83	n/a	76	n/a	1991, 1998, 2000	yes	many small transfers since 1994	No	1991	No
AY-101	67	39	n/a	75	2000	1996, 1997	yes	none from 1986 to 1997, then nearly emptied in 1997	No	1992, 2001	failed in 1999, successful exam 2001
AY-102	232	68	n/a	102	1999, 2000	1998, 1999, 2000	yes	received C-106 waste in 1998-1999, none since	No	1992	1999
AZ-101	341	17	n/a	131	1989, 1999	1995, 2000	yes	none 1984 to 1995, small transfers after	No	1993	1999
AZ-102	362	38	n/a	108	1998, 1999	1995	yes	none from 1986 to 1995, small transfers after	No	1993, 2001	No
SY-101	353	72	n/a	79	1991, 1998, 1999	2000	yes	none 1981-1997; large transfers in 1999 and 2000	No	1992	No
SY-102	363	32	n/a	88	1997	1995, 1997, 1998, 1999, 2000	yes	many transfers from SSTs from 1994; cross-site stage tank	No	1992	No
SY-103	270	131	23	83	n/a	1994	yes	none since 1989	No	1992	No

(a) Supernatant temperature is based on SACS temperature data for May 20001 obtained from TWINS database (http://twins.pnl.gov).
(b) Waste level is based on SACS data for 5/14/2001, obtained from TWINS database.
(c) Transfer history for each tank is from TWINS database.
(d) Visual examinations in 1992-1993 showed no evidence of significant degradation in any of the DSTs.

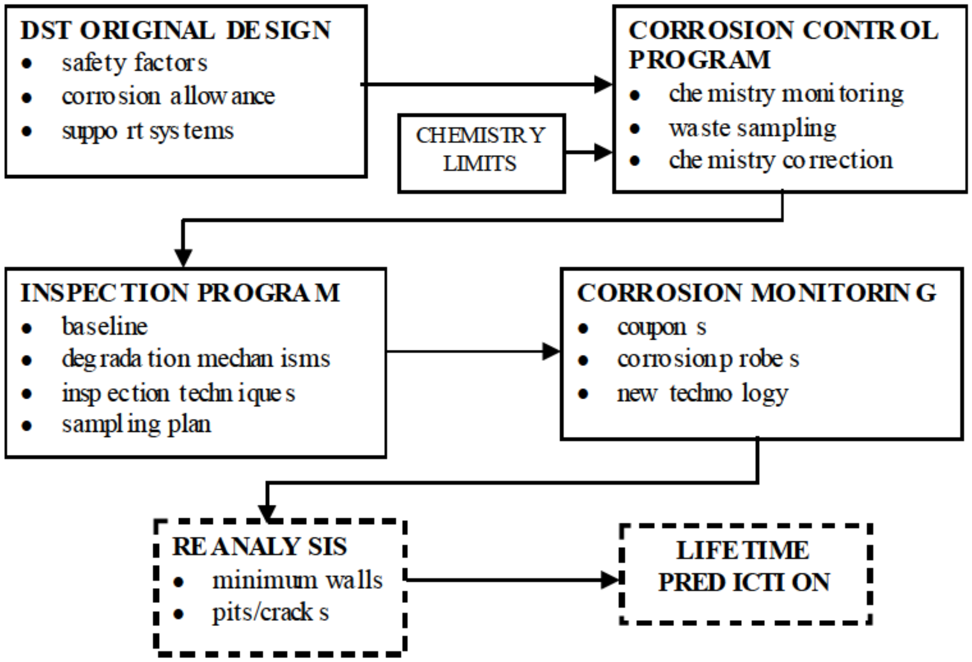


Figure 1.10. Components of the DST Integrity Program

1.3 Summary of Corrosion Mechanisms

This section discusses the dominant corrosion mechanisms in the DSTs at Hanford. The Tank Structural Integrity Panel (TSIP) classified corrosion mechanisms in five broad categories: general attack, pitting corrosion, stress corrosion cracking (SCC), microbiologically induced corrosion (MIC), and concentration cell/waterline corrosion.

There are three main areas of vulnerability to corrosion in the tanks: the interior surfaces of the primary tank exposed to the headspace air, the interior surface of the primary tank wall in contact with the waste, and the exterior surface of the primary tank wall exposed to the annulus air. These surfaces are subject to corrosion from general chemical attack, pitting, and stress corrosion cracking and may also be vulnerable to other more specialized forms of attack as the tank ages.

The major mechanisms of attack, pitting and SCC, are discussed in Sections 1.3.1, 1.3.2, and 1.3.3. The relevance of the additional corrosion mechanisms is evaluated in Section 1.3.4. Section 1.3.5 summarizes the main factors of concern related to corrosion in the DSTs.

1.3.1 General Corrosion

General corrosion is characterized by an essentially uniform loss of metal over the surface exposed to the chemical environment. This is a potentially significant aging mechanism for carbon steel surfaces in contact with the liquid waste. However, in alkaline wastes (with pH in the range 11 to 14), carbon steel forms a protective oxide at the surface that slows the rate of corrosion. Any activity that would mechanically disrupt the oxide (such as scraping or rubbing solid waste against the tank surface) could potentially increase the corrosion rate due to general attack.

The waste composition varies widely from tank to tank in the DST farms, so the potential for general corrosion will also vary. The general corrosion rate can also be expected to vary within a given tank because waste in the supernatant and sediment layers (and in a crust layer where it exists) are likely to have different chemical compositions.

Corrosion measurements using coupons in a range of chemical simulants (Divine 1985; Danielson and Bunnell 1994) have generally shown corrosion rates averaging 0.5 mil/yr (with rates as high as 5 mil/yr in some simulants) for test articles exposed to liquid waste and head-space air. However, analytical work and actual experience at Hanford strongly indicate that general attack is not a likely failure mechanism for DSTs as long as the waste is maintained within the appropriate pH ranges.

1.3.2 Pitting Corrosion

Pitting corrosion can occur on a surface when some microstructural component within the metal (usually a manganese sulfide inclusion) forms an electrochemical cell where the corroding area acts as the anode and the uncorroded surrounding surface acts as a cathode. Pitting is characterized by a localized corrosive loss of material, leading to holes in the metal. The holes (pits) are surrounded by large regions that are unattacked. Once started, pits may continue to grow autocatalytically, with penetration rates of hundreds of mils per year. Determining overall rates of corrosion for this mechanism is very difficult, however, because the length of the initiation period is nearly impossible to characterize. Pitting corrosion generally causes leaks rather than mechanical failure of a material but can also compromise structural integrity if the pitting leads to SCC.

The interior surfaces of the tank headspace are potentially vulnerable to pitting corrosion near the region in contact with liquid waste, which is also termed the "waterline." Droplets of liquid waste created by escaping gas bubbles may splash onto the tank interior surfaces near the waste level. Water vapor condensation on the walls will tend to dilute the waste and wash the dissolved solids back into the liquid. The resulting liquid wetting the exposed surfaces (which will be equilibrated with air and therefore be subject to the pH-controlling effects of carbon dioxide) will probably be a dilute (low dissolved solids) solution with a pH controlled by the carbonate/bicarbonate buffer (i.e., the pH will be less than 10). The corrosion literature amply indicates that carbon steels are vulnerable to pitting attack under these conditions.

A similar vulnerability exists in the annulus region if liquid comes in contact with the tank walls due to entry of groundwater or reflux condensation of moisture from the annulus air. Pitting corrosion could be further encouraged by contaminants (particularly chloride) in the water that are picked up from passing through the ground or running over metal surfaces. The waste repository literature data demonstrate that pitting is a major problem on the surfaces of the tanks that are in contact with air. Pitting rates in the range of 2 to 37 mil/year have been observed in hot coupon tests at Hanford (Parks 1957; Sanborn 1952), indicating that penetration could take place through 0.5-inch-thick steel plate in as short a time as 14 years. Several authors have observed that the pitting rate on surfaces exposed to air rapidly decreases with time, but the observation period over which this assessment has been made is usually six months or less. Consequently, short-term pitting data may result in an **over**estimation of the pitting rate and an **under**estimation of time for wall penetration.

Pitting and crevice corrosion rates for carbon steel surfaces in contact with liquid waste are dependent on waste composition. The presence of chloride and other halogen ions can cause localized breakdown on the surface, and the presence of nitrates and sulfates can also encourage pitting. Test data indicate that the pH must be less than 10 for pitting to occur. Ondrejcin (1984) estimated the pitting rate in the SRS evaporator coils to be 1800 mpy when the waste became dilute. At this rate, wall penetration could take place within two months. This demonstrated penetration rate shows that pitting of surfaces in contact with liquid waste has the potential to be an important failure mechanism. Detailed knowledge of the tank chemistry is necessary to predict which tanks would be vulnerable.

1.3.3 Stress Corrosion Cracking (SCC)

Stress corrosion cracking describes failure of metal by cracking that is due to the combined effects of residual or applied stresses in the material and the chemical environment seen by the surface. Prevention, detection, and mitigation of SCC are serious concerns in Hanford DSTs because SCC could result in collapse or major fracture. Cracks are often difficult to detect in the early stages, and growth rates can be high enough to crack through 1-inch-thick steel in a few months.

On the surfaces exposed to the headspace air in the tanks, SCC has not been observed but potentially could occur, depending on changes in the properties of the waste. As discussed in Section 1.3.2, liquid wetting the exposed surfaces near the waterline may have a pH of less than 10. If imposed or residual stresses exist, and if the temperature exceeds 60°C in this region, there is a strong potential for SCC. Should SCC occur, the tank could leak if later waste additions filled it to a level higher than any existing cracks.

Nitrate assisted SCC has been directly confirmed at SRS (Poe 1974; Donovan 1977) as the failure process of the early SRS waste tanks that were not stress-relieved. SCC has been observed in laboratory studies when the chemistry is outside the Ondrejcin-recommended specifications. SCC was also observed in the synthetic saltcake tests of Payer (1975). The limited SCC studies carried out to date are in a waste regime where SCC is known to occur, and the rates are so high that complete wall penetration would take place in less than six months. Little is known about the cracking rates as a function of the chemical environment.

The DST primary tanks have been stress-relieved through post-weld heat treatment, which is designed to minimize risk of SCC in the weld and/or adjacent heat-affected zones. The most likely location for SCC is where the tank is subjected to high tensile stress and in contact with waste. The primary tank lower knuckle is such a location (see Figure 1.4). The highest estimated tensile stress on the inner surface of the tank is at the point of tangency between the flat bottom and the beginning of the curved portion of the lower knuckle.

1.3.4 Additional Corrosion Mechanisms

Pitting and SCC are the most aggressive forms of corrosion any material is likely to experience. However, there are a few additional mechanisms that the Hanford DSTs might be subjected to. Anything buried in the ground is potentially subject to microbiologically induced corrosion or attack by groundwater. Containers holding corrosive liquids may experience concentration cell corrosion and galvanic attack.

Microbiologically induced corrosion (MIC) can occur when aerobic bacteria multiply in stagnant water in contact with material surfaces. The mechanism is essentially the same as general chemical attack due to unexpected local changes in the chemical composition of the solution in contact with the surface. Occurrences of MIC have been documented in the annulus region between the primary shell and secondary liner during tank construction at Hanford. There is the potential for MIC in the DSTs if groundwater leaks into the annulus or penetrates between the outer surface of the secondary tank and the concrete containment. The high radiation dose and annulus ventilation that evaporates pools of water should prevent MIC.

Concentration gradients within the waste solids in contact with the wall could lead to local oxygen concentration cells. Chelating or complexing species could also affect the anodic reaction. Galvanic attack could also be initiated at the edges of foreign objects inadvertently dropped into the tank during operational procedures. All such corrosion processes are variations of crevice/pitting corrosion. It is virtually impossible to assess the extent of the potential of this type of corrosion occurring in any of the DSTs because it would require precise knowledge of the local structure of the waste and exhaustively detailed tank history. It is more reasonable to consider it as simply part of the corrosion caused by pitting and crevice corrosion because the steps to mitigate or correct it would be essentially the same.

1.3.5 Summary of Corrosion Mechanisms

Corrosion has the potential of causing tank failure, either by allowing the tanks to leak or by causing actual structural failure. Likely corrosion failure scenarios involve pitting corrosion on the primary liner surfaces near the waterline and in the annulus space where water invasion has occurred and SCC in the lower knuckle region. Pitting is likely to result in leaks. Stress corrosion cracking, while unlikely, could cause actual tank structural failure if allowed to proceed unchecked. All other mechanisms of corrosion or material damage bear some degree of watching and perhaps mitigation on a tank-by-tank basis.

2.0 Proceedings of the Hanford DST Life Extension Workshop

In view of the corrosion observed in the visual inspection of AY-101, the long periods of annulus ventilation outage in several tanks, and the fact that four tanks are outside the chemistry corrosion limits, the Hanford DST Integrity Project determined that a thorough review of existing programs and supporting data was needed. Accordingly, an experts' workshop was held at Richland, Washington, in May 2001 to create a credible, validated technical baseline for operation and control of corrosion in Hanford DSTs. The scope of this workshop was limited to study of corrosion of the primary tank liner by exposure to the waste, to water invading the annulus, or to condensation on the dome.

2.1 Workshop Organization and Method

The four-day workshop was held May 1–4, 2001 to produced specific recommendations on how Hanford DST lifetime could be extended. Participants included corrosion experts from Hanford, the Savannah River Site (SRS), Brookhaven National Laboratory, Pacific Northwest National Laboratory (PNNL), and other expert consultants with industrial and nuclear plant experience. The list of 24 participants and presenters is given in Table 2.1, and biographical sketches are provided in Appendix A.

The first half of the workshop was devoted to presentations describing the three main components of the Hanford Tank Integrity Program: chemistry control, tank inspection, and corrosion monitoring. The tank integrity program and experience with corrosion at Savannah River were also presented by SRS staff. The second half of the workshop was spent in technical reviews of each part of the program and in developing recommendations. The detailed workshop agenda is included as Appendix B, and the slides used in the presentations are included as Appendix C. This report and the full-size color presentations are also provided on a CD inside the back cover of the document.

The reviews were guided by a series of questions on each of the program elements plus a general category. The list of questions with notes from the discussion is given in Appendix D. A summary of the review of each element and the rationale for the recommendations developed are described in Sections 2.2, 2.3, and 2.4, for chemistry control, tank inspection and corrosion monitoring, respectively. These questions produced 73 specific recommendations on Hanford DST life extension. Twenty-three of these were selected as "higher priority." A brief description of each of these recommendations is given in Appendix E. The method and criteria by which the recommendations were ranked are discussed in Section 2.5, and the ranking results are provided in Appendix F.

The participants identified in Table 2.1 were chosen as a senior review team to perform a critical review of the conclusions of the initial workshop and the final report. The Senior Review Committee, chaired by Spence Bush, met May 21 and 22, 2001. The report of this committee, which constitutes the final recommendations of the workshop, is provided in Section 3.

Table 2.1. Workshop Participants and Senior Review Committee

NAME	ORGANIZATION
Anantatmula, Mo +	CH2M Hill Hanford Group, Inc., Richland, Washington
Berman, Herb +	ADI Technology Corp.
Borenstein, Susan	APTECH, Houston, Texas
Brothers, Joe	Pacific Northwest National Laboratory, Richland, Washington
Bush, Spence +	Review & Synthesis Associates, Richland, Washington
Czajkowski, Carl +	Brookhaven National Lab, Upton, New York
Divine, Jim +	ChemMet, Ltd., PC, West Richland, Washington
Edgemon, Glenn *	HiLine Engineering, Richland, Washington
Elmore, Monte +	Pacific Northwest National Laboratory, Richland, Washington
Fredenburg, Ed	CH2M HILL Hanford Group, Inc., Richland, Washington
Johnson, Burt +	Pacific Northwest National Laboratory, Richland, Washington
Julyk, Larry *	CH2M HILL Hanford Group, Inc., Richland, Washington
Kirch, Nick *	CH2M HILL Hanford Group, Inc., Richland, Washington
Knight, Mark	CH2M HILL Hanford Group, Inc., Richland, Washington
Krahn, Steve	ADI Technology Corp.
Lentsch, Jack	CH2M HILL Hanford Group, Inc., Richland, Washington
Mickalonis, John*	Westinghouse Savannah River Company, Aiken, South Carolina
Norman, Gar	CH2M HILL Hanford Group, Inc., Richland, Washington
Pitman, Stan	Pacific Northwest National Laboratory, Richland, Washington
Posakony, Jerry +	Pacific Northwest National Laboratory, Richland, Washington
Reynolds, Dan +	CH2M HILL Hanford Group, Inc., Richland, Washington
Shuford, Dave	CH2M HILL Hanford Group, Inc., Richland, Washington
Sindelar, Bob +	Westinghouse Savannah River Company, Aiken, South Carolina
Stewart, Chuck	Pacific Northwest National Laboratory, Richland, Washington
Zapp, Phil +	Westinghouse Savannah River Company, Aiken, South Carolina
*Presentation only. + Senior Review Committee.	

2.2 Review of the Chemistry Control Program

This section describes the history, status, and review of the chemistry control program. This program element establishes specifications on waste chemical composition to prevent corrosion, compares sampling data to the limits to determine whether tanks are within the specifications, and directs the correction of the waste composition as necessary to ensure they stay within the specifications. The program also obtains corrosion test data on which to base chemistry corrosion limits and directs waste sampling and analyses to provide tank chemistry data.

2.2.1 Background

The Hanford process waste liquids were generally adjusted to a pH >10 prior to discharge into the SSTs. However, some wastes were stored at a lower pH in the SSTs. SCC of the SRS version of SSTs and the subsequent investigation in the 1970s established early chemistry limits to control SCC.

The DSTs were originally designed to operate with their contents at pH 8 to 14. These chemistry limits were based on the SRS work (see presentation by Nick Kirch in Appendix C for pre-1984 limits). The SRS work determined that the corrosion of low carbon steels, like those used in the construction of the DSTs, was dependent on the concentrations of hydroxide, nitrate, and nitrite anions in the liquid waste. Additionally, it was determined that carbonate, phosphate, sulfate, silicate, fluoride, and chloride constituents in low concentrations had little effect on corrosion potential.

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

In response to these findings, an extensive experimental data development task was initiated at PNNL. This program generated several thousand corrosion test coupons exposed to nonradioactive chemical simulants representing waste compositions consistent with known and expected waste chemistry ranges (Divine et al. 1985). The results of these coupon tests showed that, in general, corrosion outside the DST design limits was observed only in very dilute nitrite and hydroxide solutions and in high-concentration hydroxide solutions at elevated temperatures. Also, SCC was observed only on highly stressed U-bend specimens in solutions with high nitrate and low hydroxide concentrations or in high hydroxide solutions at high temperatures.

Based on this work, new chemistry control limits were set in 1984. However, supplemental work at PNNL in 1994 identified that the presence of nitrite was important even when there were low concentrations of nitrate (Danielson and Bunnell 1994). As a result, the chemistry limits were modified to include the ratio of nitrate to hydroxide plus nitrite in dilute regions. The present chemistry limits used for the DST corrosion control are summarized in Table 2.2 (see also Nick Kirch's presentation in Appendix C).

2.2.2 Summary of Review

The following are summaries of the information on chemistry controls and related subjects presented at the workshop sessions devoted to this topic. These summaries will be followed by a description of the discussions and the resulting recommendations. The full presentations are contained in Appendix C.

Jim Divine gave a detailed overview of corrosion studies from 1952 to 1984 along with insights on the weaknesses and pitfalls in the data of the studies done to date. The early studies on low-carbon steel explored both uniform corrosion rates and pitting corrosion rates as functions of pH. Uniform corrosion and pitting corrosion generally decreased with time for pH >8. The corrosion for pH values below 8 (pH 6–7) showed pitting increasing with time. Early laboratory

Table 2.2. Current DST Waste Chemistry Limits

<table>
<tr><th rowspan="2">$[NO_3^-]$ Range</th><th rowspan="2">Parameter</th><th colspan="3">Waste Temperature Range (°F)</th></tr>
<tr><th>$T < 167$</th><th>$167 \le T \le 212$</th><th>$T > 212$</th></tr>
<tr><td rowspan="3">$[NO_3^-] \le 1.0\underline{M}$</td><td>$[OH^-]$</td><td>$0.01\underline{M} \le [OH^-] \le 8\underline{M}$</td><td>$0.01\underline{M} \le [OH^-] \le 5\underline{M}$</td><td>$0.01\underline{M} \le [OH^-] \le 4\underline{M}$</td></tr>
<tr><td>$[NO_2^-]$</td><td colspan="3">$0.011\underline{M} \le [NO_2^-] \le 5.5\underline{M}$</td></tr>
<tr><td>$[NO_3^-]/([NO_2^-] + [OH^-])$</td><td colspan="3">$< 2.5$</td></tr>
<tr><td rowspan="2">$1.0\underline{M} < [NO_3^-] \le 3.0\underline{M}$</td><td>$[OH^-]$</td><td colspan="2">$0.01([NO_3^-]) \le [OH^-] \le 10\underline{M}$</td><td>$0.01([NO_3^-]) \le [OH^-] \le 4\underline{M}$</td></tr>
<tr><td>$[OH^-] + [NO_2^-]$</td><td colspan="3">$\ge 0.4([NO_3^-])$</td></tr>
<tr><td rowspan="3">$[NO_3^-] \ge 3.0\underline{M}$</td><td>$[OH^-]$</td><td colspan="2">$0.3\underline{M} \le [OH^-] \le 10\underline{M}$</td><td>$0.3\underline{M} \le [OH^-] \le 4\underline{M}$</td></tr>
<tr><td>$[OH^-] + [NO_2^-]$</td><td colspan="3">$\ge 1.2\underline{M}$</td></tr>
<tr><td>$[NO_3^-]$</td><td colspan="3">$\le 5.5\underline{M}$</td></tr>
</table>

tests in simulated PUREX waste had low general corrosion (<1 mpy) and initial rapid pitting followed by a decrease to similar low rates. The 1977 Battelle Columbus work on SCC demonstrated that the combination of nitrate and nitrite was beneficial in reducing SCC potentials.

The PNNL corrosion testing program described in Section 2.2.1 was completed in 1984. This work generated a large body of corrosion data using a broad range of simulants, concentrations, and temperatures. The data cover the expected range of current tank conditions, but the tie is weak between test and tank conditions because no comprehensive post-synthesis chemical analysis was done on the actual simulant solutions used. The composition was assumed to follow the proportions in the simulant recipe. There were also too few occurrences of experimentally induced SCC (only eight of the coupons tested) to establish exact boundaries and chemical/stress condition limits for tank controls and to validate that present controls are conservative.

Mark Knight described the history and current status of the DST chemistry control program at Hanford. Initially, the chemistry control limits were in plant Operating Specification Documents, but there was no formal program to monitor waste chemistry for continued compliance with limits during extended storage. No allowance was made for hydroxide depletion due to carbon dioxide from the atmosphere above the waste, though this is now being corrected. Tanks were identified as being out of specification, but their chemistry was not always corrected promptly due to perceived higher priorities and technical difficulties. Presently Tanks AN-102, AN-107, AY-101, and AY-102 are known to be out of specification for chemistry limits.

The average tank conditions, usually determined from a sample of the supernate, are used to assess compliance with the chemistry corrosion limits. The waste composition may be different in the various tank layers and may, in fact, also be different next to the wall than in the bulk waste. Efforts are under way to assess these differences and to obtain chemistry data and develop chemistry limits for each major waste layer.

The Waste Compatibility Assessment Program was put in place to assess proposed waste transfers based on sample data and process knowledge. The primary purpose of this program is to ensure that anticipated changes in the waste do not cause any safety problems (e.g., flammable gas retention). However, corrosion issues were not included in the assessment, so a transfer could theoretically drive the waste in the receiver tank out of specification.

Based on CHG, DOE, and other oversight group concerns, the Authorization Basis Documents (e.g., Tank Farm FSAR) (Cash 2000) were modified to make the chemistry limits a Technical Safety requirement. The present action plan developed by CHG (Staehr 2001) commits to bringing all tanks into chemistry control specification by September 2001 and to develop a formalized chemistry surveillance program to ensure that all tanks are maintained within specifications during waste transfer activities or in extended storage.

The new program recognizes the depletion of hydroxide with time by reaction with absorbed carbon dioxide, oxidation of sodium salts or organic species, and reaction with hydrated aluminum oxide. The Tank Waste Information Network System (TWINS) (http://twins.pnl.gov) contains the tank waste chemistry sampling database and Best Basis Inventory which is used to evaluate corrosion chemistry limits.

Sampling intervals are presently derived from hydroxide depletion models. There are three models (Hobbs, Carothers, and Reynolds), but they are based on different field data and underlying assumptions (Fort et al. 2001). As a result, the models can provide widely varying predictions of hydroxide depletion times. These models and their limitations are described in detail in Knight's presentation slides in Appendix C. Improvement of the models' accuracy is expected as more data is gathered from the sampling program now in place.

Dan Reynolds summarized the tank history and sampling concerns for both the SSTs and DSTs. There are 149 SSTs (concrete construction with steel liner), with 67 known leaking SSTs. None of the 28 DSTs have leaked to date. (The potential perforation of Tank AY-101 that is being investigated is in a region far above the present waste level.) The history of out-of-specification tanks was reviewed in addition to that of the four tanks presently in that condition (see Reynolds' presentation in Appendix C for a complete listing).

Difficulties with waste samples were delineated. Hydroxide measurements in waste samples have uncertainties associated with interfering chemical species (phosphate, carbonate, etc.) and inaccuracies due to sample dilution to the range of the measuring instrument. For sediment samples, supernatant entrained from higher layers during sampling could skew results. A water leach is used, which may allow an extraneous contribution to the liquid from dissolved solids. pH measurement also has pitfalls due to interference from sodium ions, other possible ionic reactions, and the inferred water equilibrium relationship, which may not hold at very high pH levels. Dan discussed how these difficulties are minimized using rule-of-thumb approaches for pH and methodology adjustments for hydroxide measurements. He then described in more detail his hydroxide depletion model (the Reynolds model mentioned by Knight).

Mo Anantatmula presented a summary of DST degradation mechanisms and then focused on the mechanisms of most concern: pitting/crevice corrosion, uniform (or general) corrosion, and SCC. The chemical reactions and physical description of these three corrosion types were presented, along with the DST regions most susceptible to each mechanism (see Appendix C for the complete presentation and Section 1.3 for a summary of corrosion mechanisms).

The principal corrosion mechanisms playing an active role in the corrosion of the DST primary wall contacting the waste are uniform corrosion, pitting/crevice corrosion, and SCC. Although uniform corrosion is an active mechanism in the DST primary wall corrosion, the most significant mechanism that would cause tank wall thinning to the minimum allowable thickness is localized pitting/crevice corrosion at or near the waterline, as seen in Tank AY-101.

SCC is of most concern for the DST bottom knuckle region because this area contains the highest applied stresses and is generally exposed to the sediment. However, because the DSTs were stress-relieved at new construction, the tanks operate at temperatures less than 50°C and, because there is little oxygen in the sediment layer, the probability for SCC is considered low. Nevertheless, SCC cannot be totally discounted in DSTs where waste chemistry has not been maintained within specified limits. Additionally, the importance of maintaining annulus ventilation to control the humidity and preclude general and pitting corrosion on the annulus side of the primary liner was discussed.

Finally, conservative estimates of the remaining useful life of the tanks (i.e., time for corrosion to reduce the tank wall thickness to the minimum calculated design wall thickness) were made to determine the critical times required to correct tank chemistry to reach minimum protective hydroxide concentration throughout the supernatant. Assuming waterline corrosion at a conservative linear (uniform corrosion) rate of 12 mils per year, assuming no attempt is made to correct out-of-specification chemistry and the waste level is never varied and remains at the current levels, the remaining useful lives for tanks were calculated as follows:

- AN-102—8 years
- AY-101—23 years
- AY-102—17.5 years.

2.2.3 SRS Chemistry Control Experience and Lessons Learned

Phil Zapp provided an overview of the SRS tank farm construction and history, their corrosion testing programs, and the corrosion control sampling program and inhibitor limits. The SCC-induced tank failures and leakage from the resulting tank wall cracks were reviewed (see Zapp's presentation in Appendix C for details). No cracks from SCC have been found in stress-relieved tanks. Micrographs of actual SCC cracks were shown (for SRS Tank 16), and various SCC tests and experiments (slow strain rate, wedge opening) were described. Results of this work, including crack growth as a function of time and elongation/crack growth at different hydroxide and nitrite concentrations, were presented. SCC can be prevented by effectively maintaining corrosion inhibitor concentrations. This requires extensive monitoring of the waste and the ability to add hydroxide and nitrite as needed. Hydroxide can be depleted by reaction with atmospheric carbon dioxide. Both hydroxide and nitrite can be depleted by radiolysis.
Zapp also described some unique SRS experiments in pitting kinetics (initiation and growth). One surprising result was the indication that pitting, once initiated, continues even when the initiating chemical environment is eliminated and nitrite added. Other pertinent differences between SRS tank farm operations and Hanford were noted. These included:

- High frequency of tank chemistry sampling (as often as every three months)
- No sampling of the sediment layers at SRS
- Significantly lower costs of obtaining and analyzing waste samples at SRS

- Use of "safety factors" (i.e., limits times 1.5) on chemistry limits to ensure inhibition.

2.2.4 Discussions and Recommendations

The above presentations and discussions of this central topic were held over a two-day period, due to the wide-ranging and varied nature of the topics, and resulted in 27 individual chemistry control recommendations. These recommendations centered around two key topics:

- Chemistry Sampling and Monitoring: These recommendations rose out of the concern over the quality and quantity of waste data relating to corrosion. The perceived large uncertainties in waste composition and in the relation of local core or grab samples to the actual waste composition were also issues.
- Correction and Maintenance of DST Chemistry: The workshop was concerned that four tanks have been out of specification for long periods and that simply adding caustic to the supernatant may not correct the whole tank promptly.

Chemistry Sampling and Monitoring Recommendations

- Sample the waste more frequently, perhaps initially at three-month intervals. Frequent sampling is preferable to dependence on available caustic depletion models.
- Develop and apply a corrosion chemistry sampling DQO for both core and grab samples. This is to ensure that corrosion data are obtained at every opportunity and to provide for consistency, reliability and quality of the sampling data.
- Use the frequent sampling to provide a database for more accurate, predictive depletion models. When the models are subsequently demonstrated to be accurate and predictive, their use in setting sampling intervals may be reinstated.
- Use the sampling to analyze caustic mixing dynamics into the nonconvective layer.
- Correlate sampling results from each tank layer with corrosion test data and corrosion probe readings.
- Evaluate the uncertainty in the sampling data due to nonuniformity of the waste and any differences between bulk samples and the chemistry at the tank wall.
- Benchmark SRS sampling and lab procedures for potential efficiencies and cost savings.
- Evaluate use of a low-cost pH probe (LaF_3) for faster sampling results.

Correction and Maintenance of DST Chemistry

- Promptly correct the chemistry in any tanks that are out of specification with inhibitor additions to prevent waterline pitting and uniform corrosion.
- Ensure management understanding and commitment to consistently maintaining tank chemistry within limits.
- Add corrosion chemistry conditions to the waste compatibility criteria to ensure the rate or volume of dilute or raw water additions do not move the waste out of specification.
- Develop a layup and sampling procedure for tanks with a waste heel.

- Document periods when tanks have been known to be out of specification, including time with unregulated waste heels or hydrotest residual water.
- Investigate the use of alternative methods or forms for maintaining chemistry (e.g., combined hydroxide and nitrite additions).
- To protect against vertical nonuniformity, apply chemistry corrosion limits to each waste layer rather than using a tank average. Identify tanks that need to be resampled to obtain more adequate data.
- Monitor the chemistry and corrosion potential of the nonconvective layer.
- Analyze nonconvective layer chemistry to determine whether natural mixing is sufficient or forced mixing is required.
- Consider increasing the margin between waste chemistry and caustic limits (i.e., >pH 12).
- Validate the long-term effectiveness of chemistry controls by comparing with ultrasonic inspection (UT), visual inspection (VT), electrochemical noise (EN) or other NDE.

2.3 Tank Inspection Program Review

Inspections of the DSTs date back to their original construction. During construction, 100% of the welds on the tanks were radiographically tested (RT). Further, the tanks were subjected to a hydrostatic test in accordance with the requirements of the applicable standards (e.g., the Boiler Pressure Vessel Code of the American Society for Mechanical Engineers).

The TSIP approach to NDE is based on the guidance provided by the ASME Boiler and Pressure Vessel Code (Section XI). Although designed for application to nuclear power plant components, this standard was selected because it represented "the only definitive document in the United States covering nuclear inservice (sic) inspection" (Bandyopadhyay 1997, p. 5-1).

An early draft of the TSIP guidelines circulated in March 1994 was used as a basis for selecting the initial six Hanford DSTs to be examined by UT and for developing associated requirements and acceptance criteria. Sections 5.3.1 through 5.3.4 of the final TSIP guidelines contain recommendations specific to NDE of steel tanks. Those recommendations and current Hanford practice are compared in Table 2.3. In general, current Hanford practice relating to tank examination meets or exceeds the TSIP guidance. For some recommendations, current Hanford practice departs from the TSIP guidance. The fourth column in Table 2.3 addresses compliance with TSIP guidance and provides rationale for any departure.

Table 2.3. Comparison of TSIP Guidance and Current NDE Practice for Hanford DSTs

Parameter	**TSIP Guidelines**	**Current Practice**	**Rationale for Departure from TSIP Guidelines**
1) Inspection Interval	Within 10 years after DST placed in service and each 10 years thereafter	• Initial inspection > 10 years after DSTs placed in service • Repeat inspections planned at 10 year or shorter intervals	• NDE of DSTs was not a priority prior to early 1990s, when TPA M-32 milestones and draft TSIP guidelines became available. • Intervals for repeat inspections is consistent with TSIP guidelines
2) Ultrasonic Inspection (UT) Requirements	Applicable portions of ASME Section XI Appendix VIII should be limited to 2100 [a,b,c,d], and Supplements 2 and 3.	• UT contractor procedure includes all elements in VIII-2100	n/a—UT procedure for DSTs complies with TSIP guidance. Supplements 2 and 3 apply to piping—not to tanks.
3) Acceptance Levels	• Wall thinning: 20% t • Pits: 50% t • Cracks <12 in.: 50% t • Cracks >12 in.: 20% t	• Wall thinning: 20% t • Pits: 50% t • Cracks <12 in.: 3/16 in. • Cracks >12 in.: 3/16 in.	• n/a for wall thinning and pits (same as TSIP) • Hanford acceptance criteria for crack depth is equal to or more stringent than TSIP guidance for crack length <12 in., but less stringent for crack length >12 in. Hanford acceptance criteria for crack length >12 in. is consistent with WHC-SD-WM-AP-036. Rationale: a single value for crack depth acceptance criteria, independent of plate thickness, is less prone to error than one that varies with plate thickness. In practice, all detectable cracks have been reported (only one to date, in AP-108).
4) Accuracy	+/- 20% of Acceptance Levels	• Wall thinning: +/- 0.02 in. • Pits: +/- 0.05 in. • Cracks: +/- 0.1 in.	Accuracy limits for thinning and pitting in Hanford DSTs are equal to or more stringent than TSIP recommendations for 1/2 in. or heavier plate sizes, but less stringent for 3/8 in. plate size. Accuracy limits for crack depth in Hanford DSTs are less stringent than TSIP recommendations. Rationale: Accuracy limits for Hanford DSTs were established not as a function of plate thickness, but based on equipment capability as demonstrated in Performance Demonstration Tests administered by PNNL in 1998 and 2000.

Table 2.3. (contd)

Parameter	TSIP Guidelines	Current Practice	Rationale for Departure from TSIP Guidelines
5) Qualification of Personnel	NDE personnel should be qualified per ANSI/ASNT CP-189, "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel."	NDE personnel are qualified in accordance with ASNT Guideline SNT-TC-1A-92	Both ASNT CP-189 and SNT-TC-1A-92 were considered in establishing qualification requirements for personnel. SNT-TC-1A was considered adequate for tank inspections, and was selected. At the time of selection most NDE technicians were being qualified to SNT-TC-1A. Additionally, IGSCC training is required for NDE Level III technicians.
6) Number of tanks examined	10% (three of 28 DSTs). Selection of more than 10% may be required to include representation of all worst-case tanks	Will examine all 28 DSTs, in initial inspection and successive inspections	n/a—exceeds TSIP guidance
7) Basis for tank selection	Select tanks to be examined on basis of age, severity of operating conditions, etc., so that tanks with the highest potential for attack are examined.	• Original sample of six DSTs was selected based on a variety of factors as documented in WHC-SD-WM-ER-529. • Six DSTs were selected for examination of tank bottoms and six for examination of lower knuckles based on a variety of factors, as documented in (Jensen 2000).	n/a—complies with TSIP guidance
8) Successive inspections	Component examinations established during the first inspection period shall be repeated during each successive inspection interval	• Repeat examinations are planned at 10-yr intervals max., covering the same areas previously examined	n/a—complies with TSIP guidance

Table 2.3. (contd)

Parameter	TSIP Guidelines	Current Practice	Rationale for Departure from TSIP Guidelines
9) Additional examinations	Examination results that exceed acceptance criterion requires extending the examination to include additional areas of similar material and service	• Examination was extended on AN-105 to include horizontal scans when wall thinning acceptance criteria was triggered. • Examination was extended on AY-101 to include vertical scans at second riser and 20-ft horizontal scan at liquid/air interface when wall thinning acceptance criterion was approximated	n/a—practice at Hanford has involved: • increasing the sample size to all 28 DSTs versus original scope of six DSTs, • extending examinations, in the same tank, when acceptance criterion was triggered or approximated, based on recommendations of the UT Inspection Panel convened per CHG procedures.
10) Inspection scope	Angle beam technique for identifying and sizing flaws shall include 45°, 60°, and 70° beam angles plus 0°.	Beam angles used are 45° and 60° plus 0°; 70° beam angle is not used.	The objective of UT of weld areas in DSTs has been to detect and size cracks in the heat-affected zone (HAZ), based on the knowledge that cracks are more likely there than in the weld metal. Laboratory experiments demonstrated that a 60° beam angle was adequate for this purpose. Cracks in weld metal would likely be detected with the 60° beam angle, but this was not evaluated in the Performance Demonstration Test.
11) Length of liquid/vapor interface	Examine 5% of the length of the liquid/vapor interface ± 1 ft for pits.	The liquid/air interface on six DSTs will be examined over a 20-ft length, 15-in. wide centered on the estimated location of the static liquid/air interface that existed for a minimum of five years. This area will be examined for pits, cracks, and wall thinning.	This scope agreed to by DOE and Ecology in draft TPA milestone M-48-14. A 20-ft length in a 75-ft-diameter tank exceeds 5% of the liquid/air interface. 15 inches centered on the liquid air interface does not comply with the TSIP guidance of +/-1 ft but can be accomplished in a single scan—otherwise, two scans would be required to encompass 12 in. above and 12 in. below the interface. However, this scope can be and has been increased depending on the condition of the tank. For example, on AY-101, two scans are being done on the liquid/air interface because thinning was found over a fairly large vertical range in the two 15-in.-wide vertical scans on the east side of the tank. In all 28 DSTs, any previous or existing liquid/air interface is examined in the top-to-bottom 30-in. wide vertical strip (consisting of two 15-in.-wide vertical strips) that is scanned in each tank.

Table 2.3. (contd)

Parameter	TSIP Guidelines	Current Practice	Rationale for Departure from TSIP Guidelines
12) Frequency of liquid/vapor interface examination	Divide the inspection interval into two periods and examine half the 5% length of liquid/air interface in each five-year sub-interval	For the six DSTs to have their liquid/air interface examined, the entire length is examined in the initial and successive 10-year inspection intervals rather than the recommended five-year intervals.	Significant wall thinning at the liquid/air interface has been found in only one of the 11 DSTs examined to date (AY-101).
13) Length of liquid/sediment interface	Examine 5% of the length of the liquid/sediment interface ±1 ft for pits, cracks, wall thinning	Any liquid/sediment interface above the lower knuckle weld is examined over a 30-in. length, within the 30-in. vertical strip examined on each DST. No horizontal scan of the liquid/sediment interface is conducted.	UT results to date for vertical scans in 11 DSTs have not found any evidence of accelerated degradation or flaws at a liquid/sediment interface that may exist or may have existed during the tank operating history. Eventually, all 28 DSTs will be examined over a ~35-ft by 30-in.-wide vertical strip. Evidence of accelerated degradation or flaws at a liquid/sediment interface could potentially cause expansion of the examination scope for that tank.
14) Length of weld joining primary tank vertical wall to lower knuckle	Examine 5% of the length of the vertical wall/lower knuckle weld and HAZ for cracks, divided into two segments, with one segment examined in each five-year sub-interval.	20 ft of weld and HAZ joining the vertical wall to lower knuckle is examined, if accessible.[a] The entire 20-ft length is examined at one time—not in two or more subintervals.	No cracks, significant wall thinning, or other problems have been observed to date in examination of the welds and HAZ in 11 DSTs.
15) Area of the predicted maximum stress region of the primary tank lower knuckle	For tanks in which the lower knuckle to bottom weld is inaccessible, examine 5% of the area of the predicted maximum stress for cracks, divided into 2 segments with one segment examined in each five-year subinterval	We have not yet examined the high-stress region, except as exposed in air slots. Six DSTs have been identified for examination of a 20-ft length of the lower knuckle, pending technology development on two approaches that are being considered. Examinations are planned to be conducted on the entire 20-ft length in each interval, rather than partially in subintervals.	Examination of six DSTs will comply with TSIP guidance pending completion of technology development. Exception: the examination scope is not presently planned to be apportioned among subintervals due to higher costs associated with multiple tank entries. Frequency of successive examinations would be increased if significant degradation or evidence of SCC is observed.

(a) Exceptions: On AY-101 and AY-102, the lower knuckle weld could not be examined due to concrete splatter. Instead, 20 ft of the lowest accessible horizontal weld is examined—which, in AY-102, was the weld joining plate #2 to plate #3. On AW-103 (the first tank examined—in 1997), welds were not examined except where included in the 10-in.-wide vertical strips.

Table 2.3. (contd)

Parameter	TSIP Guidelines	Current Practice	Rationale for Departure from TSIP Guidelines
16) Length of weld joining lower knuckle to bottom plate	Examine 2% of the length of the bottom/knuckle weld and HAZ for cracks, if accessible.	The bottom/lower knuckle weld is not examined, except through air slots when tank bottoms are examined.	n/a—TSIP guidance for lower knuckle weld depends on accessibility
17) Primary tank bottom	Examine primary tank bottom as practical for cracks, pits, and wall thinning on a "best effort" basis.	Primary tank bottoms are scheduled to be examined for wall thinning and circumferential cracks in six DSTs. Scope of examination depends on surface conditions, obstructions, and geometry constraints.	n/a—current approach complies with TSIP guidance for tank bottoms
18) Primary tank below liquid surface	Examine for wall thinning where visual examination shows evidence of external surface attack. Examine at least ten 1-ft^2 areas for wall thinning.	Each of 28 DSTs is examined over a ~35-ft by 30-in.-wide vertical strip, regardless of liquid surface level. Wall examinations also include 20 ft of vertical welds and 20 ft of vertical wall/lower knuckle weld.	n/a—current approach complies with TSIP guidance
19) Visual examination of the DST interior	Conduct visual examination by remotely operated camera for evidence of attack in the vapor region at the top of the primary tank and when a tank is essentially empty. If attack is observed, use appropriate surface or NDE procedures to determine depth of attack.	Internal DST visual examinations are planned in accordance with draft TPA milestone M-48-05 when video camera support is required for other reasons, following retrieval of waste, or when other data (e.g., UT data) indicate the need for a visual examination.	n/a—current approach complies with TSIP guidance, except that NDE of the tank dome above the vertical wall section is not planned due to access constraints.
20) Secondary tank	Conduct visual inspection of the secondary tank for degradation, five areas of 1 ft^2 for thickness measurements and 5% of the knuckle region welds for cracks.	Examination of a 20-ft length of the secondary tank knuckle and 10 ft^2 of the secondary tank floor for wall thinning, pits, and cracks is planned for three DSTs.	n/a—current approach exceeds TSIP guidance

2.3.1 Visual Inspection

All 28 DSTs were inspected visually in accordance with commitments made to the Washington State Department of Ecology under the Tri-Party Agreement (TPA) (Ecology 1998 Rev. 5) in the early 1990s. Approximately 18% of the exterior wall of the primary tanks and about 30% of the interior of the secondary tanks were examined (Walter 1992, 1993a, 1993b; Harris 1993a, 1993b; Anantatmula 1997). These examinations showed no evidence of significant degradation (Staehr 2001). These video records have been maintained and are available for comparison purposes. In fact, these records contributed to the recent assessment of corrosion in the annulus of Tank AY-101, discussed below. Visual inspection was also performed of the interior of two DSTs with low waste levels in 1997; these tanks showed small amounts of general corrosion and some pitting.

In June 2000, the Washington State Department of Ecology issued Administrative Orders to DOE and CHG that required, among other things, submitting a plan for conducting additional internal inspections of DST primary tanks.[a,b] The plan that was subsequently submitted to Ecology committed Hanford contractors to perform such visual inspections when a video camera was deployed in the internal of a tank for another reason, following waste retrieval, or when other information (e.g., ultrasonic testing data) indicated a need for such an inspection.

In addition to this, visual inspection of the external wall of the primary tank has been performed coincident with the ultrasonic inspection program. This has resulted in limited visual inspections being performed in the annuli of eleven additional tanks over the past four years (AN-105, AN-106, AN-107, AP-107, AP-108, AW-101, AW-103, AW-105, AY-101, AY-102 and AZ-101). Ultrasonic examination of the remaining 17 DSTs will be carried out in accordance with Administrative Orders from Ecology, as discussed below.

Difficulties were encountered during an attempt to perform ultrasonic inspection on Tank AY 101 in May 1999. There was a buildup of corrosion on the exterior wall in the area of the tank that was to inspected. The corrosion product caused the magnetic wheels of the “crawler” to disengage from the tank wall. Although only limited visual examination was performed at that time, corrosion observed in the area where the ultrasonic inspection equipment was deployed was far more severe than what had been observed in 1992. Plans were initiated to clean the corrosion product off of the tank wall and perform a more extensive visual inspection of the annulus of the tank; this commitment was included in the *Double Shell Tank Corrosion Mitigation Action Plan* [c].

(a) Silver D. June 13, 2000. *Failure to Comply with Major Milestone M-32 of the Tri-Party Agreement; Administrative Order No. U.S Department of Energy 00NWPKW-1250*. Letter to R French, DOE Office of River Protection and K Klein, DOE-RL.

(b) Washington State Department of Ecology. June 13, 2000. *Administrative Order No. CH2M Hill Hanford Group 00NWPKW-1251*. Letter to M.P Delozier, CH2M HILL Hanford Group, Inc.

(c) CHG. 1999. *Action Plan to Resolve Defense Nuclear Facilities Safety Board Issues Relating to the Hanford Site High-Level Waste Tank Structural Integrity Program*. Letter CHG-0004843, Contract DE-AC27-99RL14047.

Preliminary visual inspection of the annulus of AY-101 was performed through several risers in FY 2000. This inspection looked at the external surface of the primary tank and the internal surface of the secondary shell. Significant water streaking was observed on the primary- and secondary-shell walls all the way to the annulus floor (Aftanas 2001a). As a result, additional visual inspections were planned for AY-101 and AZ-102, which, like AY-101, had experienced significant periods during which its annulus ventilation system was turned off.

The planned additional inspections of AY-101 were described in *241-AY-101 Annulus Water Intrusion Investigation Plan* (Bellamy 2001). It specified visual inspections of eight risers. Widespread corrosion was observed on the primary tank wall during these inspections; therefore, the inspection was expanded to five additional annulus risers and one primary tank riser. The widespread corrosion observed on the external wall of the primary tank and indications noted on the internal wall of the tank during these visual inspections led CHG to issue an off-normal Occurrence Report.[a] In addition, an operational restriction was placed on the tank that limited the waste level to less than 80 inches until further evaluation can be performed. Further details concerning the corrosion observed in AY-101 are described by Aftanas (2001a, 2001b).

Five risers were chosen for inspection in Tank AZ-102. As discussed, this tank had experienced an extended period during which the annulus ventilation system had been turned off. Thus it was thought that similar conditions might exist in this tank and may have resulted in accelerated corrosion. Aftanas (2001a) reports that areas of light corrosion were observed during the examination, but no significant changes from the levels of corrosion observed in the 1992 baseline inspections were identified. However, the riser areas examined in 1992 were not available for inspection in 2001 due to conflicts with other ongoing work in the area.

In summary, baseline visual inspection of a limited area of the external shell of the primary tank (about 18% of the tank wall) and the internal wall of the secondary tank (about 30%) were completed in early 1990s. Two visual inspections of the internal shell of the primary tank have also been completed, and another four are planned before 2005. Since 1992, additional inspections have been performed in accordance with commitments made in the TPA. These inspections have included ultrasonic inspection of 11 tanks, during which limited visual inspections were performed on the external wall of the primary shell. Visual inspections conducted during ultrasonic inspection or that were required to resolve issues identified during the ultrasonic inspection have resulted in limited visual re-inspection of eight tanks. More comprehensive visual re-inspections have been performed for AY-101 and AZ-102. The substantial corrosion noted in AY-101 resulted in an inspection of the internal surface of this tank. Anomalies noted during this inspection are still being evaluated by CHG. Tank AZ-102 showed only light corrosion and no significant change in its status since 1992.

(a) RP-CHG-TANKFARM-2001-0004. 2001. "Corrosion Observed in Double-Shell Tank AY-101 During Video Inspection of the Annulus Section."

2.3.2 Ultrasonic Inspection

CHG has implemented an ultrasonic inspection program that uses a remotely operated magnetic-wheeled crawler. A traveling bridge attached to the crawler is outfitted with ultrasonic sensors. Remotely operated closed-circuit TV is also provided to support ultrasonic inspection.

Only the top ~3 inches of the lower knuckle can presently be examined using the magnetic crawler vehicle (structural analyses indicate that the most highly stressed region of the lower knuckle is from the mid- to the lower part of the knuckle). Additional development is required to test alternative methods for accessing this part of the knuckle (Staehr 2001). Ecology has required that CHG report on a semi-annual basis concerning progress in examining additional portions of the lower knuckle.

The Tanks Focus Area (TFA) sponsors integration of a ultrasonic inspection bridge using tandem synthetic aperture focusing technique (T-SAFT) technology with a remotely operated crawler by PNNL under a collaborative agreement with CHG. This remotely operated NDE (RONDE) system will improve the ability to inspect the lower knuckle region; cold acceptance testing and deployment in a Hanford DST are planned in FY 2002. A small crawler is in use at SRS that may allow inspection of the tank bottom through the ventilation slots (see Section 2.3.3).

Through September 1999, Ecology took exception to the scope of ultrasonic inspection performed on DSTs in support of the required DST system integrity assessment via the Administrative Orders issued to DOE and CHG.[a] They noted that "the ultrasonic testing conducted in the six (6) DSTs examined…did not include examination of the lower knuckle area in four (4) DSTs, did not examine tank bottoms in five (5) DSTs, and did not thoroughly examine the liquid/vapor interface in any of the six (6) tanks examined. Only one of the six (6) DSTs examined was ultrasonically tested in all areas." Ecology established the following minimum requirements for follow-on ultrasonic inspection, to be completed by FY 2005 (Staehr 2001):

1. 30-inch wide vertical scan of the primary tank wall for all DSTs
2. 20-ft length of circumferential weld joining the primary tank wall to the lower knuckle and the adjacent heat effected zone for all DSTs
3. 20-ft length of vertical weld joining shell plate courses of the primary tank, extended as necessary to include at least 1 ft of vertical weld in the nominally thinnest wall plate and adjacent heat affected zone
4. 20-ft circumferential scan at a location in the vertical portion of the primary tank wall corresponding to a static liquid/vapor interface that existed for any five-year period, extending at least 1 ft above that liquid/vapor interface for six DSTs
5. 20-ft long circumferential scan of the predicted maximum stress region of the primary tank lower knuckle for six DSTs

(a) Silver D. June 13, 2000. "Failure to Comply with Major Milestone M-32 of the Tri-Party Agreement; Administrative Order No. US DOE 00NWPKW-1250." Letter from Washington State Department of Ecology to K Klein, ORP, dated June 13, 2000.

6. Primary tank bottoms in each accessible air slot over a length of 10 ft toward the center of the tank from the lower knuckle joint for six DSTs (including AN-107, completed in FY 1998).

Following completion of the initial ultrasonic inspections of each DST, repeat inspections are to be conducted on an interval not to exceed 10 years.

In summary, 11 ultrasonic inspections have been completed to date. Significant experience has been gained in using ultrasonic inspection methods in the tank annuli. New technology is being developed that will greatly improve the ability to inspect critical areas of the tank.

2.3.3 SRS Inspection Program and Lessons Learned

The HLW tanks at SRS have a function similar to that of the tank farms. Waste is collected from various processing plants, notably F and H canyons, and stored awaiting further processing (e.g., at the Defense Waste Processing Facility [DWPF]). The confinement function of the tanks is important to the protection of the environment; for this reason the SRS initiated a structural integrity program for the tanks and transfer piping (WSRC 1995) and augmented that program with a life-management program for Types I and II tanks in 1998.

The tanks at SRS are divided into four "types." Types I and II were constructed from 1951 through 1956 (16 tanks); they were constructed of A285 steel and have a steel pan for secondary containment. Type III tanks were constructed from 1967 through 1981 (27 tanks); they were constructed of A516 and A537 steel and have a secondary liner. The eight Type IV tanks were built in 1958 and 1962; they have no annulus and are similar to Hanford's SSTs. The welds in the primary shell of Types I, II, and IV were not stress-relieved; the welds in Type III tanks were. Similar to the DSTs, the tanks received radiographic (RT) inspection of the welds and a leak test.

The in-service tank inspection program began in 1971, although visual inspections with a periscope had been performed on a random sample of tanks between 1961 and 1970. The program involves routine visual inspection using wide-angle photography, closed circuit television and direct (detailed) photography. The periodicity for the inspections using detailed, direct photography is as follows: DSTs (Type I, II and III) that have leaked are inspected through selected risers annually and though all risers every two years; other DSTs are inspected through selected risers every two years and through all risers every four years; single-shell tanks (Type IV) are inspected on the same periodicity as DSTs that have leaked. General, wide-angle, photography is performed on tank risers that have not received a detailed visual inspection.

Periodic ultrasonic inspection of DST and SST tank bottoms was performed between 1972 and 1985. This inspection was resumed in 1994. The results of the visual and ultrasonic inspections are documented in annual reports (WSRC 2000a).

The inspection results to-date indicate that little wall thinning or pitting has been experienced. Visual inspection has shown only minor surface corrosion on the outside walls of the primary tank. However, SCC has been observed in six Type I and four Type II tanks, and rainwater intrusion is suspected in two Type IV tanks. Tank 16 is the worst-case tank, with over 300 cracks identified. The cracks in the Types I and II tanks have been "self-healing," to-date; that is, the waste forms a crystalline deposit on the outer shell of the tank and waste leakage discontinues.

To ensure the safe operation of the Type I and II tanks with these cracks, the Life Management Program was initiated. This program involves detailed stress analysis (in accordance with ASME B&PV Code, Section VIII, Division 2 requirements), a comprehensive program of mechanical properties testing, and evaluation of flaw stability (WSRC 2000b). The information from these assessments is fed into a decision model to determine whether the flaws are acceptable for continued operations or management actions (e.g., transfer of the waste, lowering tank level, tank repair) are required.

SRS has recently begun a program to deploy an ultrasonic inspection crawler that can fit through a 5-inch riser. Initial testing was performed in FY 2000. It is anticipated that, when operational, the equipment will be used to examine vertical strips encompassing at least 1% of the tank circumference, the lower knuckle region (for a distance of at least 5% of the tank circumference), and accessible weld areas in the lowest course of plates (as accessible). The system will look for general wall thinning (limit: less than or equal to 12.5% of wall thickness), pitting (limit: greater than or equal to 50% of wall thickness), and crack-like indications of greater than or equal to 25% of nominal wall thickness and/or greater than or equal to 2 inches in length.

2.3.4 Additional Methods to be Considered

The discussion of the group produced a number of recommendations for additional investigations that could be performed. The review of technology used at SRS showed that the crawler used in their inspection program was smaller in size and thus able to fit through a larger number of risers. This presents the potential, here at Hanford, to inspect tank thickness at more positions along the circumference of the tank. It was generally agreed that CHG should investigate the possibility of using SRS technology in the tank farms at Hanford.

The potential use of eddy current inspection technology was also discussed. The apparent advantage discussed was the potential to better quantify the size of pits on the outside of the tank liner.

Another concern that was addressed was methodologies to determine the presence of through-wall perforations. Methods that were mentioned were gas and visual tracers (e.g., smoke, liquid dye penetrant). The pressure differential between the annulus and the primary sides of the tank would permit the internal of the tank to be monitored for signs of leakage. It was generally agreed that this path should be pursued because it would provide the ability to determine whether any indications observed during visual or ultrasonic inspection had propagated through the wall.

A final area discussed was review of construction records. Although not an additional method of inspection in and of itself, it was believed that review of the records for heat treatment methods and results, along with weld inspection methods, procedures, and limits, would be valuable. The results of this review would have a potential impact on, for example, the size of weld flaw to be assumed in structural assessments and whether it was necessary to perform more extensive inspection of the weld metal areas (which is not now part of the ultrasonic inspection program).

2.3.5 Recommendations and Lessons Learned

Significant corrosion has been found on both the annulus and primary tank internal surfaces in Tank AY-101, and several other tanks are outside the current chemistry controls. The extent of corrosion and the potential for it to exist on other tanks led to a discussion of how present inspection practices could be modified. Because visual inspection had proved valuable in assessing the extent and (at least qualitatively) the degree of corrosion on Tank AY-101, it was suggested that visual inspection should be performed whenever a video camera is to be deployed inside of tank regardless of the reason. It was further suggested that more frequent comprehensive visual inspections of the available tank surfaces would be beneficial; the headspace was mentioned as a potentially vulnerable area in cold tanks. It was also suggested that "stereo" photos would help interpret the results. Based on the important role that NDE results would play in determining the ultimate design life of the DSTs, it was recommended that clear quality requirements needed to be established for the conduct and interpretation of NDE results.

Additional discussion revolved around the perceived need to expedite schedules for a number of inspection activities. Based on the results of the visual inspection of Tank AY-101 (discussed above), it was recommended that the annulus region and internals of all DSTs should be inspected within the next two years. It was deemed that, due to some uncertainty with the original construction inspections and results, the ultrasonic inspection of tanks should be performed every five years, as opposed to the ten-year period presently planned. Two observations were made with regard to actions to be taken when results of monitoring efforts produce anomalies; the group believed that NDE should be performed on an urgent basis on tanks that had been out of specification with respect to chemistry limits for an extended period and that further NDE should be expedited when visual inspection results showed significant indications of corrosion. In general, the group observed that an overall NDE baseline of all 28 DSTs should be completed expeditiously.

The last area of discussion addressed new inspections or inspection methods. These are discussed in Section 2.3.4, with one exception. The group focused on the indications of waterline corrosion that had been observed in Tank AY-101. It was generally agreed that this area was particularly important. Therefore, it was suggested that NDE be performed at the waterline (or waterlines, where more than one existed) in each tank at least once every five years. It was noted that the current plan calls for ultrasonic inspection of vertical strips that would cover all historic and recent water lines.

Overall Recommendation

All 28 DSTs must be inspected to determine whether significant corrosion has occurred and to quantify its extent before meaningful structural analyses or lifetime predictions can be made. Inspection is also required to establish an as-found baseline on plate thickness because no as-built baseline was made for the non-corroded state after new construction. Additionally, the new construction welding, heat treatment, and inspection requirements should be reviewed for comparison to current standards and the possibility of undetected weld flaws.

Revisions to Present Practice

- Develop a Data Quality Objective (DQO) to formalize NDE inspections; it should include qualification standards for both the operators and equipment.
- Perform visual inspection whenever a camera is in a tank for another reason.
- Evaluate increased frequency and area coverage for visual inspection of the headspace.
- Give a high priority to qualification of the TSAFT technology to inspect the lower knuckle region, and investigate methods to ultrasonically inspect the tank bottom.

Expedite or Revise Inspection Schedule

- Perform visual inspection at least every five years.
- Perform visual inspection the annulus and interior of all DSTs within two years.
- Expedite NDE on tanks known to be or shown to be out of specification with regard to chemistry limits.
- NDE should be expedited in tanks in which significant corrosion is observed during visual inspection.
- Expedite completion of an NDE baseline for all DSTs.

Recommended New Inspections

- NDE covering the waterline area (e.g. vertical strip) should be performed in each tank at least once every five years.
- Review the capabilities of SRS's smaller NDE devices.
- Evaluate eddy current technology for characterization of pits on the outside of the primary liner.
- Develop a gas or visual tracer method to detect or confirm suspected leaks in the primary liner, above the waste surface.
- Review the new construction drawings and QC records for heat treatment, welding specifications, and weld inspection requirements to assess the potential for undetected weld flaws, especially lack of fusion conditions.

2.4 Review of the Corrosion Monitoring Program

Corrosion in the Hanford DSTs is presently monitored indirectly by tank sampling for chemistry or by after-the-fact NDE (ultrasonic or visual inspection) of the tank wall. The tank chemistry results are compared with the chemistry limits derived from laboratory corrosion coupons from numerous corrosion versus chemical environment tests. The NDE testing, such as the ultrasonic scans of the annulus side tank wall, provides detailed and accurate detection and measurement of effects of corrosion after it has occurred.

The above testing and examinations are important, but they still do not provide a real-time indication of corrosion. For example, there are four out-of-specification DSTs (AY-101, AY-102, AN-102, and AN-107) that may have suffered corrosion damage. In addition to correcting the chemistry of these DSTs by caustic additions, there is an extensive ongoing effort to locate and characterize any potential corrosion effects by remote visual examination (video cameras in the tank annulus and interior regions) and ultrasonic scans in the annulus.

Clearly, it would be advantageous to have real-time corrosion monitoring systems in the DSTs to ensure favorable chemistry and rapid warning of incipient corrosion. There are several good corrosion monitoring probe possibilities for use in the DSTs, and the two most predominant probe programs in trials at Hanford and Savannah River (electrochemical noise probes and Raman /EN probes, respectively) were presented at the workshop, along with discussions on other potentially useful probe technologies.

2.4.1 Summary of Review

The corrosion reactions generate low frequency electrical currents and voltages that show small amplitude fluctuations called electrochemical noise (EN). Different forms of corrosion generate different fluctuation profiles in current and voltage, potentially providing a signature for corrosion identification. Electrochemical noise can therefore (in principle) discriminate between uniform or general corrosion, pitting corrosion and SCC.

EN probes use electrodes made of the tank wall material, which are then wired to electronic measurement equipment. When immersed in the waste, electrodes detect the EN signatures of corrosion if the chemistry produces any corrosion on the electrode material. In effect, it is detection of localized corrosion due to the environment near the electrode. The assumption is that the tank wall is experiencing the same corrosion if it is exposed to the same environment. A typical EN corrosion monitoring system measures instantaneous fluctuations in corrosion current and voltage between three nominally identical electrodes of the material of interest (in this case, tank wall carbon steel) immersed in the environment of interest (tank waste).

The electrochemical noise phenomenon has been known for a long time, but it needed to be made into a useful tool. Extensive laboratory testing was done to prepare for using EN probes in the Hanford DSTs. The laboratory testing consisted of testing tank steel electrodes in relevant test environments and correlating electrical measurement results with metallography of the corroded surfaces. The development work found that the EN-based system could readily distinguish the different types of corrosion by their signatures in simulated waste environments, as follows:

- Uniform corrosion generates a signature of small random fluctuations in current and voltage that can be correlated with general corrosion rates
- Pitting corrosion generates multiple small sharp spikes in current and voltage, but pitting rates and number of pits cannot be determined.
- SCC (intergranular) has current and voltage spike in opposite directions (fewer peaks than pitting), with occasional current and potential bursts as the cracks propagate.

The TFA has funded the development of several generations of EN corrosion probes for Hanford. TFA also funded development of an integrated data collection and interpretation station to receive data from multiple probes. The direction of this year's work funded by TFA is to support CHG in evaluating the use of this technology as a baseline for corrosion monitoring, which was an objective of the recent EN technology review sponsored by CHG.

The current EN probes are about 55 feet in length and have multiple sets of the triple electrodes at various tank locations (e.g., vapor space, supernatant, and sediment regions). A prototype probe was installed in AZ-101 in 1996. Subsequently corrosion probes with gradually evolving design features were installed in AN-107 (1997), AN-102 (1998), AN-105 (2000) and AN-104 (2001). The latest probe in AN-104 is the fourth generation. However, even with probe construction and operation issues solved, there are still significant issues on how to interpret the data being collected. (After the workshop, the EN Steering Committee met for a technical review and decided that more laboratory work is needed on signal interpretation before continuing work in the DSTs.)

2.4.2 Additional Monitoring Considerations

The EN probes also sometimes carry other probe devices such as linear polarization resistance (LPR) probes and thermocouples. This led to a discussion of other valuable probes that might be installed. It was considered that a pH probe would be beneficial, especially when there was enough sampling data and pH data to provide good correlation. Problems with the limited lifetime of pH probes brought forth the idea to use some new low-cost pH probes of lanthanum fluoride (LaF_3), for real-time monitoring of tank pH. Measurement of supernatant and sediment corrosion potential with probes was also discussed. It was also stated that for the tank environment, resistance probes were superior to LPR. In the headspace or annulus, resistance probes are probably the only alternative.

Further interactions brought up the topic of using humidity probes in both the annulus region and the tank dome space to monitor adequacy of corrosion protection from moisture and condensate. Also, using an atmospheric corrosion resistance probe in the annulus region was discussed as a further means of monitoring annulus conditions.

2.4.3 SRS Corrosion and Chemistry Probe (Raman/EN probe)

The TFA and the DOE Control Measurement Sensor Technology (CMST) program are collaborating to fund the development of a hybrid probe for SRS. This probe integrates the EN technology deployed at Hanford with a Raman device to interrogate tank corrosion and waste chemistry monitoring into a single probe. The prototype has undergone hot cell testing with actual SRS tank waste and is undergoing cold acceptance testing in preparation for deployment at SRS in FY 2002. The combined Raman/EN probe is intended to be able eventually to provide real-time detection of pitting and SCC in carbon steel and in situ chemistry measurements of hydroxide, nitrate, and nitrite (and other oxyanions, if possible).

Raman spectroscopy uses laser excitation of chemical species and collection of the scattered light from inelastic interactions. Raman active chemical species include many others beyond the hydroxide, nitrate and nitrite important to tank chemistry. The technique was used both at Hanford and SRS in the late 1970s to analyze nuclear wastes. There is a linear relationship between the Raman response factor and concentration of hydroxide, nitrate, and nitrite, and each chemical species has a unique Raman signature.

The laser system is compact and lends itself to remote use, and the light source and fiber optic systems have up to a two-year lifespan in the SRS tanks. It may be less in the radiation levels of the Hanford tank environment, which degrades the fiber optic materials rapidly. The Raman limit of detection is presently 0.1 M, and improvements are needed to lower the limits. The equipment is sensitive to handling and is negatively affected by solids in the tank waste.

The SRS EN probe results in the development environment are very similar to the Hanford EN probe results described in the section above, and the Raman portion of the probe is generating the expected spectral curves. Deployment of the Raman/EN probe at SRS is planned for October of this year. Workshop participants are very interested in following the progress of this SRS initiative for possible application at Hanford.

2.4.4 Recommendations for Corrosion Monitoring

The workshop recognized that corrosion monitoring technology is still under development, though some devices should be ready for deployment in a few years. Continued development was encouraged. Some specific recommendations for enhancing the operation of the probes and improving the quality of data they produced are given below.

- Determine the optimum number and placement of EN probes for each tank.
- Evaluate placing an EN probe at or near the waterline (to monitor waterline corrosion) or have the capability to move the EN probe up and down.
- Consider adding a weld region to the electrode of the EN probe to more accurately reflect tank wall conditions.
- Correlate tank chemistry sampling results from the supernatant and the sediment with EN probe readings.
- Evaluate using a low-cost pH probe, like the LaF_3 discussed, to monitor DST pH levels in real time.
- Monitor the progress of the SRS Raman/EN probe program for application of this technology at Hanford.
- Evaluate the benefits of an atmospheric corrosion probe in the annulus region.
- Electrical resistance probes are recommended over the use of LPR probes.
- Consider using humidity probes to monitor the conditions in the annulus and tank headspace to determine whether humidity or condensation warrants remediation.

2.5 Ranking of Review Recommendations

As mentioned in Section 2.1, the review of the Hanford Tank Integrity Project produced 73 recommendations for DST life extension (in response to the questions given in Appendix D). The list of all recommendations is given in Appendix E. The ranking process and the results are discussed below.

The first step in ranking was to establish criteria and weighting factors by which an overall numerical score could be determined for each recommendation. The following criteria were chosen:

Time to Benefit: A recommendation that can be put into effect in a short time has a greater benefit because it acts over a longer period than one that is enacted later. Values were referenced relative to the time left in the DST mission of 27 (2001 to 2028) years. Scores of 3 (<2 years to benefit), 2 (2 to 5 years), or 1 (>5 years to benefit) were assigned with a weighting factor of 5 (10 maximum).

Cost: A lower-cost recommendation is more desirable, all else being equal, than a more expensive one. The cost was calibrated approximately by the cost of installing a mixer pump of ~ \$25 M. Building a new DST is estimated at ~\$75 M. Scores of 3 (~ \$100K), 2 (~ \$1M) and 1 (~\$10M) were assigned with a weighting factor of 6.

Probability to Extend Life: This criterion represents the probability that a recommendation, once implemented, will extend tank life significantly. This does not include the probability that the recommendation will be able to be implemented, which is covered by the feasibility criterion. Scores of 3 (high probability), 2 (medium) and 1 (low probability) were used. This criterion was assigned the highest weighting factor of 10.

Supports Commitment: The Tank Integrity Project is committed to implementing certain actions by DOE-ORP, Washington Department of Ecology, and others. A recommendation supporting a prior commitment was assigned a score of 3 and others 1. A relatively low weighting factor of 3 was assigned to this criterion.

Feasibility: Feasibility includes maturity of the technology and ability to deploy it in the Hanford waste tank environment. Scores of 3 (deployment demonstrated), 2 (deployment possible), and 1 (untested, difficult to deploy at Hanford) were assigned with a relatively high weighting factor of 8.

Some of the recommendations represented studies or management actions that could not be evaluated numerically. Examples are (refer to Appendix E), "increase management priority to stay within chemistry limits," "document history of out-of-spec. conditions," and "perform a statistically based cost/benefit analysis of additional SCC testing." This screening separated 21 of the 70 initial recommendations. However, most of them were later promoted and combined with other, more substantive ones in developing the final list.

The 49 remaining recommendations were assigned scores by counting a show of hands for each of the possible scores in each criterion. While the exact scores were being calculated, approximate scores were determined by the facilitators based the majority of votes in each criterion.

This resulted in the ranking shown in Table F.1 of Appendix F. The ranking from the exact scores is given in Table F.2 (the number of attendees voting varied between recommendations and criteria).

The top 20 recommendations from ranking the approximate scores were further ranked using a one-over-one comparison process wherein each recommendation was evaluated in comparison to each of the other 19. The comparison was quantified by counting a show of hands favoring each of the pair of recommendations considered. This produced the 20 x 20 matrix shown in Table F.3 (the number of attendees voting varied between pairs) and the ranking given in Table F.4. The one-over-one exercise generally validated the initial ranking by the approximate scores.

The top 20 recommendations from ranking the exact scores contained three recommendations that were not on the top 20 from the approximate scores. It was decided to include these three in a slightly expanded list of 23 higher-priority recommendations to carry forward for further review. The abbreviated titles are repeated below (Appendix E has a more detailed description):

1. Sample waste more often.
2. Expedite NDE on vulnerable tanks.
3. Perform NDE to cover waterline every five years.
4. Set priority, frequency, and area of NDE based on visual results.
5. Increase frequency of annulus video and number of risers.
6. Increase frequency of headspace video.
7. Perform analyses to ensure inhibitor mixes into waste.
8. Prevent or limit addition of raw water or condensate.
9. Develop layup procedure for tanks left with a heel.
10. Develop a DQO for NDE.
11. Demonstrate low-cost pH probe.
12. Develop contingency plan for tank repair.
13. Prevent waste levels of 100–150 inches.
14. Control humidity in the annulus.
15. Add chemistry conditions to waste compatibility criteria.
16. Increase the margin between waste chemistry and caustic limits.
17. Protect against rain/snowmelt invading annulus.
18. Blank off unnecessary water sources.
19. Develop gas tracer leak test.
20. Reevaluate sum total of extant corrosion test data.
21. Vary waste level to limit waterline corrosion.
22. Perform pitting initiation and inhibition tests.
23. Prevent precipitation from entering annulus ventilation intake.

This list of recommendations, along with the rest of the 73 developed at the workshop, was reconsidered by the Senior Review Committee at a later meeting. The SRC considered larger, more coherent groups of recommendations assigned higher-level priorities to broad groups. The process and results of the SRC deliberations are described in Section 3.

3.0 Report of the Senior Review Committee

3.1 Purpose and Participants

The Senior Review Committee (SRC) assembled on May 21–22, 2001 to review and analyze the results of the Hanford DST Life Extension Workshop (May 1–4, 2001). The participants at the SRC meeting are listed in Table 3.1. All SRC members had participated in the workshop and were familiar with the issues surrounding DST life extension. The purpose of the SRC review was to analyze, consolidate, balance and prioritize the original recommendations to ensure that they directed a coherent and achievable program for DST life extension.

Table 3.1. Senior Review Committee Meeting Participants

Name	Organization
Anantatmula, Mo +	CH2M HILL Hanford Group, Inc., Richland, Washington
Berman, Herb +	ADI Technology Corp.
Brothers, Joe	Pacific Northwest National Laboratory, Richland, Washington
Bush, Spence +	Review & Synthesis Associates, Richland, Washington
Czajkowski, Carl +	Brookhaven National Lab, Upton, New York
Divine, Jim *+	ChemMet, Ltd., West Richland, Washington
Elmore, Monte +	Pacific Northwest National Laboratory, Richland, Washington
Johnson, Burt +	Pacific Northwest National Laboratory, Richland, Washington
Lentsch, Jack	CH2M HILL Hanford Group, Inc., Richland, Washington
Posakony, Jerry +	Pacific Northwest National Laboratory, Richland, Washington
Reynolds, Dan +	CH2M HILL Hanford Group, Inc., Richland, Washington
Sindelar, Bob +	Westinghouse Savannah River Company, Aiken, South Carolina
Zapp, Phil *+	Westinghouse Savannah River Company, Aiken, South Carolina
*Reviewed recommendations but did not attend. + Senior Review Committee.	

3.2 Review Methodology

The SRC first reviewed all the workshop recommendations and prior ranking assessments. To facilitate the discussion and analysis by the SRT, these recommendations were grouped and considered in the following categories:

- Corrosion Testing (8 items)
- Tank Integrity Assessment and Inspection (14 items)
- Chemistry Controls (27 items)
- Corrosion Monitoring (7 items)
- Operation of Support Systems (7 items)
- Corrosion Repair and Mitigation (4 items)
- Additional Actions (5 items).

The 23 top-ranked workshop recommendations were specifically noted in this summary with the ranking number for reference (see Appendix G, "Summary of Grouped Recommendations").

The SRC discussed the items in these groupings in great detail to ensure that the recommendations covered all needs of the DST Life Extension Program. The SRC also worked at providing a balanced effort between detection and prevention of corrosion problems. The discussion led to further consolidation of the recommendations into coherent groupings within the seven categories that address all concerns yet focus on what is important for DST Life Extension. Finally, the SRC also reviewed and discussed some overarching issues such as management support of DST operations and inspections to maintain appropriate focus, budget levels, and priority for these activities.

The SRC also set priority categories and applied them to each recommendation set and subgrouping. The priorities should be interpreted as follows:

<u>Very High Priority</u>:	Action is **mandatory** on an **aggressive schedule** to protect tanks from immediate damage.
<u>High Priority</u>:	Action is **mandatory** to ensure tanks can be operated beyond their design lives.
<u>Nominal Priority</u>:	Action is recommended for possible improvement of tank lifetime.
<u>Low Priority</u>:	Action is not recommended. No low priority items are listed or discussed in this section.

3.3 Results of SRC Review by Category

The recommendations of the Senior Review Committee, which constitute the final recommendations of the Hanford DST Life Extension Workshop, are described in this section. Recommendations are given by category and ordered by the highest priority of recommendations within the category. Each category is introduced by a paragraph describing its significance and current status. Each recommendation is introduced with an accompanying need, deficiency, or problem and identified with a specific index number, e.g., "SRC-1," to facilitate tracking. To provide traceability, the initial workshop recommendations included in each SRC recommendation are indicated by listing the recommendation numbers (see Appendix E) in brackets, e.g., [W-15, 36].

Three recommendations stand out as absolutely necessary and as immediate requirements for management action to maintain and extend the DST lifetime and prevent loss of vital DST capacity to failure by corrosion. These overarching recommendations are summarized below and repeated with more detailed discussion within their respective categories:

- **Establish a top management priority to provide consistent and sufficient funding to allow the Double-Shell Tank Integrity Project to perform the immediate and long-term actions required to protect the DST resources. SRC-A [VERY HIGH PRIORITY].**
- **Establish a top management priority to provide funding to correct the waste chemistry on the four tanks that are currently out of specification as soon as possible and to consistently maintain all tanks within specifications. SRC-B [VERY HIGH PRIORITY].**

- **Establish a top management priority to provide funding to return the inoperative annulus ventilation systems on AZ-101 and 102 to service and to maintain all DST annulus ventilation and other vital support systems operational. SRC-C [VERY HIGH PRIORITY].**

3.3.1 Chemistry Control (VERY HIGH PRIORITY)

For carbon-steel tanks, maintaining the waste composition in a highly caustic chemistry region such that it inhibits corrosion is the best practical preventative measure to preserve and extend DST lifetime. A reduction of waste pH below established limits can readily lead to rapid unacceptable DST corrosion, resulting in loss of tank usable capacity and reduction of tank lifetimes. There are no other practical measures to prevent corrosion if waste chemistry is not controlled.

Current chemistry corrosion limits are based on the data of Divine et al. (1985) and have proven to be effective in that significant corrosion has been observed only in tanks outside the limits (with the possible exception of AN-105, which is presently under investigation). Four tanks are presently outside the limits, and addition of corrosion inhibitor has a high priority. However, mixing a caustic solution into the nonconvective sediment layer (sludge) by natural mechanisms is expected to be very slow. Forced mechanical mixing is not available (the SY-101 mixer pump is inoperative) and is very expensive and time-consuming to install and operate. Flammable gas retention and release concerns can also constrain caustic additions.

Chemistry control is presently monitored by a combination of waste sampling and predictions from caustic depletion models (whose bases and predictive accuracy have been questioned). The cost, methodology, frequency, and representativeness of the samples and consistency of lab analysis have also been questioned. The present chemistry controls are based on the average tank chemistry (from the Best Basis Inventory, available on the TWINS database: http://twins.pnl.gov) and do not provide chemistry limits for each of the waste layers; neither is it clear what chemistry differences may exist within these layers. Also, waste sampling and analysis have not consistently required pH or corrosion potential measurement, so data from which to evaluate effectiveness of chemical corrosion control limits is sparse.

> Potentially rapid and damaging corrosion can be prevented only by maintaining the tank waste within established specifications. This has not been done. Four tanks are known to be out of specification now. It is unacceptable that limits known to prevent corrosion are not being applied. **Ensure management commitment to getting all remaining out-of-specification DSTs into specification, maintaining them within specification, and correcting all conditions harmful to the DST lifetime. SRC-1 [W-51] VERY HIGH PRIORITY.**
>
> The current sampling program is based on caustic depletion models of questionable validity. Some tanks have not been sampled in several years, and the representativeness of the samples when taken has not been firmly established. This makes the status of chemistry controls questionable. **Perform frequent sampling and analysis of the waste instead of depending on caustic depletion models to schedule sampling. Sample and analyze all tank layers to establish existing conditions, including vertical and radial waste uniformity and analytical uncertainty, and to generate a coherent database. SRC-2 [W-1, 27, 59, 60, 61, 62] VERY HIGH PRIORITY.**

There is no requirement or procedure to analyze waste core or grab samples for corrosion chemistry when samples are obtained for other purposes. Therefore, corrosion data are extremely sparse, which compromises the basis of the chemistry controls. Data Quality Objectives (DQO) document which data are required, the sampling frequency and location, and what analyses must be performed. **Establish a Corrosion Chemistry DQO to ensure that high-quality corrosion data will be obtained. Archived waste samples should be re-analyzed under the new DQO as appropriate. SRC-3 [W-71] VERY HIGH PRIORITY.**

Chemistry control limits are based on a calculated tank average waste composition even though the composition in the supernate and the sediment layers may differ. Thus it is not certain whether maintaining the supernate within the chemistry limits will protect the wall exposed to the sediment layer, for example. **Through laboratory testing with simulants and waste samples, and through improved waste sampling, establish the appropriate chemical limits for each layer to prevent or minimize the potential for stress corrosion cracking (SCC) in the knuckle or pitting and excessive thinning of the tank wall. SRC-4 [W-37] VERY HIGH PRIORITY.**

If the waste in a tank goes out of specification, caustic is added to the convective layer. But whether caustic adequately penetrates the nonconvective sediment layer or how long it takes to mix have not yet been established. This chemistry correction is currently not guaranteed in the sediment. Thus, the dynamics of chemistry correction is currently not understood or characterized in the sediment. Forced mixing would essentially guarantee mixing but at extremely high cost and long time frames for mixer installation. [Note: there were some concerns on tank wall erosion from forced mixing of the sediment layer at Savannah River.] **Complete the measurement and analysis of natural mixing dynamics so that timely decisions can be made regarding the need for installation of mixing pumps for tank life extension purposes. SRC-5 [W-7, 36] VERY HIGH PRIORITY.**

Nitrite is known to be an effective corrosion inhibitor as long as the hydroxide concentration is sufficient. Currently, only hydroxide is added to correct waste chemistry. **Evaluate the benefits and feasibility of adding nitrite corrosion inhibitor directly, along with the caustic additions for chemistry control. SRC-6 [W-57] VERY HIGH PRIORITY.**

The high cost of waste sampling and analyses at Hanford reduces the availability of corrosion chemistry data and reduces the effectiveness of the chemistry control program. The costs are perceived to be much less at Savannah River. **Benchmark the Savannah River Site (SRS) tank farm operations for tank sampling and analysis efficiencies and effectiveness. SRC-7 [W-68, 72] VERY HIGH PRIORITY.**

It is possible for a tank to be emptied and left with a shallow depth of waste for an extended period. The high surface-to-volume ratio of this configuration greatly accelerates caustic depletion by reaction of the hydroxide in the waste with atmospheric carbon dioxide, making these tanks particularly susceptible to damaging corrosion. **Develop a layup and sampling procedure for tanks with a waste heel after being pumped out. SRC-8 [W-9] HIGH PRIORITY.**

When waste is transferred between tanks or water or any other material is added to a tank, samples taken and analyses are performed under the waste compatibility program to ensure that the contents remain within the specifications of the safety authorization basis. However, potential situations that could exacerbate corrosion are not considered. It is possible for a transfer or addition to push the waste, or a stratified layer of waste, outside of the chemistry controls, potentially leading to damaging corrosion. **Add corrosion chemistry conditions to the waste compatibility criteria to ensure that the rate or volume of dilute waste or raw water additions do not move the waste out of specification. SRC-9 [W-8, 15] HIGH PRIORITY.**

When correcting the waste chemistry in a tank, only enough caustic is added to just bring the waste back within limits. This provides no margin for potential nonuniformity of the waste, potentially long mixing times for the caustic, and natural future caustic depletion. This is another factor that has the potential to compromises the effectiveness of the chemistry controls. **Consider increasing the margin between waste chemistry and the chemistry corrosion limits (i.e., pH >12), based on corrosion studies and information from the Savannah River Site. SRC-10 [W-16] HIGH PRIORITY.**

Corrosion is possible in the colder tanks from water condensation on the dome surface. Tests have shown that ammonia vapor concentrations in the 100 ppm range can protect carbon steel from corrosion. However, measured headspace ammonia concentrations are generally lower than 100 ppm. **Evaluate addition of ammonia to the tank to raise the concentration in the headspace sufficiently to protect the tank dome from corrosion. SRC-11 [W-50] NOMINAL PRIORITY.**

3.3.2 Support Systems Operation (VERY HIGH PRIORITY)

The internal DST headspace and annulus ventilation systems are both vital to corrosion prevention because they serve to keep the humidity low and even to evaporate a significant flow should water invasion occur in the annulus. Without ventilation, reflux condensation in the annulus can cause significant corrosion. It is also possible for annulus condensate to invade the inside of the primary liner.

Annulus ventilation in several tanks has been inoperative for periods of years. This, along with possible intrusion from leaks in raw water lines above the tank dome or natural storm runoff (a possible source of stray water for all tanks), has been identified as the probable cause for the extensive corrosion observed in the AY-101 annulus. AZ-101 and 102 annulus ventilation systems are still inoperative. Until recently, it was not recognized that there were significant safety and operational drivers to keep the annulus ventilation operating or to monitor annulus air humidity. Headspace ventilation systems in most tanks have generally been operating continuously as required by operational safety requirements (OSR).

Condensation in the annulus has been found to be a direct cause of serious corrosion. Ventilation has been shown to prevent condensation, but some annulus ventilation systems are still inoperative, making corrosion likely. **Make the annulus ventilation systems in AZ-101 and 102 operational and get management priority to ensure the annulus ventilation systems are maintained operational in all DSTs. SRC-12 [W-53] VERY HIGH PRIORITY.**

It has been shown that a relative humidity of 60% can initiate pitting, and that once initiated the humidity must be below 30% to stop it. Annulus ventilation alone may not be able to maintain the humidity sufficiently low to stop pitting if it has already begun. **Heating or dehumidification should be provided for the annulus ventilation system if relative humidity reaches or exceeds 30% for extended periods. Monitor the humidity in**

some selected DST annuli and/or review of meteorological records to assess the need. SRC-13 [W-14, 25] HIGH PRIORITY.

If water were to invade the annulus region such that a significant volume of water were to build up, rapid corrosion could occur before the water could be evaporated by annulus ventilation. **Eliminate the potential for water invading the annulus as follows: SRC-14 [W-17, 18, 23] HIGH PRIORITY.**

- Re-grade or otherwise divert rain or snow melt runoff from the tank farms if it is determined to be a problem.
- Eliminate entrainment of rain or snow into the annulus ventilation system with baffles or reoriented intakes. Also evaluate sealing penetrations in the tank dome regions, which could be pathways for rain or snow melt.
- Blank-off unnecessary water sources (e.g., raw water piping) to prevent potential water intrusion from leaks or misrouting.

3.3.3 Corrosion Testing (HIGH PRIORITY)

Data from corrosion testing provides the technical basis for the chemistry controls that prevent or limit corrosion in the tanks. It is essential that this technical basis be sound and robust to ensure the tank lifetime is protected and accurately estimated.

A large body of corrosion data was generated in the mid-1980s using a broad range of simulants, concentrations, and temperatures. These data still cover the expected range of tank conditions. However, the tie between test and tank conditions is weak because no comprehensive post-synthesis chemical analysis was done on the actual simulant solutions tested. There were also too few test occurrences (only eight coupons) of SCC to establish exact boundaries and chemical/stress condition limits for tank controls and to validate that present controls are conservative. Other data have become available since the 1980s but have not been evaluated for incorporation into the chemistry controls. New data may be required to ensure present controls will cover wastes created by transferring the contents from the SSTs into the DSTs.

The actual composition of the Divine et al. (1985) simulants was inferred from the recipes used to prepare them. The temperature-dependent solubilities of various species and the potential for various reactions make the actual composition seen by the test coupons highly uncertain. This uncertainty compromises the conservatism of the technical basis of the chemistry controls, and the ability to correlate tank chemistry with test results. **Fully characterize the tank simulants originally used to determine tank chemistry controls. Determine free hydroxide, nitrate/nitrite, pH, corrosion potential, etc., in the simulant to compare with actual waste composition data. SRC-15 [W-24] HIGH PRIORITY.**

The DST knuckle region in contact with the sediment layer is the highest-stress region in the tank and may be vulnerable to SCC that could lead to catastrophic loss of tank integrity. Therefore, for DST life extension, it is important to ensure that the chemistry controls conservatively protect against SCC. **Conduct an optimum experimental test program, possibly including low strain-rate tests, to establish chemical conditions to reach SCC thresholds for the most vulnerable tank regions. Analysis of sediment and super-**

natant composition and analysis of more recent SCC data will guide the experiments. SRC-16 [W-29, 30, 58] HIGH PRIORITY.

Furthermore, the scope of the corrosion tests of Divine et al. (1985) did not cover the conditions that could result from SST retrieval or conditions typical of the waterline area. Recent pitting tests have shown that pitting is difficult or impossible to inhibit after it starts. This has potentially significant implications on tank lifetime and chemistry controls. Additional tests need to be planned to confirm the efficacy of chemistry controls to prevent or inhibit pitting over an extended tank operating range. **Carefully plan and perform cold corrosion tests for bulk corrosion, pitting initiation and inhibition and waterline corrosion on an appropriate range of conditions, to determine safety margin on present chemistry controls and extend their range. SRC-17 [W-20, 22, 31] HIGH PRIORITY.**

3.3.4 Tank Integrity Inspection (HIGH PRIORITY)

All 28 DSTs must be inspected to determine whether significant corrosion has occurred and to quantify its extent before meaningful structural analyses or lifetime predictions can be made. Inspection is also required to establish an as-found baseline on plate thickness because no as-built baseline was made for the non-corroded state after new construction.

Visual inspection of the annuli and domes and ultrasonic testing (UT) using a magnetic crawler device are under way. Significant corrosion has been found in both the annulus and internal surfaces on AY-101. Some thinning has been measured in AN-105. Several other tanks are outside the current chemistry controls, may have corrosion, and need to be inspected. Current nondestructive examination (NDE) methods cannot measure the lower knuckle of the primary liner in the area near the concrete pad. A device has been designed to inspect the tank bottom through the ventilation slots but has not yet been deployed. Other NDE technologies including eddy current testing (ET) and tandem-synthetic aperture focusing technique (T-SAFT) are under development for tank application. A smaller NDE device used at Savannah River may have application here.

Visual inspection is a good early detector of significant corrosion and all tanks should be inspected as soon as possible. The current schedule is to repeat inspections every 10 years. However, because pitting can be rapid and may be difficult to stop, visual inspection needs to be performed more frequently. **Complete the visual inspections for all DSTs to establish a corrosion baseline in two years (not to exceed three years) and increase the frequency of scheduled visual inspection thereafter. Let these results guide the priority and locations of UT testing (including UT examination of waterline areas). SRC-18 [W-5, 6, 64] HIGH PRIORITY.**

The current plan is to perform NDE every 10 years after the initial baseline. Again, the potentially high rate of corrosion and difficulty in inhibiting pitting dictates a higher frequency. The waterline region is more vulnerable to corrosion and should be inspected more frequently. **Perform volumetric NDE (UT, ET) on all tanks at least every five years, including a vertical strip to cover changing waterlines. Focus priority efforts on tanks known to be out of specification or with known corrosion. SRC-19 [W-2, 3, 4, 26, 56] HIGH PRIORITY.**

The current UT system cannot inspect the knuckle region, where high stresses make SCC a potential corrosion mechanism. Because SCC may be rapid and potentially catastrophic, inspection of this area is vital. **Continue to support T-SAFT development to achieve a viable inspection of the tank knuckle regions. SRC-20 [W-73] HIGH PRIORITY**.

The extent of pitting on the annulus side does not lend itself to measurement with the current UT method. Additionally, the UT measurements require cleaning the tank wall surface to allow the UT transducers to adequately couple to the metal. Pulsed EC techniques may overcome these difficulties and/or supplement UT inspections. **Evaluate using pulsed eddy current (ET) techniques to supplement UT inspections. SRC-21 [W-65] HIGH PRIORITY.**

Visual inspection or UT is incapable of determining whether the primary wall has been penetrated by corrosion (except in extreme cases). The existence and location of a potential pinhole leak must be determined to properly control tank operation. **Complete the procurement and use of a gas (or other) tracer technology to determine whether Tank AY-101 has a perforation. Maintain the technology for other potential tank evaluations. SRC-22 [W-19] HIGH PRIORITY.**

The current NDE program is still developing, and testing and measurements are planned on a tank-by-tank and riser-by-riser basis. To be an effective component of the DST integrity program and to ensure the ability to compare results from year to year, it must become a formalized, consistent, and routine operation. Data quality objectives document the required testing and methodology based on anticipated and as-found conditions. **Complete the DQO for UT inspections (program under way) to ensure the consistency and quality of UT measurements. SRC-23 [W-10] HIGH PRIORITY.**

A small NDE device is being used at Savannah River that may be able to inspect more of the lower knuckle and possibly penetrate the air slots under the tank bottom. **Benchmark the Savannah River Site NDE equipment and methodology for potential efficiencies and application to the Hanford DSTs. SRC-24 [W-66] HIGH PRIORITY.**

3.3.5 Corrosion Repair and Mitigation (HIGH PRIORITY)

If corrosion causes a leak in the primary tank liner or loss of structural integrity, the options are to reduce the allowable tank capacity by keeping the waste level below the leak or to remove the tank from service and move its waste to other tanks. The critical need for DST capacity to meet commitments and the time and cost of constructing a new tank make mitigating or preventing leaks extremely important and the option of repairing the tanks very attractive.

The only potential management option currently available for a tank defect situation is reducing tank capacity. Such administrative controls on tank usage would require a modification to the authorization basis and loss of tank capacity and programmatic flexibility. Commercial in situ repair technology (e.g. welding of patches, mechanical plugs, or coating) is available and used in several industries (nuclear reactors, petrochemical industry, etc.) but has not yet been evaluated for use in the constrained environment of the Hanford tanks.

The waterline area is particularly vulnerable to corrosion and may be very difficult to protect by chemistry controls. One way to limit the extent of waterline corrosion is to reduce the time any one area of the tank wall is exposed to the water line. **Systematically and periodically vary waste levels in DSTs equipped for transfers to minimize the effects of water line corrosion. Maintain this administrative control unless and until chemis-**

try limits are developed that ensure no waterline corrosion. SRC-25 [W-21] HIGH PRIORITY.

Administratively control DST tank levels to avoid maintaining waste levels in the calculated region of minimum design wall margin where corrosion would most easily bring the tank wall to the minimum acceptable thickness. This is typically in the 100- to 150-inch region, as presently analyzed. **Administratively control DST tank levels to avoid maintaining waste levels in the 100–150 inch range until reassessment with probabilistic mechanical stress analysis determines the accuracy and need of the control. RC-26 [W-13, 32] HIGH PRIORITY.**

Develop a contingency plan for weld repair of DST defects (e.g., perforation, wall thinning, etc.). This plan will include specifications and procedures, stray current corrosion considerations, and qualification of suppliers. Assess the potential use of mechanical plugs or sealants (e.g., epoxy) to seal tank leaks. SRC-27 [W-12, 28] HIGH PRIORITY.

3.3.6 Corrosion Monitoring (NOMINAL PRIORITY)

Corrosion monitoring provides continuous indication of the effectiveness of chemical inhibition by either monitoring the chemistry or the electrochemical noise generated by the different corrosion processes. This helps to protect against sudden changes in the waste condition that may not be detected by periodic sampling.

The DST Integrity program is developing EN probes for eventual deployment in the tanks. The probe design is becoming relatively mature, though the data interpretation and data recording and reduction logistics need to be improved. A combined Raman/EN probe is also under development at SRS that both measures concentrations of chemical species present and detects corrosion through EN methodology.

The electrochemical noise probe development program should continue with testing and correlation of probe responses to observed corrosion, as directed by the Tank Focus Area. SRC-28 [W-41, 42, 45] NOMINAL PRIORITY.

Maintain development and testing of the various probes [e.g., pH probes (LaF_3), Raman/EN probes being developed at SRS, electrical resistance probes, linear polarization resistance probes, corrosion potential probes, humidity probes, etc.]. Viable candidates may be employed in the DST Life Extension Program. SRC-29 [W-11, 34, 35, 67] NOMINAL PRIORITY.

Ensure integration of the cold testing corrosion programs for SCC and pitting with the probe evaluation programs to maximize probe measurement correlation with tank conditions. SRC-30 NOMINAL PRIORITY.

3.3.7 Additional Actions (NOMINAL)

The following two recommendations of Nominal Priority were discussed and reviewed by the SRC and contain actions that did not readily fit into the other categories. These are followed by two additional items that the SRC considered to be Low Priority (not recommended) but are listed here for completeness.

Reevaluate the application of cathodic protection systems for use on the DSTs. Base this evaluation on a review of this subject done at Savannah River and assessment of related industry applications. Use of cathodic protection for the DSTs may provide an alternative to mechanical mixing of the sediment to protect against SCC. Document the results and conclusions and make a final disposition of the use of this technology for the DSTs. SRC-31 [W-54] NOMINAL PRIORITY.

Address the potential for waterline corrosion from continuous condensate return, especially for the colder DSTs, and modify systems as appropriate. SRC-32 [W-63] NOMINAL PRIORITY.

PNNL-13571

Expert Panel Recommendations for Hanford Double-Shell Tank Life Extension

CW Stewart, Editor

SH Bush, Chair

HS Berman	MR Elmore
CJ Czajkowski	DA Reynolds
JR Divine	RP Anantatmula
GJ Posakony	RL Sindelar
AB Johnson	PE Zapp

June 2001

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

4.0 References

Aftanas BL. 2001a. *Year 2001 Visual Examination of Tank Annuli at Tanks 241-AY-101 and 241-AZ-102.* RPP-7764 Rev. 0, Cogema Engineering Corp., Richland, Washington.

Aftanas BL. 2001b. *Double-Shell Tank Integrity Assessment Program Corrosion Report on 241-AY-101.* RPP-7814 Rev. 0, Cogema Engineering Corp., Richland, Washington.

Anantatmula RP. July 1997. HNF-SD-WM-RPT-307, *Visual Examination of 241-AP-104 and 241-AP-107*, WHC-SD-WM-RPT-034, Westinghouse Hanford Company, Richland, Washington.

Anantatmula RP, EL Dalpiaz, EA Fredenburg, DM Ogden, and MJ Thurgood. 2001. *Double-Shell Tank Annulus Ventilation Engineering Study*. RPP-7695 Rev. 0, CH2M HILL Hanford Group, Richland, Washington.

Bandyopadhyay K, S Bush, M Kassir, B Mather, P Shewmon, M Streicher, B Thompson, D van Rooyen, and J Weeks. 1997. *Guidelines for Development of Structural Integrity Programs for DOE High-Level Waste Storage Tanks*. BNL-52527, Brookhaven National Laboratory, Upton, New York.

Bergman LM. 2000. *Operating Specification for Aging-Waste Operations in 241-AY and 241-AZ.* OSD-T-151-00017 Rev. D-12, CH2M HILL Hanford Group, Inc., Richland, Washington.

Cash RJ. December 2000. Tank Farms Final Safety Analysis Report (FSAR). HNF-SD-WM-SAR-067, CH2M HILL Hanford Group, Inc., Richland, Washington.

Bellamy J. 2001. *Annulus Water Intrusion Investigation Plan.* RPP-7540, CH2MHILL Hanford Group, Richland, Washington.

Cuta JM, DW Damschen, WL Kuhn, K Sathyanarayana, KG Carothers, JA Lechelt, and LA Stauffer. 2000. *Review of Waste Retrieval Sluicing System Operations and Data for Tanks 241-C-106 and 241-AY-102*. PNNL-13319, Pacific Northwest National Laboratory, Richland, Washington.

Danielson M.J and LR Bunnell. April 1994. "Sludge Washing Materials Study: The Behavior of Carbon Steel in a Dilute Waste Environment." TWRS PP-94-025, Pacific Northwest Laboratory, Richland, Washington.

Divine JR, WM Bowen, DB Mackey, DJ Bates, and KH Pool. 1985. *Prediction Equations for Corrosion Rates of A-537 and A-516 Steels in Double Shell Slurry, Future PUREX, and Hanford Facilities Wastes*. PNL-5488, Pacific Northwest Laboratory, Richland, Washington.

Donovan JA. March 1977. "Factors Controlling Nitrate-Cracking of Mild Steel." *Corrosion 77*, San Francisco, pp. 8.1–8.9.

Fort LA, DA Reynolds, KG Carothers, MA Knight, and MJ Klem. 2001. *Technical Basis for Chemistry Control Program*. RPP-7795 Rev. 0, CH2M HILL Hanford Group, Richland, Washington.

Han FC. 1996. *Structural Integrity and Potential Failure Modes of the Hanford High-Level Waste Tanks*, WHC-SD-TWR-RPT-002, Rev. 0, , Westinghouse Hanford Company, Richland, Washington.

Harris J. September 1993a. *Visual Examination Report for Tank Annuli at the 241-AP Tank Farm.* WHC-SD-WM-RPT-077, Westinghouse Hanford Company, Richland, Washington.

Harris J. September 1993b. *Visual Examination Report for Tank Annuli at the 241-AY and 241-AZ Tank Farms*. WHC-SD-WM-RPT-078, Westinghouse Hanford Company, Richland, Washington.

Mahoney LA, ZI Antoniak, WB Barton, JM Conner, NW Kirch, CW Stewart and BE Wells. 2000. *Results of Waste Transfer and Back-Dilution in Tanks 241-SY-101 and 241-SY-102.* PNNL-13267, Pacific Northwest National Laboratory, Richland, Washington.

Ondrejcin RS. April 1984. "Prevention of Stress Corrosion Cracking in Nuclear Waste Storage Tanks." *Corrosion 84*, New Orleans.

Parks DH. 1957. *Examination of Corrosion Test Coupons in PUREX 101 Waste Storage Tanks - RM-147*. HW-49574, General Electric Co. Richland, WA.."

Payer JH, RB Diegle, and WK Boyd. 1975. *Corrosivity of Synthetic Salt Cake*. ARC-C-22, Battelle, Columbus, Ohio.

Poe WL. 1974. "Leakage of Waste Tank 16: Amount, Fate, and Impact." DP-1358, EI duPont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Sanborn ND. 1952. *A Study of the Effect of pH of First Cycle Bismuth Phosphate Waste on the Corrosion of Mild Steel*. HW-26202, General Electric Co,. Richland, WA.

Staehr TW. 2001. *Double-Shell Tank Integrity Program Plan*. RPP-7574 Rev. 0, Cogema Engineering Corp., Richland, Washington.
Table of Contents

Walter EJ. June 1992. Visual Examination of Tank Annuli at the AW Tank Farm. WHC-SD-WM-RPT-034, Westinghouse Hanford Company, Richland, Washington.

Walter EJ. May 1993a. *Visual Examination Report for Tank Annuli at the 241-AN Tank Farm.* WHC-SD-WM-RPT-061, Westinghouse Hanford Company, Richland, Washington.

Walter EJ. September 1993b. *Visual Examination Report for Tank Annuli at the SY Tank Farm.* WHC-SD-WM-RPT-076, Westinghouse Hanford Company, Richland, Washington.

Washington State Department of Ecology, United States Environmental Protection Agency, and United States Department of Energy. 1989 and as Amended Through December 31, 1998. *Hanford Federal Facility Agreement and Consent Order*. 89-10 Rev. 5, Ecology, EPA, and DOE, Olympia, Washington.

WSRC. 1995. *SRS High-Level Waste Tank and Piping Systems—Structural Integrity Program and Topical Report*. WSRC-TR-95-0076, Westinghouse Savannah River Company, Aikin, South Carolina.

WSRC. 2000. *Annual Inspection Summary Report*. WSRC-TR-2000-00067, Westinghouse Savannah River Company, Aikin, South Carolina.

WSRC. 2000. *J-T and FAD Methods Applied to Evaluate Flaw Stability*. WSRC-TR-2000-00478, Westinghouse Savannah River Company, Aikin, South Carolina.

Appendix A

Biographical Sketches

Appendix A
Biographical Sketches

Dr. R. P. (Mo) Anantatmula

Dr. Anantatmula received a B.E. degree in Metallurgy from Indian Institute of Science, M.Sc. in Metallurgical Engineering from Banaras Hindu University, and a Ph.D. in Engineering Science (Materials) in 1973 from Washington State University. He has six years experience as team leader in the Materials Testing Group of the Waste Package Department, Basalt Waste Isolation Project (BWIP).

Dr. Anantatmula has six years experience as team leader in the Materials Testing Group of the Waste Package Department, Basalt Waste Isolation Project (BWIP). He has performed aqueous corrosion studies on the nuclear waste container materials (iron-base and copper-base alloys) for storage of high level waste in a repository constructed in basalt; used x-ray diffraction, electron microprobe, and scanning electron microscope (SEM) to understand corrosion mechanisms; developed container corrosion models and performed sensitivity and reliability analyses; and provided technical integration of research contracts in the general corrosion studies area of the BWIP container corrosion program. He has also coordinated discussions with the copper industry (Copper Development Association & International Copper Research Association) on the copper-based materials testing.

In addition, he has 12 years experience as part of Materials and Corrosion Engineering group and other groups, and he has been responsible for resolution of waste tank and associated systems corrosion issues. Other responsibilities have included assessments of Hanford double-shell tank useful life analysis and estimate. Currently, he is working on upgrading the tank liftime estimates as part of a decision analysis report on DST failure and replacement. He has performed visual inspections of several tanks at the Liquid Effluent Facility for corrosion damage and issued summary reports of corrosion status on each tank, reviewed ultrasonic (UT) inspection data on double-shell tanks as a member of the DST Integrity Review Panel, resolved inconsistencies, completed an assessment of Hanford single-shell tank degradation, and issued a report including tank-specific recommendations based on estimated corrosivity of tank wastes. As part of the committee to resolve the Enraf™ level gauge wire failure issue, he assisted in determining the cause for the 316 wire failure and recommended wire material compatible with Hanford waste tank environment. He co-authored a report on Hanford waste tank degradation mechanisms.

Mr. Herbert S. Berman

Mr. Berman is a graduate of the Massachusetts Institute of Technology in Metallurgy and Materials Science, with extensive graduate school coursework in solid state physics. He brings over 35 years of experience in the technical management, supervision and performance of nuclear/radiological work and the establishment of appropriate conduct of operations, and safety basis controls. Along with his track record of Chief Engineer positions, Mr. Berman has demonstrated expertise in materials research, testing, characterization, and failure analysis. He presently provides consulting services to government, industrial and national laboratory clients.

In turning around engineering organizations at the Rocky Flats and Pantex facilities for DOE, he demonstrated performance in managing and directing the institutional and cultural changes necessary to transform previously troubled organizations into fully functional, standards-based entities, with responsibility and accountability vested in an integrated safety management structure. This has involved directing numerous investigations of materials-related problems associated with nuclear materials storage, nuclear weapons and nuclear facilities. As the senior manager directing nuclear engineering at an naval shipyard, in addition to his DOE technical management experience, Mr. Berman has a comprehensive understanding of the engineering, environmental and safety requirements and practices both in the DOE Weapons Complex and the naval nuclear propulsion program; he has been an invited speaker at international nuclear safety forums, where he has addressed the challenges involved in integrating safety planning into nuclear work planning. In addition, he has significant experience and background in metallurgy and materials failure analyses in nuclear related applications. He also possesses a proven track record of managerial and program management accomplishments, successfully directing successively larger, more complex organizations and projects.

Ms. Susan W. Borenstein

Ms. Borenstein has over 25 years of metallurgical and corrosion engineering experience for the utility, chemical, mining, and marine industries. She has international experience in engineering innovative and economical solutions in corrosion control, material selection, failure analysis, risk-based inspection, product development and diagnosis of root cause of difficulties.

Her career experience includes

- Providing metallurgical and corrosion engineering services including failure analyses, material selection and design, expert witness testimony and engineering evaluations.
- Responsibility for providing failure analyses of various types of equipment including pressure vessels, tanks, piping, valves, controls, and other components in chemical plants, refineries, pulp and paper mills, power plants, and other industrial plants.
- Responsibility for development and implementation of risk-based inspection programs in chemical plants, refineries, and gas plants.
- Developing and teaching courses on corrosion, microbiologically influenced corrosion (MIC), metallurgy, damage mechanism identification, welding, and NDE. Provided material selection, corrosion and cathodic protection services for fossil, hydroelectric, geothermal, and nuclear power plants.
- Being an international authority on MIC and authored the Microbiologically Influenced Corrosion Handbook.

Ms. Borenstein has a BE (Materials Science and Metallurgical Engineering) from Vanderbilt University and an MS (Materials Science and Engineering) from the University of Tennessee. She has many professional affiliations and is a PE in several states.

Dr. Spencer H. Bush

Dr. Bush received BS degrees in Metallurgical Engineering and Chemical Engineering in 1948, an MS in Metallurgical Engineering in 1950, and a Ph.D. in Metallurgy in 1953, all from the University of Michigan.

Dr. Bush is a consultant on materials and safety with particular emphasis on environmental effects such as stress corrosion and radiation damage as they affect material properties and component design in nuclear reactors. In this capacity he has served on many of National committees and boards including the following:

- ASME: Member-at-large or ex-officio member of ASME Board of Nuclear Codes and Standards since 1983; Charter Member of ASME Subcommittee XI on inservice inspection; chaired numerous review groups.
- AEC/NRC: Member of Advisory Committee on Reactor Safeguards (ACRS) from 1966 to 1978, Chairman of ACRS 1971, consultant to the ACRS on various subcommittees; served as Vice-Chairman and Chairman of task groups on stress corrosion cracking and other pipe cracking issues, 1978 to 1987.
- DOE: Member of the Tank System Integrity Panel (TSIP), 1991–present.
- DOE/WSRP: Technical expert for Savannah River Piping and Vessels, 1992–1999.

His scientific contributions have been primarily in the physical and mechanical metallurgy of nuclear materials. Specific experimental work has been in temper embrittlement of steels, surface hardening of pearlitic malleable irons, gold base and chrome-cobalt based dental alloys. Work in reactor materials included kinetics studies of oxidation in zirconium alloys, effect of fabrication variables on properties of zirconium alloys, irradiation effects in uranium alloys and reactor structural materials, and stress corrosion. Substantial work has been done in reactor safety, particularly on failure mechanisms in pressurized systems. He also has explored the field of information storage and retrieval.

A major role in Dr. Bush's career has been in the synthesis of available information to develop a coherent picture of the relative roles of materials, fabrication, and nondestructive examination on the reliability of nuclear components. Based on such a synthesis of data generated throughout the world, it is possible to suggest changes leading to an improvement in reliability with a comparable improvement in system safety. Included in such syntheses are the role of seismic loads on components and systems.

Dr. Carl Czajkowski

Dr. Czajkowski, a metallurgist at Brookhaven National Laboratory, received a BS degree in Metallurgical Engineering from the University of Missouri at Rolla, an MS degree in Metallurgical Engineering at the Polytechnic Institute of NY, and a Ph.D. in Materials Science and Engineering at SUNY-Stony Brook.

He began his career as a Quality Control Materials Engineer at United Nuclear Inc. in 1971 and then moved to Ebasco Services, Inc., in 1973 to become a Quality Assurance Engineer. In 1975, he started at Long Island Lighting Co. as a Lead Mechanical QA Engineer, then became Chief Welding Supervisor at the Shoreham Nuclear Power Station. He has been at Brookhaven since 1980 and is currently in the Energy Sciences and Technology Department. He is an established expert in the field of failure analyses and nuclear materials and is involved in international projects related to nuclear power plants and waste disposal in Russia and the independent states of the former USSR. He acts as Technical Lead for the trilateral (US/Norway/Russia) construction project of a low-level nuclear waste reprocessing plant at Murmansk Russia for the US EPA.

His technical responsibilities have included both field and laboratory technical assistance to U.S. government agencies in metallurgy, welding, NDE, failure analysis, and life extension. He is responsible for "hot cell" operations at BNL, including conduct of operations and maintenance scheduling.

Investigations for NRC-NMSS have included investigations of polonium air ionizers and tritium exit signs. Additional activities have included vendor inspections; third party investigations of allegations pertaining to welding and quality control improprieties at nuclear sites; and testifying as an NRC Technical Specialist for welding at licensing hearings. DOE assignments have included potential counterfeit fastener and flange investigations; the Spent Fuel Vulnerability Study (1993), and the Plutonium Vulnerability Study (1994). NRC assignments included a four-month temporary assignment to the US NRC Materials Engineering Branch in Washington, DC.

He is a previous Member of Working Group 10 of the Joint Civilian Coordinating Committee for Nuclear Reactor Safety (JCCCNRS - USNRC/USSR).

Dr. Michael J. Danielson

Dr. Danielson received his BA from the University of Northern Iowa in 1965 and an MS in Physical Chemistry in 1968 and Ph.D. in Physical Chemistry (electrochemistry thesis) in 1970 from the University of Missouri at Rolla.

Dr. Danielson is currently a Senior Research Scientist and, since August of 1992, has worked on the performance of materials in waste-related environments. This includes the SCC behavior of carbon steel tank materials in caustic wastes, pyrophoricity of uranium, dissolution behavior of spent fuel uranium, and the development of an on-line SCC probe, which was installed into two Hanford waste tanks. Other projects he has been involved with are the SCC of 5000 series aluminum alloys, corrosion fatigue of die steels, effect of the microstructure/microchemistry of pipeline steels on their SCC behavior, and optimization of processing parameters for the production of tritium target pellets.

Dr. James R. Divine

Dr. Divine is the Chief Engineer at ChemMet, Ltd., PC, a licensed chemical engineering consulting firm in Washington State. ChemMet focuses on corrosion and water treatment, Dr. Divine received a BS degree in Chemical Engineering from the University of California, Berkeley, in 1961 and a Ph.D. in Chemical Engineering from Oregon State University, Corvallis, in 1965. For the past 36 years, he has been primarily involved with corrosion and materials selection at Hanford. The last 20 years, he has been frequently involved in studies on the corrosion of double-shell tanks (DSTs) and has assisted in preparing the Hanford Technical Specifications for the DST's. He also participated in corrosion studies of the double contained tanks at West Valley and continues as a consultant at that site as well as at Hanford.

Dr. Divine is a NACE International Certified Corrosion Specialist and licensed in seven states as a professional chemical engineer. He was recently selected to serve on the NACE/DOE corrosion panel dealing with spent fuel storage. His technical expertise includes the following:

- Evaluation of the safe and proper use of engineering materials including the investigation of corrosion and degradation of metals and polymers in waste management, nuclear, construction, and industrial operations.
- Chemical behavior of high-level wastes.
- Mitigation of the corrosion of buried materials by cathodic protection and materials selection.
- Application of chemical and electrochemical engineering principles to industrial processes.
- Decontamination using chemical methods (chemical cleaning).
- Inter-disciplinary information exchange with emphasis on chemistry and engineering.

Mr. Glenn Edgemon

Mr. Edgemon received a BS degree in Materials Engineering in 1992 and an MS degree in Metallurgical Engineering in 1993 from the Georgia Institute of Technology.

The following list summarizes his professional associations and work experience.

- 2000-2001: Chairman of National Association of Corrosion Engineer's (NACE) T-3L-15 task group on electrochemical noise
- 1999: Chairman: National Association of Corrosion Engineer's T-2A symposium on corrosion in nuclear systems, T-3L-15 symposium on electrochemical noise and T-3L-15 task group on electrochemical noise
- 1998: Named Lockheed Martin Hanford Company's Inventor of the Year for development and deployment of the 241-AN-107 corrosion monitoring system
- DST Relevant work history: July 1994–Present

- Prepared WHC-SD-WM-ER-414, "Hanford Waste Tank System Degradation Mechanisms Report," which details and ranks the most likely failure mechanisms for DSTs at the site.
- Prepared and presented 14 additional reports/papers on corrosion monitoring in DSTs.
- Responsible for laboratory research, prototype development, and current full-scale system operation and data analysis from the electrochemical noise based corrosion monitoring probes at the Hanford Site.
- Responsible for laboratory research, system design, fabrication, operation, and data analysis for the Tank W-23 electrochemical noise based corrosion monitoring system for Bechtel Jacobs Company LLC at Oak Ridge National Laboratory.
- Worked closely in a multi-company development effort to develop, fabricate, and test the Tank 43 corrosion/chemical species probe to be used at the Savannah River Site.

Mr. Monte R. Elmore

Mr. Elmore received both his BS and MS degrees in Metallurgical Engineering from South Dakota School of Mines and Technology in 1975 and 1976, respectively.

Mr. Elmore joined Pacific Northwest National Laboratory (PNNL) in September 1978. His work has principally involved corrosion testing and materials evaluation, hazardous and radioactive waste remediation investigations, and chemical process development studies. He is skilled in both bench-scale and pilot-scale experimental work and analytical evaluations, and has task and project management experience.

Prior to joining PNNL, he was a research metallurgist with Duval Corporation in Tucson, Arizona, where he was engaged in research studies on ore concentrate processing and metal electrowinning; computer process simulations; and process equipment design and development.

The following list includes some of his significant technical accomplishments:

- Evaluated steel corrosion in several environments to support extension of HLW tank life for West Valley Demonstration Project.
- Evaluated materials corrosion for Hanford Waste Vitrification Project and recently for River Protection Project's Waste Treatment Plant to select suitable materials of construction for processing equipment.
- Tested performance of nickel-plated zirconium getters for hydrogen absorption for the Tritium Target Qualification Program.
- Participated in BCD technology demonstration at Guam, building and operating off-gas analysis system to monitor PCB destruction.
- Co-developed process for acid digestion of chemical munitions that led to patent on "Munitions Treatment by Acid Digestion."

Mr. Ed Fredenburg

Mr. Fredenburg received a BS degree in Civil Engineering from Oregon State University in 1968, an MBA from Golden Gate University in 1973, an MS degree in Nuclear Engineering from the University of Washington in 1983, and is a Registered Professional Engineer in Civil Engineering in Washington.

Mr. Fredenburg has 13 years of combined experience with Bechtel and WPPSS specifically in the field of commercial nuclear power plant design and construction. In addition, his experience includes 17 years in the fields of nuclear waste storage and disposal at the Hanford site. He is currently an engineer for the CH2M HILL Hanford Group, Inc.

Dr. A. Burton Johnson, Jr.

Dr. Johnson is a Senior Staff Scientist in Materials and Engineering Analysis at the Pacific Northwest National Laboratory (PNNL). He received both BS and Ph.D. degrees in Fuel Technology from the University of Utah in 1954 and 1958, respectively.

Dr. Johnson's career at PNNL has involved corrosion investigations on several metals in and out of irradiated environments. He conducted corrosion studies in aqueous and air environments that included carbon steels. He was project manager for the Nuclear Plant Aging Research program, which involved aging assessments on materials and components comprising safety-related equipment from commercial nuclear plants, again including effects of corrosion on carbon steels. He also participated in evaluation of a license renewal application for a commercial nuclear plant, assessing systems that included carbon steel.

Dr. Johnson chaired several committees for the National Association of Corrosion Engineers. He has been involved in a number of consultant groups and coordinated research programs for the International Atomic Energy Agency. He received the American Nuclear Society Mishma Award "in recognition of outstanding contributions in research and development work on nuclear fuels and materials." He was Inland Empire Engineer of the Year.

Dr. Larry Julyk

Dr. Julyk received a BS degree in Mechanical Engineering from the University of Michigan in Dearborn, and both an MS in Engineering Mechanics and a Ph.D. in Applied Mechanics from the University of Michigan in Ann Arbor in 1975.

He has over 28 years of experience in stress, flow-induced vibration, creep-fatigue, fracture mechanics, and seismic analysis of structures and structural components. He has held key positions in a wide range of engineering mechanics related work scopes, which called upon his expertise in design, analysis, and evaluation of structural/mechanical systems for seismic and other extreme load environments. His major assignments include Design Authority civil/ structural subject expert for Tank Waste Remediation System (TWRS); support for TWRS Final Safety Analysis Report (FSAR); resolution of dome load issues for underground double-shell waste storage tanks; structural integrity evaluation of high-heat underground single-shell waste storage tank 241-C-106 for in-situ conditions; hydrogen mitigation and safety evaluation of underground double-shell waste storage tank 241-SY-101 for postulated hydrogen burn accident scenario; life assessment of pressure tubes within graphite core of DOE N Reactor; and life assessment, design analysis, and vibration assessment/monitoring of reactor internals of DOE Fast Flux Test Facility (FFTF).

Mr. Nicholas W. Kirch

Mr. Kirch received a BS degree in Chemical Engineering from Iowa State University and has 20 years of experience in nuclear waste management at Hanford with extensive tank farm process engineering/control experience. He has worked in various technical and management positions associated with tank farms since 1982. He developed the tank farm flowsheet for handling waste streams from the PUREX facility restart in 1983. He was the tank farm lead for the Waste Tank Corrosion Studies and in 1984 and authored the chemistry specification technical basis document. From 1985 to 1989, Nick managed technology development programs for tank waste retrieval.

Since 1989, Nick has managed the Process Control group. His group provided the technical information used to resolve the Hanford Priority-1 Tank Safety Issues, with Nick as author of several documents for the effort. Nick has received recognition from DOE, Tanks Advisory Council and Defense Nuclear Facilities Safety Board staff for his contributions to resolving the SY-101 Flammable Gas Safety Issue, the Ferrocyanide Safety Issue, the Organic Safety Issue, and resolution of the Defense Nuclear Facilities Safety Board 93-5 recommendation. Nick was a Westinghouse Total Quality Achievement Award division winner in 1991 and 1993, and a CH2M HILL Silver Bowl winner in 2000.

Mr. Mark A. Knight

Mr. Knight is currently the Process Control Manager for Tank Farms and is responsible for the DST Chemistry Control Program, Waste Compatibility Assessment Program for tank waste transfers, for general process engineering support to tank farm operations and to Single and Double Shell Tank projects. He received a Bachelor of Engineering in Chemical Engineering from the University of Exeter in the United Kingdom in 1986. He is also a Chartered Chemical Engineer, which is the equivalent to a U.S. Professional Engineer, with extensive experience in all aspects of the process design of complex nuclear waste processing facilities. His skills and abilities include the following:

- Design and selection of processes and mechanical equipment for liquid and solid waste treatment including: mixing, pumping, storage, solid-liquid separation, evaporation, ion exchange, off-gas treatment, dry solids handling and conveying, and mechanical handling.
- Design and selection of specialized equipment to facilitate remote maintenance or replacement in high radiation fields.
- Layout of nuclear facilities to facilitate operation and maintenance.

- Specifying and managing extensive R&T programs to underpin the design and operation of complex nuclear processes.

Mr. Knight has eight years experience with CH2M HILL Hanford Group and was responsible for managing and directing all aspects of the design of the pretreatment facility, managing a multi-discipline team of about 90 engineers and designers; responsible for development of the project schedule and budget; worked with Project Controls engineers to develop resource loaded project schedule based on input from lead engineers; provided management and technical direction to engineers and designers producing a new pretreatment facility design to combine three facilities into one, resulting in potential cost savings of $300 million; he was directly responsible for identifying significant technical issues with the pretreatment facility vessel ventilation system. He previously worked with BNFL Engineering in the United Kingdom and was responsible for managing the preliminary design of a plant to retrieve and treat settled transuranic waste sludges from aging concrete storage tanks, for leading a multi-disciplinary project team for the specification and coordination of the design input from other service offices, and for controlling the $3 million/year design and development budget for the project.

Mr. Steve Krahn

Since 1998, Mr. Krahn has been engaged in tasks supporting contractors at various DOE sites. This includes tasks for CHG involving authorization streamlining, readiness review improvement, and the recent IPE review. He has more than 22 years of experience in project and technical management. Prior to 1998, Mr. Krahn spent the preceding seven years at the Defense Nuclear Facilities Safety Board (DNFSB), the primary independent oversight body for nuclear safety matters within the DOE complex; this included a period of three years where he was the Board's Assistant Technical Director (ATD) for Operational Safety where he was the Board's staff lead for the implementation of Integrated Safety Management and led assessments of conduct of operations and nuclear facility design and construction across the DOE complex. Mr. Krahn was personally involved in the development of the DNFSB technical paper on Formality of Operations (DNFSB/TECH-15), which addresses DNFSB expectations and Board Recommendations that resulted in the development of the Integrated Safety Management System. He was also involved in detailed reviews of materials science-related problems at several DOE nuclear facilities. Earlier in his career, Mr. Krahn led the technical support for the implementation of reliability-centered maintenance programs on several classes of Navy ships and has experience on several life extension programs in nuclear ships and facilities. He has been the engagement manager for project management and Integrated Safety Management implementation support at Mound, and for the independent project management assessment of the Kaiser-Hill Rocky Flats Closure Plan. For CHG, he has managed projects involving authorization basis streamlining, readiness reviews, and Double-Shell Tank maintenance and engineering.

Dr. Jack W. Lentsch

Dr. Lentsch has a BS degree in Chemistry, an MS degree in Radiation Physics, and a Ph.D. in Nuclear Engineering. In addition, he is a Registered Professional Nuclear Engineer, a Certified Health Physicist, and a licensed Senior Reactor Operator.

Dr. Lentsch has 30 years of experience in the management of commercial nuclear power plants and high-level nuclear waste, including ten years of experience in Hanford tank farm project and program management. Currently, he is the Project Manger for the Double-Shell Tank Integrity Project at the Hanford Site. His previous experience includes nuclear safety analysis, nuclear regulation, nuclear plant design, nuclear plant operation, nuclear plant chemistry, and corrosion monitoring.

Dr. John Mickalonis

Dr. Mickalonis is a fellow engineer at Westinghouse Savannah River Company where he has worked for the last 12 years. He received his BS in Biomedical Engineering and his MS in Materials Science and Engineering at Rensselaer Polytechnic Institute. His doctorate was in Materials Engineering and received from Lehigh University. Dr. Mickalonis has performed corrosion research in the area of monitoring techniques, high-level nuclear waste systems, spent nuclear fuel storage, and corrosion modeling. Dr. Mickalonis had previously worked at the Homer Research Laboratory of Bethlehem Steel Corporation on metallic coating systems and automotive corrosion. He has been a member of ASM International and NACE International.

Dr. Edgar (Gar) Norman

Dr. Norman received his BS degree in Metallurgical Engineering from the University of Utah in 1963. He subsequently graduated from an MS level program in Nuclear Engineering at the Oak Ridge School of Reactor Technology in 1964. He received his Ph.D. in Engineering Science (Materials) from Washington State University in 1970. He has been the lead for EN-Based Corrosion Monitoring at CHG since March 2000.

Mr. Stan G. Pitman

Mr. Pitman received a BS degree in Metallurgical Engineering in 1977 and an MS degree in Metallurgical Engineering in 1978 from the Colorado School of Mines.

Since joining Battelle in June 1978, Mr. Pitman has been primarily involved in nuclear waste containment studies and evaluation of stress corrosion cracking in nuclear systems. He has developed irradiated and nonirradiated slow strain rate and corrosion fatigue test systems to evaluate stress-corrosion cracking of metals used in nuclear systems. Mr. Pitman has managed projects directed toward evaluation of stress corrosion cracking of nickel-base superalloys in high-purity water, evaluation of superplasticity in aluminum alloys, stress corrosion cracking of A537 tank steel in sodium nitrate, and failure analysis of structural components including shafts, pipes, springs, pumps, and bus bars.

Mr. Pitman has managed or participated in more than 100 applied research projects involving: corrosion-resistant materials, superalloys, maraging steels, titanium and zirconium alloys, castings, aircraft alloys, nuclear reactor materials and superplastic alloys. He supervised the operation of an in-cell mechanical testing system to evaluate delayed hydrogen cracking of irradiated Zircaloy specimens at elevated temperatures, and is currently involved in fabrication systems for nuclear reactor components and materials compatibility studies for the Hanford vitrification plant.

Mr. Gerald J. Posakony

Mr. Posakony received a BS in Electrical Engineering from Iowa State University. After working several years as a manufacturing engineer for Decimeter, Inc. and as a field engineer for Motorola, Inc., he joined the faculty of the University of Colorado Medical Center as a research engineer. He left the University to join Automation Industries, Inc., advancing to Vice President and General Manager of the Research Division in Boulder, Colorado. In this capacity, Mr. Posakony was responsible for the developmental research, instrument design, technical procedures, and manufacture of systems for nondestructive evaluation (NDE) technology in ultrasonic, eddy current, infrared, and magnetic methods.

In 1973, he joined the Pacific Northwest National Laboratory (PNNL) as manager of the NDE Section, which was responsible for the design, development, and deployment of advanced NDE technology. He became manager of the Automation and Measurement Sciences Department in 1986. The staff included physicists, computer scientists, electrical and mechanical engineers, and technicians engaged in design, development and deployment of "first of a kind" inspection and measurement systems. In 1989, he became Deputy Manager of the Applied Physics Center with managerial responsibility for staff in the Automation and Measurement Science, Computational Science, and Energy Science Departments.

While officially retired from PNNL, he remains on staff as an hourly professional to continue research, development and deployment of NDE Technology. Mr. Posakony has spent more than thirty-five years in the design, development and deployment of first-of-a-kind nondestructive inspection and measurement systems. In addition to his technical and managerial responsibilities, he has continued personal research in ultrasonic transducers, inspection technology, and ultrasonic wave propagation as well as other activities in the field of NDE.

Mr. Daniel A. Reynolds

Mr. Reynolds received a BES degree in Chemical Engineering in 1970 and an MA degree in Chemical Engineering in 1971 from Brigham Young University.

He has worked at Hanford since 1975. He began his work with the Tank Farms in 1980 and subsequently became involved with corrosion in 1984. Since that time, he has been involved with the chemical control of corrosion.

Mr. David H. Shuford

Mr. Shuford is the manager of Double-Shell Tank Maintenance and Reliability Engineering and has over 19 years management and engineering experience at Hanford in a variety of assignments, including operations, maintenance, project engineering, and research and development. He received a BS and MS in Chemical Engineering from the University of Washington in Seattle, Washington. He has four and a half years of experience in the Tank Farms. His current assignment involves providing maintenance engineering support to tank farms, which includes evaluation of equipment and material failures. In addition, he provides support to the Tank Integrity Project in the areas of NDE and corrosion engineering. Prior to coming to Tank Farms, he was the PUREX/UO_3 Plant maintenance manager and was the outage manager for the final start up and campaign of the UO_3 Plant. At N Reactor, he performed evaluations of spent fuel canister integrity in support of PUREX restart and was involved in primary coolant piping corrosion studies.

Dr. Robert L. Sindelar

Dr. Sindelar received a BS degree in Physics and Mathematics from the University of Wisconsin–Eau Claire in 1978. He received an MS degree in Nuclear Engineering in 1981 and a Ph.D. degree in Nuclear Engineering in 1985 from the University of Wisconsin - Madison. Since 1986, he has been a Senior Fellow Engineer at DOE/Savannah River Technology Center, Materials Technology Section.

His technical expertise includes a broad range of disciplines related to material performance and structural integrity demonstrations including system service life estimations and environmental degradation evaluations; testing and analysis to develop mechanical and corrosion properties of metals and polymeric materials, including effects of radiation for performance analysis; fracture and structural analysis of systems; and development of national codes and standards (ASME and ASTM). His professional experience includes the following:

- Since 1998 he has co-led a program for the NRC to evaluate the performance of safety class coating system in nuclear power plants under aging and Design Basis Accident conditions.
- Since 1996 he has led the technical task program for the development of technology for repository storage of aluminum-based, spent nuclear fuels.
- Since 1995 he has led the technical program for development of drying and storage criteria for interim dry storage of aluminum-based, spent nuclear fuels; and has led the technical program for extended wet (basin) storage of these fuels.
- Since 1993 he has co-led programs to demonstrate structural integrity of nuclear systems including the SRS high level waste storage and processing tanks.
- From 1989 through close-out in 1993, he led the technical task activities of a program to develop technical strategies with bases for predicting and extending the service life of the Savannah River Site reactors.

Dr. Charles W. Stewart

Dr. Stewart joined Pacific Northwest National Laboratory in 1973 after receiving BS and MS degrees in Mechanical Engineering from Washington State University. His early career was in computational modeling of multiphase fluid systems, including the development and application of major thermal-hydraulic analysis computer programs for nuclear reactor cores. In 1990, Dr. Stewart took leave to study bubble dynamics at Washington State University and received his Ph.D. in 1993. After returning to PNNL, Dr. Stewart managed PNNL's activities supporting installation of the mixer pump to mitigate flammable gas releases from Hanford waste tank

SY-101. He also led tasks to measure the in situ gas volume and waste rheology in several tanks and to understand the mechanisms of gas retention and release in all Hanford waste tanks. In 1998 and 1999, Dr. Stewart lead PNNL support for resolution of the “high heat” safety issue by removing waste from Tank C-106. He is currently assisting with the final remediation of gas retention in Tank SY-101.

Dr. Philip E. Zapp

Dr. Zapp is a Fellow Engineer at the Savannah River Technology Center, Westinghouse Savannah River Company. He received a BA degree in Physics from Cornell University in 1971 and a Ph.D. in Metallurgical Engineering from the University of Illinois at Urbana-Champaign in 1979.

Dr. Zapp has 22 years of research and development experience in government and industry laboratories. His varied background includes experience in materials science, including polymers, radiation damage, tritium effects on materials, advanced non-destructive testing of welds, corrosion of metals, and coatings. He has 14 years of experience in corrosion R&D of engineering alloys, related to chemical processing and high-level radioactive waste storage and processing. He has done extensive work in localized corrosion of carbon steel and has developed chemistry control limits for dilute radioactive waste storage and processing.

He is a member of NACE International and the activities related to this membership includes: participation in corrosion science and technology and corrosion in nuclear systems committees, and chairman of task group on radioactive liquid waste storage, and chairman of nuclear systems symposium, 2001. He is a member of ASTM and a former member and past chairman of Savannah River Chapter (1987-88), ASM International.

Appendix B

Workshop Agenda

Appendix B
Workshop Agenda

Tuesday, May 1, Hanford Training Center, Richland, Washington

Introduction and Background

8:00 - 8:30	Workshop overview. *Give background, describe drivers, goals and deliverables* - Jack Lentsch
8:30 - 9:00	Logistics. *State purpose, introduce panel & attendees, conduct of the workshop,, run through agenda* - Chuck Stewart
9:00 - 9:30	DST design. *Describes design, tolerances, safety factors and corrosion allowances* - Larry Julyk
9:30 - 10:00	DST support systems. *DST ventilation systems and their operating history* - Dave Shuford
10:00 - 10:15	break

Tank Inspection Program

10:15 - 12:00	UT Inspections. *Describe program for baseline and continuing testing, results of testing, and use of UT data to estimate remaining lifetime* - Ed Fredenburg and Jerry Posakony
12:00 - 12:30	Working lunch (lunch orders brought in)
12:30-1:00	Additional tank inspection videos
1:00 - 1:45	Savannah River tank inspection. *Describe SRS NDE program, results, tank cracking* - Bob Sindelar

Chemistry Control Program

1:45 - 2:15	Chemistry limits. *Describe development of current chemistry corrosion limits* – Nick Kirch
2:15 - 3:00	Corrosion testing. *Overview of 1980's testing supporting chemistry limits development* - Jim Divine
3:00 - 3:15	break
3:15 - 4:00	Chemistry Control Program. *Describe the current chemistry control program, caustic depletion models and results* - Mark Knight
4:00 - 5:00	Summary discussion. *Panel review presentation information, preview information to be given Wednesday*

Wednesday, May 2, Hanford Training Center, Richland, Washington

8:00 - 8:30	Opening business. Describe Wednesday agenda and open logistic items - Chuck Stewart

Chemistry Control Program (continued)

8:30 - 9:15	Tank history. *Show general history of DST waste chemistry and compare range of corrosion data with current and expected tank chemistry* - Dan Reynolds
9:15 - 10:00	Corrosion status and expected lifetimes. *Summarize corrosion mechanisms and tank vulnerabilities, corrosion status of out-of-spec tanks* - Mo Anantatmula
10:00 - 10:15	break
10:15 - 10:45	Nitrate enhanced stress corrosion cracking - Stan Pitman
10:45 - 11:30	Savannah River Site experience. *Describe SRS corrosion program, data and corrosion limits* - Phil Zapp

Corrosion Montoring Program

11:30 - 12:00	Corrosion monitoring. *Overview of corrosion monitoring program and corrosion probe development* - Gar Norman
12:00 - 12:30	Working lunch (lunch orders brought in)
12:30 - 1:30	Corrosion monitoring technology. *Describe electrochemical noise monitoring and results, SRS Raman probe* - Glenn Edgemon and John Mickelonis

Technical Reviews

1:30- - 3:00	Technical review chemistry control program, data and chemistry limits
3:00 - 3:15	break
3:15 - 4:30	Technical review chemistry control program, data and chemistry limits (continued)
4:30 - 5:00	Summary business. *Panel summarize the days presentations and discussions, preview discussions for Thursday*

Thursday, May 3, Hanford Training Center, Richland, Washington

8:00 - 8:15	Opening business. *Describe Thursday agenda and open logistic items* - Chuck Stewart

Technical Reviews (continued)

8:15 - 10:00	Technical review of tank inspection program, NDE methods and data
10:00 - 10:15	break
10:15 - 12:00	Technical review of corrosion monitoring program, methods and data
12:00 - 12:45	Working lunch (lunch orders brought in)
12:45 - 2:30	Construct list of recommendations for DST life extension, developed in reviews
2:30 – 3:00	Develop ranking metrics *(e.g. feasibility, effectiveness, cost, maturity of technology, etc.)*
3:00 - 3:15	break
3:15 - 4:45	Rank the list of recommendations per ranking metrics
4:45 – 5:00	Summary business. *Summarize work accomplished and remaining tasks for Friday morning* – Chuck Stewart

Friday, May 4, Hanford Training Center, Richland, Washington

8:00 - 8:15	Opening business. *Describe Friday agenda and open logistic items* - Chuck Stewart

Recommendations (continued)

8:15 - 10:00	Prioritize recommendations for life extension: *immediate, intermediate, long-term*
10:00 - 10:15	break
10:15 - 11:45	Complete prioritization
11:45 - 12:00	Thanks and closing comments - Jack Lentsch

Appendix C

DST Corrosion Mechanisms
and
Lifetime Predictions

R. P. Anantatmula

DST Life Extension Workshop
May 1–4, 2001

DST CORROSION MECHANISMS AND LIFETIME PREDICTIONS

R. P. Anantatmula

DST Life Extension Workshop
May 1-4, 2001

Degradation Mechanisms (Initial List)

- Pitting Corrosion
- Stress Corrosion Cracking
- Uniform Corrosion
- Crevice Corrosion
- Concentration Cell Corrosion
- Hydrogen Embrittlement
- Microbiologically Induced Corrosion
- Radiation and Thermal Embrittlement
- Erosion Corrosion
- Creep/Stress Relaxation
- Mechanical Wear
- Fatigue

Degradation Mechanisms (Final List)

- Pitting/Crevice Corrosion
- Stress Corrosion Cracking
- Uniform Corrosion

General Corrosion

- Mechanism definition
  - General or uniform corrosion is a chemical or electrochemical reaction that proceeds uniformly over the entire surface
- Mechanism details
  - In nitrate solutions, the following reactions are expected for general corrosion:
    - $3/4\ Fe = 1/4\ Fe_{film}^{2+} + 1/2\ Fe_{film}^{3+} + 2e^-$ at the anode (metal/film interface)
    - $NO_{3sol}^- + 2e^- = NO_2^- + O_{film}^{2-}$ at the cathode (film/solution interface)

General Corrosion (continued)

- Measurement Methods
  - Traditional weight loss technique
    - In-tank measurement with in-situ coupons
  - Linear Polarization Resistance (LPR) technique
    - A three-electrode LPR technique is used at the Hanford Site
    - The technique does not offer high degree of accuracy for systems that experience low corrosion rates such as the DST steels exposed to wastes compliant with DST waste specifications
  - Calculation of rates from UT measurements
    - Recently calculated uniform corrosion rates from UT wall thickness data for tank AN-105

Pitting Corrosion

- Mechanism definition
  - Pitting is a form of localized attack that results in holes or cavities in a metal or alloy
- Mechanism details
  - More specifically, pitting is local dissolution leading to the formation of cavities in passivated metals or alloys exposed to aqueous solutions containing aggressive anions
  - In Hanford DSTs, the following reactions are expected to occur for pitting:
    - Anodic reaction
      - $3/4\ Fe + H_2O = 1/4\ Fe_3O_4 + 2H^+ + 2e^-$
    - Cathodic reaction
      - $NO_3^- + H_2O + 2e^- = NO_2^- + 2OH^-$

Pitting Corrosion (continued)

- Savannah River Site (SRS) experience
  - Crevice attack of waste tank cooling coils from extremely diluted sludge washing solutions
  - No pitting attack observed on tank walls
- Hanford Site experience
  - Strongly dependent on the concentration of aggressive anions (Cl^-, F^-)
  - Previous studies indicated higher pitting rates in the vapor region than the liquid region
  - More recent vapor space experiments indicated
    - Pitting rates are greater than uniform corrosion rates and decrease with time
    - Ammonia at 100 ppm concentration is a very effective inhibitor for pitting (as well uniform) corrosion

Stress Corrosion Cracking (SCC)

- Mechanism definition
  - Cracking caused by the simultaneous presence of tensile stress and specific corrosive medium.
- Mechanism details
  - More specifically, the mechanism will not be operative for a given material if either the tensile stress or the corrosive medium is absent
  - In Hanford DSTs, the following reactions are expected to occur for SCC
    - Anodic reaction
      - $3/4\ Fe + H_2O = 1/4\ Fe_3O_4 + 2H^+ + 2e^-$
    - Cathodic reaction
      - $NO_3^- + H_2O + 2e^- = NO_2^- + 2OH^-$

SCC (continued)

- Savannah River Site (SRS) experience
  - Nine tanks that were not stress relieved developed through-wall cracks. In addition, small surface cracks were observed perpendicular to the butt welds and extending through the HAZ before stopping shortly after penetrating the base metal. No failures have been observed in the newer stress relieved tanks.
- Hanford Site experience
  - Based on SRS experience, nitrate SCC has been assumed to be the primary cause for failure of SSTs, which were not stress relieved.
  - Thus far, none of the DSTs (which were stress relieved) have leaked. In addition, no cracks were observed in the DSTs examined recently by UT. However, fairly high tensile stresses are expected to be present near the lower knuckle due to the combination of hydrostatic load and residual welding stresses.

DST Regions Most Susceptible to Degradation Mechanism

- General Corrosion
  - All DST surfaces that come in contact with waste
    - 0.5-in. thick vertical tank wall region is most vulnerable to exceeding ASME Code based stress limits
    - Bottom knuckle region is most vulnerable to exceeding the design imposed precautionary stress limit (90% Yield strength) against stress corrosion cracking
- Pitting Corrosion
  - Vapor space, Vapor/Liquid interface, Liquid space (if locally the waste is not compliant with specifications)

DST Regions Most Susceptible to Degradation Mechanism (Continued)

- Stress Corrosion Cracking
  - Vapor/Liquid interface, Liquid space, and Bottom knuckle (if locally the waste is not compliant with specifications and a local flaw exist that exceeds the threshold level stress intensity factor, K_{ISCC})
    - 0.5-in. thick vertical tank wall region and bottom knuckle are the most vulnerable regions because of the greater stresses at these regions

DST Lifetime Prediction Models

- Waterline Corrosion – Immediately above waste surface is likely if waste is depleted in caustic. Supported by 101-AY UT data and SRL coupon data.
  - Assume general corrosion at a linear rate of 12 mpy based on 101-AY data (Conservative approach)
  - Assume pitting corrosion as the mechanism with Pit Growth (mils) = 35 $t^{0.5}$ (with t in years) based on 101-AY data and old Hanford data on vapor space pitting

DST Lifetime Prediction Models (Continued)

- Vapor Space Pitting – Due to condensation in the dome space because of low waste level and inadequate ventilation flow.
  - Assume corrosion same as predicted by aqueous corrosion models in the literature with a conservative pitting factor of 6 using equation:

$$\ln D_g = b_0 + b_1 \ln(t) + b_2/T + b_3 T^2$$

where D_g is corrosion depth in Tm, t is time in years, T is temperature in ^{0}K, and b_0, b_1, b_2 and b_3 are constants.

DST Lifetime Prediction Models (Continued)

- Pitting Corrosion in the Sludge Region – Due to inadequate inhibitor concentration.
  - Assume pitting corrosion as the mechanism with Pit Growth (mils) = K $t^{0.5}$ (with t in years) similar to pitting correlation for waterline corrosion. The value of K is considered to be less than 35 based on SRL data on partially immersed coupons in caustic deficient solutions indicating lower pit depth values for regions below waste level. Assumed K = 27 for estimates on caustic deficient tanks. Pitting tendency seen in sludge region in 105-AN by electrochemical noise probe.

Determination of DST Failure Probability and Useful Life Estimates

- Gather available UT, ECN probe data and relevant Hanford Site and literature data
- Develop model equations for corrosion mechanisms for different tank regions as applicable
- Develop equations for DST failure times on a tank by tank basis
- Perform sensitivity analysis for the various parameters to determine the sensitivity of DST useful life
- Determine probability distributions for key parameters.
- Perform Monte Carlo simulation of DST useful life and determine confidence intervals
- Perform Value of Information Analysis to determine most cost-effective testing program.

Lifetime Estimates for Caustic Deficient Tanks

- Tank 102-AN (No UT data)
  - Assume waterline corrosion similar to 101-AY occurred from 1985 (when 400" level was reached), and also assume that the waste level remains at this level. Allowable reduction in wall thickness from Ohl et al. (1996) is 295". Assume 1 mpy corrosion since operations start in 1981 to 1985. The allowable reduction in wall thickness will be reached at this level in:

$$(295-4)/12 = 24.25 \text{ years from 1985}$$

Or 8 years from now.

It should be emphasized that the allowable reduction in thickness calculations are for design conditions.

Lifetime Estimates for Caustic Deficient Tanks (Continued)

- Tank 101-AY
  - Current waste level is at 72”. Assume waterline corrosion (general) at 12 mpy above the waste surface. Allowable reduction in wall thickness from Ohl et al. (1996) is 275”. Assume no loss in thickness at the 72” level based on UT data, and also assume waste level will be maintained at this level:

    Remaining life = (275)/12 = 23 years

  It should be emphasized that the allowable reduction in thickness calculations are for design conditions.

Lifetime Estimates for Caustic Deficient Tanks (Continued)

- Tank 102-AY
  - Current waste level is at 235”. Assume waterline corrosion (general) at 12 mpy above the waste surface. Allowable reduction in wall thickness from Ohl et al. (1996) is 245”. Assume maximum loss in thickness thus far of 35 mils at this level based on UT data, and also assume waste level will be maintained at this level:

    Remaining life = (245-35)/12 = 17.5 years

    It should be emphasized that the allowable reduction in thickness calculations are for design conditions.

Key DST Locations Where Data Are Required

- UT Data, Corrosion Probe Data and Laboratory Test Data are Needed in the Following Locations
  - Liquid/Vapor interface
  - Sludge region
    - Future lab tests should be designed to more appropriately simulate conditions in the sludge region
  - Vapor space

Recommendations To Extend Life of DSTs

- Annulus ventilation should be “ON” all the time and maintained at appropriate levels
- Tank ventilation rates and waste levels should be maintained at appropriate levels to prevent condensation in dome space
- Waste surface should not be maintained at a constant level for extended periods at **low levels**
- Small amounts of caustic should be added periodically to the waste surface at **high levels** (if maintained for long periods) to combat waterline corrosion

Tank History

Dan Reynolds

CH2M HILL Hanford Group, Inc.

May 2001

CH2MHILL

Tank History

By
Daniel Reynolds,
CH2M-Hill Hanford

Background

- 149 Single Shell Tanks
  - Concrete structure with carbon steel liner
  - 67 have declared leakers
- 28 Double Shell Tanks
  - Concrete structure with carbon steel liners
  - Primary tank with secondary liner
  - None have leaked

Double Shell Tank Farms

Farm	# of tanks	Year Construction began	Material
AY	2	1968	A 515
AZ	2	1971	A 515
SY	3	1974	A 516
AW	6	1978	A 537
AN	7	1980	A 537
AP	8	1983	A 537

Double Shell Tanks Under Construction

Double Shell Tanks That Have Been Outside of Corrosion Limits

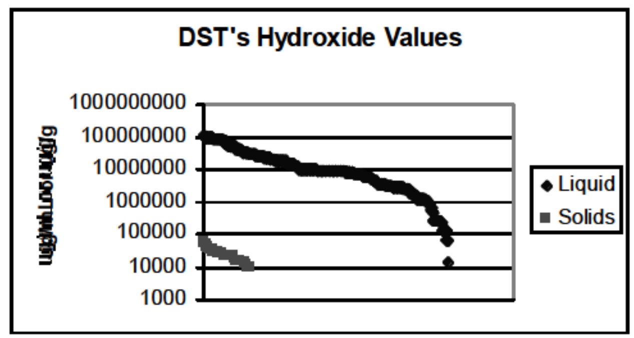
Tank	Comment
AN-102	Currently included in a recovery plan.
AN-107	Currently included in a recovery plan.
AY-101	Caustic added January 2001
AY-102	Caustic added February 2001
AP-103	Caustic added on July 1, 1997
AP-107	Waste went to evaporator. Waste from AW-103 added to the heel.
AP-108	Waste went to evaporator. Waste from AW-105 added to the heel.
AP-104	Waste added

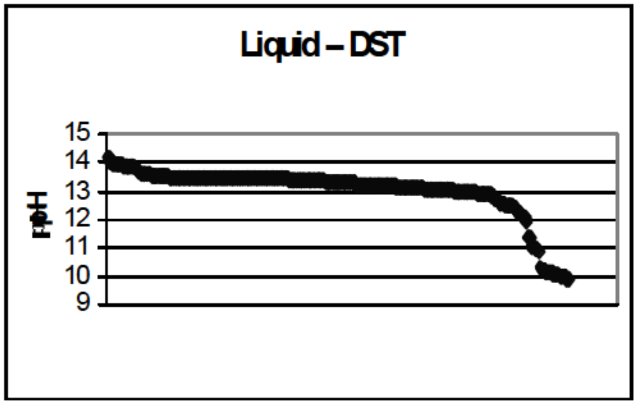
Other Tanks

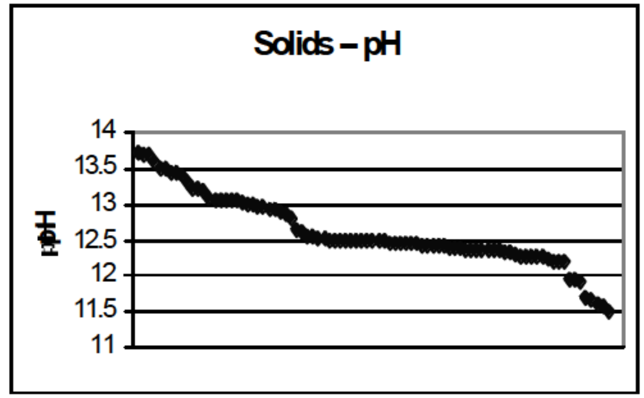
Tank	[OH]	Date
AN-101	0.00495	3/2/85
AZ-102	0.00714	2/19/86

Current Concerns

Tank	Chemicals	Comments
AY-102		
AN-106	[NO3] = 1.1	Based on BBI OH Limit > 0.11
AW-105	[NO3] = 0.55 [NO2] = 0.05	Based on BBI OH Limit > 0.17







[OH] Difficult to Measure

- Interfering species: carbonate, phosphate, aluminate , sulfate, etc.
- Dilution of sample to instrument range
- Solids use a water leach. Not clear on dissolved solids contribution nor amount of interstitial liquid.

pH Measurement Problems

- Sodium ion interference.
- Measures a_{H+}.
- Infer water equilibrium:
  - H_2O _ $H^+ + OH^-$
  - Other ionic reactions possible
  - $H^+ + PO_4^{-3}$ _ $HPO_4^=$

Rule of Thumb on pH

- When pH < 12.5, use pH instead of hydroxide measurement unless there is a judgment that hydroxide titration curve shows "clean break".
- Log [OH] = pH -14

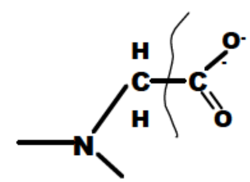
Steps in OH Analysis

- Water leach solids.
- Add $BaCl_2$ to precipitate barium carbonate, barium sulfate, barium phosphate, barium aluminate , etc.
- Dilute appropriately to stay within bounds of auto-titrator.
- Titrate.

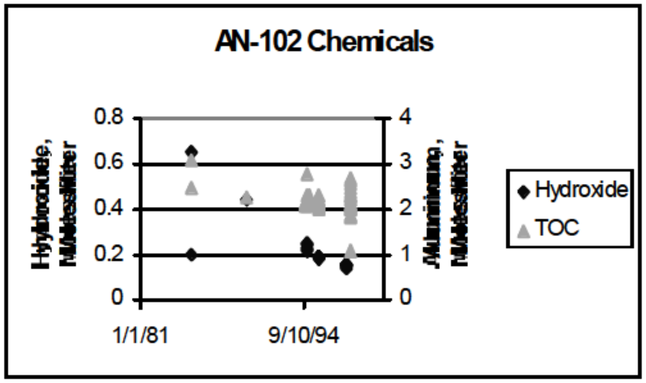
Two Major Routes to Hydroxide Depletion

- Organic Degradation
- Carbon Dioxide Adsorption

Organic Degradation



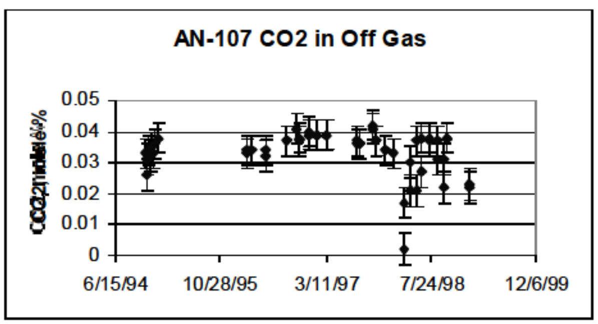
$$CO_2^{=} + 2\langle OH^{-} \blacklozenge CO_3^{=} + H_2O$$



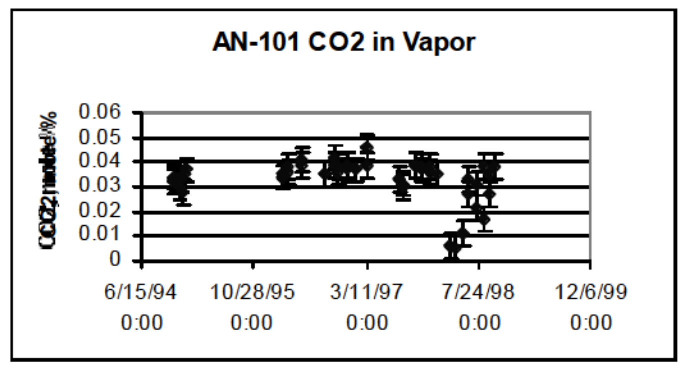
CO_2 Absorption

- Absorbs from ventilation air and air lift circulators.
- Total inventory of hydroxide important
  - Tanks with heels of waste
  - Low hydroxide to begin with
- Tends to an equilibrium value of pH - 10

BTF0800-01 8/10/00



BTF0800-01 8/10/00



BTF0800-01 8/10/00

Special Cases

- Ammonia scrub solutions from PUREX
  - AP-107 and AP-108
  - Tested for corrosion and found acceptable
  - Declared out of spec some years later
- Retrieval of single shell tanks
  - A number of single shell tanks have pH < 11
  - C-106 and AY-102 is an example

BTF0800-01 8/10/00

Conclusions

- Certain wastes have shown to have hydroxide depletion with time.
- Organic degradation is slow.
- Carbon dioxide absorption important in tanks with a small heel or low starting inventory of hydroxide.

BTF0800-01 8/10/00

SRS HLW Tank Inspection Program—

Results and Analysis

Bob Sindelar

Technical Basis for Hanford DST Life Extension

May 1, 2001

SRS HLW Tank Inspection Program-Results and Analysis

Bob Sindelar - SRTC-Materials Technology Section (SI Program Support)
Bruce Wiersma - SRTC- MTS (HLW Life Management Program)
Jim Elder - Technical Services Division-Quality Services Department (NDE Group)
Ruel Waltz - High Level Waste Engineering (HLW Tank Inspection Program)

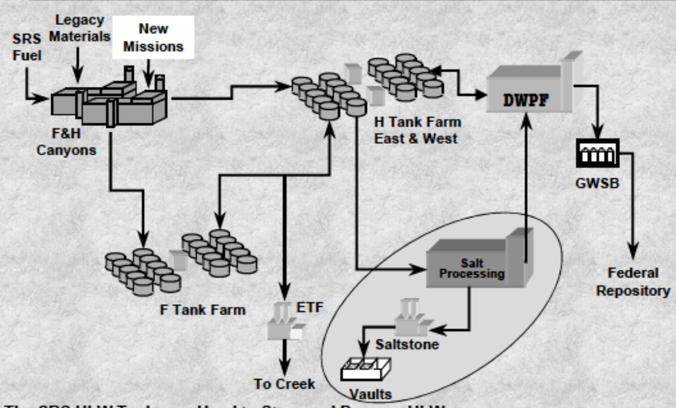
Technical Basis for Hanford DST Life Extension

May 1, 2001

Outline

- Tank Inspection Program Relation to Tank Integrity/Tank Life Management Program
- Overview of SRS Tank Materials, Dimensions, Service History
- Overview of Inspection Program
- Summary of Inspection Results
- Summary of Flaw Stability Analysis

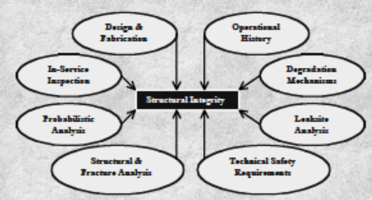
SRS High-Level Waste Mission - Role of HLW Tanks



The SRS HLW Tanks are Used to Store and Process HLW.
The Confinement Function of the Tanks is Paramount to Protecting the Environment

Elements of Structural Integrity

- SRS-HLW Historically Had Activities to Demonstrate Structural Integrity of HLW Tanks
- SRS-HLW Tank & Transfer Piping Structural Integrity Program, 1995, "SRS High Level Waste Tank and Piping Systems - Structural Integrity Program and Topical Report," Westinghouse Savannah River Co., WSRC-TR-95-0076
- DOE Tank Structural Integrity Panel Guidelines, 1997, "Guidelines for Tank Structural Integrity Programs for DOE High-Level Waste Storage Tanks," Brookhaven National Laboratory, BNL-52527
- SRS-HLW Life Management Program to Address Type I & II Tank Issues, 1998



In-Service Inspection is a key element of the demonstration of structural integrity

Waste Tanks at SRS

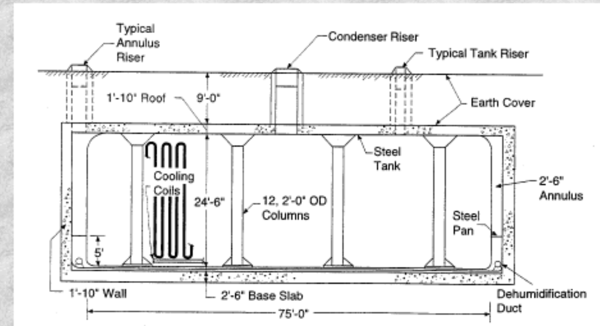
Savannah River Technology Center SRTC We Put Science to Work

Tank No.	Type	Const Date	Document Project No.	DuPont Specification Document No.	Steel Specification Primary Tank	Steel Liner Code	Concrete Code
1-8 F	I	'51-'53	8980	3206	A285 Grade B	ASME-49	Joint Com
9-12 H	I	'51-'53	8980	3206	A285 Grade B	ASME-49	Joint Com
13-16 H	II	'55-'56	8980 PWO	3537,3546,3549	A285 Grade B	ASME-52	ACI 318-51
17-20 F	IV	'58	981030	3552, 3557	A285-54T Gr B	ASME-52	ACI 318-51
21-24 H	IV	'62	981089	3583	A212-57T Gr B	ASME-56	ACI 318-71
25-28 F	III	'75-'78	9S1493	6797	A516 Gr 70 (N)	*	ACI 318-71
29-32 H	III	'67-'70	981232	5096	A516 Gr 70	*	**
33-34 F	III	'69-'72	9S0974	5500	A516 Gr 70	*	**
35-37 H	III	'74-'77	9S1463	6791	A516 Gr 70 (N)	*	**
38-43 H	III	'78-'80	9S1618	6993	A537 Class I (N)	*	**
44-47 F	III	'77-'80	9S1747	7100	A537 Class I (N)	*	**
48-51 H	III	'78-'81	9S1826	7182	A537 Class I (N)	*	**

* ASME 56 to 65 as appropriate
** ACI 318 - 71 to 77 as appropriate

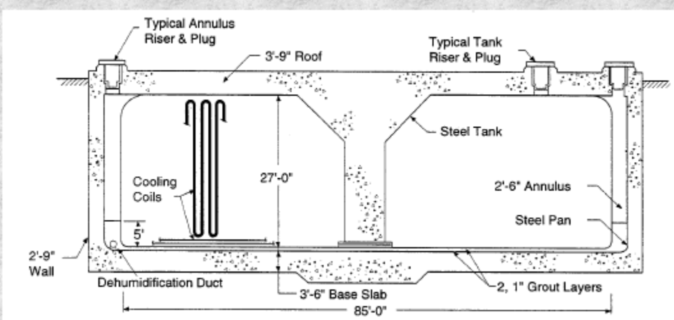
Type I Tank

Savannah River Technology Center SRTC We Put Science to Work



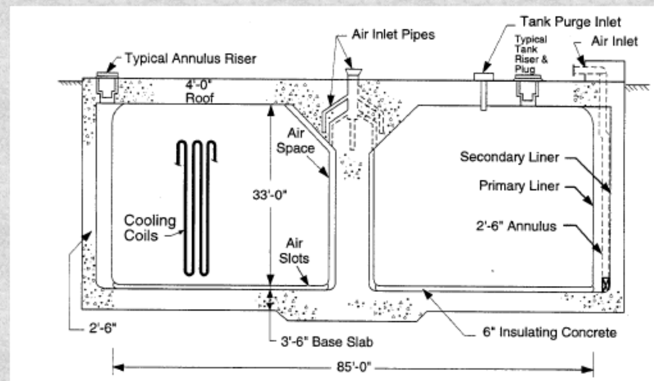
Type II Tank

Savannah River Technology Center SRTC We Put Science to Work

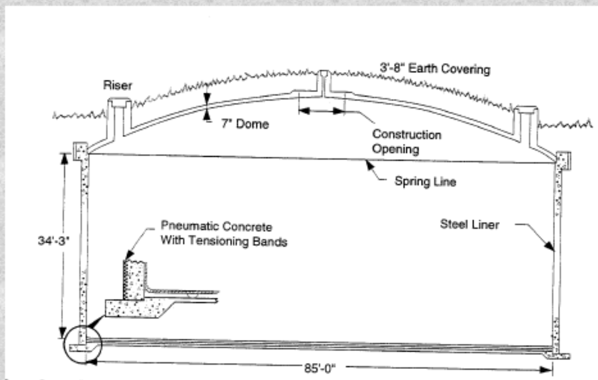


Type III Tank

Savannah River Technology Center SRTC We Put Science to Work



Type IV Tank



Tank Materials

- TANK MATERIALS OF CONSTRUCTION EVOLVED BASED ON DEGRADATION CONCERNS

ASTM A285-B Carbon Steel (Type I and II, and IV)
ASTM A212-B Carbon Steel (Type IV)
↓
ASTM A516-70 Carbon Steel (Type III)
↓
ASTM A516-70 (Normalized) Carbon Steel (Type III)
↓
ASTM A537 Class I Carbon Steel (Type IIIA)

- Improved resistance to SCC and brittle fracture
- Stress-relief of Type III/IIIA primary

- COOLING COILS CONSTRUCTED FROM ASTM A53 OR A106-B CARBON STEEL

Tank Fabrication and Pre-Service Inspection

	Paint			Stress-Relief+			Visual			Radiograph Welds			Leak Tests		
Tank Type	P	S	CW	P	S	CW	P	S	CW	P	S	CW	P	S	CW
I	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	V+W	V+W	A+W
II	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	V+W	V+W	A+W
III/IIIA	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes*	Yes**	Yes	V+W	V+W	H+W
IV	No	No	-	No	No	-	Yes	Yes	-	Yes	Yes	-	V+W	-	-

P - Primary S- Secondary CW - Cooling Water
V – Vacuum test of bottom plates W – Water test for leaks A – Air test for leaks H- Halide test

+ - Stress relief at 1100 F per ASME code
* - Horizontal roof welds not radiographed
** - For tanks 29-34 only bottom, knuckle and lower parts of the center column were radiographed.

Waste Characteristics

- Three forms:
  - Supernate - liquid waste from the canyon
  - Sludge - metal oxides that settle to the bottom of the tank (iron, manganese, etc.)
  - Saltcake - crystallized waste that has returned from the evaporator.

Waste Characteristics

- Concentration Range of Major Anion Constituents in Supernate

Waste	Nitrate (M)	Hydroxide (M)	Nitrite (M)	Form
Fresh	1-5	0.6-1.5	0.5 -1	Sup/Sl
Salt Receiver	1-3	3-13	0.5 -1.5	Sup/Sa
Dilute Low-Level	0.01-0.5	0.01-0.6	0.01 -.5	Sup

  - Note: some tanks contain only sludge or salt

- Maximum Waste Storage Temperatures

Waste	Supernate (C)	Salt (C)	Sludge (C)
Fresh	50-70	-	120-140
Salt Receiver	30-50	50-80	-
Dilute Low-Level	20-35	-	-

Tank Inspection Program Inspection Methods

- In-Service Inspection Program Began November 1971*
- Inspection Program Described in WSRC-TR-95-0076
- Routine Visual Imagery Techniques
  - Wide-angle Photography (field of view ~100°)
  - Direct Photography by Shielded Camera
  - Closed Circuit Television
- Non-routine Ultrasonic Steel Thickness Measurements
- New P-scan UT System for Thickness and Flaw Characterization Implemented in 2000

*Random Examinations of Several Tanks from 1961 to 1970 Using Periscope

Tank Inspection Program Inspection Frequencies

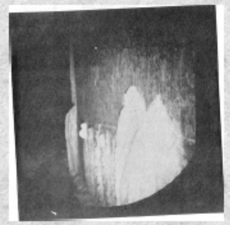
- Detailed (Shielded Camera)
  - DST with Inactive Leak Sites
    - Selected Annulus Risers Once/year
    - All Annulus Risers Every 2 years
  - Other DST
    - Selected Annulus Risers Once Every 2 years
    - All Annulus Risers Once Every 4 years
  - Single-Shell Tanks
    - Selected Risers Once Every Year
    - All Risers Every 2 years
- General (Wide-angle Photographic)
  - DST - All Annulus Risers that are not given Detailed Inspections
- Steel Thickness Measurements
  - DST Walls and SST Bottoms
  - Periodic: 1972-1985, Resumed 1994

Tank Inspection Program Inspection Results

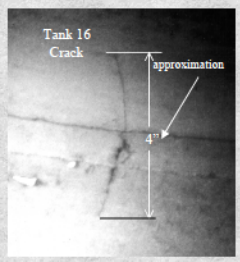
- Annual Inspection Summary Reports (e.g. WSRC-TR-2000-00067, May 2000)
  - Detailed Inspection Plans, Reports, Records
- Wall Thinning or Pitting Not Observed*
  - > 24,000 UT Measurements 1972-1985, Resumed UT in 1994
  - *Tank 23 Showed Minor Detectable Corrosion
- Minor Surface Corrosion on Outer Walls
- Cracking Observed in Type I & II Tanks (Rainwater Intrusion in Type IV)

Summary of Tank Cracks

- A total of 12 tanks have exhibited leaksites
  - Type I - 1F & 6F, 9-12H
  - Type II - 13-16H
  - Type IV - 19-20F (rainwater intrusion)
- Tank 16 (out of service) is the worst case with over 300 cracks
- Cracks were perpendicular to the weld*
- Longest measured crack was 6 inches in Tank 16*



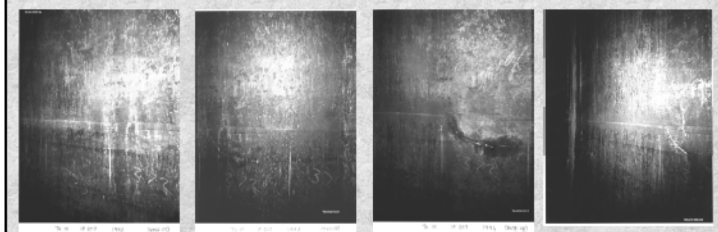
Tank 16 Salt Deposits



In-Situ PT of Tank 16 Crack

*Analysis of Tank 15 Indication is in Progress

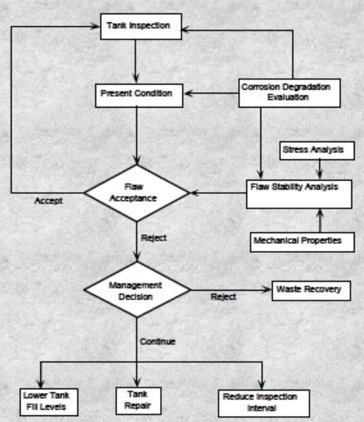
Inspection Results: Tank 15 Curving Crack in Vapor Space



1992 1994 1996 1998

Life Management Program

- Program to Ensure Safe Operation of SRS HLW Type I and II Tanks with Cracks
- Detailed FE Stress Analysis to 1998 ASME Section VIII, Division 2
- Comprehensive Mechanical Property Testing Program in Progress (Initial results reported in ASME JPVT May 2000, Vol. 122 and ASME 2000 PVP Conference)
- J-T and FAD Methods Applied to Evaluate Flaw Stability (WSRC-TR-2000-00478)



Application of P-Scan Crawler Technology

- SRS UT equipment utilized in the past performed wall thickness measurements only
- Industrial UT equipment for flaw characterization and weld examination needed to be modified to negotiate 5 inch riser in SRS HLW Tanks
- SRS worked with FORCE Institutes to modify their UT equipment to negotiate the 5 inch riser and add camera

Force Institutes AMS-1T

- Steerable, magnetic wheel scanner
- Negotiates 5 inch riser
- Pneumatic camera arm to raise the scanner arm during inspection
- Color camera used for navigation and evaluation.
- Capable of using up to 4 probes at one time for weld inspection, flaw sizing and wall thickness mapping

Inspection Support Equipment

Control Trailer and Generator at Tank Farm

Planned Inspection Coverage for the Type I and II Tanks

- Vertical Strips: the combined width of the vertical strips will be at least 1% of the tank circumference. Examination of four strips, one in each quadrant of the tank, are planned (where accessible).
- Lower knuckle: a horizontal strip will be examined for a distance of 5% of the tank circumference.
- Weld areas in the lowest course section (if accessible):
  - One vertical weld including the junction with the girth weld and the lower knuckle for one foot in each direction.
  - Top girth weld for a distance of 5% of the circumference of the tank in one or more segments.

Inspection Criteria

- The following conditions will be reported:
  - General thinning ≥ 12.5% of nominal thickness
  - Pitting ≥ 50% of nominal thickness
  - Crack-like indications ≥ 25% of nominal thickness in depth or ≥ 2 inches in length.

Tank 13 Inspection Results

- Completed Tank 13 Inspection in September 2000 using New UT System
- P-scan Data Collected in Four Vertical Strips, 8.5 Inches Wide; Two Strips per Riser 180 Degrees Apart
- P-scan Data of Total of 194 Inches of Girth Weld and One Vertical Weld
- No Reportable Indications

Conclusions

- SRS HLW Tank Inspection Program is a Key Element of the Structural Integrity/Life Management Program
- No Observed Thinning of Tanks (Internal or External Surface Attack)
- Cracking of Several Tanks Observed
- Improvements to Inspection Program Being Implemented
- Flaw Stability Analysis Methodology Established to Support Flaw Disposition

Ultrasonic Testing (UT) Inspections

Ed Fredenburg
Jerry Posakony

DST Life Extension Workshop
May 1–4, 2001

UT Inspections

Requirements & Objectives – Ed Fredenburg
Methods & Equipment – Jerry Posakony
Results – Ed Fredenburg

Federal Law & Regulations

- Resource Conservation and Recovery Act of 1976 (RCRA)
- 40 CFR 265 – *Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities*
  - Subpart J--*Tank Systems*
    - Section 265.191 *Assessment of existing tank system's integrity*
- In 1987 USDOE issued a final rule (10 CFR 962) stating that the hazardous waste components of radioactive waste are subject to RCRA

State of Washington Regulations

- EPA authority under RCRA delegated to Washington State Department of Ecology based on its substantially equivalent regulations (51 FR 24504, July 1987)
- Washington Administrative Code, Chapter 173-303 *Dangerous Waste Regulations,* Section 640 *Tank Systems*
    - Assessment "must determine that the tank system is adequately designed and has sufficient structural strength and compatibility with the waste…to ensure that it will not collapse, rupture, or fail."
    - Assessment must include "Results of a leak test, internal inspection, or other tank system integrity examination"
    - Assessment must be completed by January 12, 1990

Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement)

- M-32 *Complete Identified Dangerous Waste Corrective Actions* (9/30/99)
- M-32-04 *Complete Double-Shell Tank Interim Status Actions* (6/30/94)
- M-32-04-T03 *Complete all DST Visual Examinations and Prepare and Submit Reports* (9/30/93)
- M-32-04-T05 *Submit to Ecology a Final Plan and Schedule for Completion of the Double-Shell Tank Integrity Assessments* (6/30/94)

Tank Structural Integrity Panel (TSIP) Guidelines for Development of Structural Integrity Programs for DOE HLW Tanks

- Sample size:
  - 10% of tanks (or more, if required to represent all worst-case conditions)
- Areas to examine and scope:
  - 5% of primary tank liquid/vapor interface for pitting
  - 5% of primary tank liquid/sludge interface for pits, cracks, wall thinning
  - 5% of the primary tank vertical wall/lower knuckle weld for cracks
  - 2_% of the area of the predicted maximum stress region of the primary tank lower knuckle for cracks
  - primary tank bottom plate on a "best effort basis"
  - 5 sq. ft. of secondary tank wall for wall thinning
  - 5% of secondary tank lower knuckle welds for cracks
  - visually exam vapor region on primary tank interior

TWRS Tank System Integrity Assessments Program Plan (June 1994)

- Identified 6 DSTs (out of 28) to receive ultrasonic testing based on draft TSIP guidelines issued in March 1994.
- Objectives: wall thickness and detection and sizing of cracks and pits, with particular attention on weld seams, liquid/vapor interface, and high-stressed lower knuckle region.
- Planned completion by end of FY 1995.*
  - * (DOE & Ecology subsequently agreed to extend completion date to end of FY99, in *Double-Shell Tank System Integrity Program Plan*, Rev. 0, November 1997)

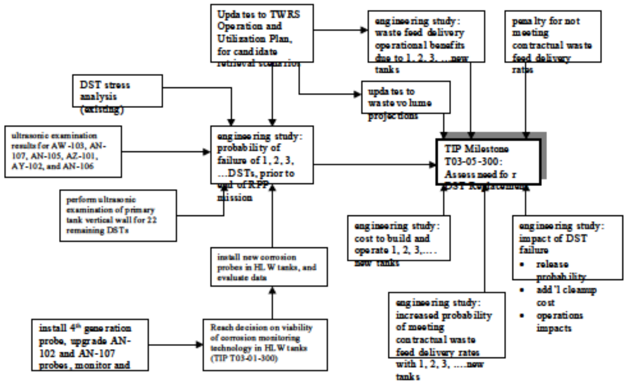
Administrative Orders #00NWPKW-1250 & 1251

- Scope of UT of primary tank, for all 28 DSTs
  - 30" wide strip over entire length of vertical wall
  - 20' horizontal weld at vertical wall/lower knuckle
  - 20' (min.) vertical weld, including 1' in nominally thinnest plate
- Scope of UT of primary tank, for selected DSTs
  - 20' of high stress region of lower knuckle, for 6 DSTs
  - tank bottom through air slots, for 6 DSTs
  - 20' at liquid air interface existing 5 years or longer, for 6 DSTs
- Time Frame
  - Complete UT by end of FY05, at 4 DSTs per year FY01-FY05
  - Issue Integrity Assessment Report for DST System, by mid FY06

Support to Decision on DST Replacement

- Project W-236A, Multi-Function Waste Tank Facility, was phased out in 1995 based partly on a study that concluded DSTs had at least 10 years remaining life.
- RPP Milestone T03-05-300 schedules a decision on need for new DSTs by April 2005.
- Inputs to decision on need for new DSTs include:
  - prevalent corrosion mechanisms
  - corrosion rates
  - required tank space to support retrieval and processing
  - mission duration
  - other factors

Conceptual Model of Inputs to Decision on DST Replacement



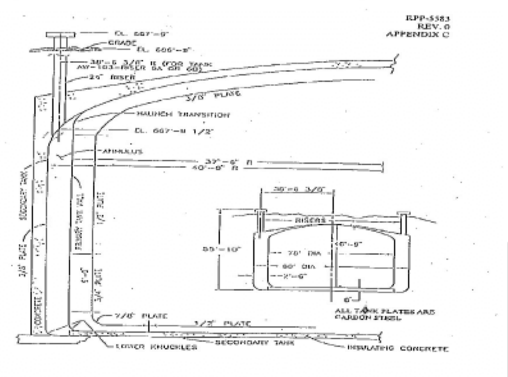
Acceptance & Reporting Criteria for UT

- Acceptance Criteria*
  - wall thinning: 20% of nominal plate thickness
  - pit depth: 50% of nominal plate thickness
  - crack depth: 3/16" (0.1875")
- Reporting Criteria**
  - 50% of values above

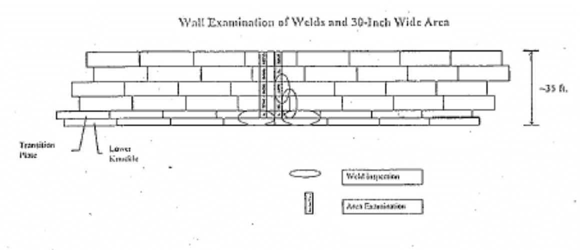
* Exceedance of acceptance criteria requires convening Inspection Review Panel to evaluate data and make recommendations to the tank farm facility manager.

** Exceedance of reporting criteria requires notification of the project cognizant engineer, and is specifically addressed in the final UT report.

Cross Section of DST Annulus



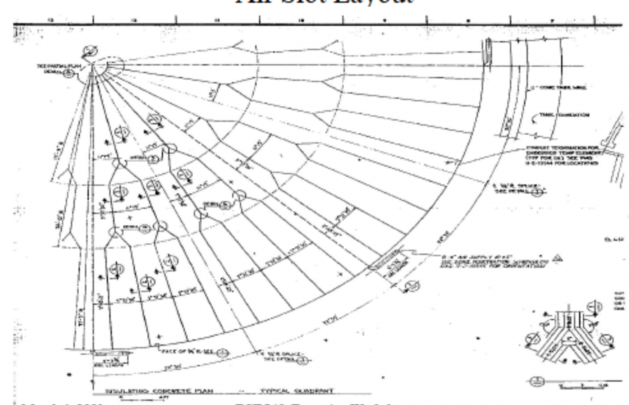
Minimum UT Scope for Each DST
(Wall Examination of Welds and 30-Inch Area)



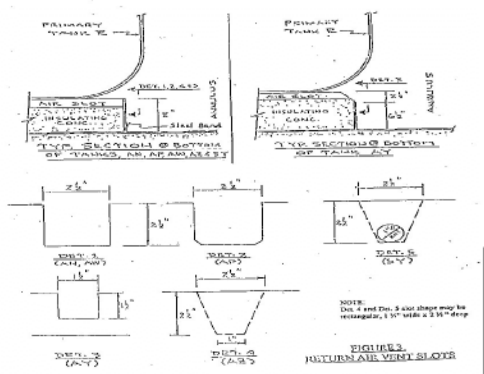
UT of Primary Tank Lower Knuckle

- Existing UT equipment cannot reach "high-stress" region of primary tank lower knuckle.
- Administrative Orders 00NWPKW-0250 & 0251 require semi-annual report on status of technology development for lower knuckle UT, until equipment is deployed.
- Procurement of flexible arm attachment to existing P-scan UT system is in process, with qualification and testing scheduled later this year.
- TSAFT technology is also under development, by PNNL

Air Slot Layout



Air Slot Geometry



UT Schedule for DSTs, through FY24

("TIAP DST Lifecycle Schedule")

TIAP DST Lifecycle Schedule

	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
AN-101						1									2									3				
AN-102					1								2										3					
AN-103								1^{KL}								2^{KL}										3^{KL}		
AN-104								1^{KL}									2^{KL}									3^{KL}		
AN-105			1			2^{*}							3^{*}									4^{*}						
AN-106			1								2									3								
AN-107		1^{BS}								2^{BS}									3^{BS}									
AP-101							1^{K}								2^{K}										3^{K}			
AP-102							1^{L}								2^{L}									3^{L}				
AP-103							1									2									3			
AP-104									1									2									3	
AP-105									1^{L}										2^{L}									3^{L}
AP-106									1^{K}									2^{K}										3^{K}
AP-107				1							2										3							
AP-108				1								2									3							
AW-101					1^{BL}							2^{BL}									3^{BL}							
AW-102						1^{K}								2^{K}										3^{K}				
AW-103	1									2									3									4
AW-104						1^{L}								2^{L}									3^{L}					
AW-105					1							2										3						
AW-106						1								2									3					
AY-101					1^{B}								2^{B}									3^{B}						
AY-102			1							2										3								
AZ-101			1								2									3								
AZ-102							1^{BK}									2^{BK}									3^{BK}			
SY-101									1^{BK}									2^{BS}									3^{BK}	
SY-102								1									2									3		
SY-103								1^{B}									2^{B}										3^{B}	

Notes:
* = vertical strip only (FY02 repeat exam of AN-105) plus secondary tank lower knuckle (secondary tank floor completed in FY99)
B = primary tank bottom
K = primary tank knuckle high stress region
L = liquid/air interface
S = secondary tank knuckle and floor
All tanks (except AN-105 in FY02) = 30" vertical strip, 20' horizontal weld, 20' or more vertical weld

DST UT Lifecycle Schedule Rev 4-04-01.xlsSheet1 4/10/01

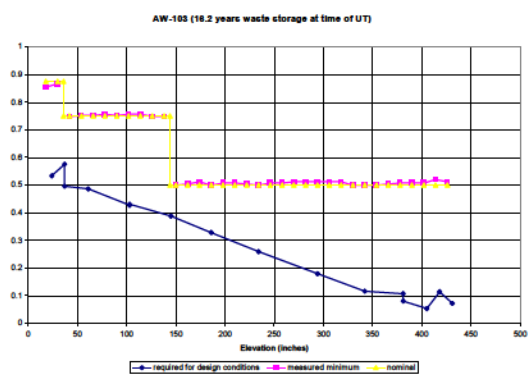
Summary of UT Results to Date

- Primary Tank Vertical Wall & Welds
  - 11 DSTs examined (welds and HAZ examined in 10 DSTs)
  - thinning up to ~20%, associated with previous liquid/air interface, found in 2 DSTs (AY-101, AN-105)
  - some evidence of pit-like indications, in 1 DST (AN-105)
  - crack-like indication (6" x 0.14") found in _" plate in 1 DST (AP-108)—no cracks identified in any other DST plate, welds, or HAZ
  - Large structural design margin remains in all DSTs examined
- Primary Tank Bottom
  - 2 DSTs examined to date (11 air slots in AN-107, 4 air slots in AW-101)
  - no crack-like indications
  - no wall thinning in excess of reporting criteria

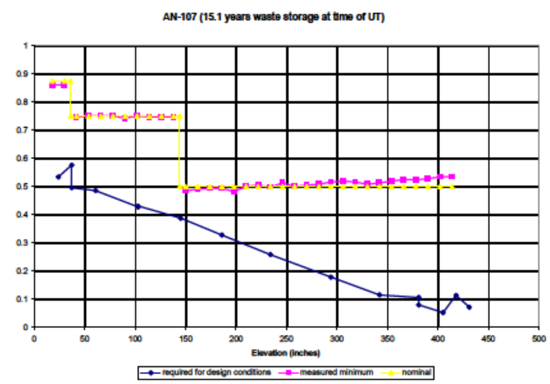
Summary of UT Results to Date (cont…)

- Primary Tank Lower Knuckle
  - presently only able to examine the top ~3 inches (no cracks, pits, or significant thinning observed)
  - Procurement and testing in process to begin examination of the high-stress region in FY02
- Secondary Tank
  - knuckle examined on 1 DST (AN-107)—no pits, cracks, or thinning
  - floor examined on 2 DSTs (AN-107, AN-105)—no pits or cracks; ~10% thinning found on AN-105

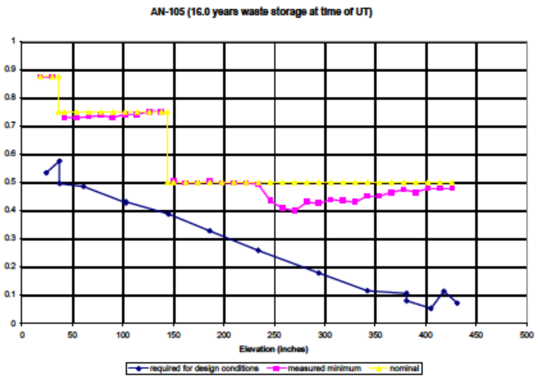
AW-103 (16.2 years waste storage at time of UT)



AN-107 (15.1 years waste storage at time of UT)



AN-105 (16.0 years waste storage at time of UT)



May 1-4, 2001 DST Life Extension Workshop

Figure S.1 "Sketch of the UT Vertical Scan Paths No. 1 and 2….)

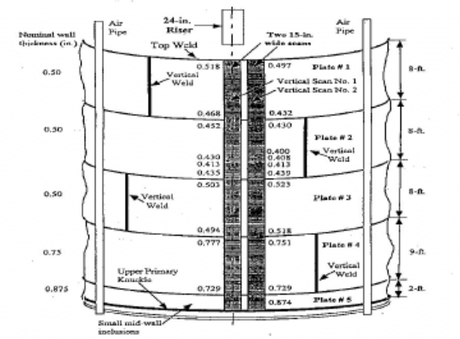
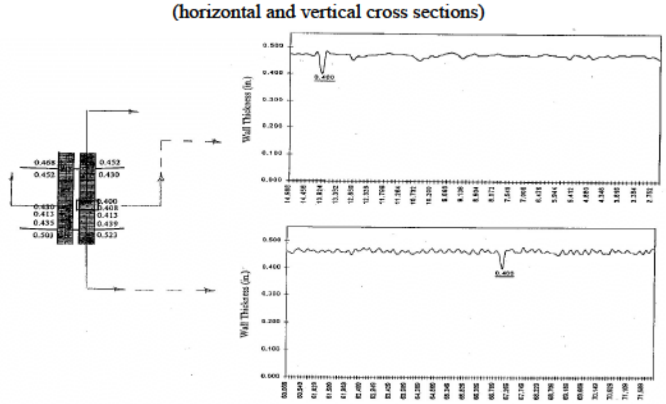


Figure S.1. Sketch of the UT Vertical Scan Paths No. 1 and No. 2 on Primary Tank 241-AN-105[a]

May 1-4, 2001 DST Life Extension Workshop

AN-105 "Pit-Like" Indication

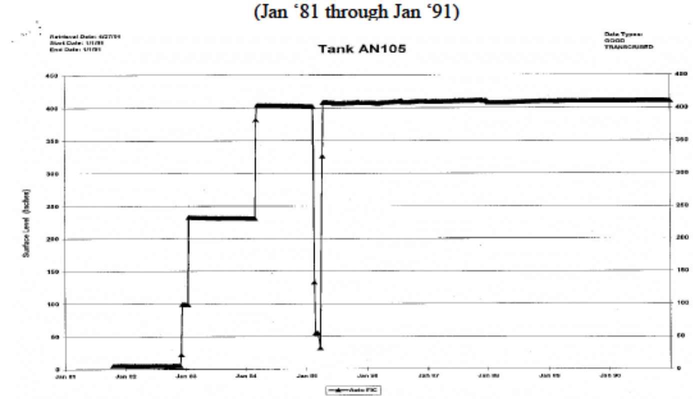
(horizontal and vertical cross sections)



May 1-4, 2001 DST Life Extension Workshop

AN-105 Liquid Level

(Jan '81 through Jan '91)



May 1-4, 2001 DST Life Extension Workshop

Estimate of Remaining Life for AN-105

(Table 2a. "Summary of Code-Based Allowable Minimum *Uniform* Wall Thickness Evaluation……")

Table 2a. Summary of Code-Based Allowable Minimum *Uniform* Wall Thickness Evaluation (STEP 1) for 241-AN-105 Primary Tank at UT Minimum Measured Wall Thickness Indication Locations.

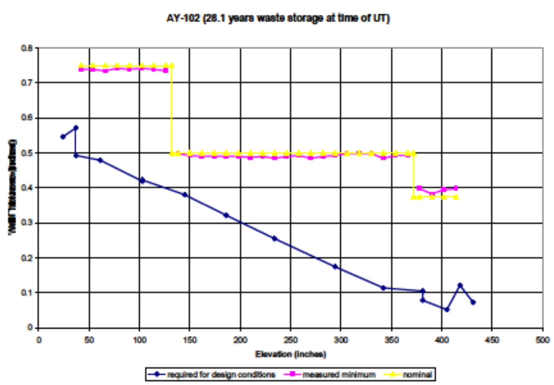
					Design Conditions				Current Conditions			
Plate (course) number	Design thk (in.)	t_{mm} UT min. thk (in.)	Location relative to bottom of primary tank (in.)	Estimated Corrosion rate (mils/yr)	Code-based min. uniform thk, t_{min} (in.)	Predicted* Time to reach t_{min} (years)	95% S_y t_{min} (in.)	Predicted* Time to reach 95% S_y t_{min} (years)	Code-based min. uniform thk, t_{min} (in.)	Predicted* Time to reach t_{min} (years)	95% S_y t_{min} (in.)	Predicted* Time to reach 95% S_y t_{min} (years)
1	max 0.530	0.452	336	max 4.88	0.141	63.8	0.114	69.4	0.121	67.8	0.086	75.1
	nom 0.500			nom 3.00		103.8		112.7		110.2		122.0
	min 0.490			min 2.38		131.1		142.4		139.2		154.1
2	max 0.530	0.400	240	max 8.13	0.256	17.7	0.190	25.9	0.208	23.7	0.125	33.8
	nom 0.500			nom 6.25		23.1		33.7		30.8		44.0
	min 0.490			min 5.63		25.6		37.4		34.2		48.8
4	max 0.780	0.729	36	max 3.19	0.579	47.2	0.465	82.9	0.496	73.2	0.347	119.8
	nom 0.750			nom 1.31		114.5		201.4		177.7		291.0
	min 0.740			min 0.69		218.7		384.4		339.2		555.6

*Projected remaining time relative to date of UT examination for wall thickness to just reach Code t_{min} or 95% S_y t_{min} based criteria thickness. The 95% S_y t_{min} based criteria thickness is provided for reference only.

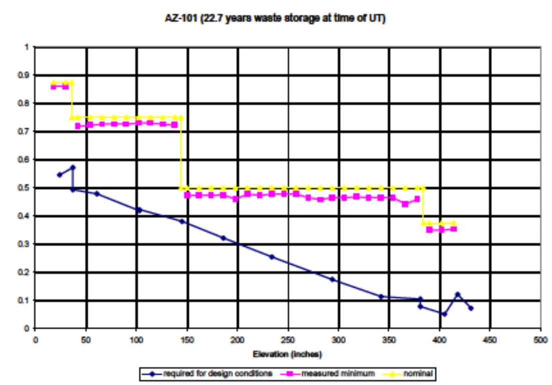
Conservatisms in Calculation of Remaining Service Life for AN-105

- Localized wall thinning (pitting) treated as uniform corrosion
  - time to failure = time for pit to reach minimum wall thickness required based on allowable stress, rather than time to penetrate through wall
- Corrosion rate assumed constant over time
- Calculated minimum 17 years remaining service life is based on design conditions. For operating conditions, corresponding remaining service life is 23 years.

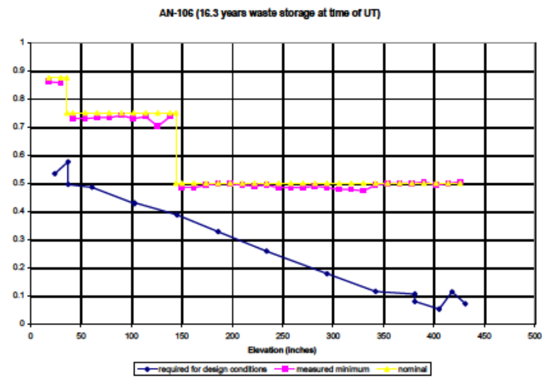
AY-102 (28.1 years waste storage at time of UT)



AZ-101 (22.7 years waste storage at time of UT)

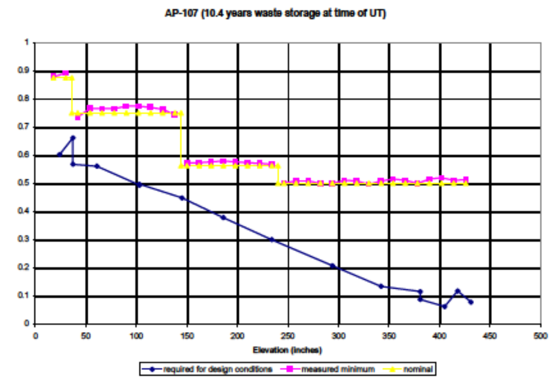


AN-106 (16.3 years waste storage at time of UT)



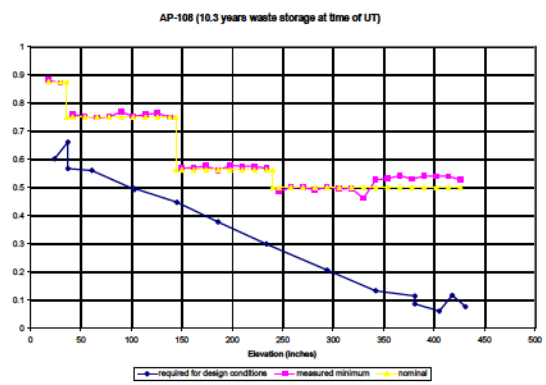
May 1-4, 2001 DST Life Extension Workshop

AP-107 (10.4 years waste storage at time of UT)



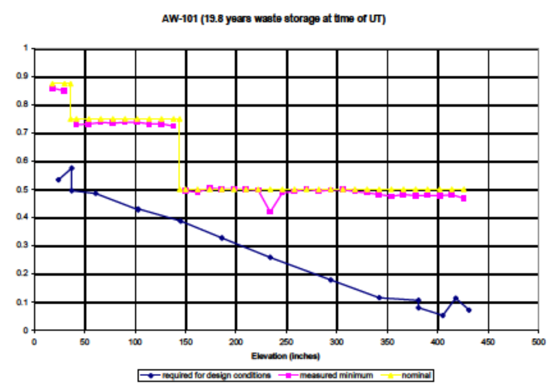
May 1-4, 2001 DST Life Extension Workshop

AP-108 (10.3 years waste storage at time of UT)



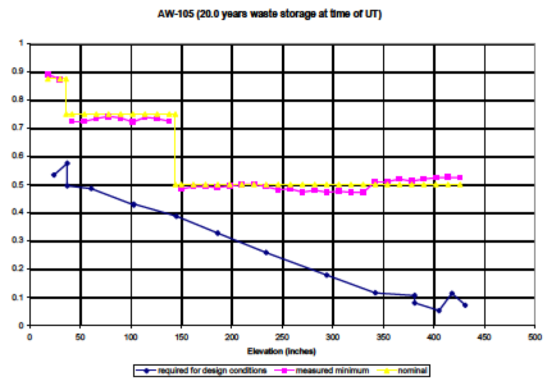
May 1-4, 2001 DST Life Extension Workshop

AW-101 (19.8 years waste storage at time of UT)

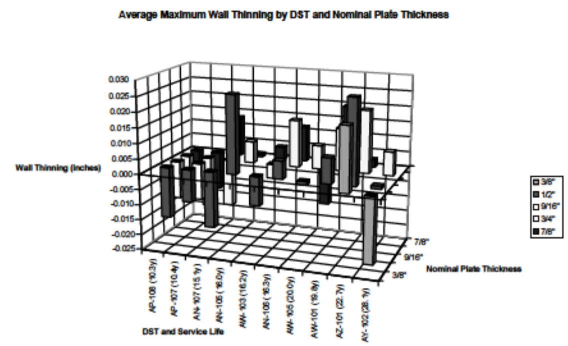


May 1-4, 2001 DST Life Extension Workshop

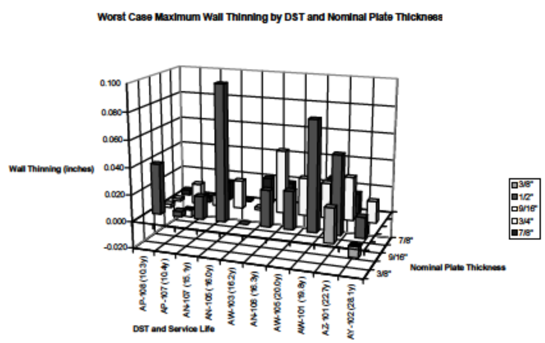
AW-105 (20.0 years waste storage at time of UT)



Average Maximum Wall Thinning by DST & Nominal Plate Thickness

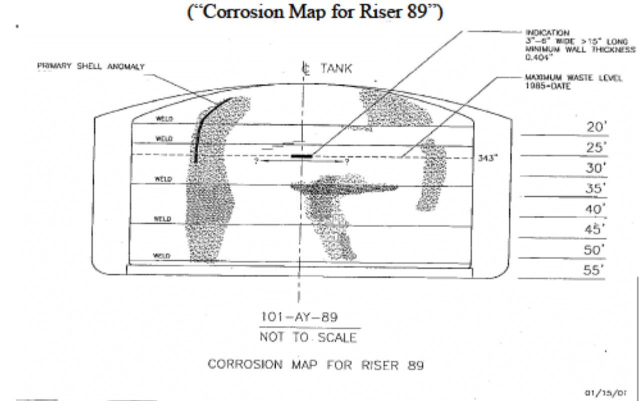


Worst Case Maximum Wall Thinning By DST and Nominal Plate Thickness



AY-101 Wall Thinning Illustration

("Corrosion Map for Riser 89")



High-Level Waste Tank Corrosion Monitoring at Hanford

E. C. Norman

CH2M HILL Hanford Group, Inc.

May 2, 2001

High Level Waste Tank Corrosion Monitoring at Hanford

E. C. Norman
CH2M HILL Hanford Group, Inc.
Wednesday, May 2, 2001

Overview

- Project background
- Summary of FY01 Program
- Program development
- Current status
- Independent Technical Review
- Conclusions

Corrosion Monitoring at Hanford

- Corrosion monitoring is currently provided by chemistry sampling
- Compare tank samples to lab results on coupons
- This is expensive, increases worker exposure and does not *measure* corrosion
- Several out-of-spec tanks exist, which are being mitigated
- Project started in 1995 to develop real-time corrosion monitoring using electrochemical noise (EN) based systems

Program Description

- Five EN based systems have been installed at Hanford
- Each system improved
- FY01 Program:
  - ÿ Upgrade existing systems to correct data collection problems
  - ÿ Deploy new system in double-shell tank (DST) AN-104
  - ÿ Conduct external peer-review of system and technology
  - ÿ Start process of turning systems over to site operations
  - ÿ Get corrosion monitoring into baseline operating strategy
- Goal: have four systems operating properly at Hanford by FY02

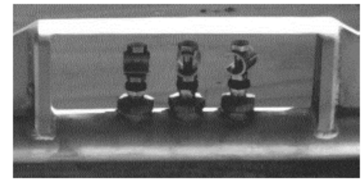
Program Development

- Two-year laboratory study at PNNL and ORNL - 1995
- Prototype installed in AZ-101 - 1996
- First full-scale system installed in AN-107 - 1997
- Second full-scale system installed in AN-102 – 1998
- Third full-scale system installed in AN-105 – 2000
- Fourth full-scale system installed in AN-104 - 2001

CH2MHILL Hanford Group, Inc.

Prototype Probe for AZ-101

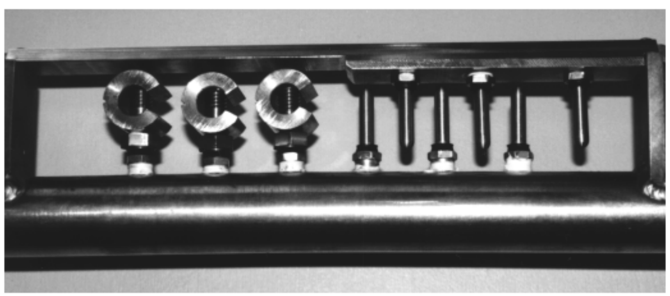
In-tank Probe



Electrode Detail

CH2MHILL Hanford Group, Inc.

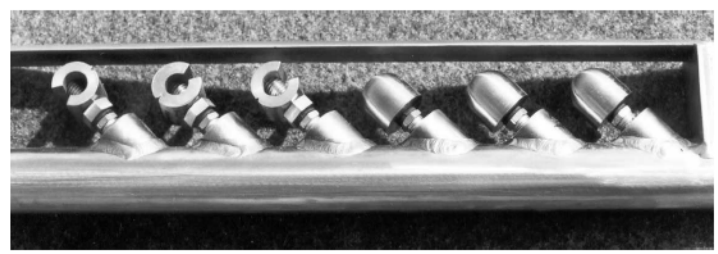
1st Generation Probe for AN-107



Electrode detail: C-ring channel, pin channel, 3 pins for weight loss data

CH2MHILL Hanford Group, Inc.

2nd Generation Probe for AN-102



Electrode detail: C-ring channel and bullet electrode channel

CH2MHILL Hanford Group, Inc.

3rd Generation Probe for AN-105

Electrode detail showing new gasket design: C-ring channel and bullet electrode channel

CH2MHILL Hanford Group, Inc.

4th Generation Probe for AN-104

Probe installation: Mid-pick on way over to riser

CH2MHILL Hanford Group, Inc.

4th Generation Probe for AN-104

Field installation: Outdoor cabinet with probe and indoor cabi

Project Status

- AN-104 and AN-105 systems showing uniform corrosion rate of about 1 mpy
- AN-102 and AN-107 systems providing unrealistic data – we believe gaskets have failed
- A new probe will be installed in AN-107 this month
- Site will evaluate effectiveness of program in FY01

Independent Technical Review

- Review by outside panel of corrosion monitoring experts – May 14-16, 2001
- Assess design and operating strategy for EN-based systems currently deployed at Hanford
- Answer questions such as:
  - Is the technology ready for routine use?
  - How should the technology be transitioned into current site operating procedures?

13

Conclusions

- Development of EN based corrosion monitoring for waste tank environments nearing completion
- Two systems at Hanford are installed, operating and returning data on waste tank corrosion
- Some lab testing needed to improve data analysis

14

EN-Based Corrosion Monitoring

G. L. Edgemon

HiLine Engineering and Fabrication

May 1, 2001

EN Based Corrosion Monitoring

Prepared by:

G. L. Edgemon
HiLine Engineering & Fabrication, Inc.
2105 Aviator Drive
Richland, WA 99352
509-943-9043
glenne@hilineeng.com

Overview

- What is electrochemical noise (EN)?
- How does EN work?
  - Lab and field applications
- Laboratory development work
- Hanford DST system development
  - Lessons learned (abundant)
- Known technical issues and future work
- Conclusions

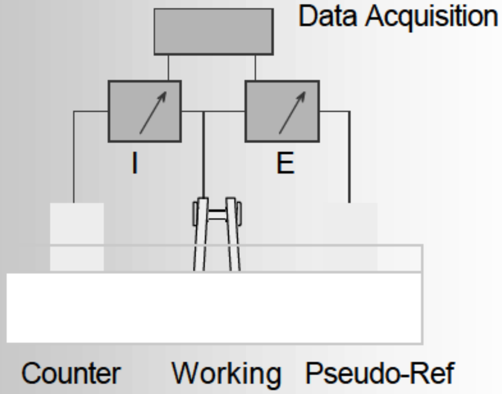
What is EN?

- Electrochemical Noise: Low frequency and small amplitude fluctuations in current and voltage caused by corrosion and other reactions
- Different forms of corrosion create different fluctuations in current and voltage
- Study fluctuations - determine type of corrosion
- EN based systems are well suited for detecting and identifying the onset of localized corrosion
- Detection of localized corrosion is the key…

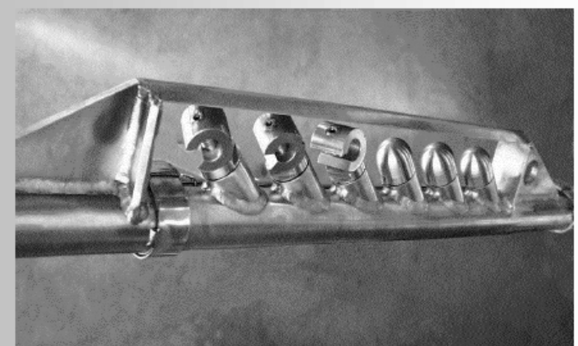
What is EN Based *Corrosion Monitoring?*

- A typical EN based corrosion-monitoring system measures instantaneous fluctuations in corrosion current and voltage between three nominally identical electrodes of the material of interest (tank steel) immersed in the environment of interest (tank waste).
- EN has been around forever, but can you use it as a tool?

EN System for the Laboratory



EN System for the Field



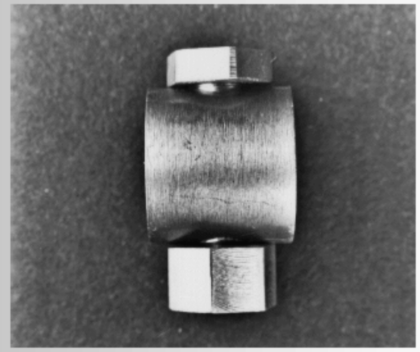
Laboratory Development Work

- In relevant test environments....
  - Detect and discriminate between uniform and localized corrosion with EN
  - Verify EN results with metallography
  - Develop electrode design for field
  - Develop lab EN hardware and software for field
- 6000 hours of lab testing: WHC-SD-WM-TI-77
- Selected data presented here

Test Summary: Uniform Corrosio

- ASTM A537-Class 1 coupons and C-rings
- Surface areas: 5 - 27 cm^2
- $NaNO_3$, NH_4NO_3, and simulated wastes
- 33 separate tests
- Data presented: 500 hour exposure, 2M $NaNO_2$ + 4M $NaNO_3$ + 0.2M NaOH at 35°C
- Corrosion rate after 1 hour: 0.1 mpy

Electrode After 500 Hours (2.5X)



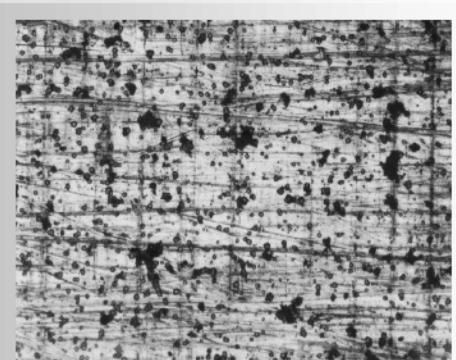
Uniform Corrosion: EN Signature

- Random fluctuations in current and voltage
- Data may be offset from zero depending on differences in electrode surface condition
- Reduction in frequency and magnitude of peaks over time with passivation
- Thousands of hours of data from lab and field

Test Summary: Pitting

- ASTM A537-Class 1 coupons and U-bends
- Surface areas: 5 - 48 cm^2
- Testing in a variety of inhibited off-normal waste solutions
- 26 separate tests
- Data presented: 240 hour exposure, 5 M $NaNO_3$ + 0.3 M NaOH at 90°C

Electrode After 240 Hours (10X)



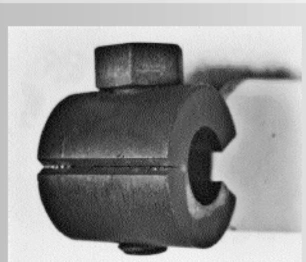
Pitting: EN Signature

- Multiple small sharp spikes in current and voltage
  - Voltage drop, current in either direction
- Localized anodic dissolution of base metal
- Electrons released, some travel through ZRA
- Pitting "rate" not attainable with current technology
  - Unknown number of active pitting sites

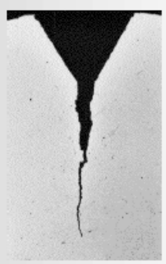
Test Summary: Intergranular Stres Corrosion Cracking (IGSCC)

- ASTM A537-Class 1 C-rings and U-bends
- Surface areas: 24 - 47 cm^2
- $NaNO_3$, NH_4NO_3, and simulated wastes
- 27 tests (9 producing SCC)
- Data presented: 143 hour exposure, 4 M NH_4NO_3 at 97°C
- Only working electrode stressed

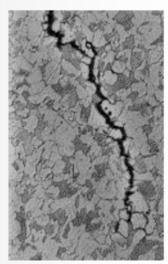
Electrode After 143 Hours



2.5X



15X



400X

Intergranular SCC: EN Signature

- Active path dissolution models crack advance
  - Continuous grain boundary dissolution + periodic mechanical fracture of grain boundary surface
- Positive mean current, negative mean potential
  - Based on sign convention of equipment
- Occasional current and potential bursts
- Fewer peaks than pitting
- Crack growth “rate” not attainable with current technology - unknown crack surface area

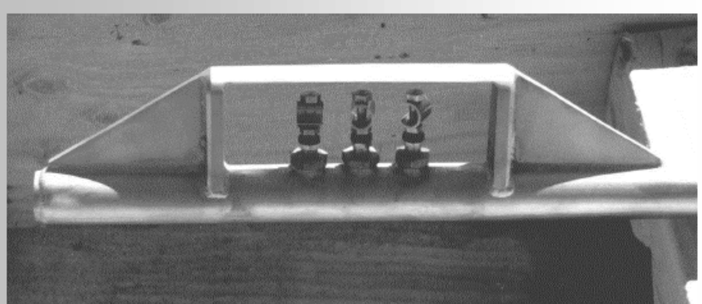
Program Development

- Two year laboratory started in 1995
- Prototype system in August 1996
- First-generation system in September 1997
- Second-generation system in August 1998
- Third-generation system in January 2000
- Fourth-generation system in January 2001

AZ-101 System Description

- Installed in AZ-101 in 1996
- 3 channels
  - 1 in waste, 2 in vapor space
- EN, LPR, and Tafel scans possible
- Small 27 cm^2 C-ring electrodes
  - Working pre-cracked and strained
- Archived ASTM A537-CL 1 material
  - From 241-AP farm corrosion coupon material

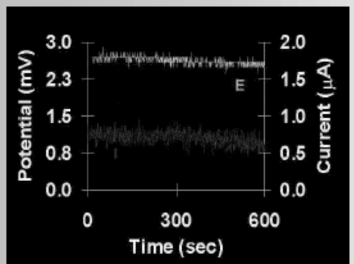
AZ-101 System Electrodes



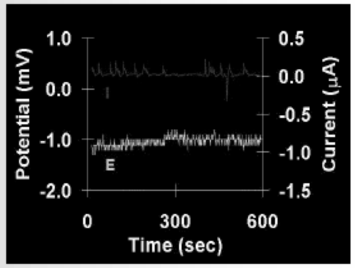
AZ-101 System Lessons Learned

- System worked well in field for two years
- System detected pitting during water additions
- Gasket material/design caused concern
- Voltage sensitivity issues (+/- 0.1 mV)
- Multiplexed vs. simultaneous data collection
- Remote operating system – absolute mess
- Need better range of available depths
- Communications with operations personnel

AZ-101 Raw Data



2 days prior to 26,000 gal H_2O dump

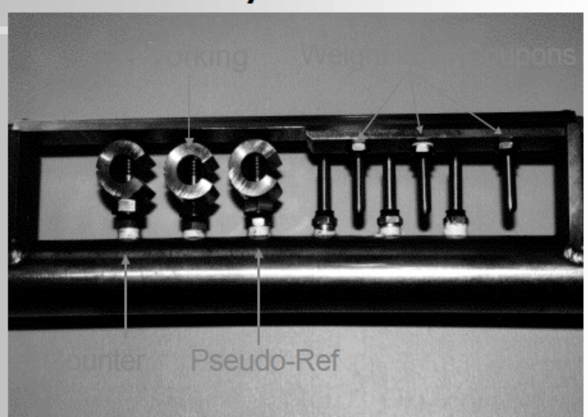


2 days after 26,000 gal H_2O dump

AN-107 System Description

- First full-scale probe: approximately 55′ length
- 1” schedule XXS 304L pipe 4” riser
- 4 channels of C-ring and 4 channels of pin electrodes
- 44 cm^2 C-rings, 5 cm^2 pins
- Long term weight loss coupons
- ~450′ above ground cabling, grounded shield
- DOS based, operated remotely via the Hanford LAN
- Multiplexed data collection

AN-107 System Electrodes



AN-107 System Lessons Learned

- Moved to larger pre-cracked C-rings
- Improved remote access system
- Corrected shortcomings in voltage sensitivity
- Achieved full range of tank depths
- Electrostatic interference common to all channels
- Gasket material/design concerns
- Excessive signal loss down long lengths of cable
- Y2K non-compliant hardware
- No funding provided for data analysis following installation

AN-102 System Description

- Second full-scale probe: approximately 55′ length
- 1″ schedule XXS 304L pipe – 4″ riser
- 4 channels of C-ring and 4 channels bullet electrodes
- 44 cm^2 C-rings, <u>10</u> and <u>25</u> cm^2 bullets
- Angled mounting ports for electrodes
- 300′ above ground cabling, grounded shield
- Windows based software, no remote access
- Simultaneous 8-channel data collection, EN & LPR

AN-102 System Electrodes

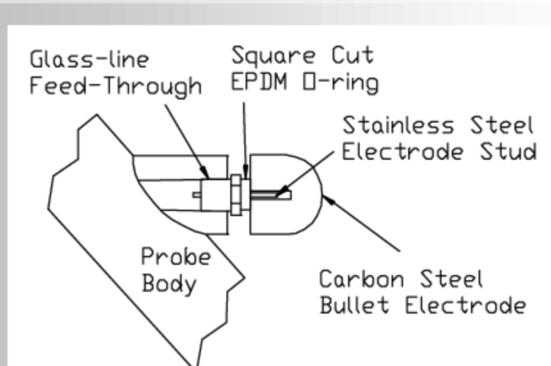
AN-102 System Lessons Learned

- Angled mounting ports helped wiring and install
- Simultaneous EN and LPR on 8 channels
- Specialized software for plotting/data analysis
- Electrostatic interference and signal loss in field common to all channels on 300′ analog data cable
- Gasket design issues persist
- <u>Lack of timely funding</u> for AN-107 led to build of AN-102 system with similar cabling/data transmission issues

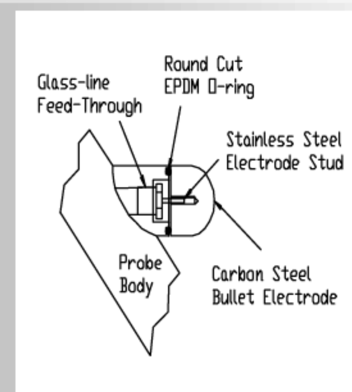
AN-105 System Description

- 55' in length, 1" schedule XXS 304L pipe – 4" riser
- 44 cm² C-rings, 25 cm² bullet electrodes
- Angled mounting ports for electrodes
- New dual gasketed, round-cut O-ring design
- Moved data collection hardware to field: 10' cable
- Driven screens on each channel
- 1 analog cable with 18 individually shielded pairs
- Analog signal converted to digital before transmit
- 22 thermocouples, 3 gas sampling ports, adjustable collar, set of strain gauges

Old Gasket Design



New Gasket Design

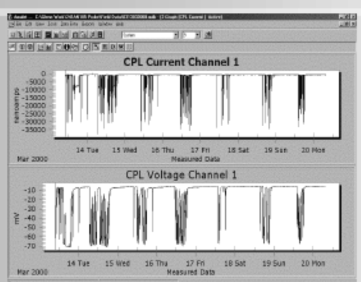


AN-105 System Electrodes

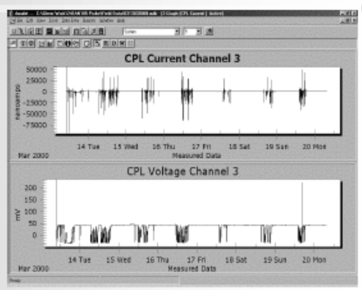
AN-105 System Lessons Learned

- System now functioning as designed
- Returning full-time EN data with periodic LPR
- System hardware proven to be field hardy
- Internet based remote access system very stable
- System showing primarily uniform corrosion
- System showing *uniform* corrosion rate of ~0.3 mpy
- Occasional system hang demands instrument techs
- Driven shields improperly applied removed 4/00
- System showing occasional voltage EN pitting transients on channels 7 & 8

Data With Driven Screens

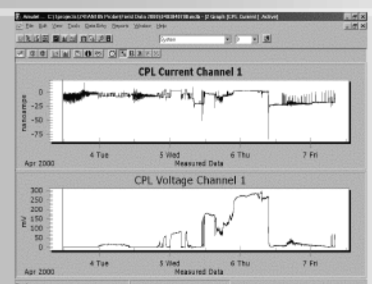


Vapor space channel

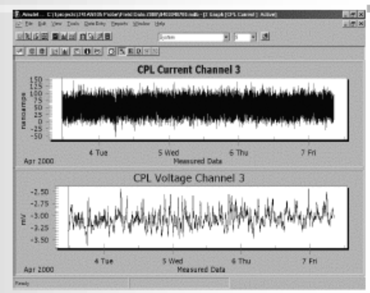


Liquid phase channel

Data Without Driven Screens



Vapor space channel



Liquid phase channel

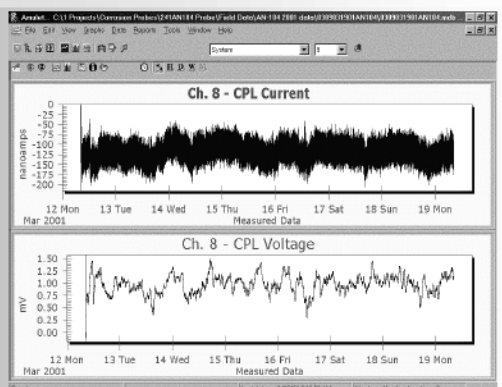
AN-104 System Description

- All design features of AN-105 probe left the same with three exceptions:
  - Added built-in water lance to facilitate installation
  - 2 individually shielded pairs per channel, 1 separate cable for each channel (vs. 1 cable with 18 twisted pairs in AN-105)
  - Driven screens ultimately disconnected

AN-104 System Lessons Learned

- System functioning as designed
- Returning full-time EN data with periodic LPR
- Remote access system very stable
- System showing uniform corrosion on all channels
- System showing uniform rate of ~0.3 mpy
- Occasional system hang demands instrument techs in field to reset hardware

AN-104 Typical Data



Future Work

- Now that good data can be reliably collected, do we fully understand how to interpret these data?
  - What does gasket failure look like?
  - What does crevice corrosion look like?
  - What does IGSCC in realistic waste look like?
  - Are electrodes optimally sized?
  - Are electrodes optimally placed?
- Are we ready to transition this from development to operation?
  - Corrosion monitoring by *exception*

Conclusions

- Initial lab work: basis for current operation
  - Characterized uniform, pitting and IGSCC
- Each system has improved on previous design
- Reliable EN and LPR now possible
  - Primarily uniform corrosion at less than 1 mpy
- Technical review upcoming
  - Address technical concerns and review operation
- Should improve safety and save on costs
- Lessons learned being passed to other sites

Technical Basis for Hanford Double-Shell Tank Life Extension

Jack W. Lentsch

Tank Integrity Project Manager

May 1–4, 2001

Technical Basis for Hanford Double-Shell Tank Life Extension

May 1- 4, 2001

Jack W. Lentsch
Tank Integrity Project Manager

CH2MHILL
Hanford Group, Inc.

Hanford Double-Shell Tanks

- 28 tanks in 6 tank farms
- ~ 1 Mgal capacity each
- ~ 21 Mgal waste
- ~ Several MCi each (80 MCi total)
  - Sr-90 and Cs-137
- Approximately 15 - 30 years old
- Approximately 50 year design life
- Some tanks will exceed their design lives before their mission is complete

CH2MHILL

Tank Integrity Project

- Project established in January 2001
- Project mission
  - Ensure DST integrity to a horizon of 2028 and beyond
- DSTs are required to:
  - Store current inventories
  - Receive single-shell tank waste
  - Stage and feed waste to vitrification plant

CH2MHILL

Tank Integrity Project

- Objectives
  - Correct current out-of-specification waste chemistry and restore vital systems
  - Develop controls and surveillance programs to prevent and assess future corrosion

CH2MHILL

Goals and Deliverables for Meeting

- Review Hanford DST Integrity Programs
- Review current condition of Hanford DSTs
- Review Tank Experience at Savannah River
- Recommend changes to Hanford programs to extend the life of the DSTs
  - Assign priorities
- Provide input to report in June 2001 on the Technical Basis for Hanford DST Life Extension

CH2MHILL

Past History

- The Hanford DSTs had a conservative design
  - Good alloys
  - Thick walls
  - Stress relieved
- Chemistry limits were conservative
- There have been no DST leaks to date
- There are some signs of degradation
- Safety issue resolutions have had a higher priority than tank integrity

CH2MHILL

Future

- Preserving the current DSTs is much cheaper than building new DSTs
- We must prevent both excessive uniform corrosion and the onset of pitting and cracking
- Past history is not the best predictor of future corrosion
- We cannot wait for the onset of pitting and cracking to take action

CH2MHILL

Future (continued)

- We must concentrate our efforts on
  - Chemistry control
  - Corrosion monitoring
  - In-service inspections
  - Support system maintenance
- We must preserve our original safety factors for future uncertainties

CH2MHILL

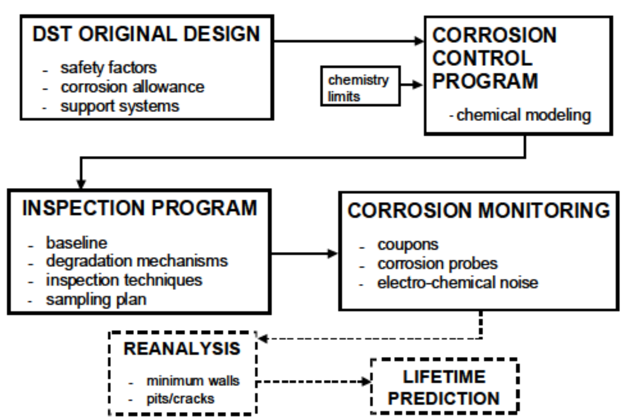
Focus Areas

- We must develop a sound technical basis for preserving the DSTs
- We must be systematic in protecting all regions of the tanks:
  - Supernate regions
  - Sludge regions
  - Vapor spaces
  - Annuli

Focus Areas (continued)

- We must particularly guard against progressive types of corrosion that cannot be stopped once they develop
  - Pitting
  - Cracking
  - Crevice corrosion
  - Microbiological induced corrosion

Technical Basis for Hanford DST Lif



Nondestructive Examination/Inspection Need

Jerry Posakony

May 1–4, 2001

Nondestructive Examination/Inspection Need

- Select/Develop Remote Means for Nondestructively Evaluating the Integrity of the Radioactive Double-Shell, Carbon Steel Storage Tanks in the 200 Area on the Hanford Reservation
- **NDT System Must be Able to Detect and Characterize:** Wall Thinning, Corrosion/Pitting, and Cracks in the Wall and Tank Bottom, Stress Corrosion Cracks (SCC) in the Heat-Affected Zones (HAZ) of Welds as well as in the High-Stress Region of the Knuckle of the Primary Tank

NDT Examination/Inspection Requirements

Conditions on the Inner Wall of the Tank

- Wall thinning that exceeds 20% of nominal
- Pitting that exceeds 25% of plate thickness
- SCC that exceeds 0.1 inch through wall

Required Accuracy

- Wall thinning – within +/- 0.02 inch
- Pits – size depths within +/- 0.05 inch
- Cracks – size depths on inner surface within +/- 0.10 inch
- Location – locate indications within +/- 1.0 inch

Request for Quotation Highlights

Other Requirements

A. NDT System must be capable of remote inspection of the inner and outer walls of the tanks through a 24 inch riser that provides access to the tank annulus

B. Personnel Qualifications – Certified in accordance with ASNT SNT-TC-1A
  - Special training in crack detection and sizing

C. Inspection Procedure – Develop procedure to be used for tank inspection

D. Satisfactory completion of a Performance Demonstration Test (PDT) required to validate the capability of proposed system. PDT to be developed and administered by the Pacific Northwest National Laboratory

Nondestructive Test Methods

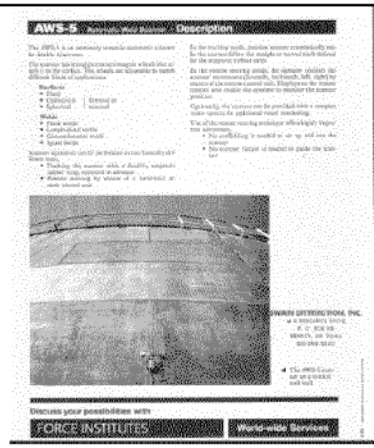
- Accoustic Emission
- Eddy Current
- Remote Field Eddy Current
- Infrared Thermography
- Magnetic Particle
- Magnetic Flux Leakage
- Dye Penetrant
- Gamma Radiography
- Neutron Radiography
- Visual
- Ultrasonic

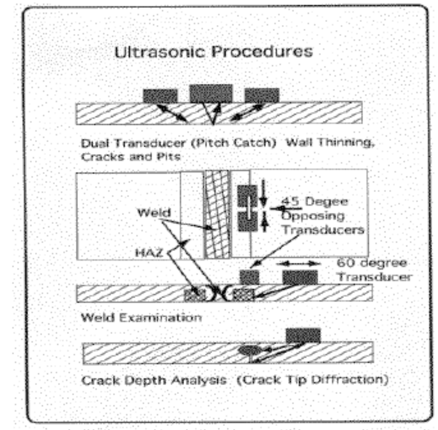
PNNL Responsibilities

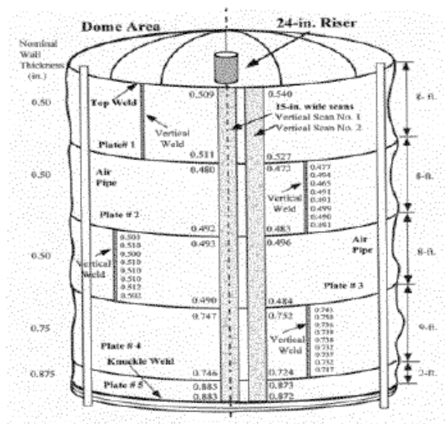
- Assist in selecting the ultrasonic system that will be used for the ultrasonic examination of the double shell tanks
- Evaluate the effectiveness of the ultrasonic procedure proposed for the tank examination
- From documentation provided, confirm the qualification of the personnel that will be performing the examinations and analyzing the data
- Develop and administer the Performance Demonstration Tests (PDT) to validate the performance of the system and the personnel performing data analysis
- Review data recorded during tank examinations, resolve questions and prepare a report summarizing the results recorded by the agency performing the tests
- Assist in interpreting questions pertaining to the recorded data

Reporting Requirements

- Document a detailed data report on all anomalies
- Provide B-C-Scan hardcopies of each foot of the area inspected
- Record A-Scan data of each reportable defect for post analysis
- Work with PNNL and CHG personnel to resolve questions in the documentation

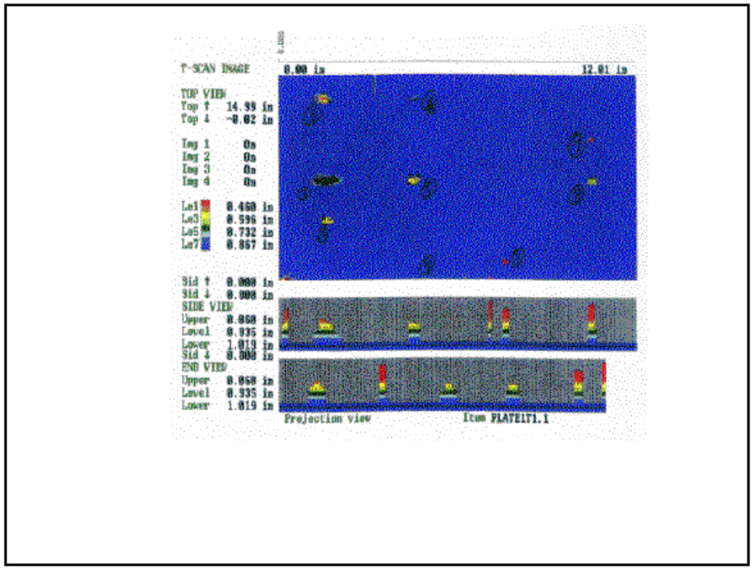


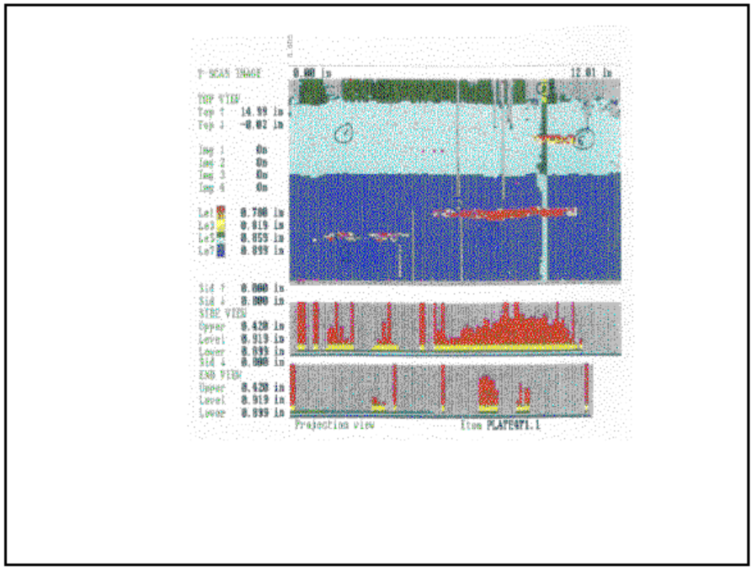


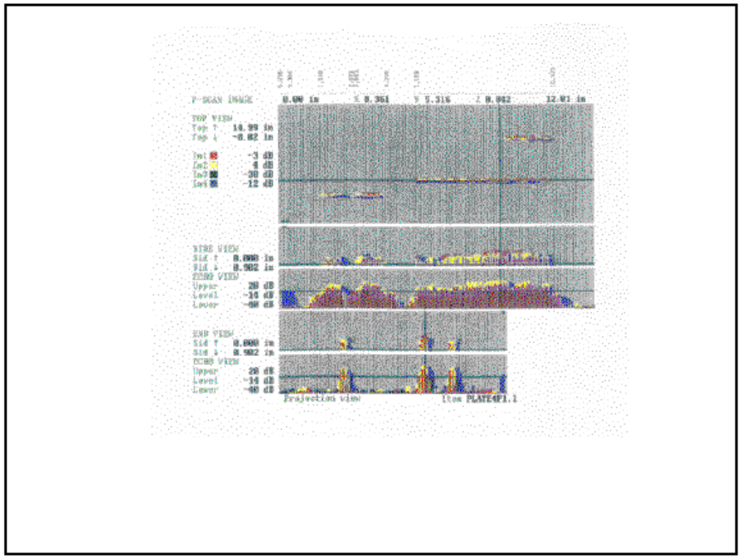


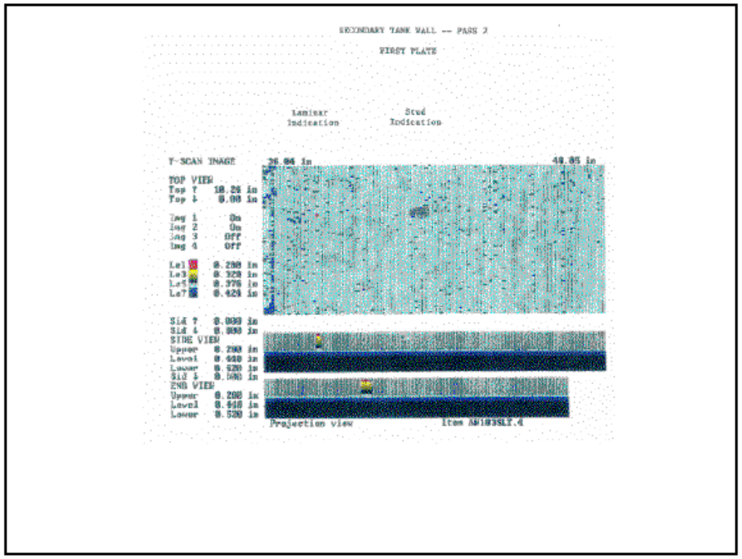
Performance Demonstration Tests (PDT)

- The Pacific Northwest National Laboratory (PNNL) has developed a series of one-half, three-quarters and seven-eights-inch steel plates that contain a variety of machined and natural defects including: simulated wall thinning, round bottomed holes (simulating pitting), and laboratory-grown stress corrosion cracks
- The various defects are of different depths, sizes, and/or lengths
- PNNL has measured and calibrated each defect, and the PDT compares the performance of the system proposed for tank inspection with the known type and size of the defects
- Satisfactory completion of the PDT is required prior to tank inspection


T-SCAN IMAGE
TOP VIEW
SIDE VIEW
END VIEW
Projection view


T-SCAN IMAGE
TOP VIEW
SIDE VIEW
END VIEW
Projection view


T-SCAN IMAGE
TOP VIEW
SIDE VIEW
END VIEW
Projection view


SECONDARY TANK WALL -- PASS 2
FIRST PLATE
Laminar Indication
Stud Indication
T-SCAN IMAGE
TOP VIEW
SIDE VIEW
END VIEW
Projection view

Corrosion Testing

1980 to 1984 and Beyond

J. R. Divine

ChemMet, Ltd., PC

May 1–4, 2001

Corrosion Testing

1980-1984
&
Beyond

Technical Basis for Hanford DST Life Extension
May 1-4, 2001

J R Divine
ChemMet, Ltd., PC

Acknowledgement

Thanks to:

Douglas B Mackey

Who saved the data
And
Prepared my graphics

Early Work

1952

Uniform corrosion rates:
- L: - 0.5 mpy decreasing with time
- V: 2.4 mpy, pH 6; - 0.2 mpy, pH 7 & 8

Pitting corrosion rates:
- L: not noted
- V: decreased with time at pH 8
- increased with time at pH 6 & 7, reached - 8 mpy

Early Work (continued)

1954

10 month laboratory test on SAE 1010 in simulated PUREX waste

Uniform corrosion rates: Started at generally <1 mpy, decreased.

Pitting corrosion rates: Initially 20 to 30 mpy; by 3 months 8 to 10 mpy. By 10 months, 2 mpy.

Field test using SAE 1020 in the liquid in REDOX Tank 104, 241 S

Uniform corrosion rate: - 0.6 mpy (T, boiling - 250 °F to 300 °)
Pitting corrosion rate: - 5 mpy

Early Work (continued)

1955
A 10 year in-tank corrosion test using SAE 1020, Cor-Ten, Mayari-R, and Carrilloy T-1 was started in June in Redox 107, 241 SX, and PUREX, 101, 241 A, tanks.

Uniform corrosion rates: All alloys: trivial, Š 0.02 mpy

Pitting corrosion rates:
SAE 1020: - 1.9, range 0.8 to 4 mpy
Mayari-R: 2.8, range 1.2 to 5.3 mpy
Cor-Ten: 2.9, range 0.7 to 6.2 mpy
Carrilloy T-1: no data

Early Work (continued)
1977 Electrochemical Tests

Payer, Battelle Columbus, noted the free corrosion potential is normally more positive than the cracking regime.

With NO_3^- and AlO_2^- the potentials more negative, but interacted to reduce SCC.

NO_2^- made potentials more positive.

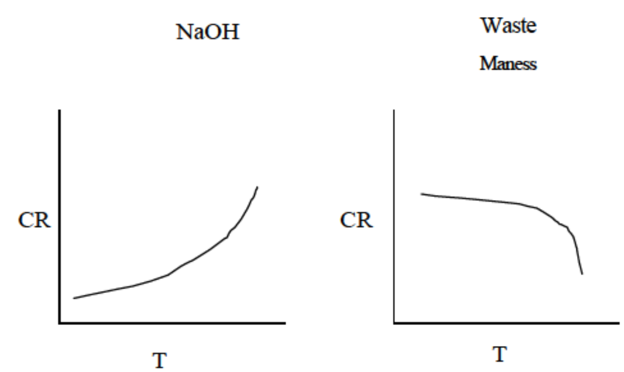
For the three species alone, SCC was worsened when it occurred.

But the combination was beneficial.

1980 — An Environmental Impact Statement was prepared for the new 241-AN and 241-AW tanks. Insufficient data, Hanford, SRL, etc. to characterize the corrosion of the new tanks.

Part of the problem was temperature effect.

Questions



New Program

1981 — Initiated preparation in March for tests using A-537 and A-516 carbon steel at 25, 40, 50, 60, 70, 80, & 100 °C and 140 & 180 °C. Preparation was halted in September to redefine DSS chemistry.

1982 — Restarted test preparation in March with revised DSS waste compositions. Started 4, 8, and 12 month tests.

1983 — Completed DSS test, started Future PUREX and then Hanford Facilities Waste. Designed and constructed in-tank corrosion probe.

1984 — Completed testing & analysis

TEST OPERATING PARAMETERS

	DSS		Future PUREX		Hanford Facilities	
M -->	min	Max	min	Max	min	Max
OH	0.5	10	0.001	5	.0001	2
Al	0	2.95s	0	1.1s		
NO_3	1	6.5s	0.02	5		
NO_2	0.2	8.2s	0	2	0	0.01
CO_3	0	0.18s				
PO_4	0	1.2s			0	5s
SO_4	.012s	0.05			0	2.9s
CMPLX	0	1				
CITRATE	0	0.6	0	2		
F			0.01	1		
Zr			0	s		
Fe				0.4		

Coupon Types

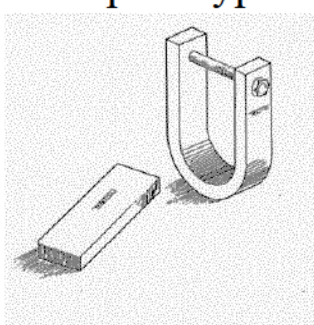


FIGURE 1. Weight Loss and U-Bend Specimens

Test Method:

- Test statistically designed - polynomial equation
- Wt Loss Coupons & U-Bend specimens
- No weld specimens
- No significant electrochemical work
- PTFE bottles
- Samples sheared from plate, no machining
- Heat treated at 1100 °F for 1 hour
- Not descaled before use —> error of - 0.2 mpy, noticeable at 4 months
- Not soaked in water before use

Conclusions

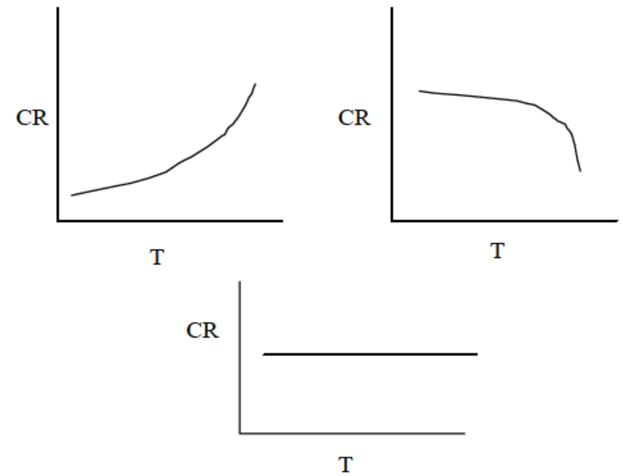
Uniform corrosion rates

Generally < 1 mpy

Mostly < 0.5 mpy

>> 1 mpy in dilute solutions or

concentrated caustic @ T>140 °C (280°F)



PITTING

	Future PUREX		Hanford Facilities	
	#60	#65	#2	#7
OH^-	.001	.001	0.0001	0.0001
Al^{+++}	.5	1.1		
NO_3^-	2.5	2.5		
NO_2^-	.01	.01	0.01	0.01
PO_4^{---}			0	0.4
SO_4^{--}			0.8	0
CITRATE	.6	1.3		
F^-	.1	.2		
Zr	0	0		
Fe^{+++}	0	0		

SCC

	DSS		Future PUREX					
	#30 180°	#36 180°	#71 <100	#72 <100	#81 <100	#78 140	#79 140	#102 140
OH	10	10	.2	0.2	0.2	5	9	0.5
Al	0.1	0.1	0	0.05	0.1	1	0	0.027
NO_3	1	5	2	5	5	0.3	0.2	3
NO_2	.2	.2	0.01	0.01	0.1	0.2	0.01	0.01
CO_3	0.085	.12						
PO_4	.2	.25						
SO_4	0.05	0.013						
CMPLX	0	.36						
CITRATE	.2	.2	0	0	0.09	0	0	0.09
F			0.1	1	0.2	0.49	0.2	0.01
Zr			0	0	0	0	0	0.05
Fe			0	0	0	0	0	0.2

Sample Data Plot

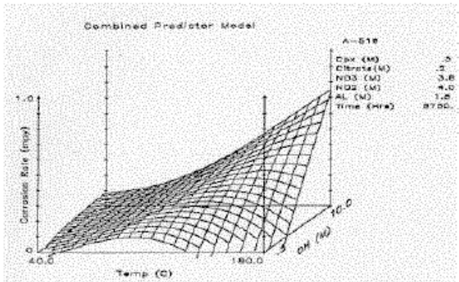


FIGURE 2. Unrestricted Plot of Concentrated DSS Corrosion Rates

Purposely left blank

Equations

$NO_3^- + H_2O + 2e^- \rightarrow NO_2^- + 2OH^-$ $E_o = 0.01$ V

and

$NO_2^- + 5H_2O + 6e^- \rightarrow NH_3 + 7OH^-$ $E_o = 0.48$ V

(reportedly slow in caustic except in presence of $Fe(OH)_2$)

or

$2NO_2^- + 3H_2O + 4e^- \rightarrow N_2O + 6OH^-$ $E_o = 0.15$ V

also

$Fe + 2OH^- \rightarrow Fe(OH)_2 + 2e^-$ $E_o = -0.877$ V

$Fe(OH)_2 + OH^- \rightarrow Fe(OH)_3 + e^-$ $E_o = -0.56$ V

$3Fe + NaOH + NaNO_2 + 3H_2O \rightarrow Na_2FeO_2 + 2Fe(OH)_2 + NH_3$

SRS Corrosion and Chemistry Probe

J. I. Mickalonis

WSRC

Savannah River Site

May 1–4, 2001

SRS Corrosion and Chemistry Probe

J. I. Mickalonis
WSRC
Savannah River Site

SRS Corrosion and Chemistry Probe

Collaborators

- SRS - E. Tshishiku (PI), D. Hobbs
- Hanford/HiLine - G. Edgemon
- EIC Labs - J. Bello
- DOE Tank Focus Area - M. Terry, T. Thomas
- DOE Control Measurement Sensor Technology - G. Baastian

SRS Corrosion and Chemistry Probe

Basic Requirements

- Real time detection of pitting and stress cracking corrosion in carbon steel
- In-situ chemistry measurements
  - NO_3^-: 0.02-3.2 M
  - OH^-: 0.03 - 13.4 M
  - NO_2^-: 0.05 - 3.0 M
  - other oxyanions, if possible

SRS Corrosion and Chemistry Probe

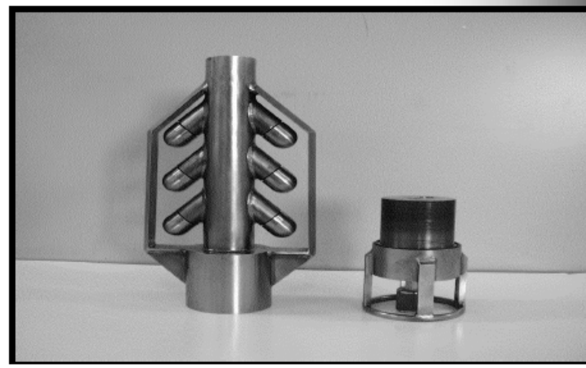
Basic Requirements

- Measurements at variable height
- Fit through an 8” riser
- 2-year life in tank environment (chemical and radiation degradation)

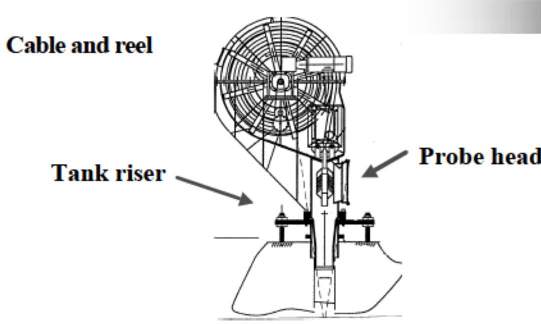
SRS Corrosion and Chemistry Probe
Basic Description

- Techniques
  - EN - corrosion of A537 and A106
  - Raman spectroscopy - chemistry
- Height adjustable in tank - cable and reel
- Probe head dimensions - 6 in (w) _ 14 in (l)
- Stainless steel housing and components

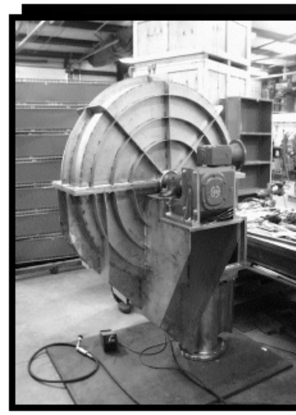
SRS Corrosion and Chemistry Probe
Probe Head

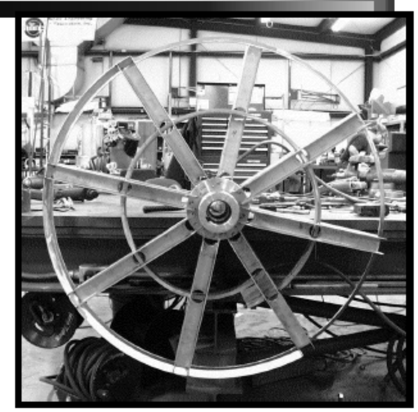


SRS Corrosion and Chemistry Probe
Deployment Assembly Schematic

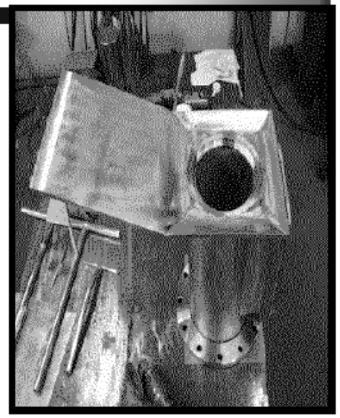


SRS Corrosion and Chemistry Probe
Deployment Assembly Housing





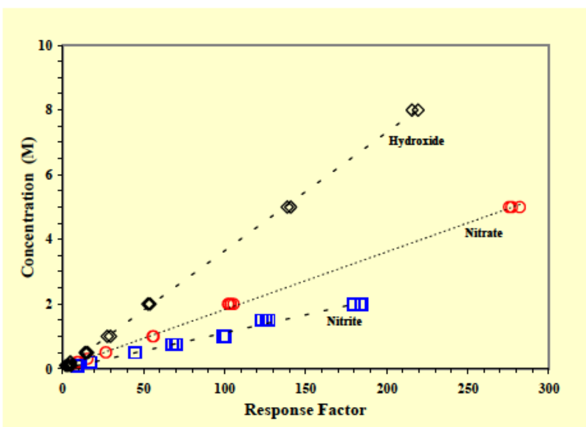
SRS Corrosion and Chemistry Probe
Deployment Assembly Housing



SRS Corrosion and Chemistry Probe
Raman Spectroscopy

- Monochromatic excitation laser with inelastic scattered light collected
- Raman active species include polyatomic molecules
  - oxyanions: NO_3^-, NO_2^-, OH^-, SO_4^{2-}, CO_3^{2-}, $Al(OH)_4^-$, PO_4^{3-}, CrO_4^{2-}
- Previously applied to nuclear wastes at SRS ('75) and Hanford ('77, '94)

SRS Corrosion and Chemistry Probe
Raman Spectroscopy



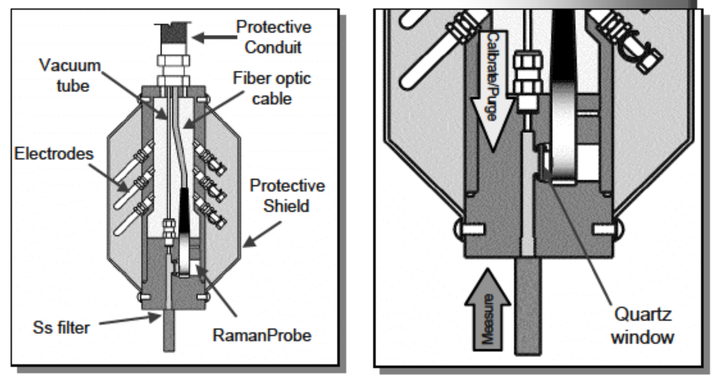
SRS Corrosion and Chemistry Probe
Advantages of Raman

- Laser provides remote use in a compact system
- Stable and light source and fiber optic systems
- Charge coupled detectors have excellent sensitivity to low signals
- Raman active species have unique signatures

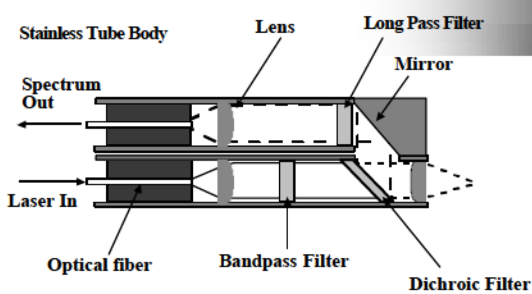
SRS Corrosion and Chemistry Probe
Disadvantages of Raman

- Limit of detection at 0.1 M, improvements to hardware needed to further lower limits
- Sensitive to solids
  - § removal by filtering
  - § internal standard
- Sensitive to handle

SRS Corrosion and Chemistry Probe
Probe Head Design

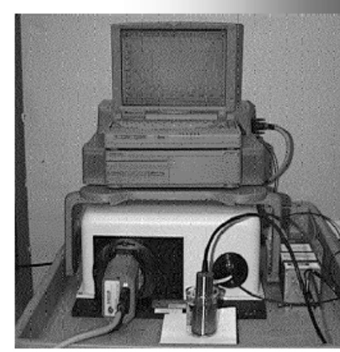


SRS Corrosion and Chemistry Probe
Raman Probe Schematic

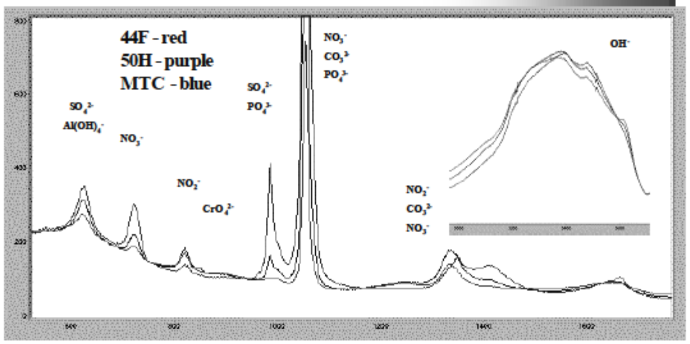


SRS Corrosion and Chemistry Probe
Raman Instrumentation

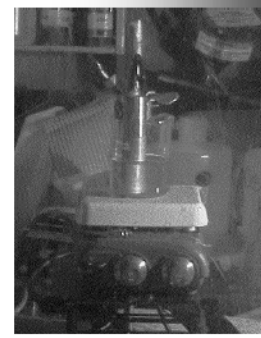
- Echelle Spectrograph
- CCD Detector
- Diode Laser
  - – 670 nm wavelength
  - – maximum output: 180 mW
- Toshiba Tecra 550CDT computer using EIC data acquisition software and Galactic Industries Grams/32 spectral processing software



SRS Corrosion and Chemistry Probe
RS Treated Waste Results



SRS Corrosion and Chemistry Probe
Raman Probe in Filtered Waste Solution



SRS Corrosion and Chemistry Probe
RS Treated Waste Results

		Conc (M)	Conc (M)	Difference
Nitrate	1050 peak	IC	Raman	Raman-IC
	44F	0.475	0.455	-4.2%
	50H	2.36	2.55	8.1%
	Composite	0.890	1.05	18%
	722 peak	IC	Raman	Raman-IC
	44F	0.475	0.425	-10.5%
	50H	2.36	2.41	2.1%
	Composite	0.890	0.983	10%
Nitrite		IC	Raman	Raman-IC
	44F	0.462	0.467	1.1%
	50H	0.257	0.241	-6.2%
	Composite	0.676	0.649	-4.0%
Free OH		Titration	Raman	Raman-Titration
	44F	4.02	3.80	-5.5%
	50H	1.30	1.30	0.0%
	Composite	2.54	2.57	1.2%

Potential Applications Of Raman To Waste Analysis

- Characterization of sulfate layers in a glass melt
- Detection of organic compounds that form a separate phase in tank waste
- *In Situ* analysis of aluminate and silicate in tank waste

SRS Corrosion and Chemistry Probe

Project Status

- Cold test May '01
- Deployment planned for October '01

Technical Basis for Hanford

Double-Shell Tank Life Extension:

DST Design

Larry J. Julyk

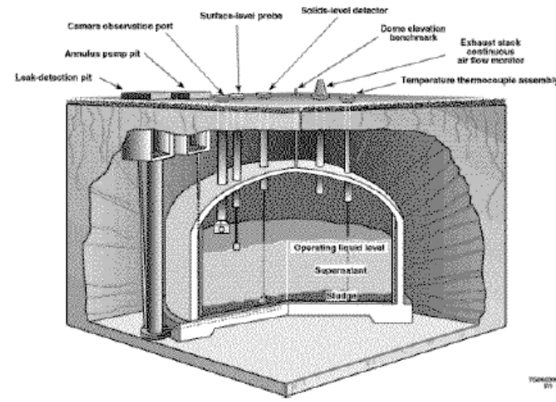
May 1, 2001

Technical Basis for Hanford Double-Shell Tank Life Extension: DST Design

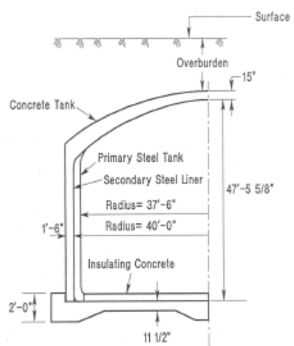
Larry J. Julyk

May 1, 2001

DST Design



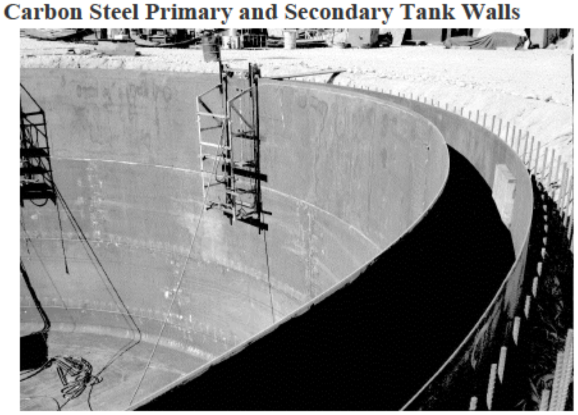
DST Design



- Carbon steel fully-enclosed primary inner tank contains waste
  - 75-ft diameter by 46 ft 9 in. tall.
  - Anchored to dome of concrete structure.
  - Welded (full penetration) steel plates.
  - Welds stress relieved (1,100 °F for 1 hr/in. of thickness) to mitigate nitrate-induced stress corrosion cracking (SCC).
  - Weld examination (100% x-ray, magnetic particle).
  - Hydro leak test (39 ft of water for 24 hr).
- Carbon steel secondary liner.
  - Provides containment barrier if primary tank should leak.
  - Anchored to wall of concrete structure.
- 8-in. thick insulating concrete pad with radial air flow passages and surrounded by steel ring.
  - Protects foundation concrete during stress relieving and operation.
- Reinforced concrete outer tank.
  - Resist soil and surface live loads.
- Reinforced concrete foundation with drain slots connecting to leak detection system.

DST Design

- Carbon Steel Primary and Secondary Tank Walls



DST Design

- Steel Dome of Primary Tank

DST Design

- Reinforcement Steel

DST Design

- Concrete Dome and Risers Extensions

DST Design

- Design Parameters

Parameter \ Tank	AY*	AZ*	SY	AW	AN	AP
Constructed	1968-70	1971-77	1974-76	1978-80	1980-81	1983-86
No. of Tanks	2	2	3	6	7	8
Design Life	30-40	20-30	50	50	50	50
Initial Service	mid-1971	late-1976	1977	mid-1980	1981	1986
Capacity (Mgal)	1	1	1.162	1.162	1.162	1.162
Max. Waste Depth (ft)	30.3	30.3	35.2	35.2	35.2	35.2
Max. SpG	1.6 2.5 sludge	1.6 2.5 sludge	1.7	2	2	2
Max. Heat Generation Rate/Tank (Btu/h)	4,000,000	4,000,000	50,000	100,000	100,000	100,000

*Aging Waste Facility DSTs equipped with air-lift circulators (ALCs) – designed for high-level radioactive boiling waste.

DST Design

- Air-Lift Circulators

CH2MHILL

DST Design

- Design Parameters (Continued)

<table>
<tr><th colspan="2">Tank / Parameter</th><th>AY</th><th>AZ</th><th>SY</th><th>AW</th><th>AN</th><th>AP</th></tr>
<tr><td rowspan="3">Design Max. Waste Temp. (°F)</td><td>Vapor</td><td></td><td>220</td><td>220</td><td>212</td><td>212</td><td>212</td></tr>
<tr><td>Liquid</td><td></td><td>260</td><td>250</td><td>350</td><td>350</td><td>300*</td></tr>
<tr><td>Sludge</td><td>350</td><td>350</td><td>250</td><td>350</td><td>350</td><td>300*</td></tr>
<tr><td colspan="2">Max. Historical (°F)</td><td>~247</td><td>~263</td><td>~155</td><td>~135</td><td>~150</td><td>~107</td></tr>
<tr><td colspan="2">Current Operational Limit (°F)
(LCO to prevent tank "bump")</td><td colspan="6">195 all levels of waste or
195 in top 15 ft of waste and 215 in waste below 15 ft</td></tr>
<tr><td rowspan="2">Vapor Pressure (in. water gauge)</td><td>Primary</td><td colspan="5">-6 to +60</td><td>-12 to +60</td></tr>
<tr><td>Annulus</td><td>-20 to 0</td><td colspan="4">-6 to 0</td><td>-20 to 0</td></tr>
<tr><td rowspan="2">Soil Overburden</td><td>Density (lb/ft^3)</td><td colspan="6">125</td></tr>
<tr><td>Height (ft)</td><td>8.3</td><td>8.3</td><td>7.5</td><td>7.5</td><td>7.5</td><td>7.5</td></tr>
<tr><td rowspan="2">Live Load</td><td>Uniform (lb/ft^2)</td><td colspan="6">40</td></tr>
<tr><td>Concentrated (tons)</td><td colspan="6">100</td></tr>
<tr><td rowspan="2">Seismic (SSE)</td><td>Horizontal (g)</td><td colspan="6">0.25</td></tr>
<tr><td>Vertical (g)</td><td colspan="6">0.17 (2/3 Horizontal)</td></tr>
</table>

* Maximum temperature of primary tank steel reduced to 210 °F following observed reduction in yield strength of material coupons during stress-relief process in AP tanks.

CH2MHILL

DST Design

- Reinforced Concrete Outer Tank

<table>
<tr><th rowspan="2">Tank Farm</th><th rowspan="2">Construction (year)</th><th colspan="4">Design Code / Specified Compressive Strength (ksi)</th><th colspan="2">Reinforcement</th></tr>
<tr><th>Dome</th><th>Wall</th><th>FDN</th><th>Insulating</th><th>Rebar</th><th>Ties</th></tr>
<tr><td rowspan="2">AY</td><td rowspan="2">1968-70</td><td colspan="3">ACI 318 (1963)</td><td rowspan="2">0.200</td><td rowspan="2">A432 Gr. 60</td><td rowspan="2">A432 Gr. 60</td></tr>
<tr><td>3</td><td>3</td><td>3</td></tr>
<tr><td rowspan="2">AZ</td><td rowspan="2">1971-77</td><td colspan="3">ACI 318 (1963)</td><td rowspan="2">0.200</td><td rowspan="10">A615 Gr. 60</td><td rowspan="2">A615 Gr. 60</td></tr>
<tr><td>3</td><td>3</td><td>3</td></tr>
<tr><td rowspan="2">SY</td><td rowspan="2">1974-76</td><td colspan="3">ACI 318 (1971)</td><td rowspan="2">0.130</td><td rowspan="2">A615 Gr. 40</td></tr>
<tr><td>4.5</td><td>4.5</td><td>3</td></tr>
<tr><td rowspan="2">AW</td><td rowspan="2">1978-80</td><td colspan="3">ACI 318 (1971)</td><td rowspan="2">0.130</td><td rowspan="2">A615 Gr. 40</td></tr>
<tr><td>5</td><td>5</td><td>4.5</td></tr>
<tr><td rowspan="2">AN</td><td rowspan="2">1980-81</td><td colspan="3">ACI 318 (1971)</td><td rowspan="2">0.130</td><td rowspan="2">A615 Gr. 40</td></tr>
<tr><td>5</td><td>5</td><td>4.5</td></tr>
<tr><td rowspan="2">AP</td><td rowspan="2">1983-86</td><td colspan="2">ACI 349 (1976)</td><td>ACI 318</td><td rowspan="2">0.130</td><td rowspan="2">A615 Gr. 60</td></tr>
<tr><td>5</td><td>5</td><td>4.5</td></tr>
</table>

CH2MHILL

DST Design

- Carbon Steel Primary and Secondary Tank

<table>
<tr><th>Tank Farm</th><th>Construction (year)</th><th>Design Code (ASME B&PV)</th><th>Material (ASTM)</th><th>Min. Yield (ksi)</th><th>Min. Ultimate (ksi)</th></tr>
<tr><td>AY</td><td>1968-70</td><td>Section VIII, Div. 2 (1965)</td><td rowspan="2">A515 Gr. 60</td><td rowspan="2">32</td><td rowspan="2">60</td></tr>
<tr><td>AZ</td><td>1971-77</td><td>Section III (1968)</td></tr>
<tr><td>SY</td><td>1974-76</td><td>Section III, Div. 1 (1971 with 1973 Addenda)</td><td>A516 Gr. 65</td><td>35</td><td>65</td></tr>
<tr><td>AW</td><td>1978-80</td><td>Section VIII, Div. 2 (1974 with Summer 1975 Addenda)</td><td rowspan="3">A537 Class 1</td><td rowspan="3">50*</td><td rowspan="3">70</td></tr>
<tr><td>AN</td><td>1980-81</td><td>Section VIII, Div. 2 (1974 with 1976 Addenda)</td></tr>
<tr><td>AP</td><td>1983-86</td><td>Section VIII, Div. 2 (1980 with Winter 1981 Addenda)</td></tr>
</table>

* Reduced to 48 ksi following stress-relief process in AP tanks.

CH2MHILL

DST Design

- **Primary Tank Wall Thickness – nominal (in.)**

Region \ Tank		AY/AZ	SY	AW/AN	AP
Dome	Center	1/2	1/2	1/2	1/2
		3/8	3/8	3/8	3/8
Upper Haunch		3/8	3/8	3/8	1/2
Vertical Wall		3/8 1/2 3/4	3/8 1/2 3/4	1/2 1/2 3/4	1/2 9/16 3/4
Lower Knuckle		7/8	7/8	7/8	15/16
Bottom		3/8 / 1/2	1/2	1/2	1/2
	Center	1	1	1	1

- Mill Plate Tolerance: +30/-10 mils
- Corrosion Rate Allowance: 1 mil/yr

DST Design

- **Primary Tank Allowable Wall Thickness**
  - Use predicted induced internal moments (M) and normal forces (N) (based on previous analyses) for design conditions including seismic (SSE conservatively evaluated as Level C event).

    $\sigma_i = N_i/t + 6M_i/t^2$
  - Evaluate all load combinations against code allowable stresses

    $P_m \le k\, S_m$ general primary membrane

    $P_L \le 1.5\, k\, S_m$ local primary membrane

    $P_L + P_b \le 1.5\, k\, S_m$ primary membrane + bending

    $P_L + P_b + Q \le 3\, S_m$ primary + secondary range

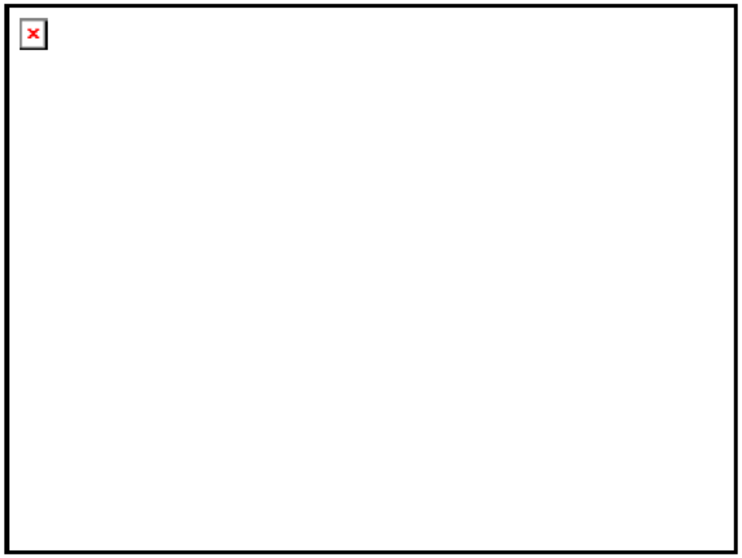
    $S_m = \min\{1/3\, S_U(RT),\ 1/3\, S_U(T),\ 2/3\, S_y(RT),\ 2/3\, S_y(T)\}$

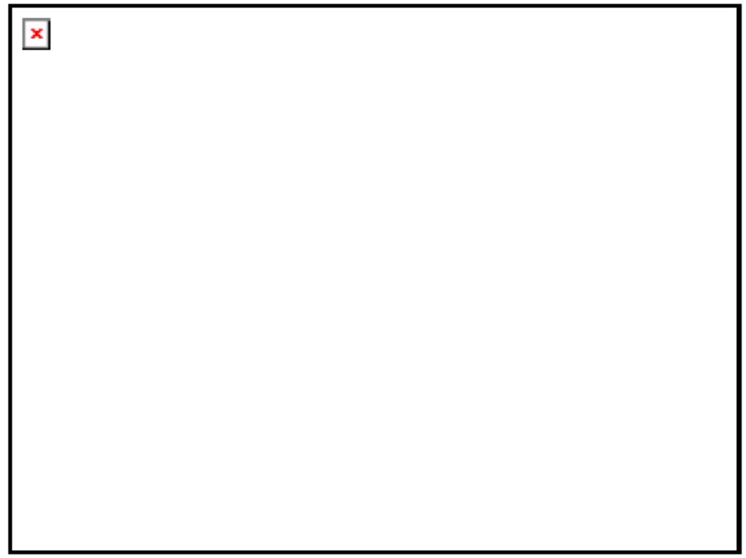
    k = 1, 1.1, 1.2 and 2 (Level A, B, C, and D service condition)

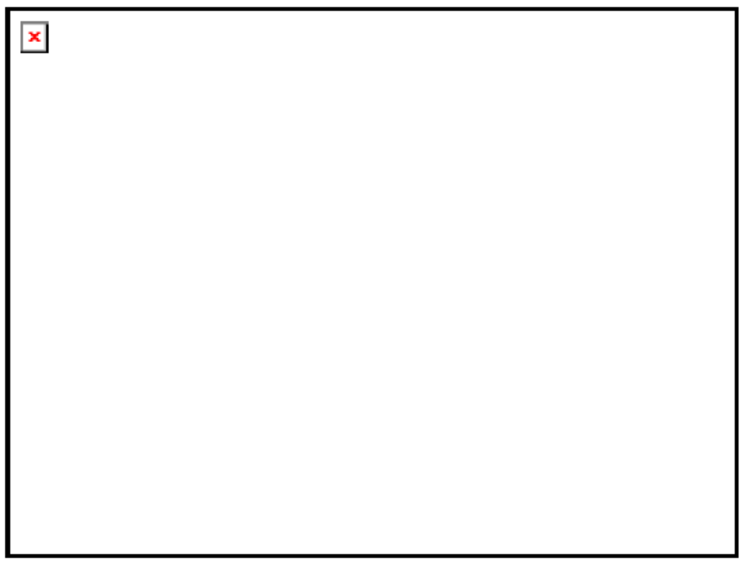
    $P = \max\{|\sigma_i - \sigma_j|\}$ i, j = 1, 2, 3 stress intensity

DST Design

- **Primary Tank Allowable Wall Thickness (continued)**
  - Evaluate additional design imposed restraint (precautionary measure against SSC) that the maximum tensile principle stress on inside surface of primary tank shall not exceed 90% of yield strength at temperature. Include primary stresses plus
    - Thermal induced stresses
    - Stresses from concrete creep induced loads and
    - Assumed remaining residual stress of 5 ksi
    - Exclude seismic induced stresses.
  - Determine required wall thickness at each location of primary tank to just meet code allowable stress limits and precautionary measure against SSC for all load combinations.
  - Typically controlled by primary stresses with seismic load combination except for lower knuckle and upper haunch which is controlled by precautionary measure against SSC criterion.







Chemistry Control Program

Mark Knight

May 1, 2001

Chemistry Control Program

Mark Knight

Process Control Manager

CH2M HILL Hanford Group, Inc.

May 1, 2001

CH2MHILL Hanford Group, Inc.

Background

- **Chemistry limits for DSTs originally contained in Operating Specification Documents**
- **No formal program in place to routinely monitor waste condition for continued compliance with limits during prolonged storage.**
- **Waste Compatibility Assessment Program**
  - Assesses waste conditions resulting from waste transfers
  - Assesses final waste condition against chemistry limits based on best available sample data and process knowledge.
  - No allowance made for hydroxide depletion since last sample date.

CH2MHILL Hanford Group, Inc.

Background (cont.)

- **Tanks were identified to be out of specification.**
  - AN-107, AN-102, AY-101, and AY-102 now, others in past
- **Action plans were developed to correct conditions but not always completed due to technical difficulties and/or programmatic decisions taken to resolve other major tank farms safety issues.**
- **Tanks remained out of specification for prolonged periods.**
- **DNFSB letter dated August 29, 2000 summarized concerns with adherence to chemistry controls.**
- **CHG provided an Action Plan to ORP on November 17, 2000 to address DNFSB concerns.**
- **DOE-HQ letter dated November 30, 2000 to DNFSB committed to corrective actions.**

CH2MHILL Hanford Group, Inc.

Action Plan

- **Restore DST bulk tank chemistry to be within specification by September 2001.**
- **Develop chemistry surveillance program**
- **Elevate the chemistry controls implemented through the OSDs to the level of a TSR control.**
- **Implement TSR for chemistry control by March 2001.**

CH2MHILL Hanford Group, Inc.

Authorization Basis Changes

- **Tank Farms Technical Safety Requirements (TSR), HNF-SD-WM-TSR-006 and Tank Farms Final Safety Analysis Report, HNF-SD-WM-SAR-067 have been amended to add the DST Chemistry Control Program as Administrative Control (AC) 5.15.**
- **Implementing Procedure HNF- IP-1266, Tank Farm Operations Administrative Controls, amended to add section 5.15 Chemistry Control.**
- **AB changes implemented on March 31, 2001 in accordance with DOE's agreement with DNFSB.**

CH2MHILL Hanford Group, Inc.

Program Purpose

- **The Administrative Control provided by the chemistry control program protects the Design Feature attribute related to the intrinsic structural integrity of the DSTs that provides a barrier to waste release for various accident scenarios.**
- **The DSTs by design have two barriers, a primary tank and a secondary tank.**
- **The purpose of the chemistry control program is to minimize corrosion of the steel in contact with the waste thereby helping to protect the intrinsic structural integrity of the DST primary tank.**

CH2MHILL Hanford Group, Inc.

Program Elements

- **The Chemistry Control Program consists of five key elements:**

  a) Limits are established for nitrate, nitrite, and hydroxide concentrations. Limits are identical to those formally imposed through OSDs.

  b) Waste chemistry is periodically monitored through waste sampling. Sampling frequencies are established for each DST, based on observed and predicted rates of caustic consumption, to determine nitrite, nitrate, and hydroxide concentrations and to verify that the measured concentrations are within established limits.

CH2MHILL Hanford Group, Inc.

Program Elements (cont.)

c) Maintain a database to track nitrite, nitrate, and hydroxide concentrations in each DST. The database is used to monitor compliance with the chemistry concentration limits and to determine patterns of caustic consumption.

d) The effect of waste transfers on nitrite, nitrate, and hydroxide concentrations in the sending and receiving tanks is evaluated to ensure the established concentration limits are maintained.

e) A recovery plan will be issued to ORP within 30 days of identifying that a DST is outside the established limits for waste chemistry.

CH2MHILL Hanford Group, Inc.

Program Implementation

- **Sampling and Analysis Schedules**
  - Tanks are sampled in accordance with field working schedules. The schedules are derived from the *'Technical Sampling Basis –Waste Information Requirements Document"* (TSB-WIRD), which is published annually.
  - Each TSB-WIRD identifies the tanks scheduled for sampling during the current year, with projections for the following and out-years.
  - Sampling schedules are based on current waste composition and projected trend for hydroxide depletion.
  - The technical basis for evaluating the waste chemistry trend is documented in *"Technical Basis for the Chemistry Control Program, "* RPP-7795.

CH2MHILL Hanford Group, Inc.

Program Implementation (cont.)

- **Data Analysis and Tracking**
  - Tank waste characterization data is maintained in the *"Tank Characterization Database"* within the *"Tank Waste Information Network System, "* (TWINS), and is updated whenever a new laboratory analysis report is received.
  - The Best Basis Inventory (BBI) uses data from the system to estimate tank inventories for selected analytes, and is updated quarterly.
  - A Caustic Limits Report (new)is generated from the BBI to compare nitrite, nitrate, and hydroxide concentrations with established limits.
  - The Caustic Limits Report is generated and reviewed quarterly for each DST. The Shift Manager is notified of any concentrations that is outside the limits.

CH2MHILL Hanford Group, Inc.

Program Implementation (cont.)

- **Transfer Analysis**
  - Prior to waste transfers, the final states of sending and receiving DSTs are evaluated for compliance with the waste chemistry limits through the *"Tank Farm Waste Compatibility Program. "*
  - Sample analysis may be requested by the evaluator, if desired for confidence in the calculations results.
  - Sample analyses for waste compatibility must be less than five years old.
  - Independent verification is required for waste compatibility analyses.

CH2MHILL Hanford Group, Inc.

Program Implementation (cont.)

- **Recovery Actions**
  - When a DST is identified to be out of spec.
    - The Shift Manager Shall be notified and an Occurrence Report generated.
    - A Recovery Plan shall be submitted to ORP within 30 days.
    - Activities to restore the chemistry spec. shall be completed in accordance with the Recovery Plan.

CH2MHILL Hanford Group, Inc.

So What's New?

- **Recognition of change of chemistry with time.**
- **Need to use assessment of rate of chemistry (caustic depletion) change to establish sampling schedules.**
- **The first assessment has just been completed with issue of RPP-7795, Rev. 0 *" Technical Basis for Chemistry Control Program."***
- **What was done? What did we find?**

CH2MHILL
Hanford Group, Inc.

Hydroxide Depletion

- **Free hydroxide known to be consumed by:**
  - Absorption of carbon dioxide from forced air ventilation of tanks
  - Oxidation of sodium salts of organic species
  - Reaction with hydrated aluminum oxide
- **Reactions as follows:**
  1) $OH^- + CO_2 \rightarrow HCO_3^-$
  2) $HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$
  3) $HOCH_2CO_2^- + NO_3^- + OH^- \rightarrow O_2CCO_2^{2-} + NO_2^- + H_2O$
  4) $Al(OH)_3 + OH^- \rightarrow Al(OH)_4^-$

CH2MHILL
Hanford Group, Inc.

Depletion Models

- **Theoretical models not available.**
- **Limited empirical modeling available.**
- **Three empirical models used for initial assessment.**
  - Hobbs (1987) developed a model for hydroxide depletion due to carbon dioxide absorption from waste tanks at SRS.
  - Carothers (2000) developed a model for hydroxide depletion in tank 241-AN-102 at the Hanford site.
  - Reynolds (1989) developed a model for hydroxide depletion in tank 241-AN-107 at the Hanford site.

CH2MHILL
Hanford Group, Inc.

Hobbs Model

- **Measured inlet and outlet carbon dioxide concentrations in the vent streams from a range of tanks at the Savannah River Site.**
- **Correlated fraction of CO_2 absorbed to pH of waste.**
- **Rate of CO2 absorption (moles/time) proportional to ventilation flow rate.**
- **2 moles OH^- react with each mole CO_2**
- **Rate of hydroxide depletion twice rate of CO2 absorption**
- **Change in hydroxide concentration related to waste volume.**

CH2MHILL
Hanford Group, Inc.

Features of Hobbs Model

- **Rate of hydroxide depletion**
  - Directly proportional to ventilation flow rate.
  - Directly proportional to log[OH⁻].
  - Inversely proportional to waste volume.
- **Limitations of model:**
  - May overestimate rate of CO_2 absorption, particularly at low waste volumes.
  - Does not account for other depletion mechanisms since it does not measure change in concentration in waste directly but infers it from changes in ventilation.

CH2MHILL
Hanford Group, Inc.

Carothers Model

- **Based on review of actual hydroxide sample data from Complexed Concentrate waste stored in 241-AN-102 over time.**
- **No reaction mechanism postulated.**
- **Accounts for depletion from all mechanisms; CO2 absorption, organic oxidation, hydrated aluminum oxide reactions.**
- **Data fitted to first order kinetic equation to give:**

$$[OH]_t = [OH]_i e^{-(0.0003t)}$$

  - Carothers Model
    - Limitations:
      - May only be applicable to tanks with very similar waste composition since no correlation made to concentrations of important species in waste.
      - Waste was at a high level in 241-AN-102 at time of study. May not account for increased change of concentration at low waste volumes.

CH2MHILL
Hanford Group, Inc.

Reynolds Model

- **Based on fit of actual sample data from Complexed Concentrate waste stored in 241-AN-107 to second order kinetic equation.**

  $1/[OH]_t = 1/[OH]_i + 4.43E\text{-}04t$

- **Limitations:**
  - Similar to Carothers. May only be applicable to similar CC wastes.
  - Also based on measurements at high tank level. May not account for increased depletion at low waste volume.

CH2MHILL
Hanford Group, Inc.

Findings of RPP-7795

- 16 tanks show in excess of 5 years to reach hydroxide limit by all model predictions.
- 4 tanks already known to be deficient prior to caustic addition – AY-101, AY-102, AN-102, AN-107.
- Two tanks predicted to be already hydroxide deficient based on worst case models - AN-106 (heel), AW-105.
- Five tanks identified to become deficient in 1-5 years - AP-102, AP-103, AP-108 (heel), AW-102 (heel), AZ-102.
- One tank mistakenly shown to be deficient based on false sample analysis – AW-104.
- Significant variability in results of models.

CH2MHILL
Hanford Group, Inc.

Cross-Over of Model Predictions

- The same model does not always predict the most rapid depletion.
- Hobbs very sensitive at lower tank volumes < 250 kgal.

CH2MHILL
Hanford Group, Inc.

What Next?

- **Need to revise RPP-7795, "*Technical Basis for Chemistry Control Program.*"**
- **Near Term (one month) Actions:**
  - Correct AW-104, and other minor inconsistencies.
  - Verify calculations for AN-106 and AW-105 and determine path forward – sample to confirm model, transfer waste, or add caustic.
- **Longer Term (End fiscal year) Actions:**
  - Determine path forward for other tanks predicted to be out of spec. within 5 years.
  - Try to improve model bases.
  - Review SHIMS data for CO_2 to confirm or not Hobbs data.
  - Review other tanks that have had stable waste conditions and multiple samples taken to develop other depletion correlations.

CH2MHILL Hanford Group, Inc.

What Next?

- Review hydroxide depletion data vs other waste components e.g. [Al], [TOC], waste volume.
- Review model applications vs waste type.
- Add recommendations of sample periodicity to RPP-7795 based on waste volume.

- **Other considerations:**
  - Consider depletion of other chemicals?
  - Recent sample data from AY-102 shows significant depletion of nitrite within sludge layer.

CH2MHILL Hanford Group, Inc.

Chemistry Limits

N. W. Kirch

May 1, 2001

Chemistry Limits

N. W. (Nick) Kirch
May 1, 2001

CH2MHILL Hanford Group, Inc.

Historic Chemistry Limits

- Chemical process plants used nitric acid for dissolution of nuclear fuel; plants required to adjust waste to pH > 10 prior to discharge to SSTs.
- Some wastes were stored at lower pH in SSTs
- Double-shell tanks were designed for a pH of 8-14.
- In the late 1970s, chemistry limits for corrosion control were established based on stress corrosion cracking investigations performed at Savannah River Laboratory.

CH2MHILL Hanford Group, Inc.

Synopsis of Savannah River Work

- It was found that the corrosion of low carbon steel, such as in Double-Shell Tanks, was dependent on hydroxide, nitrite and nitrate concentration
- Minor constituents, such as carbonate, phosphate, sulfate, silicate, fluoride or chloride, in low concentrations were found to have little effect on the corrosion potential.

CH2MHILL Hanford Group, Inc.

Pre-1984 Chemistry Limits (1of 3)

COMPOSITION SPECIFICATIONS FOR
241-AY, AZ, AN, AW, SY, AND A-350 TANKS

CAUSTIC PREDOMINANT SOLUTIONS ($OH^- > NO_3^-$)	
OH^-	1.0 M ≤ OH^- ≤ 8.0 M
NO_3^-	≥ 0.5 M
NO_2^-	≥ 0.5 M

CH2MHILL Hanford Group, Inc.

Pre-1984 Chemistry Limits (2 of 3)

NITRATE PREDOMINANT SOLUTIONS ($NO_3^- > OH^-$)	
For 3.0 M < NO_3^- < 5.5 M	
OH^-	$\geq$ 0.3 M
$OH^- + NO_2^-$	$\geq$ 1.2 M
NO_3^-	$\leq$ 5.5 M
For 1.0 M < NO_3^- < 3.0 M	
OH^-	$\geq$ 0.1 (NO_3^- Concentration)
$OH^- + NO_2^-$	$\geq$ 0.4 (NO_3^- Concentration)

CH2MHILL Hanford Group, Inc.

Pre-1984 Chemistry Limits (3 of 3)

DILUTE SOLUTIONS (OH^- < 1.0 M, NO_3^- < 1.0 M)	
OH^-	$\geq$ 0.01 M
NO_2^-	$\geq$ 0.011 M

CH2MHILL Hanford Group, Inc.

Issues with Pre-1984 Chemistry Limits

- In 1980, during preparation of Environmental Impact Statement for the 241-AW and 241-AN tank farm, it was identified that the available corrosion data did not adequately describe all wastes proposed for storage.
- Limits required chemical additions as waste was concentrated in 242-A evaporator
  - For example, a waste with 0.9M OH^- and 0.2M NO_2^- if concentrated to 1.2 M OH^- and .27 M NO_2^- required NO_2^- addition up to >0.5M.

CH2MHILL Hanford Group, Inc.

Response to Issues with Chemistry Specification

- An experimental data development task consisting of several thousand corrosion coupon tests was performed by Pacific Northwest National Laboratory in the early 1980s.
  - For temperatures within the normal operating range for double-shell tanks (at or below 100 °C), no corrosion rates above the design limits and no stress corrosion cracking were observed in compositions consistent with the waste chemistry specifications.
  - Corrosion outside the design limits was observed only very dilute OH^- and NO_2^- solutions, and in concentrated OH^- solutions at high temperatures.
  - Stress corrosion cracking was observed only on highly stressed U-bend coupons in solutions of high NO_3^- and low OH^- concentrations and in high OH^- concentrations at high temperatures.

CH2MHILL Hanford Group, Inc.

Chemistry Limits Implemented in 1984 (1of2)

NORMAL OPERATING TEMPERATURES ($T \leq 100°C$)	
For $NO_3^- \leq 1.0\ \underline{M}$	
OH^-	$0.01\ \underline{M} \leq OH^- \leq 5.0\ \underline{M}$
NO_2^-	$0.011\ \underline{M} \leq NO_2^- \leq 5.5\ \underline{M}$
(For solutions below 75°C, the OH^- limit is 8.0 $\underline{M}$)	
For $1.0\ \underline{M} < NO_3^- \leq 3.0\ \underline{M}$	
OH^-	0.1 (NO_3^- Concentration) $\leq OH^- < 10\ \underline{M}$
$OH^- + NO_2^-$	≥ 0.4 (NO_3^- Concentration)
For $NO_3^- > 3.0\ \underline{M}$	
OH^-	$0.3\ \underline{M} \leq OH^- < 10\ \underline{M}$
$OH^- + NO_2^-$	$\geq 1.2\ \underline{M}$
NO_3^-	$\leq 5.5\ \underline{M}$

CH2MHILL
Hanford Group, Inc.

Chemistry Limits Implemented in 1984 (2of2)

HIGH OPERATING TEMPERATURES ($T > 100°C$)
The normal operating temperatures apply with the exception that hydroxide concentration must be less than 4 $\underline{M}$.

CH2MHILL
Hanford Group, Inc.

Modification of Chemistry Limits since 1984

- Supplemental work in 1994, identified that even at low NO_3^- concentrations, some presence of NO_2^- was important for protection against stress-corrosion cracking.
- Chemistry limit was modified to include NO_3^- to $OH^- + NO_2^-$ ratio in dilute regions.

CH2MHILL
Hanford Group, Inc.

Current DST Waste Chemistry Limits

For [NO_3^-] Range	Variable	For Waste Temperature (T) Range		
		$T < 167\ °F$	$167\ °F \leq T \leq 212\ °F$	$T > 212\ °F$
[NO_3^-] $\leq 1.0\underline{M}$	[OH^-]	$0.010\underline{M} \leq [OH^-] \leq 8.0\underline{M}$	$0.010\underline{M} \leq [OH^-] \leq 5.0\underline{M}$	$0.010\underline{M} \leq [OH^-] < 4.0\underline{M}$
	[NO_2^-]	$0.011\underline{M} \leq [NO_2^-] \leq 5.5\underline{M}$	$0.011\underline{M} \leq [NO_2^-] \leq 5.5\underline{M}$	$0.011\underline{M} \leq [NO_2^-] \leq 5.5\underline{M}$
	[NO_3^-] / ([OH^-] + [NO_2^-])	< 2.5	< 2.5	< 2.5
$1.0\underline{M} <$ [NO_3^-] $\leq 3.0\underline{M}$	[OH^-]	$0.1([NO_3^-]) \leq [OH^-] < 10\underline{M}$	$0.1([NO_3^-]) \leq [OH^-] < 10\underline{M}$	$0.1([NO_3^-]) \leq [OH^-] < 4.0\underline{M}$
	[OH^-]+[NO_2^-]	$\geq 0.4([NO_3^-])$	$\geq 0.4([NO_3^-])$	$\geq 0.4([NO_3^-])$
[NO_3^-] $\geq 3.0\underline{M}$	[OH^-]	$0.3\underline{M} \leq [OH^-] < 10\underline{M}$	$0.3\underline{M} \leq [OH^-] < 10\underline{M}$	$0.3\underline{M} \leq [OH^-] < 4.0\underline{M}$
	[OH^-]+[NO_2^-]	$\geq 1.2\underline{M}$	$\geq 1.2\underline{M}$	$\geq 1.2\underline{M}$
	[NO_3^-]	$\leq 5.5\underline{M}$	$\leq 5.5\underline{M}$	$\leq 5.5\underline{M}$

CH2MHILL
Hanford Group, Inc.

Corrosion Program and Corrosion Control Limits for SRS High-Level Radioactive Waste Tanks

Philip E. Zapp

Savannah River Technology Center

May 3, 2001

Corrosion Program and Corrosion Control Limits for SRS High-Level Radioactive Waste Tanks

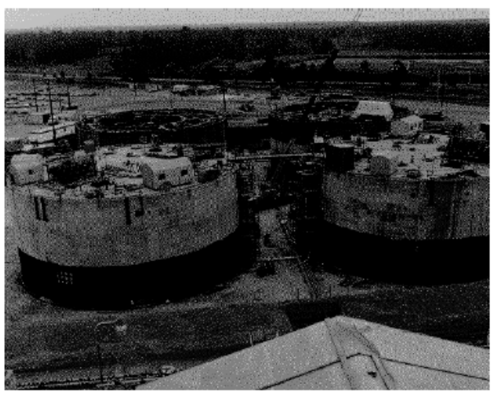
Philip E. Zapp
Savannah River Technology Center
Westinghouse Savannah River Company

Workshop on the Technical Basis for
Hanford DST Life Extension
May 3, 2001

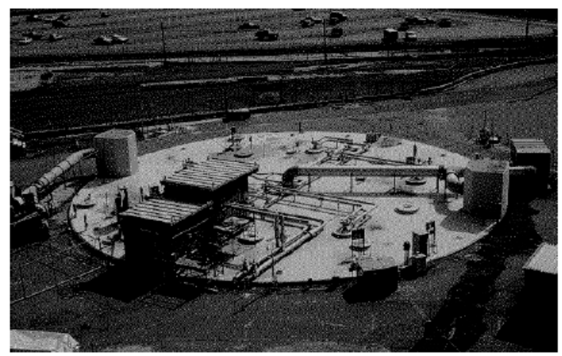
Outline

- Background
  - Tank Designs, Steels, Fabrication
  - Corrosion Experience
- Corrosion Testing Programs
  - Stress Corrosion Cracking: Minimum Inhibitor Levels
  - Pitting: Minimum Inhibitor Levels
  - Pitting: Pit Growth Study in Uninhibited Solutions
- Corrosion Control Limits
  - Technical Safety Requirements
  - Administrative Controls
  - Inhibitor Limits & Sampling Frequency

SRS Type III Tanks under Construction



SRS Type III Tank Top



Waste Tank Steels

ASTM A285 Grade B Carbon Steel

ASTM A516 Grade 70 Carbon Steel

Improved Resistance to Stress-Corrosion Cracking

ASTM A516 Grade 70 (Normalized) Carbon Steel

Heat Treatment for Mechanical (NDTT) Concerns

ASTM A537 Class 1 Carbon Steel

Cooling Coils: ASTM A53 and A106

Corrosion Observations

- Stress Corrosion Cracking

Tank Type	Secondary	Number of Tanks	Cracked Wall (Tank Number)	Stress Relieved?
I	5-Ft Pan	12	1, 6, 9, 10, 11, 12	No
II	5-Ft Pan	4	13, 14, 15, 16	No
III	Full Height	27	None	Yes
IV	None	8	20	No

- Pitting in Cooling Coils in Highly Dilute Waste, Types I and II
- Possible Pitting in Type IV Tanks from Rainwater
- No General Corrosion

Corrosion Testing Programs

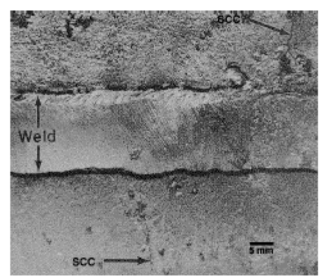
- Nitrate Stress Corrosion Cracking

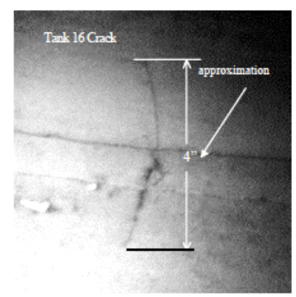
  Concern in Concentrated, Stored Wastes (Nitrate > 1 M)
  Cracks Associated with Weld Residual Stresses
  Tests of Crack Initiation and Propagation
  Electrochemical Tests for Confirmation of Simulant Use
  Minimum Nitrite and Hydroxide Concentrations

- Pitting Corrosion

  Concern in Dilute Wastes (Nitrate < 1 M) Prepared for Vitrification
  Electrochemical and Coupon Immersion Tests
  Actual and Simulated Waste
  Minimum Nitrite Inhibitor as Function of Nitrate, Chloride, Sulfate, and Temperature

SCC Research





Images of Cracking in Tank 16 Wall

SCC Research

- Slow Strain Rate Tests under Potential Control
  - 13% Elongation-to-Failure Criterion
  - Response Surface Polynomial in Nitrate, Nitrite, Hydroxide and Temperature
- Wedge-Opening Loaded Specimen Tests for Crack Propagation
  - Growth/No Growth Criterion
  - Generated Inhibitor Limits

Stress Corrosion Crack Growth

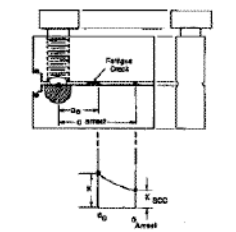


Figure 10. Modified WOL Specimen[20]

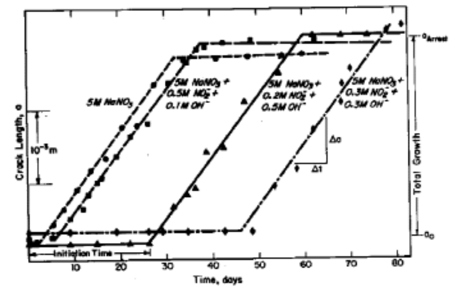


FIGURE 11. Crack Length as a Function of Time[19]

Source: J. A. Donovan, DP-1476

SCC Propagation Results

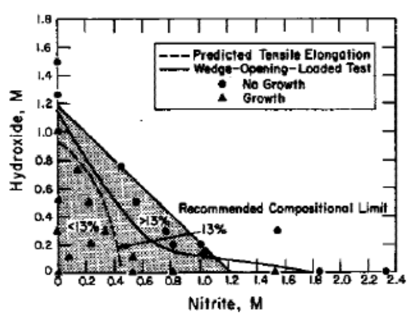


FIGURE 15. Comparison of Electrochemical Tensile Test With Wedge-Opening-Loaded Specimens in 5M $NaNO_3$ at 97°C

Source: J. A. Donovan, DP-1476; R. S. Ondrejcin, DP-1478

Pitting Research

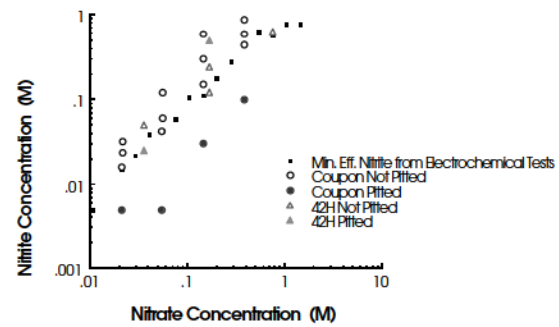
Pitting Tests

- Temperatures from 23 °C to 60 °C and Compositions Spanning Expected Range
- Cyclic Potentiodynamic Polarization Scans
  - ASTM Method G 61
  - Buffered pH, Fixed at Steady-State Value
  - Comparison of Forward Scan with Reverse Scan Current Density for Pitting Susceptibility
  - Microscopic Examination for Pitting Presence
- Coupon Immersion Tests
  - Partially Immersed for 120 days
  - Open Circuit Potential, Freely Decreasing pH
  - Air Flow over Test Solutions
  - Microscopic Examination for Pitting Presence, > 1 mil depth

Dilute Sludge Waste Composition

Anion	Concentration in Moles/Liter	
	Undiluted	Fully Diluted
Nitrate	1.4	0.021
Sulfate	0.095	0.0014
Chloride	0.022	0.00031
Fluoride	0.011	0.00016
Hydroxide	2.09	0.030
Nitrite	1.1	0.016
Steady State pH		9.5

Results of Coupon Immersion Tests at 40 °C in Simulated and Actual Washed Sludge Slurries



- Maximum Pit Depth in Pitted Coupons ~ 15 mils, in 4 Months, Near and Above Waterline in Partially Immersed Coupons

Empirical Fit of Minimum Effective Nitrite Concentration to Nitrate Concentration

$$[NO_2] = 0.025\,[NO_3^-]^{0.98}\,10^{0.041T}$$

T in °C
Concentrations in Moles per Liter

- Similar Relationships Developed for Nitrite Level Required to Prevent Chloride- and Sulfate-Induced Pitting

Pitting Kinetics Study

Pitting Kinetics Study Questions

- How fast will pits grow in an uninhibited waste?
- What is deepest expected pit in specified time?
- Can growing pits be arrested?

Pitting Kinetics Study Approach

Type 1 Extreme Value Distribution

- Double Exponential Form for Probability F(X)

$$F(x) = e^{-e^{-y}} \qquad y = \alpha\,(x - u)$$

where α and u are distribution parameters and y is termed the "reduced variate"

- $F(x)$ = Probability of Pit Deeper Than x
- "Return Period," T = $1/(1-F(x))$; Area for Deepest Pit, Expressed As Multiple of Experimentally Tested (Coupon) Area
- Return Period for 85-Ft-Diameter Tank = 1200

Pitting Kinetics Study- Typical Corrosion

6 in. by 2 in. ASTM A537 Coupons

Pitting Kinetics Study Conclusions

- Extrapolation based on type 1 extreme value statistics leads to 0.094 inch (2.4 mm) max. pit depth in 1.2 years (<20% wall thickness)
- “Non-protective” nitrite concentrations may be beneficial
- Arrest of growing pit by adding nitrite not demonstrated

SRS Waste Tank Corrosion Control Documents

- Liquid Radioactive Waste Handling Facilities Technical Safety Requirements (TSRs)
- Corrosion Control Program White Paper - implements administrative controls of TSRs

Administrative Control Limits: Inhibitors

SRTC
We Put Science to Work

Table 2.6.2-1
Minimum Corrosion-Inhibitor Concentration Limits

Applicability	Parameter	Minimum Needed	Units
L1. $5.5 < [NO_3^-] \le 8.5$ Molar	$[OH^-]$	0.6	Molar
	$[OH^-] + [NO_2^-]$	1.1	Molar
L2. $2.75 < [NO_3^-] \le 5.5$ Molar	$[OH^-]$	0.3	Molar
	$[OH^-] + [NO_2^-]$	1.1	Molar
L3. $1.0 \le [NO_3^-] \le 2.75$ Molar	$[OH^-]$	$0.1[NO_3^-]$	Molar
	$[OH^-] + [NO_2^-]$	$0.4[NO_3^-]$	Molar
L4. $0.02 < [NO_3^-] < 1.0$ Molar AND $[OH^-] < 1.0$ Molar			
L4a. – Either Inhibit with $[OH^-]$ OR Inhibit with $[NO_2^-]$	$[OH^-]$	1.0	Molar
L4b. For $[NO_3^-]$	$[NO_2^-]$	$0.038 \times [NO_3^-] \times 10^{1.64}$	Molar
L4c. For $[Cl^-]$	$[NO_2^-]$	$6.11 \times 10^{[1.64+1.38 \log[Cl^-]]}$	Molar
L4d. For $[SO_4^{=}]$	$[NO_2^-]$	$0.04 \times 10^{[1.64+0.84 \log[SO_4^{=}]]}$	Molar
	pH	10.3	pH Units
L5. $[NO_3^-] \le 0.02$ Molar AND $[OH^-] < 1.0$ Molar			
L5a. – Either Inhibit with $[OH^-]$ OR Inhibit with $[NO_2^-]$	$[OH^-]$	1.0	Molar
L5b. For $[NO_3^-]$	$[NO_2^-]$	$0.00076 \times 10^{1.64}$	Molar
L5c. For $[Cl^-]$	$[NO_2^-]$	$6.11 \times 10^{[1.64+1.38 \log[Cl^-]]}$	Molar
L5d. For $[SO_4^{=}]$	$[NO_2^-]$	$0.04 \times 10^{[1.64+0.84 \log[SO_4^{=}]]}$	Molar
	pH	10.3	pH Units
L6. Influents to waste tanks from other areas on site. *	pH	9.5	pH Units

Administrative Control Limits: Sampling

SRTC
We Put Science to Work

Table 2.6.2-2 Sample Frequency for Waste Tanks*

	Category	Frequency	Deadline for Analytical Results Incorporation in ERD
ACTIVE WASTE TANKS	Evaporator Feed Tanks and Drop Tanks	3 Months	First regularly scheduled ERD** after 90 days from sample date
	Receiver With Nitrate Concentration Less Than 1 Molar	3 Months	First regularly scheduled ERD** after 90 days from sample date
	Receiver With Nitrate Concentration Greater Than or Equal to 1 Molar	6 Months	First regularly scheduled ERD** after 90 days from sample date
	SLURRIED WASTE TANKS***	1 Month <u>AND</u> Within 1 month after slurry pumps/mixers are stopped	First regularly scheduled ERD** after 90 days from sample date
STATIC WASTE TANKS	Nitrate Concentration Less Than 1 Molar	3 Months	First regularly scheduled ERD** after 90 days from sample date
	Nitrate Concentration Greater Than 1 Molar and Hydroxide Concentration Less Than 3 Molar	1 Year	First regularly scheduled ERD** after 90 days from sample date
	Nitrate Concentration Greater Than 1 Molar and Hydroxide Concentration Greater Than 3 Molar	4 Years	First regularly scheduled ERD** after 90 days from sample date

Administrative Control Limits: Ventilation

SRTC
We Put Science to Work

- Annulus Ventilation
  - Heated Air
  - Maintain Minimum Primary Wall Temperature > NDTT
  - Prevent Significant General Corrosion of Primary
  - Limits on Time to Restore to Operation
    - Type I and II Tanks: 30 Days
    - Type III Tanks: 90 Days

Double-Shell Tank Support Systems:

Ventilation

D. H. Shuford

May 1, 2001

DOUBLE-SHELL TANK SUPPORT SYSTEMS: VENTILATION

D. H. Shuford

May 1, 2001

Primary Tank Ventilation

<u>Safety Functions:</u> Ventilate tank headspace to dilute and remove flammable gases continually released from stored waste; Heat removal (AY-102, AZ-101)

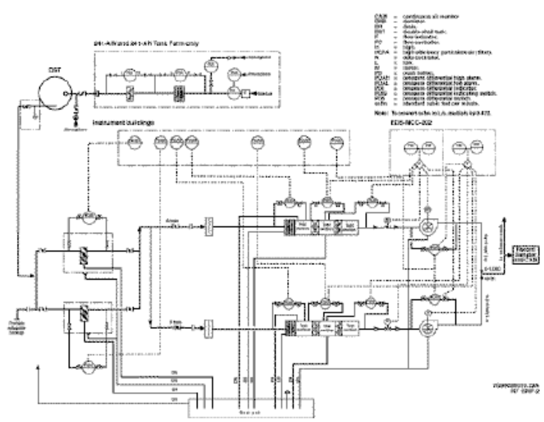
<u>Environmental Function:</u> Confinement; that is, maintain negative pressure in tank headspace to preclude unfiltered emission.

<u>Operational Function:</u> Remove heat by removal of water vapor from tank head space

<u>Exhaust Configuration:</u> *Typically* two parallel filtration trains and fans, each with demister, heater, prefilter and two testable HEPA filter stages in series. Only one train operates at a time, allowing for continued operation during maintenance activities.

2

Typical DST Primary Ventilation System



3

Primary Tank Ventilation Operation

- LCO 3.2.1 requires primary tank ventilation system be "OPERABLE"
- Operability confirmed by maintaining negative pressure in the tank head space
  - Immediate restoration required if not "OPERABLE"
- System flow rates vary from 50 to ~300 cfm per tank
  - AY/AZ tank flow rates vary from 100 to 600 cfm per tank, limited by total exhaust stack flow <1050 cfm
- System availability very good, no long term outages

4

Tank Annulus Ventilation

Safety Function: Primary tank leak detection by ventilation tank annulus space and monitoring each tanks' exhaust with a Continuous Air Monitor (CAM); Heat removal (AY-102)

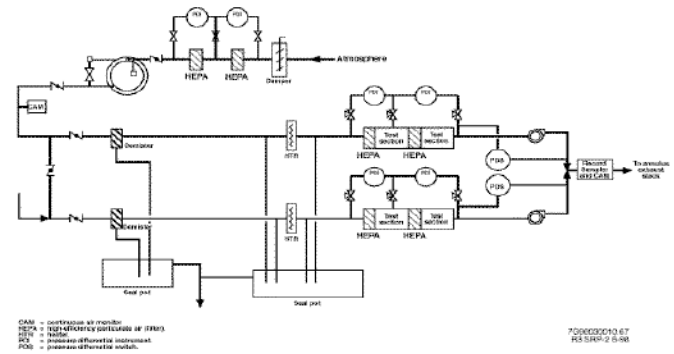
Environmental Function: Secondary containment leak detection via CAMs.

Operational Function: Heat and moisture removal.

Exhaust Configuration: *Typically* two parallel filtration trains and fans, each with demister, heater, prefilter and two testable HEPA filter stages in series.

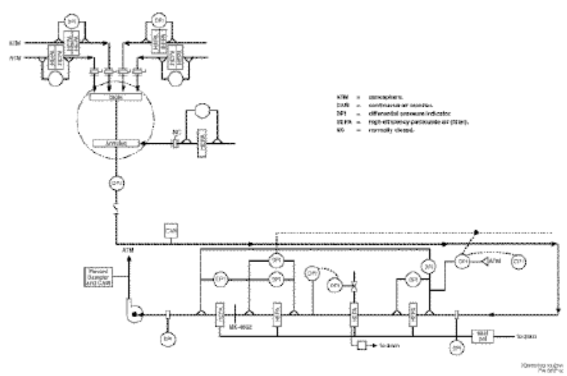
5

Typical Annulus Ventilation System (AN, AP, AW, Farms)



6

241-AY, AZ Annulus Ventilation System



7

Annulus Ventilation System Operation

- LCO 3.2.6 requires either the annulus leak detection system or the annulus continuous air monitor be "OPERABLE"
  - Extended operation with just the leak detection system not unusual
- LCO 3.3.3 requires that AY-102 annulus ventilation system be "OPERABLE"
  - Recent requirement from C-106 sluicing 2 years ago
- Annulus flow rates vary from 200 (SY) to 1075 (AP) cfm per tank
- System availability not as high as primary ventilation system
  - Lack of "Hard" driver for system operation
  - Extended system outages have been observed in AY and AZ tank farms

8

Annulus Ventilation System Role in Corrosion Control

- Thermal-hydraulic modeling and analysis performed
  - Assess probable cause of AY-101 Corrosion
  - Characterize moisture removal capabilities of the annulus ventilation systems in AY-101/102 and AZ-101/102
- Model results indicated natural breathing not sufficient to prevent widespread condensation on the tank walls and subsequent corrosion
- With forced ventilation moisture removal rates are significant (30 - 200 gallons per day at 1000 cfm)
- Even lower flowrates (100-200 cfm) are sufficient to mitigate water ingress like that assumed in AY-101

9

CH2MHILL

Planned Work

- Repair AZ-101/102 annulus ventilation system and return to service by 9/30/01.
- Develop technical basis for TSR-level control on annulus ventilation system operation.

10

CH2MHILL

Nitrate-Assisted Stress Corrosion Cracking

of Low-Strength Tank Steels

Mike Danielson, Monte Elmore, and Stan Pitman

Pacific Northwest National Laboratory

May 1–4, 2001

Nitrate-Assisted Stress Corrosion Cracking of Low Strength Tank Steels

Mike Danielson, Monte Elmore, and Stan Pitman
Pacific Northwest National Laboratory
PO Box 999
Richland, WA 99352

Role of SCC in DST Life Extension

- SCC is the fastest operating failure process
  - Considered most important potential degradation mode
  - Initial SRS tank failure was by SCC
  - Hanford single-shell tank leaks were probably caused by SCC

Resources Available to Evaluate Probability of SCC

- Experimental Studies
  - Ondrejcin studies (slow strain rate)
  - Donovan/Sarafian studies (fracture mechanics approach)
  - Divine, et.al (1985) (U-bend specimens)
  - Bunnell, Danielson, Lund (U-bend specimens, slow strain rate tests, sludge-washing conditions)

Resources Available to Evaluate Probability of SCC, continued

- Literature Reviews/Theoretical Studies
  - Beavers, Thompson, and Parkins
  - Anantatmula, Schwenk
  - Structural Integrity Panel (BNL-52527)
  - Many others…

Ondrejcin Data

- Study focused on defining variables controlling SCC
  - Used a statistically designed experiment. Temperature, nitrate, nitrite, and hydroxide independent variables
  - Slow strain rate test method (strain rate=1.3E-6/s) used to define safe/unsafe regimes from SCC
  - Threshold for SCC defined as less than 13% elongation before failure. Parametric equation developed relating independent variables to SCC
  - Limitations: 1)may not detect SCC at small rates, 2)no rate data that is applicable to real stressing state, 3) no determination of threshold stresses or stress intensities

Donovan Data

- Used CT specimens at high nitrate concentrations. Determined both rate and threshold stress intensities.
- Stage II cracking rate believed to be 1E-8 m/s (about 1 mm/month).
- K_{Iscc} as low as 14 ksi in $^{1/2}$
- Testing was limited -- no broad investigation of effects of environmental variables.
- Cracking may occur after long initiation times, and proceed at relatively high rates.

Sarafian Data

- 1975 PhD thesis expanding work of Donovan.
- Primary objective was to determine the influence of microstructure and heat treatment on SCC behavior of A516, gr. 70 Steels
- No exploration of the effect of chemistry on crack growth and K_{Iscc}
- Hot rolled steel most susceptible to stress corrosion crack growth, normalized most resistant.

Divine Data

- Evaluated corrosion and SCC over a broad range of waste tank chemistries
- U-bend specimens were used to evaluate susceptibility to SCC
- Cracking occurred only at low-temperature, low concentration and high-temperature, high concentration conditions.

Bunnell/Danielson/Lund Data

- Sludge-washing (dilute waste) conditions, including high-chloride solutions.
- Static (U-bend) and SSR tests were used.
- Nitrate 0.25-1M; Nitrite 0.01-.393 M, hydroxide 0.01-.389 M, Chloride to .5M.
- No crack growth was observed in 180-day tests at 93 C.

Summary of Experimental Studies

- Propensity for cracking is increased by higher nitrate concentrations, inhibited by nitrite, hydroxide concentrations.
- Primary effect of inhibitors is to increase initiation time for crack growth to occur.
- Threshold stress intensity is a function of temperature (lower threshold at lower temperatures).

Conclusions

- SCC failure is the most likely process for tank failure because crack growth can occur quickly, after long initiation times.
- The available experimental data are not adequate to support a life extension model.
  - Crack growth rates and K_{Iscc} not determined as a function of chemical environment.
  - The SCC process may be ongoing, at a low rate, even within Ondrejcin's recommended chemistry specifications.
  - The same conclusion is even more likely for tanks that are outside of the Ondrejcin chemical specification.

Recommendations

- Determine crack growth rates and K_{Iscc} using fracture mechanics based concepts as a function of chemistry and temperature, using prototypical tank steels and heat treatments.
- Create a life prediction model for SCC incorporating stresses, composition of tank steel and welds, waste composition, and temperature.

Hanford DST Life Extension Workshop

Logistics

Chuck Stewart

May 1, 2001

Hanford DST Life Extension Workshop LOGISTICS

CHUCK STEWART

PNNL

Overall Agenda

Tuesday, May 1
- 8:00 - 10:00 Introduction and Background
- 10:15 - 1:45 Tank Inspection Program
- 1:45 - 4:00 Chemistry Control Program

Wednesday, May 2
- 8:15 - 10:30 Chemistry Control Program (continued)
- 10:30 - 1:30 Corrosion Monitoring Program
- 1:30 - 4:30 Technical review chemistry control program

Thursday, May 3
- 8:15 - 10:00 Technical review of tank inspection program
- 10:15 - 12:00 Technical review of corrosion monitoring program
- 12:45 - 3:00 Brainstorm list of recommendations for DST life extension
- 3:15 - 5:00 Rank the list of recommendations

Friday, May 4
- 8:15 - 10:00 Select and prioritize specific recommendations
- 10:15 - 11:45 Develop outline, assignments & schedule for report
- 11:45 - 12:00 Closing remarks

Technical Basis for Hanford DST Life Extension

- **Purpose:** *Thorough assessment of the Hanford DST Integrity Program and tank data*
- **Deliverable:** *Prioritized list of recommendations on how DST life can be extended*
- **Scope:**
  - **Physical:** Primary tank liner
  - **Review:** Hanford DST Integrity Program and tank data
- **Desired Outcome:** *A credible, validated technical baseline for DST operation and control*

Technical Review Structure

- **Summarize the big picture:**
  - What we (panel) know
  - What we don't know that we'd like to know
- **Evaluate:**
  - Which parts of the program are adequate
  - Identify problems or issues with the program
  - Lessons learned from current program
- **Recommend:**
  - Changes or additions that should be made
  - New techniques, approaches, actions that should be evaluated

Summary Structure

- **Review:**
  - List recommendations developed in Technical Reviews
  - Brainstorm additional ideas for DST life extension
- **Evaluate:**
  - Develop ranking metrics (e.g. feasibility, effectiveness, cost)
  - Rank list of recommendations
- **Select:**
  - Prioritize the ranked recommendations: *immediate, intermediate, long-term*
  - Choose the short list of top recommendations in each class

LOGISTICS OUTLINE

- **Purpose, deliverable, scope**
- **Panel introductions**
- **Overall agenda**
- **Conduct of business**

Panel

Jack Lentsch	CHG, Project Manager
Chuck Stewart	PNNL, Moderator

Mo Anantatmula+	CHG
Herb Berman	ADI Technologies
Susan Borenstein	APTECH
Spence Bush+	Review & Synthesis Assoc.
Carl Czajkowski+	BNL
Jim Divine+	ChemMet
Monte Elmore+	PNNL
Ed Fredenburg	CHG
Burt Johnson+	PNNL
Mark Knight	CHG
Gar Norman	CHG
Stan Pitman	PNNL
Jerry Posakony+	PNNL
Dan Reynolds+	CHG
Dave Shuford	CHG
Bob Sindelar	SRS
Phil Zapp+	SRS

Conduct of Business

- **Stay relaxed, work hard, have fun**
- **Please turn cell phones, pagers off**
- **Coffee and morning bagels supplied** (donations welcome)
- **Lunch options:**
  - Bring a brown-bag (refrigerator available)
  - Vending machines
  - Order lunch from menu, we need cash with order

Conduct of Business (continued)

- **Presentations:**
  - Hardcopy will be available after presentation
  - Questions for clarification during talk, hold discussion to end
  - Discussion may be politely truncated if it strays too far from the focus of the workshop
  - "Parking lot" sheet will capture issues for later resolution
- **Review and concluding discussions**
  - Hopefully open and self-moderated, but gently guided if needed
  - "Parking lot" applies here too

Appendix D

Questions For Technical Reviews

Appendix D
Questions for Technical Reviews

D.1 Technical review: Chemistry control program, data, and limits

1. What are the best ways to protect the tanks from the non-uniform corrosion (pitting, waterline, crevice, and SCC) in the different DST regions of consideration (e.g., sludge, supernatant, liquid, and dome space condensate, and outside wall surfaces in the annulus)?

   A. What are best ways to protect the inner shell from non-uniform corrosion?
   - Perform analyses to insure inhibiter added to supernate mixes into supernate and the nonconvective layer. Develop new ways or places to add caustic.
   - Consider volatile treatment (ammonia)
   - Reduce the uncertainty in waste chemistry data relating to corrosion (see below).
   - Sample waste more often instead of depending on models.
   - Develop lay up procedure for tanks left with a heel for extended period.
   - Prevent or limit addition of large volumes (inches) of raw water or condensate to supernate (local dilution = waterline corrosion).
   - Consider varying waste level to limit waterline corrosion. Alternatively, consider washing the wall with waste.
   - Increase management priority to stay within limits
   - Review history of out-of-spec conditions (i.e. table of tank, condition, duration)
   - Add chemistry conditions to waste compatibility criteria

   B. What are best ways to protect walls exposed to annulus from non-uniform corrosion?
   - Keep ventilation running
   - Assure relative humidity is sufficiently low via heating or dehumidification (and define "sufficient", both initial max<30% and hysteresis)
   - Monitor humidity in annulus exhaust.
   - Blank off unnecessary water sources.
   - Protect against rain/snowmelt (sloping, draining, etc.)
   - Paint or coat the annulus surfaces

2. Are there any immediate changes to be made to the DST corrosion monitoring and control programs, based on the new corrosion findings? (covered under ?)
   - Chemistry limits need to be applied to each layer, not average (BBI). Requires data from each layer and tests that apply to each layer.

3. Could introduction of tank liquid additives or some other approach such as sacrificial anodes or impressed current, extend the tanks useable life?
   - NO sacrificial anodes. Cannot guarantee protection, especially in sludge. Would only work if high current applied and covered all surfaces. Mill scale, rocks, etc. probably shielded from protection. May be a hazard to concrete rebar if not in good

contact. May reduce margin of protection of chemistry controls. Not used at SRS either.

- Cathodic protection on piping may be a threat to tank.
- Re-evaluate potential for cathodic protection (consider SRS document)
- Ammonia (100 ppm may do it) discussed under ?
- Nitrite in addition to OH discussed under ?

4. Most caustic additions depend on "natural mixing" within the tanks, does the panel consider this to be adequate or rapid enough to reach equilibrium in a reasonable time? (see #1 document due out soon)

5. In the longer term would mechanical mixing and/or periodic level changes have enough benefit to warrant the cost? (see #1)
   - Well mixed tank much easier to sample and interpret than stratified
   - Well mixed tank not susceptible to dilute surface (e.g. condensate return, concentration cell)
   - Cost of mixing is very high.
   - Level variation requires careful records and planning

6. Are current models adequate to characterize and control tank chemistry? Are there any other technical applications or tank chemistry modeling efforts that should be done to support the DST Life Extension effort? Is it worth the effort to improve depletion models:
   - More frequent sampling instead of depletion models
   - But use existing data to do an initial tweak on the models while new data is being accumulated.

7. Are present chemistry limits adequate for present and projected future tank usage, or do they require re-evaluation?
   How can present chemistry limits be assured adequate for present and future tank usage?
   - Re-create corrosion test recipes and measure pH, corrosion potential for better comparison with tank data.
   - Compare UT results and visual exams to chemistry limits – if no corrosion on tanks in-spec, limits OK. (2 tanks visual, 11 UT) – AN105 thinning, AP108 indication
   - NDE not in compliance with TSIP – not looking for construction-induced flaws, among other things. Don't have a baseline on original flaws or plate thickness, weld penetration.
   - Reassess sum total of extant corrosion test data.
   - Increase the margin between waste chemistry and caustic limits.
   - Assess whether alternate form of limits (i.e. nitrite + OH). Benchmark SRS chemistry controls & implementation.
   - Limits need to be applied to each layer

8. Are any of the Lessons Learned from SRS applicable to Hanford? Are there Hanford Lessons Learned that have not been incorporated?

- SRS uses much higher inhibiter concentration for conservative protection.
- Sampling effort did not consider corrosion

9. Does this Panel recommend a series of tests or measurements to resolve uncertainty in the DST Life Extension Program? If so, what specific test or measurements should be performed? (see #7)
   - Consider additional SCC testing defined via DQO-like process based on needs and tank conditions. (stress level, strain rate, simulant, test matrix, test type, materials, duration, etc.)
   - Perform slow strain rate coupon testing to determine vulnerability to initiation to SCC with Hanford alloys and chemistry ranges.
   - Tests should address potential heel chemistry & conditions.
   - Consider absence of tank leaks as long-term SCC test data.
   - Repeat prior tests with chemical analysis, better simulants, sludge, vapor phase, etc. to broaden operating range.
   - Simulants should consider retrieval of old SSTs (e.g. tributyl phosphate, bismuth phosphate waste)
   - Perform pitting initiation and inhibition tests (start aggressive, transition to inhibited, see if rate slows).
   - Perform statistically based cost/benefit assessment of additional SCC testing

10. Data quality has been a topic of concern from oversight groups. What would the panel recommend to better quantify the data usefulness, and accuracy in representing the tank contents?
    How can the uncertainty of waste chemistry data relating to corrosion be reduced?
    - Describe the uncertainty in data due to nonuniformity of waste, both supernate and nonconvective.
    - More frequent multiple samples
    - Recognize analytical uncertainties, incorporate into sampling strategy.
    - Develop a corrosion DQO for both grab and core samples and apply it consistently. This covers future data. Include interstitial liquid, sludge.
    - Review DST characterization data base to determine best estimate of composition relating to corrosion & document results. Identify tanks that need to be re-sampled to get adequate data.
    - Determine the potential for stratification or other non-homogeneity that might exacerbate corrosion.
    - Consider relation of bulk sample to material seen by the wall.

D.2 Technical review: Tank inspection program, NDE methods, and data

1. Does the accuracy and resolution of the UT process allow early detection of corrosion mechanisms of concern (i.e., SCC, pitting, waterline corrosion)? Have we seen any indications of cracking or SCC?
   - It depends: size of flaw big enough, operators & equipment qualified & calibrated, look in the right place at the right time.

   Should NDE program consider pre-existing flaws?:
   - Current UT procedure does not detect most pre-existing weld flaws (does not follow TSIP recommendation to look at weld flaws)
   - Use probabilistic analysis for structural analysis to decide if additional inspection is needed.

2. Is a Visual and NDE survey performed every 10 years (as presently scheduled) adequate to ensure DST conditions remain satisfactory? Given the recent inspection results, is it satisfactory to wait until 2005 (per the present program plan) to complete the Visual and NDE technical baseline?
   - Reduce NDE period to 5 years maximum for waterline to assure (demonstrate) adequate monitoring
   - Increase frequency of annulus video and number of risers
   - Increase frequency of headspace video
   - Complete visual baseline of annulus and internal in one year.
   - Set priority, frequency and area of NDE based on visual results.
   - Expedite NDE vulnerable tanks (i.e. have been out of spec)
   - Schedule exam when tank is pumped down, do exam whenever camera is in the tank for another purpose.
   - Re-evaluate current schedule for establishing a benchmark.

3. Is an effort to develop equipment and techniques to inspect the crevice formed between the tank wall and the cement ring worthwhile? Are there already existing techniques and equipment available to do this?
   - NO

4. Does the panel consider the "wagon track" pitting corrosion of the weld HAZ, note on the exterior of AY-101, to be an additional concern on the interior tank surfaces? How would this pitting corrosion be best measured and evaluated?
   - If pits on inside are big enough & deep enough, UT will detect them.
   - Resolved in #1

5. Cracking or SCC in the tank knuckle region has been postulated, is this a realistic concern? Are the stresses there above the SCC initiation threshold in the knuckle region, and how would we measure or evaluate SCC in this difficult to reach region?

- If SCC in knuckle, it is still in initiation period because no leaks yet. However, very small leak might have occurred and gone undetected. Leaks not detected if annulus vent off.
- If leak is so small as to be undetected, probably not a serious problem
- Area has not been inspected yet. Arm will extend UT into slot. TSAFT is expected to be able to see everything.

6. Does this Panel recommend a series of tests or measurements to resolve uncertainty in the DST Life Extension Program? If so, what specific tests or measurements should be performed?
   - Resolve cause AN105 thinning and ECN indication in NCL.
   - Check construction materials for change at corrosion area.
   - Develop administrative control to avoid area approximately 100-150 inches with minimum wall thickness margin.
   - Re-do stress analysis and take UT horizontally in 100-150 inch band before applying administrative control.

7. What is the selection logic to use for prioritizing tank schedules for enhanced DST monitoring and inspections that will support extending the design life of the tanks (e.g., more frequent Visual and UT inspection, etc.)?

8. Are current inspection tools adequate or are better tools or applications available to resolve specific issues for the different tank regions and different corrosion mechanisms?
   - Current tools cannot measure pitting & cannot access areas away from 24 inch risers.
   - Clean the wall to measure pits, this may be very difficult (Phil Zapp experience). Do each pit individually.
   - Evaluate use of EC for characterizing pits on outside of primary liner
   - Reaching device in the works to get between risers
   - Consider SRS small inspection devices

9. Data quality has been a topic of concern from oversight groups. What would the panel recommend to better quantify the tank inspection and NDE data usefulness, and accuracy in representing the tank condition?
   - Incorporate NDT sensitivity tests in lab corrosion tests
   - Develop a DQO for NDE.

D.3 Technical review: Corrosion monitoring program, methods, and data

1. Should the EN monitoring electrodes contain a weld region like those in the tank wall, in order to detect weld HAZ pitting corrosion?
   - Yes if practicable, with ECN lab testing.

2. Should the EN monitoring electrodes be positioned to bridge the waterline air interface in order to detect the waterline corrosion?
   - Yes if practicable (floating probe?)

3. What is the selection logic to use for prioritizing tank schedules for enhanced DST monitoring and inspections that will support extending the design life of the tanks (e.g., more frequent chemistry sampling, visual and UT inspection, etc.)?
   - Staging tanks receiving waste from SSTs or cross-site to East Area
   - Consider a probe that can be adjusted up and down or moved from tank to tank.
   - Monitor SRS progress with Raman/ECN probe.

4. Is ECN probe ready for deployment? What conditions must be met before it is ready?
   - ECN can be used as a warning indicator to take a grab sample, do visual or NDE. Not intended as a stand-alone method.
   - ECN has potentially quickest response to adverse chemistry.
   - Potential to reduce sampling frequency after some operating experience.
   - Data volume and interpretation needs improved.
   - Gasket design needs finalized

5. What is the Panel's assessment of the potential corrosion severity of crevice corrosion in the wetted tank to cement ring region of AY-101 (i.e., was this region wetted)? Should other tanks be of concern for this crevice corrosion mechanism?

6. What is the Panel's assessment for the need and methodology for monitoring SCC in the tank knuckle regions?

7. Another corrosion mechanism apparently not yet evaluated is Stray Current Corrosion. Does the panel consider this mechanism to be viable enough to warrant further evaluation (i.e., equipment grounding paths, etc.)?
   - Grounding of welding machines might create a problem, but not likely unless current path is through the waste. Evidence would be hard to find.
   - Evaluate procedures on use of power equipment, especially mixer pump, on and around tanks

8. Does the panel consider there to be corrosion concerns to be evaluated or measured at the other interface regions in the tank (i.e., sludge/tank, sludge/sludge+liquid, and sludge+liquid/liquid interfaces)?
   - No bands of thinning or pitting corresponding to NCL top in 12 tanks inspected

9. Does this Panel recommend a series of tests or measurements to resolve uncertainty in the DST Life Extension Program? If so, what specific test or measurements should be performed?
   - Additional ECN lab testing in correct simulant range would be beneficial.
   - How long is ECN probe an effective detector of pitting, cracking?

10. Are there any other technological applications that should be used to support the DST Life Extension Program? If so, what specific test or measurements should be performed?
    - Linear polarization resistance (LPR) not effective in DST waste
    - Consider use of electrical resistance probes in lieu of LPR.
    - Electrical resistance probes would be useful in addition to ECN probe.
    - Consider installing atmospheric corrosion probes in annulus (excess humidity indicator)

11. Considering that a pH test presently costs about $120 K per measurement, is there a less expensive or better way to monitor pH in the tanks?
    - Mike Danielson (PNNL) LaF_3 probe cost $50, last 2-3 weeks.
    - Benchmark SRS lab analysis for pH.

D.4 Technical review: General issues to consider/review

1. What is the feasibility of weld repair patches, or other repair methods, in the annulus region, to add wall thickness in regions of deep interior pitting?
   - No technical reason that penetrations could not be patch welded in annulus. Access and remote operation would be the main obstacle.
   - NDE of weld would be necessary.
   - Bottom or lower knuckle difficult.
   - Develop contingency plan for welding, write a spec, investigate suppliers. Also investigate mechanical plugs, coatings.
   - Consider cost/benefit compared to new tank.

2. If new HLW storage tanks were to be constructed, how should they differ in design from the present DST construction or configuration? Could any of these new design features be added to the existing tanks?
   - More reliable & redundant ventilation systems, plus apply to existing tanks.
   - Thicker walls, larger radius on knuckle.
   - 316L Stainless
   - Improved accessibility for NDE. To the point of tracks, etc. for devices to ride on.
   - Increase accessibility to tank bottom
   - Coat annulus surface

3. The original tank design had dehumidified and heated air circulation in the annulus region. Is the present configuration with use of outside air, without dehumidification or heating, satisfactory for long-term use?
   - NO, need dehumidifier or heater or ? to keep relative humidity below 30% when needed as indicated by humidity monitoring.
   - Monte Elmore to supply report on 30% humidity requirement.
   - Install baffle or change orientation of annulus intake to prevent precip from entering.

4. The interior primary tank air circulation in some tanks is recirculated and is a once through system in others. What is the best configuration? How is observation of corrosion in the dome region of re-circulated air tanks explained?
   - Evaluate as more inspections are done.
   - Recirc or other humidity control system may be needed on low temperature tanks.

5. Does this Panel recommend any additional modifications or actions that would provide benefit to the DST Life Extension Program? If so, what specific changes should be evaluated for application, or what operational changes should be initiated?
   - Develop gas tracer (He, Freon, etc.) or dye leak test for evaluating suspected leakers
   - Determine cause of leaks in SSTs in those feasible to inspect (if any). Attributing all failure to SCC does not have a sound technical base.
   - Consider tank visual inspection as part of SST retrieval.

6. Are the bands of corrosion covering the weld regions (seen in the annulus photographs) the result of inadequate post-weld stress relief at the original construction or explainable by other means? Does this have any implications for SCC in these regions?
   - Check drawings for weld details and methods of RT.
   - Review construction heat treat and QC records.

Appendix E

Description Of Workshop Recommendations

Appendix E
Description of Recommendations

The specific recommendations developed from the review of the Hanford DST Integrity Program were developed in response to a perceived need or deficiency (see Appendix D). The context and rationale behind each of the 73 recommendations is given below. The final SRC priority given to each one is also indicated. The recommendations fall into three groups: the 23 ranking highest in the evaluation (Section E.1), the 26 (#24–#49) other recommendations that were ranked (Section E.2), and the 24 (#50–#73) that were not ranked (Section E.3).

E.1 The Top 23 Recommendations

They are listed here in their rank order, although the position is not the final determination.

1. **Sample waste more often.** Sampling to evaluate chemistry corrosion limits should be done more often to detect tanks going out of limits as soon as practicable. More frequent sampling is intended to replace caustic depletion models. An interim update of depletion models is also recommended in #55 (see also #7, 11, 27, 37, 59, 60, 61, 62, 63, 68). [Assigned VERY HIGH PRIORITY by SRC.]
2. **Expedite NDE on vulnerable tanks.** Thanks whose waste chemistry is known to have been out of specification are more likely to have had significant corrosion and should be inspected first. This should be an element of the DQO in #10. This recommendation is also one of several calling for more frequent inspections and expediting the initial baseline (see also #3, 4, 5, 6, 10, 26, 32, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]
3. **Perform NDE on waterline every 5 years.** The current plan is to perform NDE every 10 years after an aggressive effort to inspect all tanks as soon as possible to establish a baseline. The water line (region just above and below the waste level) is deemed more vulnerable to corrosion and should be inspected more frequently. Current procedures inspect a vertical strip that covers all historic waterlines. This recommendation is one of several calling for more frequent inspections and expediting the initial baseline (see also #2, 4, 5, 6, 10, 26, 32, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]
4. **Set priority, frequency and area of NDE based on visual results.** If significant corrosion is discovered in the video inspection, the tank should have priority for the next NDE inspection. The inspection should be planned to concentrate on the areas of corrosion. This recommendation is one of several calling for more frequent inspections and expediting the initial baseline (see also #2, 3, 5, 6, 10, 26, 32, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]
5. **Increase frequency of annulus video and number of risers.** Annulus video is an early detector of significant corrosion and should be performed often. Recommend also planning to complete baseline in one year. This recommendation is one of several calling for more frequent inspections and expediting the initial baseline (see also #2, 3, 4, 6, 10, 26, 32, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]

6. **Increase frequency of headspace video.** The current schedule calls for video inspection of annulus and headspace very 10 years. Because significant corrosion can occur in a year, a much more frequent inspection is recommended. This recommendation is one of several calling for more frequent inspections and expediting the initial baseline (see also #2, 3, 4, 5, 10, 26, 32, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]
7. **Perform analyses to insure inhibiter mixes into waste.** Caustic solution is typically added to the supernate when tank chemistry needs to be corrected. However, the density of the solution is higher and initially forms a stratified layer beneath the supernate. Mixing into the nonconvective layer is by diffusion and porous media flow which may be very slow. Analyses will focus on the time required for mixing. New methods or locations to add caustic that provide faster mixing also need to be investigated (see also #1, 11, 27, 37, 59, 60, 61, 62, 63, 68). [Assigned VERY HIGH PRIORITY by SRC.]
8. **Prevent or limit addition of raw water or condensate.** The density of water is significantly lower than that of the supernate. Though it eventually mixes with the supernate, it forms a dilute layer at the waterline for some time that can initiate or exacerbate waterline corrosion. [Assigned HIGH PRIORITY by SRC.]
9. **Develop layup procedure for tanks left with a heel.** In tanks with, say, 50 kgal of waste or less, the surface-to-volume ratio causes a relatively rapid depletion of caustic by reaction with carbon dioxide in the air. A layup procedure would specify frequent inspection and initial addition of extra inhibitor to prevent potentially rapid corrosion. [Assigned HIGH PRIORITY by SRC.]
10. **Develop a DQO for NDE.** The current NDE strategy uses a combination of remote video inspection and UT measurement to detect corrosion and measure its effects. The areas measured and how the measurements are conducted are somewhat limited by the tank geometry and technology. The data quality objective (DQO) process identifies the kinds of measurements and inspections, the locations, frequency and accuracies required to solve the problem at hand independent of the technology. The results of a DQO will define technology requirements and provide a firm technical basis for other aspects of the tank inspection program (see also #2, 3, 4, 5, 6, 26, 32, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]
11. **Demonstrate low-cost pH probe.** Information on a low-cost, disposable LaF_3 probe to monitor or measure pH was provided to the workshop. This would greatly reduce the cost and increase the availability of pH measurements and would make maintaining the chemistry controls much easier (see also #1, 7, 27, 37, 59, 60, 61, 62, 63, 68). [Assigned NOMINAL PRIORITY by SRC.]
12. **Develop contingency plan for tank repair.** If a tank fails by corrosion, it probably costs much less to repair it than build a new tank. Commercial remote welding technology is available. Planning would consist of writing a specification and procedures, investigate and qualify suppliers, and possibly modifying the AB. Use of mechanical plugs and coatings should also be considered. [Assigned HIGH PRIORITY by SRC.]
13. **Prevent waste levels of 100-150 inches.** See # 32. This elevation range has the minimum structural wall thickness margin. Waterline corrosion in this area would be more detrimental than elsewhere. An administrative control is recommended that keep the waste level higher or lower. However, because such a restriction on the waste level has severe impacts on tank space, operations and costs, a probabilistic

structural analysis and horizontal UT inspection of the area should be performed to confirm that the limit is needed. [Assigned HIGH PRIORITY by SRC.]

14. **Control humidity in the annulus.** Studies have shown that the relative humidity must be kept below 30% to prevent corrosion. Therefore, the humidity in the DST annuli should be kept below that level and relative humidity monitored to ensure it. Heating or dehumidification systems should be installed if necessary (see #17, 18, 23, 25, 35, 49, 53). [Assigned HIGH PRIORITY by SRC.]
15. **Add chemistry conditions to waste compatibility criteria.** The current waste compatibility criteria and the waste compatibility DQO do not include any conditions or data requirements related to corrosion. This potentially allows dilute waste or even raw water to be transferred into tanks, driving them outside the chemistry corrosion limits. Analysis of waste samples collected prior to transfers also needs to include measurement of pH and nitrite, nitrate and hydroxide concentrations. Corrosion protection needs to be made as important as flammable gas retention and criticality in the waste compatibility criteria and DQO. (see #71) [Assigned HIGH PRIORITY by SRC.]
16. **Increase the margin between waste chemistry and caustic limits.** At SRS the pH is typically kept much higher than the chemistry limits require. This provides extra margin for caustic depletion, inadvertent dilution, or in case the chemistry limits prove to be inadequate in specific ranges. However, the additional caustic is not desirable because of cost, tank space limitations, eventual waste vitrification, and flammable gas retention, and the total cost/benefit ratio must be carefully considered. (see #72) [Assigned HIGH PRIORITY by SRC.]
17. **Protect against rain/snowmelt invading annulus.** In some DST farms the grading is such that runoff from rain and snowmelt collect over the tanks and might percolate through the soil and invade the annulus. Re-grading or diversion should be done to prevent this (see #14, 18, 23, 25, 35, 49, 53). [Assigned HIGH PRIORITY by SRC.]
18. **Blank off unnecessary water sources.** Service water systems may develop leaks or valves may be inadvertently mispositioned such that water invades the DST annuli. Water sources should be blanked off outside the tank farms when not in use to prevent this. Water invasion along with inoperative ventilation has been determined as the cause of significant corrosion observed in AY-101. (see #14, 17, 23, 25, 35, 49, 53). [Assigned HIGH PRIORITY by SRC.]
19. **Develop gas tracer leak test.** Where significant corrosion has occurred it can be difficult to determine whether the primary liner has actually been penetrated. A gas tracer (He, Freon, SF_6, etc.), dye or smoke test would provide a quick indication and possibly a quantification of the presence of a leak. [Assigned HIGH PRIORITY by SRC.]
20. **Re-evaluate sum total of extant corrosion test data.** Additional corrosion test data have become available since the work of Divine et al. (1985), which forms the basis of the current chemistry limits. All available data need to be evaluated and incorporated into the database supporting the chemistry limits as appropriate (see # 22, 24, 29, 30, 31, 58). [Assigned HIGH PRIORITY by SRC.]
21. **Vary waste level to limit waterline corrosion.** The effect of waterline corrosion can be minimized by varying the waste level so corrosion is spread over a larger area. However, varying the waste level requires installation of transfer systems in many tanks and the severely limited DST space makes such a strategy very difficult to apply. Therefore, the potentially beneficial effects of this action must be carefully considered against the costs. [Assigned HIGH PRIORITY by SRC.]

22. **Perform pitting initiation and inhibition tests.** Pitting is assumed to self-propagate once initiated. SRS tests show pit growth may slow after inhibitor is applied but does not stop. Additional tests need to be performed to determine if and how pitting can be inhibited once initiated (see #20, 24, 29, 30, 31, 58). [Assigned HIGH PRIORITY by SRC.]
23. **Prevent precipitation from entering annulus ventilation intake.** Baffles can be installed or the orientation of the inlet duct adjusted to prevent the intake from ingesting rain or snow (see #14, 17, 18, 25, 35, 49, 53). [Assigned HIGH PRIORITY by SRC.]

E.2 Balance of Ranked Recommendations

Many of the following recommendations were also brought forward or grouped with those above in the final set.

24. **Re-create corrosion test recipes and measure chemistry.** The composition of the solutions used in the corrosion tests of Divine et al. (1985) was determined from the recipe used to prepare them. No chemical analysis was performed to measure pH or composition. This seriously compromises the technical basis for the chemistry corrosion limits and comparison with tank sample data. A representative sampling of the simulant solutions should be prepared and subjected to chemical analysis and measurement of electrochemical potential (see #20, 22, 29, 30, 31, 58). [Assigned HIGH PRIORITY by SRC.]
25. **Monitor humidity in annulus exhaust.** The relative humidity in the DST annuli needs to be monitored to prevent corrosion. Humidity monitoring could also sense water intrusion (see #14, 17, 18, 23, 35, 49, 53). [Assigned HIGH PRIORITY by SRC.]
26. **Accelerate current schedule for establishing a UT benchmark.** The tank wall thickness was not measured as built, so there is no well-established baseline from which to determine the amount of historic corrosion from UT measurements. However, the current wall thickness is being established so that future corrosion can be quantified. The faster the baseline can be established, the quicker actual corrosion rates can be calculated and lifetime predictions made. This recommendation is one of several calling for more frequent inspections and expediting the initial baseline (see also #2, 3, 4, 5, 6, 10, 32, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]
27. **Determine relation of bulk sample to material seen by the wall.** Waste samples are taken from the bulk waste at various elevations but far from the wall. However, corrosion of the primary liner by definition occurs at the wall and is determined by waste composition near the wall. Because annulus ventilation and radiation to the secondary liner are important heat dissipation paths, the wall is cooler than the bulk waste and thus has at least a slightly different liquid composition. Solution chemistry should be considered as a function of temperature to estimate the relationship of pH at the wall to that in the bulk waste to ensure that chemistry corrosion limits are effective (see also #1, 7, 11, 37, 59, 60, 61, 62, 63, 68). [Assigned VERY HIGH PRIORITY by SRC.]
28. **Develop procedures on use of power equipment in tanks.** The stray electric currents produced by electric motors or welding may initiate or accelerate corrosion if they pass from the waste to the wall. The potential for electrically induced corrosion

needs to be evaluated and procedures developed for installing and operating power equipment (especially mixer pumps or welding) to avoid it. [Assigned HIGH PRIORITY by SRC.]

29. **Plan additional SCC testing defined via DQO-like process.** The existing data contain too few occurrences of stress corrosion cracking (SCC) to be incorporated into the chemistry limits. The duration of the initiation period is highly uncertain and makes stressed coupon testing difficult. Low strain rate tests bypass the initiation period but only indicate SCC rather than quantify its rate. An SCC test program should be evaluated based on needs and tank conditions including actual stress level, current and expected tank chemistry and temperatures, tank materials, and other factors so that useful data can be made available in a reasonable amount of time (see #20, 22, 24, 30, 31, 58). [Assigned HIGH PRIORITY by SRC.]
30. **Perform slow strain rate coupon testing of SCC.** This type of test avoids the uncertainty of SCC initiation and detects conditions where materials are vulnerable to SCC (see #20, 22, 24, 29, 31, 58). [Assigned HIGH PRIORITY by SRC.]
31. **Repeat prior corrosion tests with chemical analysis.** The conditions simulated in the coupon tests of Divine et al. (1985) do not cover the expected conditions resulting from eventual SST retrieval. Additional tests need to be planned to extend the tank operating range to cover these conditions. At the same time, the lessons learned from the prior tests and better chemical analyses need to be applied to improve the data quality (see #20, 22, 24, 29, 30, 58). [Assigned HIGH PRIORITY by SRC.]
32. **Do stress analysis and take UT horizontally in 100-150 inch band.** See # 13. The 100 to 150 inch band has the lowest wall thickness margin for corrosion thinning (see also #2, 3, 4, 5, 6, 10, 26, 33, 56, 64, 66). [Assigned HIGH PRIORITY by SRC.]
33. **Incorporate NDE sensitivity tests in lab corrosion tests.** The usefulness of NDE data in tanks can be improved by performing NDE tests along with laboratory corrosion tests where the corrosion rates and depths are measured by other means (see also #2, 3, 4, 5, 6, 10, 26, 32, 56, 64, 66). [not recommended by SRC.]
34. **Test use of electrical resistance probes in lieu of LPR.** Linear Polarization Resistance (LPR) is based on electrochemical theory that the current is directly proportional to the corrosion rate for small changes of the potential. It requires that the only electrochemical reaction is corrosion. Electrical resistance (ER) probes assume that a piece of metal becomes thinner as it corrodes causing its electrical resistance to increase. Thus, the resistance is directly proportional to the amount of corrosion. Each has advantages and disadvantages that need to be quantified. [Assigned NOMINAL PRIORITY by SRC.]
35. **Install atmospheric corrosion probes in annulus.** Atmospheric corrosion probes would instantly detect whether high humidity or other conditions were causing corrosion. This would be a direct indicator of corrosion as opposed to monitoring humidity which indirectly relates to corrosion (see #14, 17, 18, 23, 25, 49, 53). [Assigned NOMINAL PRIORITY by SRC.]
36. **Mix the waste with mixer pumps.** Mixing suspends settled solids and erases temperature and concentration gradients to make the waste approximately uniform. This simplifies sampling and increases confidence that all surfaces of the tank are protected from corrosion if the waste is within the chemistry corrosion limits as determined from a bulk sample. However, installation and operation of mixer pumps is exceedingly expensive. Mixing is not completely uniform because the mixer pumps can only be run intermittently to prevent excessive temperature rise. Mixer pumps

are not considered a practical aspect of corrosion prevention. [Not recommended by the SRC.]

37. **Apply chemistry corrosion limits to each waste layer.** The current practice is to compare the average tank chemistry as determined from the Best Basis Inventory to the limits. However, the waste composition near the waterline, in the supernate, and in the sediment differs measurably from the average based on core sample analyses. Corrosion protection can be ensured by considering each layer separately. This requires a pH measurement from each layer (see also #1, 7, 11, 27, 59, 60, 61, 62, 63, 68). [Assigned VERY HIGH PRIORITY by SRC.]
38. **Do probabilistic structural analysis to decide on weld inspection.** The current NDE program is aimed at detecting flaws in the heat-affected zone around the weld, not in the weld itself. The extent of original weld flaws is unknown. Weld specifications on drawings and heat treatment and weld QC records should be reviewed to help assess the need for weld inspection. See also # 69 and 70. [not recommended by SRC.]
39. **Resolve cause of thinning and EN indication in AN-105.** Tank AN-105 is determined to be within the chemistry corrosion limits. Nevertheless, UT measurement has detected wall thinning, and the electrochemical noise probe indicates active corrosion in the nonconvective layer. These observations cast some doubt on the efficacy of the chemistry limits, and the cause must be determined at a high priority. A possible change in wall material in the thinning region should be investigated (see # 44). [not recommended by SRC.]
40. **Clean the wall to measure pit depth.** Current NDE technology cannot measure the depth of small pits, especially when coated with corrosion product. It is recommended that selected areas of the tank wall be cleaned and representative pits be measured individually to assess the true extent of pitting corrosion when detected. [not recommended by SRC.]
41. **Incorporate a weld region in EN probe.** The corrosion characteristics of the material in a weld are expected to differ from the heat-affected-zone or bulk plate. Including a weld into a series of EN probes would allow the probe to detect weld corrosion. Lab tests should be conducted to find out whether the weld region is more or less vulnerable to corrosion. (see #42, 45) [Assigned NOMINAL PRIORITY by SRC.]
42. **Evaluate a portable, adjustable EN probe.** It would be advantageous to have an EN probe that could be moved up and down as the waste level changes or from tank to tank. (see #41, 45). [Assigned NOMINAL PRIORITY by SRC.]
43. **Control headspace humidity in low temperature tanks.** The primary ventilation system and heat generation in the waste keeps the relative humidity relatively low in the warmer tanks. However, heaters or dehumidifiers or recirculating ventilation systems may need to be considered in the colder tanks if humidity is observed to remain high. [not recommended by SRC.]
44. **Check construction materials for change at corrosion area in AN-105.** See # 39. [not recommended by SRC.]
45. **Place EN probe to bridge the waterline.** Condensation or raw water additions will stratify at the waterline and the resulting dilute liquid can initiate corrosion. An EN probe placed in this area could detect this problem. One should be placed near the water line if practicable. The possibility of a floating probe was also mentioned. (see #41, 42). [Assigned NOMINAL PRIORITY by SRC.]

46. **Wash the inside wall with supernate.** Condensation on the dome and flow of condensate down the wall and dilution of waste at the waterline is a potential source of corrosion. Periodically washing the inside of the primary liner above the waste level with supernate, which would be presumably within corrosion chemistry limits, would reduce the potential for condensation-induced dome corrosion. However, the effort required to install and operate such a system would be similar to that of a mixer pump and the cost probably exceeds the potential benefit. [not recommended by SRC.]
47. **Do tank visual inspection of SST during retrieval.** A relatively large number of SSTs have or are suspected to have leaks that have been attributed to stress corrosion cracking. This does not have a sound technical base and it would be very beneficial to establish the cause of SST leaks by direct inspection. Inspection would be practical after most of the waste is removed by retrieval. However, benefit is minimal since SST retrieval, especially of leakers, is not scheduled until far into the future. [not recommended by SRC.]
48. **Determine cause of leaks in SSTs that can be inspected.** See # 47. [not recommended by SRC.]
49. **Paint or coat the annulus surfaces.** Technology exists to remotely apply paint or other coating to protect the annulus surface from corrosion from condensation or water invasion (see #14, 17, 18, 23, 25, 35, 53). [not recommended by SRC.]

E.3 Unranked recommendations

These were considered studies or were already being performed and were not ranked. The order of these final recommendations does NOT imply their relative ranking. Many were grouped with higher priority recommendations in the final set.

50. **Evaluate volatile treatment (ammonia) in vapor space.** It is known that the presence of ammonia vapor as low as 100 ppm inhibits corrosion. Since ammonia is already ubiquitous in the DSTs headspace, though seldom at this high a concentration, it may be possible to add sufficient ammonia to the waste to protect the headspace from corrosion. Added ammonia should not present a problem to vitrification. [Assigned HIGH PRIORITY by SRC.]
51. **Increase management priority to stay within chemistry limits.** Potentially rapid and damaging corrosion can be prevented only by maintaining the tank waste within established specifications. This has not been done. Four tanks are known to be out of specification and have been for years. It is unacceptable that limits known to prevent corrosion not be applied. This recommendation was brought forward in a special category of management issues along with #53. [Assigned VERY HIGH PRIORITY by SRC.]
52. **Document history of out-of-spec conditions.** Tanks may have been out of specification for significant periods. Water addition for post-construction hydrostatic testing may have exposed the liner to raw water for several weeks. Tanks may have been left with a heel for a long period after flushing. A table of tank, condition and duration would indicate which tanks should get priority for visual inspection and NDE. However, concerns were expressed about the ability to get sufficiently accurate data for the early part of the tanks' history. [not recommended by SRC.]

53. **Keep annulus ventilation running.** Condensation in the annulus has been found to be a direct cause of serious corrosion. Ventilation has been shown to prevent condensation, but some annulus ventilation systems are still inoperative, making corrosion likely. Annulus ventilation systems must be maintained at top priority. This recommendation was brought forward in a special category of management issues along with #51. [Assigned VERY HIGH PRIORITY by SRC.]
54. **Evaluate potential for cathodic protection.** An SRS document has recently considered the effectiveness of applying an electric potential between waste and wall to prevent corrosion. There was a concern that it would not be possible to assure uniform protection. Thus chemistry controls could not be relaxed and the benefit would be lost. [Assigned NOMINAL PRIORITY by SRC.]
55. **Use existing data to improve depletion models.** See also #1. More frequent sampling is favored over development of new depletion models. However, sufficient data probably exists to improve empirical models considerably while new sample data is being accumulated. [not recommended by SRC.]
56. **Validate chemistry limits with UT results and visual exams.** Validation is based on the observation that, if no corrosion is observed or measured on tanks that are within-specification, the chemistry corrosion limits are adequate. However, data is sparse (two tanks visual, 11 UT). Also wall thinning and EN observed in AN-105 which is in-specification. Also some indication of corrosion in AP-108 indication (see also #2, 3, 4, 5, 6, 10, 26, 32, 33, 64, 66). [Assigned HIGH PRIORITY by SRC.]
57. **Evaluate alternate form of chemistry limits.** It was suggested that the combination nitrite + OH might be a better limit than pH or OH alone. SRS uses this double limit. (see #72). [Assigned VERY HIGH PRIORITY by SRC.]
58. **Perform statistically based cost/benefit of additional SCC testing.** This recommendation should be part of #29 (see also #20, 22, 24, 30, 31). [Assigned HIGH PRIORITY by SRC.]
59. **Evaluate data uncertainty from waste nonuniformity.** Waste may be nonuniform laterally or vertically such that samples taken to verify corrosion limits do not represent the composition of waste in contact with the wall. Uncertainty in both supernate and nonconvective layers should be assessed, though the supernate is expected to be quite uniform (see also #1, 7, 11, 27, 37, 60, 61, 62, 63, 68). [Assigned VERY HIGH PRIORITY by SRC.]
60. **Incorporate analytical uncertainties with sample uncertainties.** Uncertainty in laboratory analysis results may be misinterpreted as spatial nonuniformity. Analytical uncertainties should be established and applied consistently when evaluating chemistry limits (see also #1, 7, 11, 27, 37, 59, 61, 62, 63, 68).
61. **Determine best estimate waste composition relating to corrosion.** Mine the DST characterization data base and document results. This is already being done (see also #1, 7, 11, 27, 37, 59, 60, 62, 63, 68). [Assigned VERY HIGH PRIORITY by SRC.]
62. **Identify tanks that need to be re-sampled for adequate data.** Since there has been no safety driver for analyses related to corrosion on core samples, data on pH and OH are very sparse. Some tanks may need to be resampled or archived samples need to be re-analyzed to produce the required data (see also #1, 7, 11, 27, 37, 59, 60, 61, 63, 68). [Assigned VERY HIGH PRIORITY by SRC.]
63. **Determine the potential for adverse stratification.** Stratification of flush water, condensate return or of an incoming transfer may create a dilute layer that is out of specification. Operations and designs need to be assessed for these or other non-

homogeneity that might exacerbate waterline corrosion (see also #1, 7, 11, 27, 37, 59, 60, 61, 62, 68). [Assigned NOMINAL PRIORITY by SRC.]

64. **Schedule visual inspection whenever camera is in the tank.** This should especially include times when tank is pumped down, or when a visual exam is being performed for another purpose. This recommendation is one of several calling for more frequent inspections and expediting the initial baseline (see also #2, 3, 4, 5, 6, 10, 26, 32, 33, 56, 66). [Assigned HIGH PRIORITY by SRC.]
65. **Evaluate use of EC for pits on outside of primary liner.** Eddy current inspection has the potential for measuring pit depth and should be evaluated for inclusion in the tank NDE program. [Assigned HIGH PRIORITY by SRC.]
66. **Evaluate use of smaller SRS NDE inspection devices.** It is possible that the smaller devices in use at SRS could cover a larger fraction of the lower knuckle and other areas where the current magnetic crawler cannot access (see also #2, 3, 4, 5, 6, 10, 26, 32, 33, 56, 64). [Assigned HIGH PRIORITY by SRC.]
67. **Monitor SRS progress with Raman/EN probe.** The Raman probe being developed by TPA at SRS can potentially measure pH in situ. The combined probe would provide much more useful information than the EN probe alone. [Assigned NOMINAL PRIORITY by SRC.]
68. **Benchmark SRS lab analysis cost for pH.** The opinion is that pH analysis as Hanford costs much more than at SRS. If SRS is indeed cheaper, the reasons need to be determined and the Hanford procedures revised as appropriate (see also #1, 7, 11, 27, 37, 59, 60, 61, 62, 63). [Assigned VERY HIGH PRIORITY by SRC.]
69. **Evaluate drawings for weld details and methods of RT.** Also see #70. Weld flaws that were not detected and repaired during construction could also serve as additional sites or pathways for corrosion besides reducing tank integrity themselves. Evaluating drawings and RT methods can help determine the potential for undetected weld flaws. Construction heat treatment and QC records should also be examined. [not recommended by SRC.]
70. **Evaluate construction heat treat and QC records.** See #69. [Not recommended by SRC.]
71. **Develop a corrosion DQO.** The Data Quality Objectives (DQO) that drive waste sampling and analyses do not include parameters important to corrosion control. Sample analyses need to include pH and nitrite, nitrate and hydroxide concentrations. To insure that corrosion data is obtained at every opportunity, a corrosion chemistry DQO must be developed and applied consistently. Relevant archived samples should be re-analyzed under the new DQO. (see #15). [Assigned VERY HIGH PRIORITY by SRC.]
72. **Benchmark SRS chemistry control program.** SRS uses a combined OH and NO_2 limit, and a factor of safety to keep pH higher than the limit. (see #57, 66, 67, 68). [Assigned VERY HIGH PRIORITY by SRC.]
73. **Support T-SAFT development to inspect lower knuckle.** Current UT inspection of the lower knuckle of the primary liner severely limited by the curved section and obstruction of the supporting concrete pad. Tandem-synthetic aperture focusing technique (T-SAFT) is expected to be capable of inspecting this region. [Assigned HIGH PRIORITY by SRC.]

Appendix F

Rankings

Appendix F
Rankings

Table F.1. Approximate Ranking of Recommendations

Action	Time to benefit	Cost	Probability to extend life	Supports commitments	Feasibility	SCORE
Weighting factor:	**5**	**6**	**10**	**3**	**8**	**32**
Value Range:	1-3	1-3	1-3	1 or 3	1-3	
Sample waste more frequently	3	2	3	3	3	90
Perform NDE on waterline every 5 years	3	2	3	3	3	90
Increase frequency of annulus video and number of risers	3	2	3	3	3	90
Develop lay up procedure for tanks left with a heel	3	3	3	0	3	87
Develop contingency plan for tank repair	3	3	3	0	3	87
Perform analyses to insure inhibitor mixes into waste	3	3	2	3	3	86
Develop a DQO for NDE	3	3	2	3	3	86
Expedite NDE on vulnerable tanks	3	2	3	0	3	81
Develop gas tracer or dye leak test	3	2	3	0	3	81
Blank off unnecessary water sources	3	2	2	3	3	80
Increase frequency of headspace video	3	2	2	3	3	80
Prevent or limit addition of large volumes of raw water or condensate	3	3	2	0	3	77
Add chemistry conditions to waste compatibility criteria	3	3	2	0	3	77
Re-evaluate sum total of extant corrosion test data	3	3	2	0	3	77
Increase the margin between waste chemistry and caustic limits	3	3	2	0	3	77
Set priority, frequency and area of NDE based on visual results	3	3	2	0	3	77
Prevent waste levels of 100-150 inches	3	3	2	0	3	77
Demonstrate low-cost, disposable LaF_3 pH probe	3	3	2	0	3	77
Control humidity in the annulus	2	2	3	0	3	76
Protect against rain/snowmelt invading annulus	3	2	2	3	2	72
Re-create corrosion test recipes and measure chemistry	3	2	2	3	2	72
Vary waste level to limit waterline corrosion	3	2	2	0	3	71
Monitor humidity in annulus exhaust.	3	2	2	0	3	71
Perform pitting initiation and inhibition tests (start aggressive, transition to inhibited, see if rate slows)	3	2	2	0	3	71
Accelerate current schedule for establishing a UT benchmark	3	2	2	0	3	71
Determine relation of bulk sample to material seen by the wall	2	2	2	3	2	67
Develop procedures on use of power equipment, especially mixer pump, on and around tanks	2	2	2	3	2	67
Plan additional SCC testing defined via DQO-like process	2	2	2	0	3	66
Perform slow strain rate coupon testing of SCC	2	2	2	0	3	66
Repeat prior corrosion tests with chemical analysis	2	2	2	0	3	66
Re-do stress analysis and take UT horizontally in 100-150 inch band before applying administrative control	2	2	2	0	3	66
Incorporate NDT sensitivity tests in lab corrosion tests	2	2	2	0	3	66

Table F.1. Approximate Ranking of Recommendations

Action	Time to benefit	Cost	Probability to extend life	Supports commitments	Feasibility	SCORE
Weighting factor:	**5**	**6**	**10**	**3**	**8**	**32**
Test use of electrical resistance probes in lieu of LPR	2	2	2	0	3	66
Install atmospheric corrosion probes in annulus	2	2	2	0	3	66
Install baffle or change orientation of annulus intake to prevent precipitation from entering	2	2	2	0	3	66
Mixing waste with mixer pumps	2	1	2	0	3	60
Apply chemistry corrosion limits to each layer	2	2	2	0	2	58
Do probabilistic structural analysis to on weld inspection	2	2	2	0	2	58
Resolve cause of thinning and ECN in AN-105	2	2	2	0	2	58
Clean the wall to measure pit depth	2	2	2	0	2	58
Incorporate a weld region in ECN probe	2	2	2	0	2	58
Evaluate portable, adjustable EN probe	2	2	2	0	2	58
Control headspace humidity in low temperature tanks	2	2	2	0	2	58
Check construction materials for change at corrosion area AN-105	2	3	1	0	2	54
Place ECN probe to bridge the waterline	2	2	2	0	1	50
Washing the wall with waste	2	2	1	0	2	48
Do tank visual inspection as part of SST retrieval	2	2	1	0	2	48
Determine cause of leaks in SSTs	1	1	2	0	2	47
Paint or coat the annulus surfaces	2	1	1	0	1	34

Table F.2. Detailed Ranking of Recommendations

Action	Time to benefit				Cost				Probability to extend life				Supports commitments			Feasibility				Score
Values and Weight factor:	**3**	**2**	**1**	**5**	**3**	**2**	**1**	**6**	**3**	**2**	**1**	**10**	**3**	**1**	**3**	**3**	**2**	**1**	**8**	**32**
Develop a DQO for NDE	8	4	0	2.7	8	4	0	2.7	5	5	3	2.2	3	0	3	10	3	0	2.8	82
Perform analyses to ensure inhibitor mixes into waste	10	4	0	2.7	7	3	1	2.5	4	8	1	2.2	3	0	3	10	4	0	2.7	82
Increase frequency of headspace video	9	5	1	2.5	1	14	0	2.1	7	7	1	2.4	3	0	3	13	2	0	2.9	81
Sample waste more often	12	1	0	2.9	0	7	4	1.6	8	4	2	2.4	3	0	3	10	3	0	2.8	80
Perform NDE on waterline every 5 years	8	6	2	2.4	2	11	2	2.0	8	6	2	2.4	3	0	3	13	3	0	2.8	79
Increase frequency of annulus video and number of risers	9	6	1	2.5	1	10	3	1.9	8	6	1	2.5	3	0	3	10	4	0	2.7	79
Develop lay up procedure for tanks left with a heel	11	4	0	2.7	9	3	1	2.6	8	5	2	2.4	0	0	0	13	2	0	2.9	76
Expedite NDE on vulnerable tanks	13	3	0	2.8	5	8	1	2.3	10	4	1	2.6	0	0	0	13	3	0	2.8	76
Set priority, frequency and area of NDE based on visual results	11	2	2	2.6	9	5	0	2.6	7	6	2	2.3	0	0	0	14	1	0	2.9	76
Prevent or limit addition of large volumes (inches) of raw water or condensate	14	1	0	2.9	9	4	1	2.6	7	7	1	2.4	0	0	0	10	4	1	2.6	75
Add chemistry conditions to waste compatibility criteria	11	3	0	2.8	13	1	0	2.9	3	9	2	2.1	0	0	0	10	2	0	2.8	75
Develop contingency plan for tank repair	7	5	1	2.5	7	5	1	2.5	11	1	3	2.5	0	0	0	10	4	1	2.6	73
Increase the margin between waste chemistry and caustic limits	11	3	0	2.8	12	1	1	2.8	3	8	4	1.9	0	0	0	12	2	0	2.9	73
Demonstrate low-cost, LaF_3 pH probe	10	2	1	2.7	6	4	0	2.6	5	7	1	2.3	0	0	0	7	6	0	2.5	72
Prevent waste levels of 100-150 inches	11	4	2	2.5	11	2	1	2.7	5	8	2	2.2	0	0	0	10	5	0	2.7	72
Protect against rain/snowmelt invading annulus	8	4	2	2.4	1	7	6	1.6	5	5	3	2.2	3	0	3	6	6	1	2.4	72
Vary waste level to limit waterline corrosion	9	4	1	2.6	3	10	1	2.1	5	7	1	2.3	0	0	0	10	3	0	2.8	71
Perform pitting initiation and inhibition tests	7	5	4	2.2	6	8	0	2.4	5	8	2	2.2	0	0	0	13	2	0	2.9	70
Prevent precipitation from entering annulus intake	6	7	0	2.5	4	6	0	2.4	3	8	2	2.1	0	0	0	11	3	0	2.8	70

Table F.2. Detailed Ranking of Recommendations

Action	Time to benefit				Cost				Probability to extend life				Supports commitments			Feasibility				Score
Values and Weight factor:	**3**	**2**	**1**	**5**	**3**	**2**	**1**	**6**	**3**	**2**	**1**	**10**	**3**	**1**	**3**	**3**	**2**	**1**	**8**	**32**
Control humidity in the annulus	7	7	0	2.5	2	11	1	2.1	8	5	2	2.4	0	0	0	9	6	0	2.6	70
Determine relation of bulk sample to material seen by the wall	5	8	1	2.3	4	10	1	2.2	4	6	5	1.9	3	0	3	4	8	3	2.1	69
Incorporate NDE sensitivity tests in lab corrosion tests	6	5	2	2.3	4	4	1	2.3	5	7	2	2.2	0	0	0	8	4	0	2.7	69
Accelerate current schedule for establishing a UT benchmark	11	2	1	2.7	4	6	2	2.2	3	7	3	2.0	0	0	0	11	3	0	2.8	69
Monitor humidity in annulus exhaust	9	6	0	2.6	7	7	0	2.5	1	9	5	1.7	0	0	0	14	1	0	2.9	69
Develop gas tracer leak test	8	5	2	2.4	7	7	0	2.5	7	4	5	2.1	0	0	0	8	8	0	2.5	68
Blank off unnecessary water sources	8	6	1	2.5	4	8	2	2.1	4	7	2	2.2	0	0	0	10	5	0	2.7	68
Evaluate procedures on use of power equipment in tanks	7	3	1	2.5	10	2	0	2.8	1	4	7	1.5	0	0	0	10	2	0	2.8	67
Re-evaluate sum total of extant corrosion test data	9	3	2	2.5	10	3	0	2.8	1	7	6	1.6	0	0	0	11	1	2	2.6	67
Re-create corrosion test recipes and measure chemistry	6	7	2	2.3	8	7	0	2.5	1	7	6	1.6	0	0	0	14	2	0	2.9	66
Plan additional SCC testing defined via DQO-like process	3	8	4	1.9	7	7	0	2.5	3	6	5	1.9	0	0	0	11	3	1	2.7	65
Install atmospheric corrosion probes in annulus	6	6	2	2.3	3	9	1	2.2	2	8	4	1.9	0	0	0	8	2	1	2.6	64
Test use of electrical resistance probes in lieu of LPR	4	10	0	2.3	5	8	0	2.4	1	7	6	1.6	0	0	0	9	5	0	2.6	63
Perform slow strain rate coupon testing of SCC	0	10	5	1.7	2	12	0	2.1	4	7	4	2.0	0	0	0	11	2	1	2.7	63
Do stress analysis and take UT horizontally in 100-150 inch band	5	8	1	2.3	0	11	0	2.0	1	8	3	1.8	0	0	0	7	5	0	2.6	62
Resolve cause of thinning and EN indication in AN-105	6	8	1	2.3	6	8	1	2.3	7	4	4	2.2	0	0	0	1	10	4	1.8	62
Repeat prior corrosion tests with chemical analysis	2	9	4	1.9	0	11	3	1.8	2	9	2	2.0	0	0	0	12	2	1	2.7	62
Do probabilistic structural analysis to decide on weld inspection	3	8	1	2.2	1	12	0	2.1	3	6	4	1.9	0	0	0	4	9	0	2.3	61

Table F.2. Detailed Ranking of Recommendations

Action	Time to benefit				Cost				Probability to extend life				Supports commitments			Feasibility				Score
Values and Weight factor:	**3**	**2**	**1**	**5**	**3**	**2**	**1**	**6**	**3**	**2**	**1**	**10**	**3**	**1**	**3**	**3**	**2**	**1**	**8**	**32**
Incorporate a weld region in EN probe	5	8	1	2.3	4	8	1	2.2	1	8	5	1.7	0	0	0	6	7	1	2.4	61
Check construction materials for change at corrosion area in AN-105	6	4	2	2.3	9	4	0	2.7	0	4	9	1.3	0	0	0	6	5	2	2.3	59
Evaluate a portable, adjustable EN probe	1	12	2	1.9	4	5	3	2.1	4	4	5	1.9	0	0	0	3	7	2	2.1	58
Control headspace humidity in low temperature tanks	3	8	4	1.9	0	8	5	1.6	5	5	4	2.1	0	0	0	3	11	0	2.2	58
Mix the waste with mixer pumps	1	5	5	1.6	0	0	13	1.0	4	6	3	2.1	0	0	0	8	3	1	2.6	56
Apply chemistry corrosion limits to each waste layer	4	8	2	2.1	1	7	6	1.6	2	11	3	1.9	0	0	0	2	9	3	1.9	55
Do tank visual inspection as part of SST retrieval	2	5	7	1.6	1	7	3	1.8	2	8	7	1.7	0	0	0	7	6	2	2.3	55
Place ECN probe to bridge the waterline	2	9	2	2.0	1	11	2	1.9	1	9	4	1.8	0	0	0	0	5	9	1.4	50
Clean the wall to measure pit depth	3	10	1	2.1	0	8	5	1.6	0	9	3	1.8	0	0	0	0	7	6	1.5	50
Washing the wall with waste	4	10	1	2.2	1	3	5	1.6	1	5	9	1.5	0	0	0	1	9	4	1.8	49
Determine cause of leaks in SSTs	1	6	8	1.5	1	5	8	1.5	4	5	6	1.9	0	0	0	1	9	6	1.7	49
Paint or coat the annulus surfaces	4	6	5	1.9	0	4	10	1.3	2	4	8	1.6	0	0	0	1	4	10	1.4	44

Table F.3. One-Over-One Evaluation of Approximately Ranked Recommendations

i/j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	˜i	S1 = 100*˜i/ (˜i+˜j)
1		9	7	11	11	11	11	6	13	12	13	3	11	12	11	11	10	6	10	9	187	80
2	4		7	10	10	9	14	3	13	16	13	10	13	13	15	4	11	3	12	13	193	74
3	5	7		10	12	11	12	0	12	13	11	6	15	14	14	4	11	6	6	12	181	68
4	2	4	5		9	9	9	2	11	12	10	5	11	12	12	5	7	7	7	13	152	59
5	2	3	3	5		7	10	4	8	9	9	5	11	12	11	3	6	5	6	12	131	50
6	2	3	3	4	6		10	0	8	5	6	2	10	10	11	3	6	1	1	12	103	40
7	3	1	3	2	4	5		1	7	3	6	1	11	9	9	3	5	2	1	7	83	31
8	7	11	15	12	11	15	14		12	13	13	8	14	13	14	6	12	10	10	15	225	82
9	0	3	2	3	4	7	7	2		4	3	2	12	6	11	1	6	3	1	11	88	33
10	0	0	2	2	7	9	12	1	10		6	1	11	10	11	1	2	3	5	9	102	38
11	0	2	1	5	5	9	8	2	11	7		6	13	11	11	0	8	4	4	12	119	45
12	4	3	8	9	10	13	13	7	12	15	7		14	13	12	7	11	8	8	13	187	71
13	0	0	1	2	2	2	3	0	1	1	1	0		1	8	0	4	0	1	6	33	13
14	0	0	1	1	1	4	5	1	6	4	3	2	9		9	1	3	0	2	7	59	24
15	1	0	1	2	3	2	6	0	4	4	3	1	5	3		2	1	2	3	10	53	21
16	3	9	9	9	11	10	11	9	13	12	13	8	13	12	10		11	7	8	13	191	75
17	3	3	4	6	7	7	8	3	8	11	7	3	9	9	11	2		2	3	9	115	46
18	6	7	7	7	8	12	12	3	11	13	10	6	13	13	10	7	11		9	13	178	71
19	2	3	8	8	9	13	13	4	16	9	10	6	11	11	11	5	9	4		13	165	63
20	3	0	0	0	2	3	7	0	3	1	0	0	8	5	3	0	3	0	0		38	15
˜j	47	68	87	108	132	158	185	48	179	164	144	75	214	189	204	65	137	73	97	209		

Note: Entry in Cell ij (Row i, Column j) indicates number of votes for Recommendation i in comparison to Recommendation j. Order is as given Table F.1.

Table F.4. Result of One-Over-One Ranking

Sort Order	Matrix Order	Score	Recommendation
1	8	82	Expedite NDE on vulnerable tanks
2	1	80	Sample waste more frequently
3	16	75	Set priority, frequency and area of NDE based on visual results
4	2	74	Perform NDE on waterline every 5 years
5	12	71	Prevent or limit addition of large volumes of raw water or condensate
6	18	71	Demonstrate low-cost, disposable LaF_3 pH probe
7	3	68	Increase frequency of annulus video and number of risers
8	19	63	Control humidity in annulus
9	14	58	Develop lay up procedure for tanks left with a heel
10	5	50	Develop contingency plan for tank repair
11	17	46	Prevent waste levels of 100-150 inches
12	11	45	Increase frequency of headspace video
13	6	39	Perform analyses to insure inhibitor mixes into waste
14	10	38	Blank off unnecessary water sources
15	9	33	Develop gas tracer or dye leak test
16	7	31	Develop a DQO for NDE
17	14	24	Re-evaluate sum total of extant corrosion test data
18	15	21	Increase the margin between waste chemistry and caustic limits
19	20	15	Protect against rain/snowmelt invading annulus
20	13	13	Add chemistry conditions to waste compatibility criteria

Appendix G

Summary of Grouped Recommendations

Appendix G

Summary of Grouped Recommendations

This list was used as the primary input for the Senior Review Team deliberations May 21 and 22, 2001. The recommendations are adapted from the overall list of recommendations in Appendix E and grouped roughly in accordance with the statement of workshop conclusions with some adjustments. The top 23 recommendations are indicated by the number shown in brackets.

G.1 Corrosion Testing Summary

1. Re-create and analyze simulant solutions used for Divine et al. (1985) corrosion tests for DST chemistry controls (measure pH, concentration of hydroxide, nitrate and nitrite, and corrosion potential)
2. Based on the analysis results of the Divine simulants, along with new corrosion data, re-evaluate chemistry control limits, and establish metrics for DST chemistry monitoring.
3. Perform a comprehensive review of existing data on corrosion and SCC and plan for any additional needed SCC with a DQO-like process.[20]
4. Consider a statistically based cost/benefit assessment to determine the optimum SCC test program scope.
5. The SCC test matrix should include low strain rate coupon testing to provide SCC vulnerability data, while avoiding the uncertainties of the initiation period.
6. SCC testing shall include sensitivity tests of EN and NDE methods for detecting pitting and cracking.
7. Conduct tests to investigate changes to pitting corrosion rates in solutions of varying pH and effects on pitting rates after removal of initiating conditions.[22]
8. Pitting testing shall include sensitivity tests of EN and NDE methods for detecting pitting and general corrosion.

G.2 Tank Inspection Summary

1. Expedite completion of the as-found NDE baseline effort (visual mapping, wall thickness, pitting, thinning, etc.).
2. Establish a policy/procedure to perform visual inspection (VT) whenever a camera is in a tank or annulus.
3. Ensure VT is performed at least every five years.
4. Ensure that the VT of both annulus and interior of all 28 DSTs have been completed by May 2002.
5. Evaluate using an increased frequency and area coverage (i.e., number of risers) for VT of the annulus and tank headspace.[5][6]
6. NDE shall be expedited on tanks known to be, or which have been, outside chemistry limits.[2]
7. NDE shall be performed at the waterline(s) in each tank at least once every five years.[3]
8. NDE shall be expedited on tanks in which significant corrosion is observed during visual inspections.[4]

9. Review capabilities of SRS's smaller NDE devices.
10. Evaluate Eddy Current (ET) technology for characterizing pits on the outside of the primary liner.
11. Give a high priority to qualification of the T-SAFT technology, to inspect the lower knuckle region, and also investigate methods to UT in the bottom slots.
12. Develop a gas or visual tracer method to detect or confirm suspected leaks in the primary liner, above the waste surface.[19]
13. Develop a DQO for NDE inspections. The DQO is to include operator and equipment qualification standards.[10]
14. Review the new construction drawings and QC records for heat treatment, welding specification, and weld inspection requirements, to assess the potential for undetected weld flaws, especially lack of fusion conditions. This will permit an evaluation of the need for additional NDE or risk modeling.

G.3 Chemistry Control Summary

1. Waste chemistry shall be measured by frequent sampling, perhaps initially at three-month intervals. Frequent sampling is preferable to dependence on available caustic depletion models.[1]
2. A corrosion chemistry sampling DQO shall be developed and applied for both core and grab samples.
3. Use the frequent sampling to provide a database for more accurate, predictive depletion models.
4. Correlate sampling results from each tank layer with corrosion test data and corrosion probe readings.
5. Use the sampling to analyze caustic mixing dynamics into the nonconvective layer.
6. Evaluate the uncertainty in the sampling data due to nonuniformity of the waste and any differences between bulk samples and the chemistry at the tank wall.
7. Evaluate use of a low cost pH probe (LaF_3) for faster sampling results.[11]
8. Benchmark SRS sampling and lab procedures for potential efficiencies and cost savings.
9. Ensure management understanding and commitment to consistently maintaining tank chemistry within limits.
10. Any tanks without of specification chemistry in the supernatant shall be promptly corrected with inhibitor additions to prevent waterline and uniform corrosion.
11. Increase the margin between waste chemistry and caustic limits.[16]
12. Monitor the chemistry and corrosion potential of the nonconvective layer (NCL).
13. Analysis of the NCL chemistry should be used to determine if natural mixing is sufficient, or if forced mixing is required.[7]
14. Evaluate the required number and position of corrosion probes.
15. Evaluate the need for more frequent NDE of tank wall conditions at the NCL level.
16. Address the potential for waterline corrosion from continuous condensate return and modify systems as required.
17. Evaluate the required number and position of corrosion probes.
18. Evaluate the need for more frequent NDE of tank wall conditions at the NCL level.
19. Address the potential for waterline corrosion from continuous condensate return and modify systems as required.

20. Add corrosion chemistry conditions to the waste compatibility criteria.[15]
21. Ensure that the rate or volume of dilute or raw water additions do not move the waste out of specification.[8]
22. Develop a layup and sampling procedure for tanks with a waste heel.[9]
23. Document periods when tanks have been known to be out of specification, including time with unregulated waste heels or hydrotest residual water.
24. Investigate the use of alternative methods or forms for maintaining chemistry (e.g., combined OH + NO_2 additions, etc.).
25. Expedite the determination of the cause of wall thinning and pitting and EN probe response in AN-105, which appears to be within specification.
26. Validate the long term effectiveness of chemistry controls by comparison with UT, VT, EN, or other NDE.
27. To protect against vertical nonuniformity, chemistry corrosion limits shall be applied to each waste layer rather than using a tank average. Tanks that need to be resampled to obtain more adequate data shall be identified.

G.4 Corrosion Monitoring Summary

1. Consider adding a weld region on the EN probe.
2. Evaluate placing an EN probe at or near the waterline or have the capability to move the EN probe up and down.
3. Determine the optimum number and placement of EN probes for each tank.
4. Monitor the progress of SRS Raman/EN probe technology.
5. Evaluate the benefits of an atmospheric corrosion probe in the annulus.
6. Electrical resistance probes have been recommended over the use of LPR.
7. Evaluate eddy current probes to characterize pitting on the annulus surface of the primary liner.

G.5 Support Systems Summary

1. Need to ensure management understanding of the importance of maintaining annulus ventilation (AV) operational.
2. Humidity should be monitored in both the annulus and headspace.
3. Heating and/or dehumidification should be provided if the annulus relative humidity reaches or exceeds 30% for extended periods.[14]
4. The need for improving humidity control in the primary (internal) ventilation system, especially for low temperature tanks, should be evaluated.
5. Annulus and primary ventilation inlets should be reoriented or provided with baffles to prevent entrainment of rain or snow in the inlet air.[23]
6. If groundwater is found to significantly contribute to DST corrosion, regrade or otherwise protect from this water source.[17]
7. Blank-off unnecessary water sources (e.g., raw water) to prevent potential water intrusion from leaks or misrouting.[18]

G.6 Corrosion Repair and Mitigation Summary

1. Develop a contingency plan for repair by welding, including specifications, qualification of suppliers, and procedures.[12]
2. Investigate the potential use of mechanical plugs or coatings to seal leaks.
3. Perform a cost/benefit analysis for repair versus replacement or restricted use.
4. Consider waste level controls to systematically vary the waste level, and avoid waste levels in the 100- to 150-inch range (minimum design margin levels). Base these controls on recalculating minimum design wall using probabilistic stress analysis and horizontal UT inspections of the area. [13][21]

G.7 Additional Actions Summary

1. Reevaluate the application of cathodic protection systems on DSTs. Start with a survey of the SRS review of this subject.
2. Evaluate present controls on the use of electrically powered equipment on or in the tanks, to ensure stray current corrosion is not a concern.
3. Consider washing or spraying the inside of the primary liner above the waste level with supernatant, to minimize dome corrosion.
4. Evaluate addition of ammonia to the tank so the volatile gas content above the supernatant can protect the metal.
5. Consider applying paint or other protective coatings to the inside of the annulus to minimize corrosion from water intrusion or high humidity.

Appendix H

Senior Review Committee Meeting Agenda

Appendix H

Senior Review Committee Meeting Agenda

Monday, May 21, Hills Street Conference Center, Richland, Washington

Introduction and Background

8:00 - 8:15	Senior Team Review Expectations - Jack Lentsch
8:15 - 9:00	Senior Team Review Methodology - Spence Bush [Team Leader]
9:00 - 9:15	Logistics – Joe Brothers
8:45 - 9:45	Overview of DST Workshop Recommendations - Herb Berman
9:45 - 10:00	Break (order lunch)

Senior Team Deliberations – Spence Bush, Team Leader

I. Tank Integrity Assessment and Inspection Program and Recommendations

10:15 - 12:00	Additions, Deletions, Modifications and Priorities for NDE Inspection Frequency and Techniques.
12:00 - 1:00	Lunch

II. Chemistry Control Program and Recommendations

1:00 - 2:00	Chemistry Control Limits
2:00 - 3:45	Corrosion Studies and Testing
3:30 - 3:45	Break
3:45 – 5:00	Summary Discussion and Plans for Tuesday

Tuesday, May 22, Hills Street Conference Center, Richland, Washington

8:00 - 8:15	2nd Day Opening Remarks – Jack Lentsch

III. Corrosion Monitoring Program

8:15 - 10:15	Corrosion Monitoring (Tank and Annulus) Corrosion Probes (e.g., type, placement, quantity, etc.)
10:15 - 10:30	Break
10:30 - 12:00	Operation of Support Systems (e.g., annulus and headspace ventilation)

12:00 - 1:00 Lunch

IV. Corrosion Repair and Mitigation

1:00 - 2:30 Waterline and Lay-up Controls, Weld or Mechanical repairs, Coatings, Cathodic protection, etc.

2:30 -2:45 Break

V. Summary Conclusions and Recommendations

2:45 - 4:00 Additions, Modifications and Priority Changes to Workshop Results

4:00 - 5:00 Outbrief CHG management on the Final Recommendations of the Senior Review Team

Distribution

No. of
Copies

Offsite

Herb Berman
8591 Bridle Court
Longmont, CO 80503-8810

Susan Borenstein
APTECH
12012 Wickchester, Ste 120
Houston, TX 77079

Spence Bush
630 Cedar Street
Richland, WA 99352

Carl Czajkowski
Brookhaven National Laboratory
Building 475B
Upton, NY 11973

Jim Divine
ChemMet, Ltd., PC
PO Box 4068
Richland, WA 99353

Steve Krahn
ADI Technology Corp.
1800 N. Beauregard St., Ste 200
Alexandria, VA 22311

Phil Ohl
Vista Engineering
Richland, Washington

3 Savannah River Technology Center
Westinghouse Savannah River Co.
SRL, 773A
Aiken, SC 29801
John Mikelonis
Bob Sindelar
Phil Zapp

No. of
Copies

R. F. Naventi
Bechtel Hanford, Inc.
3350 George Washington Way
Richland, WA 99352

Onsite

4 DOE Office of River Protection

HL Boston	H6-60
DC Bryson	H6-60
VL Callahan	H6-60
SL Johnson	H6-60
MJ Royack	H6-60

45 CHG

DI Allen	R2-50
RM Anantatmulah	R1-04
JR Bellomy	R3-83
WE Bryan	T4-07
KG Carothers	R2-11
AF Choho	R3-73
C Defigh-Price	T4-08
GP Duncan	R2-58
GL Edgemon	R3-83
EA Fredenburg	R1-04
LJ Julyk	R3-83
NW Kirch	R3-73
MA Knight	R2-11
JG Kristofzski	R2-50
JW Lentsch (25)	R2-58
R Ni	H6-18
EA Norman	R1-04
MJ Ostrom	S6-17
RS Popielarczyk	S5-07
RE Raymond	S7-70

DA Reynolds	R2-11
JP Sederburg	R2-50
DH Shuford	R3-83
MJ Sutey	R2-58

No. of
Copies

CHG (contd)

JE Van Beek	R3-47
DJ Washenfelder	R2-12
RD Wojtasek	T4-08

29 Pacific Northwest National Laboratory

JM Bates	K7-15
SQ Bennett	K7-90
JW Brothers (5)	K9-20
JM Cuta	K7-15
MJ Danielson	P8-15
MR Elmore (5)	K2-12
AB Johnson	K8-34
WL Kuhn	K7-15
EK Mercer	K7-15
SG Pitman	P8-18
GJ Posakony	K5-26
C. W. Stewart (5)	K7-15
Information Release (5)	K1-06