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241-AN Double-Shell Tanks Integrity Assessment Report

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Abstract: This report presents the results of the integrity assessment of the 241-AN double-shell tank farm facility located in the 200 East Area of the Hanford Site. The assessment included the design evaluation and integrity examinations of the tanks and concluded that the facility is adequately designed, is compatible with the waste, and is fit for use. Recommendations including subsequent examinations, are made to ensure the continued safe operation of the tanks.

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**DELIVERABLE FOR CONTRACT
NUMBER 503, RELEASE NUMBER 57,
THE INTEGRITY ASSESSMENT REPORT
OF 241-AN DOUBLE-SHELL TANKS
(HNF-4860, Rev. 0)**

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Date Published:

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241-AN DOUBLE-SHELL TANKS
INTEGRITY ASSESSMENT REPORT

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**CERTIFICATION OF
241-AN DOUBLE-SHELL TANKS
INTEGRITY ASSESSMENT REPORT**

"I certify under penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based upon my assessment of the plans and procedures utilized for obtaining this information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment."

Tarlok S. Hundal, P.E.

9/1/99
Date

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241-AN DOUBLE-SHELL TANKS

INTEGRITY ASSESSMENT REPORT

1.0 INTRODUCTION

The AN Tank Farm contains seven underground tanks located in the 200 East Area of the Hanford Site (Figure 1). These tanks contain liquid radioactive aqueous waste. Six tanks (241-AN-101, 241-AN-102, 241-AN-103, 241-AN-104, 241-AN-105, and 241-AN-106) were constructed by Project B-130 and Tank 241-AN-107 was constructed by Project B-170. Project planning was completed by 1976, construction was started in 1977 and completed in 1981, and the tanks were placed into service during September of 1981 (Brevick 1995b). Both projects were constructed concurrently using the same design and construction specifications, with only slight design changes between Tank AN-107 and the first six tanks. Waste is transferred to and from these tanks through a network of interconnecting underground piping and other ancillary facilities.

Lockheed Martin Hanford Corporation (LMHC) manages this facility for the U. S. Department of Energy, Richland Operations Office (DOE-RL). Chapter 173-303-640 (2) of the Washington State Department of Ecology (WDOE) Dangerous Waste Regulations, Washington Administrative Code (WAC 1998) requires the performance of an integrity assessment for each existing tank system to determine that the tank system is not leaking or unfit for use. The *Double-Shell Tank System Integrity Program Plan* (DOE 1997) provided guidelines for the assessment activities.

2.0 PURPOSE

The purpose of this integrity assessment is to evaluate the condition of the AN Tank Farm tanks and determine if they were adequately designed, with sufficient structural strength and compatibility with the waste so that they will not collapse, rupture, or fail during the facility's use. The assessment will provide conclusions and recommendations.

The following shall be considered:

- **Design Standards:** identify and evaluate the standards and requirements to which the tank system was designed and constructed.

- **Waste Characteristics:** identify the waste (past and projected) and evaluate the compatibility of the tank components with the waste.
- **Corrosion Protection Measures:** identify the material and evaluate the design and operational practices for corrosion protection.
- **Age:** document, estimate, or otherwise determine the age of the system.
- **Integrity Examinations:** identify the existing condition of each component material based on leak testing, visual examination, and ultrasonic (UT) inspection.

3.0 SCOPE

The scope of this integrity assessment is the primary steel tank and the secondary steel-lined concrete tank for the seven AN double-shell tanks. The integrity assessment of the transfer pipelines and pits associated with the AN Tank Farm is not included in this report. The assessment of these pipelines and pits was reported in *Double-Shell Waste Transfer Piping/Pit System Integrity Assessment Report* (Hundal 1997).

4.0 DESCRIPTION

The AN tanks were similar to the earlier double-shell tanks (AY, SY) and are almost identical to the AW tanks, which were constructed at about the same time. The double-shell tank design evolved with experience and with changing national design standards, but all are very similar. As shown in Figure 2, the tanks are domed cylinders with two shells: the 75-ft. diameter steel primary tank and the 83-ft. (outside diameter) steel-lined concrete shell. There is a 30-in. annular space between the tanks' cylindrical walls. The steel-lined concrete tank is about 48 ft. high from the top of the footing slab to the top of the dome. The dome is elliptical, with semi-axes of 40 ft. and 15 ft. The tank is supported by a concrete foundation pad that is 90 ft. in diameter and varies in thickness from 1 ft. to 2 ft. The tanks are on a rectangular grid with east-west and north-south center to center spacing of 107 ft.

The top of the concrete foundation has a grid of leak detection channels sloping into a central sump with a deeper channel sloping down towards the outside of the foundation. Any leakage from the bottom of the secondary tank would flow to the secondary leak detection sump. The foundation has an embedded 19.25-inch-wide bearing plate for the tank's concrete wall on which the 18-inch-thick concrete tank wall is allowed to slip to minimize thermal and shrinkage stresses in the concrete. Slippage would be limited by curbs on top of the foundation.

The secondary steel tank, generally 3/8 in. thick, lays on the foundation. It is not anchored, but analysis (Blume 1978) has shown that uplift and sliding are prevented by the soil backfill and

cover. An 8-inch-thick insulating concrete ("castable refractory") pad was poured on the secondary tank bottom, within a 3/4 -inch-thick steel ring. The primary tank bottom, which is generally 1/2 in. thick, rests on the insulating pad. The insulating pad has embedded air distribution pipes, central air distribution plenum, and radial channels on its top surface. The channels both cool the bottom of the primary tank and channel any leakage from the primary tank bottom to the primary leak detection sump in the annulus.

The steel dome of the primary tank is covered with concrete anchors ("J-bars") that are spaced about 24 in. apart to firmly connect the tank to the concrete dome. There are several penetrations through the dome providing access to the annulus and the interior of the tank. Each penetration consists of a steel pipe, varying in size from 4 in. to 42 in., penetrating through and welded to the steel plate of the dome. The pipes have welded studs for anchorage to the concrete dome.

The secondary steel tank terminates above its upper knuckle, where it is in contact with the primary steel tank. The secondary steel tank was used as the inner form for the reinforced concrete wall.

The concrete wall is approximately 37 ft. high and supports the secondary steel tank's outer surface. The top of the wall contains a heavily reinforced tension ring to support the elliptically-domed top. The dome is 15 ft. high. The outside of the primary steel tank and the portion of the secondary tank that is part of the knuckle are covered with welded concrete anchors so the concrete and steel shell are composite. There are two layers of steel reinforcement throughout the concrete dome, and a third layer in the dome's haunch. The dome was poured in two lifts, with sufficient time between pours that the first pour was self-supporting when the second was made. The concrete dome is 15 in. thick at the top and over 30 in. thick at the haunch.

4.1 DESIGN STANDARDS

The design goals were established by a Functional Design Criteria (FDC) (ARH 1975). The principal requirements were

- The tanks were to be designed to contain 1,000,000¹ gallons of aqueous, caustic, radioactive wastes having a maximum specific gravity of 2.0, a maximum temperature of 350 °F, and a heat generation rate of 100,000 BTU per hour.
- The inner steel tank was to have a design life of 50 years with a corrosion rate of 0.001 in. per year. Fatigue due to thermal cycling and liquid level fluctuations were considered.
- The design forces used for design of the primary tank are a combination of hydrostatic loading; internal pressure (-0.22 psi to 2.2 psi); heat generation within the contents and high temperature liquid; the site Safe Shutdown Earthquake; and construction loads.

¹ 1,000,000 gallons corresponds to a fill height of 30 ft. 3 in. Later analysis justified a capacity of 1,160,000 gallons, or a fill height of 35 ft. 2 in. with a specific gravity of 1.7.

- The secondary tank was to provide temporary containment in the event the primary tank leaked, as well as leak detection capability, support to the primary tank, and resistance to external forces due to soil loading. The concrete shell was to provide the structural capability to support the liner and the primary tank while the secondary steel tank provided containment. The design forces that were considered were lateral loads from the primary tank; 6.5 feet of compacted earth cover; and a uniform live load of 40 psf plus a concentrated live load of 50 tons above the tank. The design pressure and hydrostatic loads were the same as those used for the primary tank.

Construction specification B-130-C3 (Vitro 1978c) governed the tank foundations. Soil load-bearing capacity and dynamic properties were established by in-situ investigations and are contained in various reports (Blume 1976a, Udine 1956). Design of the concrete foundation was governed by the Hanford Site Design Criteria (SDC 1974), which cited the American Concrete Institute concrete code (ACI 1971) as the governing code. The foundation concrete was required to have a 28-day strength of 4,500 psi.

The steel tanks and insulating concrete were governed by design specification B-130-D1 (Vitro 1978a) and construction specification B-130-C4 (Vitro 1978b). The design specification contains the "information needed for the contractor to design and analyze the steel tanks in accordance with American Society of Mechanical Engineers (ASME) Code Section VIII, Division 2, Alternate Rules for Pressure Vessels" (ASME 1974). American Bridge Division of American Steel Corporation, the steel tank contractor, was responsible for the design and fabrication of the tanks. The following are the principal requirements of the specification:

- The tank manufacturer was to have "complete design responsibility for the structural integrity of the tanks." In order to fulfill his responsibility, the manufacturer was to submit a "complete set of stress analysis calculations establishing that the designs shown by the drawings (ERDA 1978), to be used for construction, comply with the requirements" of the design specification. The design report was to be certified by a professional engineer.
- Stress analysis techniques and allowable stress intensities of ASME Section VIII, Division 2, Appendix 1, 4, and 5 were to be used (ASME 1974). In addition to limiting stress intensity (maximum shear) to the code allowable, the maximum principal stress (maximum tensile stress) was to be limited to minimize the potential for stress corrosion. The primary tank was to be stress relieved after fabrication by internal heating to 1,100°F (Vitro 1978b).
- The primary and secondary steel tanks were to be made of ASTM A537, Class 1, (ASTM 1975b) carbon steel ordered to the requirements of ASTM A20 (ASTM 1975a) and supplementary requirement S12 (UT examination per ASTM A578 [ASTM 1975c]) with an acceptance standard level of II. This is manganese-silicon carbon steel with room temperature yield strength of 50 ksi and ultimate tensile strength of 70 ksi. Welding materials were to be certified in conformance with ASME Section II, Part C, and have a tensile strength not less than that of the base material.

- In addition to the requirements of the FDC (ARH 1975), the design and construction specifications provided the liquid level fluctuations, the number and size of thermal cycles, temperature gradients, the method of analyzing hydrodynamic loads (sloshing), and the displacement of the tank's attachment point on the dome.
- The tanks were to be hydrostatically tested by being filled with water to a depth of 35 ft. for 24 hours.

Construction specification B-130-C5 (Vitro 1978d) governed the construction of the concrete tank shells and specification B-130-C6 (Vitro 1978e) governed backfilling around the tanks. Vitro Engineering, a Hanford Site Architect/Engineer, maintained overall responsibility for the design of the concrete shell. John A. Blume Engineering (JABE) was the seismic analysis subcontractor for the AN Tank Farm and they provided several design reports demonstrating the adequacy of the design to meet the design requirements. JABE engaged Dr. Y. R. Rashid to perform a thermal-creep analysis of the secondary tank, using reduced concrete strength, creep strain, and non-linear analysis of the effects of cracking. The Hanford Site design standards in effect at the time (SDC 1974) imposed the ACI 318 (ACI 1971) concrete code for reinforced concrete structures, required the ultimate strength method of design, and required certain load combinations to be considered.

4.2 WASTE CHARACTERISTICS AND COMPATIBILITY

The design operating specifications for AN tanks (Vitro 1978a) include the following temperature requirements:

- Temperature

Vapor	212 °F
Immersed regions	350 °F

 A 30-in. temperature transition region at the liquid/vapor interfaces was defined.
- "The primary tank will have a maximum of two complete thermal cycles (70°F to 350°F and back to 70°F). At the completion of the second thermal cycle, the primary tanks will be permitted to heat to 350°F and will cycle between 350°F and 275°F until the end of their useful life."

Except during the stress relief process (Vitro 1978b), none of the tanks have exceeded 150°F.

The tank farm technical specifications (Kirch 1984) are based on laboratory corrosion tests at temperatures up to 356°F (180°C).

All tanks were filled with untreated process water for approximately a week during hydrotesting. They were then drained, though a small heel remained; plywood was laid on the bottoms of the tanks while the final work was completed. During this wet lay-up, some corrosion occurred and is documented for AN-107 (Divine 1980).

The tanks first received aging waste in 1981 (Brevick 1995b); each of the tanks has had a slightly different waste history. Waste descriptions, past and future, are described below in Table 1. Based on forecasts by Kirkbride et al (Kirkbride 1999), the AN tanks are proposed to be source or staging tanks for the vitrification process beginning around 2005-2018.

Table 1 Tank Composition History and Forecast

AN-101	
Past Waste Descriptions	<p>The initial waste into AN-101, in 1981, was non-complexed from PUREX. Non-complexed waste was transferred in and out until 1990 when it began receiving low-level waste from B Plant, decontamination waste from N Reactor, and dilutes non-complexed waste from more than 30 200-East Area single-shell tanks. The tank is a dilute receiver that currently receives non-complexed saltwell waste (Brevick 1995a) (Benar 1996).</p> <p>It contains less than 0.1 wt. % organics and complexants.</p>
Projected Future Waste	<p>According to Strode and Boyles (Strode 1998), AN-101 will receive dilute non-complexed waste and saltwell liquid until the end of 2000. After that point it should receive double-shell slurry feed that will be processed in about 2010/2015. Kirkbride et al (Kirkbride 1999) shows that the tank may be empty in 1999/2000 but refilled in stages by 2018.</p>
Safety Considerations <ul style="list-style-type: none"> • Corrosion • Flammability • Waste Compatibility • Criticality 	<p>Based on the work of Hu (Hu 1997) and Divine et al (Divine 1985), corrosion is not a significant consideration at this time. Hu also notes that, based on theoretical calculations, insufficient hydrogen is generated to be of concern even if active ventilation ceases; there is no suggestion there are field measurements that show concern. The current waste is compatible on the bases of criticality, flammability, compatibility, and corrosion (Blaak 1998) (Benar 1996).</p>

Table 1 Tank Composition History and Forecast (continued)

AN-102	
Past Waste Descriptions	<p>AN-102 began service in 1981 with the receipt of non-complexed waste from SY-102. It continued to receive non-complexed waste through 1982. In 1983, it received complexant concentrate waste and then non-complexed waste until mid 1984. In early 1984, it received low-level waste from PUREX followed by more complexant concentrate through 1992. It has not received further waste since then (Brevick 1995a).</p> <p>It contains less than 2 wt. % organic material.</p>
Projected Future Waste	<p>According to Strode and Boyles (Strode 1998) and Kirkbride et al (Kirkbride 1999), AN-102 will continue to contain its complexant concentrate until about 2006/2008 when it will be processed.</p>
Safety Considerations <ul style="list-style-type: none"> • Corrosion • Flammability • Waste Compatibility • Criticality 	<p>Based on the work of Hu (Hu 1997), corrosion is not a significant consideration at this time. The work of Divine et al (Divine 1985) suggests the corrosion rate is in a region of increasing concern but still well below the design limit of 1 mpy (0.001 inch/y). Hu also notes that, based on theoretical calculations, sufficient hydrogen is generated to be of concern in about three months if active ventilation ceases; Lambert (Lambert 1998) reports compatibility based on the flammability, waste compatibility, and criticality criteria. His reported concentrations differ slightly from the data in Table 2, but do not change the above corrosion results.</p>

AN-103	
Past Waste Descriptions	<p>AN-103 began service in 1981 with the receipt of non-complexed waste from SY-102, which continued into early 1984. In addition, in 1983, the tank received low-level waste from B Plant and dilute non-complexed waste from the 200 East Area single-shell tanks. For two years in 1984 and 1986, it received double-shell slurry waste. Since that time it has only contained double-shell slurry other than some wash water. It is inactive and a concentrated waste holding tank (Brevick 1995a).</p> <p>It contains approximately 3 wt. % organic material.</p> <p>The tank is on the Hydrogen Watch List.</p>
Projected Future Waste	<p>According to Strode and Boyles (Strode 1998) and Kirkbride et al (Kirkbride 1999), AN-103 will maintain its existing double-shell slurry through 2000 with processing beginning around 2003/2006.</p>
Safety Considerations <ul style="list-style-type: none"> • Corrosion • Flammability • Waste Compatibility • Criticality 	<p>Based on the work of Hu (Hu 1997) and Divine et al (Divine 1985), corrosion is not a significant consideration. Hu also notes that, based on modeling and field measurements, insufficient hydrogen is generated from radiolysis to be of concern even if active ventilation ceases. These numbers are based on undisturbed waste. If the waste were to turn over or be disturbed by the insertion of probes or other devices, there could be a sudden release of flammable gas. This is discussed and control methods (control of ignition sources and monitoring) are described by Noorani et al (Noorani 1998).</p>

Table 1 Tank Composition History and Forecast (continued)

AN-104	
Past Waste Descriptions	<p>AN-104 began service in 1981 with the receipt of non-complexed waste, mostly from AW-102, which continued through 1982. Since late 1982, the tank has contained double-shell slurry feed waste. In late 1983, it also received some low-level waste from PUREX. It has not received waste since 1985. It is an inactive concentrated waste holding tank (Brevick 1995a).</p> <p>It contains approximately 2 wt. % organic material.</p> <p>The tank is on the Hydrogen Watch List.</p>
Projected Future Waste	<p>According to Strobe and Boyles (Strobe 1998) and Kirkbride et al (Kirkbride 1999), AN-104 will maintain its current double-shell slurry inventory through 2000. It is expected that the slurry will be processed beginning in 2001/2006, depending on the final operating plan selected.</p>
Safety Considerations <ul style="list-style-type: none"> • Corrosion • Flammability • Waste Compatibility • Criticality 	<p>Based on the work of Hu (Hu 1997) and Divine et al (Divine 1985), corrosion is not a significant consideration unless the waste is diluted. Hu also notes that, based on field measurement, insufficient hydrogen is generated from radiolysis to be of concern even if active ventilation ceases. Theoretical modeling suggests that sufficient hydrogen is generated to be a concern if active ventilation ceased for about two years. These numbers are based on undisturbed waste. If the waste were to turn over or be disturbed by the insertion of probes or other devices, there could be a sudden release of flammable gas. This is discussed and control methods (control of ignition sources and monitoring) are described by Noorani et al (Noorani 1998).</p>

Table 1 Tank Composition History and Forecast (continued)

AN-105	
Past Waste Descriptions	<p>AN-105 began service in 1981 with the receipt of non-complexed waste, which continued until late 1982. It then received double-shell slurry feed waste from AW-102 and AN-104 until 1985 when the receipt of waste ceased. It is an inactive concentrated waste holding tank (Brevick 1995a).</p> <p>It contains approximately 2.5 wt. % organic material:</p> <p>The tank is on the Hydrogen Watch List.</p>
Projected Future Waste	<p>According to Strode and Boyles (Strode 1998), one option for AN-105 is to maintain its existing double-shell slurry through 2000 for processing in 2001. Beginning in about 2002, it would be expected to receive dilute waste from various 200 East Area sources, including AN-101, AW-105, AP-106, and AP-108. The other option is to maintain its existing double-shell slurry feed until 2006/2007 when it would be processed.</p>
Safety Considerations <ul style="list-style-type: none"> • Corrosion • Flammability • Waste Compatibility • Criticality 	<p>Based on the work of Hu (Hu 1997), corrosion should not be a significant consideration. Based on the waste compositions shown in Table 2 and the work of Divine et al (Divine 1985), the corrosion rate in the bulk waste will be negligible. However, a nondestructive examination (Jensen 1999e) suggests minor wall thinning has occurred in a portion of the tank. Anantamula (Anantamula 1999) attributes this corrosion to vapor space corrosion and associated pitting. Posakony et al (Posakony 1999) confirms that the measurements show a thinning in one region. Based on work done in the single-shell tanks in the 1940s, as reported by Divine and Carlos (Divine 1992), the worst case pitting rates over phosphate waste, pH 7-8, was only about 12 mpy. Similar values were reported by Chang (Chang 1998) in the annulus region of waste tanks at the West Valley site. At present, it is uncertain whether the observed corrosion is real or is an artifact present from construction. No clear explanation is available unless extremely low pH waste was present.</p> <p>Hu also notes that, based on field measurement, insufficient hydrogen is generated from radiolysis to be of concern even if active ventilation ceases. Theoretical modeling suggests that sufficient hydrogen is generated to be a concern if active ventilation ceased for about five months. Jo et al (Jo 1997) confirms that there are no criticality, flammability, or energetics concerns. These numbers are based on undisturbed waste. If the waste were to turn over or be disturbed by the insertion of probes or other devices, there could be a sudden release of flammable gas. This is discussed and control methods (control of ignition sources and monitoring) are described by Noorani et al (Noorani 1998).</p>

Table 1 Tank Composition History and Forecast (continued)

AN-106	
Past Waste Descriptions	<p>AN-106 began service in 1981 with the receipt of water from Tank AN-101. Then in 1983, it received concentrated phosphate waste and non-complexed waste from AW-102 as well as concentrated customer waste. In 1984, it received a small amount of unknown waste. From 1984 until 1990, it contained Hanford facility waste (Brevick 1995a). Then in 1993, waste was transferred from AN-106 to AP-102 and in 1994, double-shell slurry feed waste was transferred from AW-106 to AN-106. (Douglas1996)</p> <p>It contains much less than 0.1 wt. % organic material.</p> <p>The temperatures over the four-year period, through June 1994, from PCSACS, have averaged about 75 °F with a maximum of about 80 °F.</p>
Projected Future Waste	<p>According to Strode and Boyles (Strode 1998), AN-106 will add concentrated phosphate waste to the current liquid complexant concentrate. The waste would be processed in about 2006. Kirkbride et al (Kirkbride 1999) show that the tank could be emptied in 1999/2000 but refilled in stages by 2018.</p>
Safety Considerations <ul style="list-style-type: none"> • Corrosion • Flammability • Waste Compatibility • Criticality 	<p>Based on the work of Hu (Hu 1997) and Divine et al (Divine 1985), corrosion is not a significant consideration unless additional nitrate is added without a compensating amount of hydroxide and nitrite. Hu also notes that, based on theoretical calculations, insufficient hydrogen is generated to be of concern even if active ventilation ceases.</p>

AN-107	
Past Waste Descriptions	<p>AN-107 began service in 1981 with the receipt of non-complexed waste from AN-102; this continued until mid-1983. Since then, the tank has contained complexant concentrate waste, most of which was received from AZ-102 during late 1983. It has not received any waste since late 1986 and is considered inactive and a concentrated waste holding tank. (Brevick 1995a)</p> <p>It contains approximately 3.1 wt. % organic material.</p>
Projected Future Waste	<p>According to Strode and Boyles (Strode 1998), AN-107 is expected to have caustic added in 2000 to adjust the free hydroxide concentration, but will otherwise maintain its current complexant concentrate waste until about 2005/2006 when it will be processed. It is expected to contain double-shell slurry feed thereafter until about 2016.</p>
Safety Considerations <ul style="list-style-type: none"> • Corrosion • Flammability • Waste Compatibility • Criticality 	<p>Based on the work of Hu (Hu 1997), corrosion is not a significant consideration. Based on Divine et al (Divine 1985), the tank is in a region of increasing corrosion rate though it appears well less than the design limit of 1 mpy (0.001 inch/y) and not within the region of enhanced stress-corrosion cracking. Pfluger (Jensen 1999a) has reported that UT thickness measurements found no wall thinning or pitting that exceeded the evaluation criteria. Blackburn (Blackburn 1990) was unable to show that stress-corrosion cracking would occur though he believed the risk was greater than if the tank were within specification. Hu also notes that, based on theoretical calculations, sufficient hydrogen is generated to be of concern in about six weeks if active ventilation ceases; there are field measurements that show no hydrogen present (Jo 1996). The current waste is marginally compatible with the tank material. Based on Jo et al (Jo 1996), there are no flammability or criticality concerns. The waste is exothermic but there is no explosion hazard.</p>

Not all tanks have had safety compliance analyses performed because they are not currently candidates for waste transfer. However, Mulkey (Mulkey 1998) has noted that any waste transfer will require a compatibility assessment.

In addition to any above noted observed compliance with the safety considerations, including corrosion, a more detailed corrosion evaluation follows. Average anion data, Table 2, the chemical species critical to compatibility of the waste with the tanks, have been taken from the Hanford files and abstracted from the noted documents. These data have been evaluated using the relationships developed by Divine et al (Divine 1985). The tanks are in general compliance with the corrosivity requirements as noted in Table 1.

Table 2 Tank Anion Content and Temperatures

	NO ₃ ⁻ mol/L	NO ₂ ⁻ mol/L	OH ⁻ mol/L	PO ₄ ⁻³ mol/L	SO ₄ ⁼ mol/L	AlO ₂ ⁻ mol/L	Organic mol/L	T ^{#, a} °F
AN-101 ^b	1.27	0.85	1.57	0.02	0.02	0.52	0.01	66.4, 82
AN-102 ^{c, d}	3.68	1.88	0.12	0.06	0.15	0.55	0.01	90.7, 104
AN-103 ^{e, f}	2.14	2.96	5.84	0.01	0.01	1.17	0.04	103.7, 150
AN-104 ^g	2.84	2.76	4.12	0.03	0.02	1.42	0.01	91.8, 107
AN-105 ^{h, i}	2.66	2.70	3.44	0.01	0.01	na	0.02	96.0, 129
AN-106 ^j	1.06	0.38	1.11	0.02	0.06	0.12	0.09	72.4, 113
AN-107 ^k	3.83	1.47	0.097	0.03	0.1	0.03	0.01	91.8, 107

a - Brevick 1995a; b - Esch 1996a; c - Esch 1996b; d - Esch 1999a; e - Steen 1997a; f - Esch 1998a; g - Steen 1997b; h - Steen 1997c; i - Esch 1998b; j - Douglas 1996; k - Esch 1999b

Temperatures are average and maximum service values respectively.

Data from Hu (Hu 1997) for the nitrate and nitrite concentrations vary slightly from the data shown in the table, but do not change the conclusions.

4.3 CORROSION PROTECTION

The corrosion protection is provided by design (selection of materials) and construction procedures (heat treatment) (Vitro 1978a) and administrative controls (Kirch 1984). There are no cathodic protection of the internal structures and no intended cathodic protection of the exterior of the secondary tank or rebar. The protective features are discussed in the following paragraphs.

4.3.1 Corrosion Degradation Considerations

Several corrosion or degradation mechanisms were identified by an expert panel (BNL 1997) and are listed below:

- General (uniform) corrosion

- Pitting and crevice corrosion
- Stress-corrosion cracking
- Microbiologically-influenced corrosion
- Concentration cell or waterline corrosion
- Fatigue
- Erosion and erosion corrosion
- Wear
- Hydrogen embrittlement/Hydrogen-induced cracking
- Thermal embrittlement
- Radiation embrittlement
- Creep and stress relaxation

In addition, radiation- enhanced corrosion and atmospheric corrosion must be examined.

Of these, only the first four plus atmospheric corrosion are of concern. The remaining eight mechanisms plus radiation enhanced corrosion would, if applicable, mainly affect the primary tank. They are briefly described and then readily eliminated.

- **Concentration cell and waterline corrosion** has been considered a possible problem. However, Zapp (Zapp 1992) has noted that unless the pH of the bulk waste is less than 9.5, there is no significant effect. Escalante (Escalante 1992) observed in his work that the waterline or meniscus region tends to be cathodically protected by the bulk waste.
- **Fatigue** is typically a concern only when the number of operating cycles exceeds about 1,000. According to the design documents (Vitro 1978a), the expected number of operating cycles, during the entire life, are less than 1,000. Further, Schwenk and Scott (Schwenk 1996) have shown that the combination of system chemistry and the less severe operational cycling make fatigue corrosion insignificant.
- **Erosion and erosion corrosion** were discussed by Smith and Elmore (Smith 1992). They observed little effect even when high velocity pumps were used to mix the waste. In normal operation, the flows are too slow to be of concern.
- **Wear** is the degradation of the metal surface by motion against another surface. If the two surfaces are of the same composition, the wear is usually called fretting. There are two main locations where wear might occur: a) the lower surface of the bottom of the primary tank where it is in contact with the insulating concrete, and b) the region where the primary and secondary tanks meet at the top. The driving force for the motion is thermal expansion. As with fatigue, the number of temperature cycles is small so the amount of movement will be minimal. Though damage is visible after one cycle, it is not severe on iron even at 300,000 cycles (Davis 1987). Similar wear effects on the secondary tank are ignored because of the lower temperature differentials.
- **Hydrogen embrittlement and hydrogen-induced cracking** have not been observed in metals with strengths less than about 75 ksi (Davis 1987).
- **Thermal embrittlement** also does not occur at temperatures at or below the design temperature; there is essentially no diffusion of carbon in the metal (Bardes 1987).

- **Radiation embrittlement**, induced by high neutron fluxes, is not of concern in the tanks, because, unlike nuclear power plants, they generate essentially no neutrons and those produced, are rapidly thermalized by the aqueous solutions (Davis 1987).
- **Creep and stress relaxation** are high temperature (e.g., greater than about 500°F) phenomena. Again, according to the design documents (Vitro 1978a, Vitro 1978b), the design temperature is only 350°F. For A537 steel, there is little creep at temperatures up to the design value (Bardes 1987).
- **Radiation-enhanced corrosion** has been observed in neutral pH systems when the gamma dose rate exceeds 10^3 R/h (Davis 1987). Similar results were found by providing hydrogen peroxide. Because of the high alkalinity of the waste and the presence of the nitrite, no significant radiation effect is expected in the double-shell tanks.

The remaining five topics that are of potential concern can affect either of the tanks or, in some cases, the concrete.

- **General (uniform) corrosion** in the liquid waste is a function of the waste composition. When the waste composition is maintained within the technical specifications (Kirch 1984), the corrosion rate is expected to be less than about 0.0005 in. per year (Divine 1985).

In general, the corrosion of the exterior of the annulus will be small because it is in contact with concrete. Local exceptions may occur if rainwater has penetrated between the concrete and the steel and reduced the pH. Corrosion of steel in Hanford soil tends to be approximately 0.006-0.008 in. per year (Jaske 1955) with some pitting.

- **Pitting and crevice corrosion** is not expected to occur in the tanks that are maintained within the corrosion specifications (Kirch 1984). However, in dilute simulated wastes, severe localized corrosion was observed (Divine 1985). These values are excluded by the corrosion specifications.

No pitting is expected on the annulus.

It is not believed that significant corrosion occurred during construction and, more specifically, during and after hydrotesting. Divine (Divine 1980) examined the interior of AN-107 and determined that some pitting, less than 0.03 in., had occurred and that may have included the thickness of the mill scale present. At the Savannah River Site, pitting on the floor of the primary tank was observed during the wet lay-up as described below under microbiologically-influenced corrosion (Ondrejcin 1981).

- **Stress-corrosion cracking** of carbon steel waste tanks has been observed. Tank 16, a Savannah River Site Type II tank (the secondary tank is a 5-ft. high "pan"), went into service in May 1959. By November 15, 1959, crystallized waste was observed in an annulus inspection to be protruding from the exterior surface of the primary (Poe 1974). The cause was attributed to nitrate-induced cracking.

The general corrosion literature notes that caustic cracking can occur if the steel is stressed and the temperature exceeds 140°F (Davis 1987). In his work, Divine (Divine 1985) noted

that caustic cracking of U-bends occurred at 140°F in concentrated caustic solutions or in dilute environments. In both cases, the **damaging** concentrations are outside the limits given by the corrosion specifications (Kirch 1984).

Because of its low operating temperature, the **secondary tank** should be immune to caustic cracking even in contact with the concrete.

- **Microbiologically-influenced corrosion** usually occurs in neutral pH water but can occur under extremes of pH and temperature. The most likely scenario is for microbiologically-influenced corrosion to initiate during the hydrotest period. It is estimated that water remained in the tanks for about four to six weeks because it was used as a means of support for fresh poured concrete dome loads (ABD 1977b). Then, a small heel of water remained and plywood was put down to protect the tank. During this period and the wet lay-up time, microbiologically-influenced corrosion could have started (some corrosion was noted during construction, as noted in the discussion of pitting). It is unknown whether the temperatures, radiation, or tank chemistry would sterilize the system.
- **Atmospheric corrosion** will be prevalent in all locations and is expected to be more severe inside the tanks. Corrosion of carbon steel in the liquid waste at the West Valley Nuclear site in New York amounted to less than 0.001 in. per year, a value comparable to that at Hanford (Chang 1998). In the vapor space above the West Valley waste, however, the corrosion rate was approximately 0.004 in. per year.

The basic atmospheric corrosion rate in the annulus is expected to be low because the relative humidity is low at Hanford; typical corrosion rates are estimated at about 0.0003 in. per year. Due to the radiation field in the annulus, formation of nitric acid from humid air is feasible. However, based on an average humidity of about 55% over the year (Hoitink 1998) and the average radiation field in the annulus (Hu 1997), the estimated annular atmospheric corrosion rate is negligible.

4.3.2 Corrective measures

Only one intentional corrective measure for corrosion control is specified for out of specification tanks (Mulkey 1998): to adjust the chemistry to within specified values.

4.4 AGE OF THE SYSTEM

The design life of the double-shell tanks was 50 years. The farm went into operation in the middle of 1981 (Brevick 1995b), so it now **has been** in service for 18 years (in 1999).

4.5 INTEGRITY EXAMINATIONS

4.5.1 Leak Test

The primary tanks were leak tested after the post-weld heat treatment. Filling the tank with water to a height of 35 ft. and inspecting all accessible joints after 24 hours (Vitro 1978b) performed the leak test. The joints were coated with chalk prior to filling the tank to make leaks easier to detect. No leaks were reported in the construction files.

Once the tanks were placed into service, the primary tank leak detection system, having liquid detection and airborne-radiation detection capability, was monitored; no leaks have been detected.

The principal leak detection method is the daily monitoring of fixed-height and variable-height conductivity probes that detect the presence of liquid. The fixed height probes are adjusted to 1/4 in. above the floor of the secondary tank floor and function-tested at least every 182 days (FDH 1999a). If the insulating concrete absorbed none of the leakage, a leak of less than 100 gallons from the primary tanks could be detected. It should be noted that function testing involves pouring water down the conductivity probe, which can partly explain evidence of past liquid puddles on the tank floor under the probe.

Continuous Air Monitoring (CAM) is currently a supplementary leak detection system. Exhaust airflow is continuously sampled for radiation and an alarm condition occurs if the radioactivity level (counts per minute) rises to a predetermined setpoint. If an alarm occurs, the CAM's paper filter is read to determine the cause.

The leak detection systems are monitored daily and the results are reviewed and recorded (FDH 1999b). No leaks have been detected.

4.5.2 Visual Examinations

Video tapes of the portions of the AN tanks visible from two risers in the annulus were examined for visible cracks, potential leak sites, and other physical impairments by trained engineers. The examination method was tested and an acceptance report (Sumsion 1992) written prior to the examination, and the visual resolution met ASME standards for visual examinations (ASME 1989). Approximately 18% of the outer surface of the primary tanks and 30% of the inner surfaces of the secondary tanks were viewed using remotely-controlled video cameras lowered into the annulus (Walter 1993). Manned entry is not feasible due to the high radiation levels encountered (50 R/hr for AN-102). This visual examination found no indications of primary steel shell tank leakage.

Rust was noted over many areas of both tanks, with more observed on the secondary tank wall than on the primary. Some areas where condensation had gathered in the past were observed and

no liquid was noted. There was a water stain caused by a previous puddle under a leak detection sensor, but no source was attributed in the visual examination report. It was noted in the Leak Detection section of this report, however, that testing the conductivity probe leak detection system involves pouring water down the sensor to simulate a leak.

Two tanks in the AP Tank Farm were internally examined using similar video equipment (Anantatmula, 1997) and no significant indications were noted. The two tanks were chosen because they contained very low waste volumes, exposing large areas of the tank wall. The significance for the integrity assessment of the SY tanks is that conditions in the tanks that were examined favor atmospheric (or vapor phase) corrosion, and the only indications of this were minor.

4.5.3 Ultrasonic Examinations

In May 1996, the Tank Waste Remediation System Decision Board recommended and DOE-RL agreed that the condition of the double-shell tanks should be determined by UT examination of a limited area in six of the 28 double-shell tanks. The Washington State Department of Ecology (WDOE) has agreed that with the strategy of limited UT examination of six double-shell tanks (DOE 1997). Data collected during the UT examinations was used to assess the condition of all 28 tanks. Portions of the primary tank wall of all six selected tanks were examined, and portions of the secondary steel liners of three of these six tanks were also examined.

The UT examinations of the six double-shell tanks were completed between November 1996 and June 1999 according to the following schedule:

TANK	DATE
AW-103	11/24/96 (Leshikar 1997)
AN-107	4/9/98 (Jensen 1999a)
AZ-101	5/28/99 (Jensen 1999e)
AY-102	6/4/99 (Jensen 1999d)
AN-105	6/15/99 (Jensen 1999b)
AN-106	6/22/99 (Jensen 1999c)

UT examinations were performed on secondary liners in three tanks: AW-103, AN-105, and AN-107. A vertical strip of wall was examined in Tank AW-103, the lower knuckle was examined in AN-107, and the liner floor was examined in Tanks AN-105 and AN-107. See the individual UT reports listed in Table 3 for the specific areas examined in each double-shell tank. No reportable levels for thinning, cracking, or pitting were found in any of the steel liners.

Six double-shell tanks were selected for UT examination of primary steel tanks based on several factors relating to their design and operating history. These included plate material, waste level and chemistry history, waste physical characteristics, waste temperature, and tank age (Schwenk and Scott 1996). Each known or suspected corrosion mechanism for these steels when exposed to waste environments was considered and four observable conditions were defined that could be detected and measured by the UT equipment. Table 3 lists the main reasons each tank was selected for UT examination and the observable corrosion condition(s) considered "most favored" by that tank's design and operating history.

The areas of each tank that were examined generally conform to the Engineering Task Plan (Pfluger 1999), and are shown schematically in Figures 3, 4, and 5. The examinations concentrated on the vertical wall region of the primary tank that is comprised of four or five courses (rings) of welded plates. The plate thickness is constant for each course, but is greater for the lower courses. The range of plate thickness is not the same for all double-shell tank farms. Generally, two vertical 15-inch-wide by full-height (35 feet) strips were examined as well as 20-ft. lengths of both horizontal and vertical welds in the lower region of the tank. Additional horizontal strips were examined on Tank AN-105 due to the thinning detected in the second plate on that tank. In addition, some primary tank lower knuckles and tank bottoms (above the ventilation slots) were examined. The secondary liner was examined in three tanks. The P-Scan UT inspection system that was used examined the full-thickness volume of the steel plate comprising the tank wall to detect and quantify wall thinning, pitting, and cracking. Reportable levels were 10% of thickness for thinning, 25% of thickness for pitting, and a crack with a depth of 0.18 inches.

The equipment, procedures, and personnel were qualified to the requirements of Sections V and XI of the ASME Code as described in the examination report for AW-103 (Leshikar 1997) and a demonstration was conducted on a full-size tank section mock-up. The mechanical UT scanner was housed in a remotely-controlled crawler to provide a 15-inch-wide scan path as the crawler advanced in a straight path along the primary tank wall. Water was used as the UT couplant. The electronic data was continuously transmitted via cables to a data acquisition trailer deployed at the site. The data report that was generated for each tank was reviewed independently by two experts and approved by a Level III UT Inspector. A formal report was then issued.

The results of the UT examinations of primary tanks are summarized in Table 4 along with the regions of each tank examined. The detailed descriptions of areas examined for each tank are contained in the individual reports. There were no reportable cracks found in any of the six tanks. There was no reportable localized pitting or waterline attack found in any of the six tanks. There was reportable thinning only in two small areas of AN-105, located in the second ring down from the top knuckle. There was no reportable thinning for the other five tanks examined.

TABLE 3. Six Tanks Selected for UT Examination. (Pfluger, 1999)

Tank Number	Main Reason for Selection							Corrosion Condition Favored					
	Tank Age	Waste Temp	Low Inhibitor Levels	Abnormal Operation			Static Waste Height	Tank Steel	Other Chem. Species Cracking	General Corrosion (Thinning)	Pitting	Water-line Attack	Stress Corrosion Cracking
				Sludge Levels	H ₂	Changing Waste Height							
AW-103		X		X						X			
AN-107			X								X		X
AZ-101	X	X					X	X		X	X	X	X
AY-102	X	X					X	X		X			X
AN-105					X		X					X	
AN-106									X				X

TABLE 4. Summary of Primary Tank UT Examination Results.

Tank Number	Area Examined (see the referenced ultrasonic inspection reports for details)						Summary of Results			
	Plate Material						Reportable Thinning (>10% thickness)	Reportable Pitting (>25% thickness)	Reportable Waterline Attack ¹	Reportable Cracking (>0.18 in)
	Vertical Wall	Lower Knuckle	Tank Bottom (slots)	Lower Knuckle Weld	Lowest Vertical Weld	2 nd -lowest Vertical Weld				
AW-103	X						no	No	no	no
AN-107	X	X	X	X	X	X	no	No	no	no
AZ-101	X			X	X	X	no	No	no	no
AY-102	X			(3)	X	X	no	No	no	no
AN-105	X	X		X	X	X	yes ²	No	no	no
AN-106 ⁴	X			X	X	X	no	No	no	no

1) Reportable level depends on geometry of observed attack.

2) Second ring from top showed general thinning <10% with two very small areas up to 20%. Top ring also showed general thinning <10% (Jensen 1999b).

3) An attempt was made to inspect the lower knuckle weld, but due to concrete spatter at this location, it could not be inspected. However, in lieu of this lower knuckle weld, the horizontal weld between the next course of plates above the knuckle was inspected. See the UT report for 241-A-Y-102 (Jensen 1999d).

4) Tank AN-106 replaced AY-101 tank. Inspection of AY-101 failed because the crawler was unable to maintain contact with the primary tank wall. A build-up of unidentifiable scale, rust product, and apparent regions of concrete spatter caused poor contact between the crawler wheels and the tank wall.

5.0 CONCLUSIONS

Based on the evaluations of the design standards, the waste characteristics and compatibility with the tank material, the corrosion protection, the age of the tanks, and the integrity examinations, the 241-AN tanks are not leaking and are fit for continuous use. Recommendations made in Section 6.0 will ensure the continued safe operation of the facility.

5.1 DESIGN STANDARDS

Design loads and temperatures for the AN Tank Farm were developed using experience with the earlier double-shell tank farms and the single-shell tanks. The AN Tank Farm was designed using nationally recognized codes and standards, and the design reports included sufficiently detailed analysis to demonstrate that the design objectives were met. A registered engineer certified that the stress limits of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 2 were met for the loads specified by the design specification (ABD 1977a). There were quality assurance programs in place during construction that included deficiency reporting, material certifications, inspection and testing, and auditing. It can be concluded from this that the seven AN tanks were adequate to meet the requirements when they were put into service.

In addition to the design reports during construction (ABD 1977a, Blume 1978, Blume 1981), several more recent reports have been prepared concerning double-shell tank analysis. These are summarized in *241-AW/AN Analysis Documentation Review* (Scott 1998) and referenced in the "Basis for Interim Operation" (Noorani 1998) that demonstrated the safety of the tank farms. Of particular interest is a 1994 report, *241-AW/AN Waste Storage Tanks - Supplemental Gravity Load Analysis* (WHC 1994), which analyzed the effect of increased soil density and fill height above the dome. This analysis duplicated the JABE finite element analysis (Blume 1981) with increased loads due to an increase of soil backfill height and density, and higher surface loading, and found adequate margins of safety. While non-linear effects due to cracking and creep were not considered, the concrete temperature has not been high enough for this to be a concern.

The maximum content temperature noted in Section 4.2 were 150°F, significantly below the design temperature (350°F). A more recent nuclear concrete code (ACI 1985) states that high temperature effects need be considered only at temperatures above 150°F. Since the concrete temperature will be less than the content temperature due to the temperature of the surrounding soil and airflow through the annulus, it can be concluded that the design basis temperature is adequate. As an example of the conservatism in this issue, the design report (Blume 1976b) considered a concrete compressive strength of 4,500 psi at 70°F and 2,763 psi at 350°F. The concrete strength that was specified for the

AN tanks was 5,000 psi. Additionally, the design specification (Vitro 1978a) states that the high design temperature was to accommodate a high temperature evaporation process that was never installed, so the design temperature will probably not be imposed on the AN tanks.

Even if concrete temperatures were to rise significantly, there is considerable data available for concrete in general, and Hanford concrete in particular, to show that the original temperature effects evaluation are adequate.

Construction records are available in the project files contained in Hanford records holding system. Material certifications and shop drawings show that the design was followed, and adequately reconciled when differences occurred.

One difference between the as-built tank and the design drawing is that the primary steel tank is constructed of 1/2-inch-thick plate up to the tank's upper knuckle (ABD 1977c). The design drawing called for a wall thickness of 3/8 in. in the top course. This may have been to accommodate the increase in the tank capacity to 1,160,000 gallons that occurred during the construction of the AW and AN tank farms (Blume 1981).

Section 3341 of specification B-130-C4 required insulating concrete to meet ASTM standard C401 (ASTM 1970) for castable refractory material and to have a minimum compressive strength of 130 psi. The insulating concrete was Combustion Engineering Lite Wate #70, produced by the Pryor - Giggy Company. Testing by the Battelle Pacific Northwest Laboratories, in the construction records, indicated a compressive strength, both dry and saturated, of over 1,200 psi.

5.2 WASTE CHARACTERISTICS AND COMPATIBILITY

Most of the wastes contained within the tanks meet the Hanford corrosion specifications (Kirch 1984) and therefore are compatible with the steel tanks. AN-107 is outside the permitted limits, but has not moved into a region of high corrosion rate; its waste is considered marginally compatible with the tank. Future wastes are also expected to meet these specifications.

The secondary tank is designed for a maximum of one week in contact with the waste to eliminate the chance for stress-corrosion cracking (Vitro, 1978a).

5.3 CORROSION PROTECTION

As described in Section 4, several corrosion concerns were examined:

- General (uniform) corrosion

- Pitting and crevice corrosion
- Stress-corrosion cracking
- Microbiologically-influenced corrosion
- Concentration cell or waterline corrosion
- Fatigue
- Erosion and erosion corrosion
- Wear
- Hydrogen embrittlement/Hydrogen-induced cracking
- Thermal embrittlement
- Radiation embrittlement
- Creep and stress relaxation
- Radiation-enhanced corrosion
- Atmospheric corrosion

The last nine failure mechanisms in the list were readily eliminated in Section 4.3.1 as being insignificant or inapplicable to the tanks. The first five are of potential concern and evaluated in more detail. None were found to be of critical importance.

Atmospheric corrosion of the steel in the internal dome region is expected to be higher than that of the steel submerged in the liquid. The actual rate of corrosion is a function of the relative humidity and the ammonia concentration and cannot be calculated but must be evaluated by nondestructive techniques.

Uniform corrosion rates in the tank, under the liquid are expected to be small as are the rates in the annular space and on the exterior of the secondary tank. However, if rainwater has penetrated the concrete and reached the secondary tank, relatively high, but unknown, corrosion rates could be attained on the outside of the secondary. Nevertheless, these rates are not expected to impact the allowed one-week exposure time (Vitro 1978a) of the secondary containment to the waste, which is only applicable if the primary fails catastrophically by cracking. Catastrophic failure of the primary tank by corrosion is not probable.

Pitting and crevice corrosion during operation is not important when the waste is maintained within the technical specifications. There is a slight possibility of pitting on the exterior of the secondary tank, but even at the maximum forecast pitting rate, it will not impact the effectiveness of the secondary to contain leaks.

Stress-corrosion cracking has been shown to be of minor significance because of heat treatment of the primary and because of the waste chemistry. Further, experience at Savannah River shows that if the tank cracks, the waste is likely to plug the crack. Therefore, catastrophic failure is not likely.

Microbiologically-influenced corrosion at this time is not a significant concern. Most effects of microbiologically-influenced corrosion occur within a few weeks or months

and the most hazardous period was during the hydrotesting of the tanks nearly 20 years ago.

Waterline corrosion has been discounted when the bulk waste pH is greater than 9.5.

No corrective action has been proposed for any potential corrosion problem except for adjusting the waste chemistry (Mulkey 1998).

5.4 FACILITY AGE

The tanks have been in service for 18 years (in 1999); the design life, based on the corrosion estimate and fatigue due to thermal cycling and change in liquid level, is 50 years.

5.5 MATERIAL CONDITIONS

Review of visual examination records and UT examination record found no evidence of leaking or degradation that would make a tank unfit for service. The thinning in one level of Tank 241-AN-105 found by UT examination is unexpected from a corrosion point of view from current contents, and may be explained by conditions occurring during its first year of use. Additionally, a structural evaluation shows (Appendix B) that the remaining wall thickness is adequate for a minimum of 17 years of continued service.

5.5.1 Primary Tank

The visual examinations and leak detection system review showed that the primary tanks in the AN double-shell tanks are not leaking, there was no evidence of any past leakage, and no degradation of the insulating concrete.

The six tanks that were UT-examined are tanks that are expected to corrode more than the general tank population. The preponderance of evidence from the UT examination of these six tanks suggests that the primary steel tanks in Hanford double-shell tanks are not degrading to the extent that they are unfit for service. The following conclusions are reached for corrosion of the primary tanks.

Stress-corrosion cracking was not found in any of the six tanks examined, including four tanks that favored this corrosion mechanism. Tanks AZ-101 and AY-102 were fabricated from the least crack-resistant of the three steels used for double-shell tanks and had the longest exposure time and the highest waste temperatures. AY-102 also had the most fill/empty cycles that would result in more stress cycles for the lower knuckle. AN-106 had a high level of phosphate that could contribute to corrosion cracking and AN-107 had a low level of corrosion inhibitor.

Waterline attack was not found in any of the six tanks examined, including two tanks that favored this corrosion mechanism. Tanks AZ-101 and AN-105 had remained at the same waste levels for extended periods (96 months for AZ-101 and 103 months for AN-105).

Pitting was not found in the six tanks examined by UT, as defined by the inspection criteria (Pfluger 1999). However, localized pit-like indications were observed in tank AN-105 (Jensen 1999b). In addition, earlier visual examinations of two tanks that had previously held waste and a thermocouple tree that had been removed from a waste tank did show some moderate pitting. The interiors of the primary tanks for AP-104 and AP-107 were examined by visual means in 1997 when they were nearly empty (Anantatmula 1997). Both tanks had held waste for some period during their 10 years of operation. AP-104 had contained flush water and decontamination waste (from N Reactor) for several months and then was at the six-in. level for the following eight years. The thermocouple tree was examined by visual means just after removal from AZ-101 interior after 20 years of waste exposure (Schwenk and Scott 1997).

General corrosion (thinning) at reportable levels was found in localized areas of one plate course of AN-105 primary tank and was not found in any of the other five tanks examined. For AN-105, there was general wall thinning at less than reportable levels for the ring nearest the top knuckle (referred to as Plate #1 in the UT report) and for the second ring down from the knuckle (Plate #2 in the UT report). The reportable corrosion thinning (> 10% of thickness, or 0.050 for the 1/2 in. plate) occurred only in two very small areas of the second plate course down from the top knuckle. The Inspection Review Panel (Appendix A) suspects the thinning in this tank is due to vapor-phase corrosion (general corrosion and pitting) during an earlier 16-month period when the tank contained double-shell slurry feed and the waste level was lower (Brevick 1995b). In fact, the waste level was immediately below the area of higher-than-average thinning in Plate #2 for 14 months. The panel also stated that the tank is currently full and contains waste that is considered to be benign from a corrosion standpoint. The structural analysis performed for the two small, thinned areas showed the plate to be structurally acceptable. Importantly, the three tanks with the highest waste temperature showed no reportable thinning.

The thinning that was found in AN-105 was unexpected and two recent studies provide the structural implications, a possible explanation, and recommendations. The study attached as Appendix A concludes that the probable cause of the thinning was vapor space (or atmospheric) corrosion above the liquid level early in its operating history. Further, the corrosion rate should be lower now that the area is submerged in liquid that is benign from a corrosion standpoint. The study attached as Appendix B calculated a minimum remaining life of over 17 years. The calculation assumes a linear corrosion rate (maximum thinning divided by the year of service) and calculates a minimum remaining life using the ASME code and design conditions.

5.5.2 Secondary Tank

The visual examinations and leak detection system review showed that the secondary steel liners in the AN Tank Farm are not leaking, and there was no evidence of any past leakage.

The UT examinations that were carried out on three secondary liners showed that the secondary liners in Hanford double-shell tanks remain structurally sound and are not corroding by thinning, cracking, or pitting to any appreciable extent.

6.0 RECOMMENDATIONS

The following recommendations are made to help ensure the continued safe operation of the double-shell tanks in the AN farm.

1. Consider the tanks in this farm for subsequent ultrasonic and visual examinations. Subsequent examinations should be performed on six tanks from the 28-tank population within the next ten years.
2. Within the next two years, ultrasonic inspections of the lower knuckle and bottom of the primary and secondary tanks should be performed on five of the 28 tanks.
3. Corrosion probes should be installed in tank AN-105 in the region of reported thinning. An alternative would be to install electrochemical noise (ECN) probes as recommended in the report included in Appendix A.
4. Tank AN-105 should be reexamined by similar ultrasonic thickness measuring instruments in 5 years to determine a corrosion rate.
5. Assuming that atmospheric (vapor space) corrosion to be the cause of the thinning observed in Plate # 2 of AN-105, the volume should be kept high and the contents monitored carefully to comply with the corrosion specifications.

7.0 FIGURES

ZBAC0121

Figure 2

ACAD FILE: ZBAC00140

Figure 3

ACAD FILE: ZBAC00142

Figure 4

ACAD FILE: ZBAC00143

Figure 5

8.0 REFERENCES

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APPENDIX A - Possible Causes for Wall Thinning

Consisting of 19 pages
including cover page

INTEROFFICE MEMO

LOCKHEED MARTIN

From: Life Extension Equipment Engineering 74700-99-RPA-008
 Phone: 373-0785 R1-30
 Date: August 9, 1999
 Subject: POSSIBLE CAUSES FOR WALL THINNING OF ISOLATED REGIONS OF
 PRIMARY WALL OF TANK 241-AN-105 AS REVEALED BY THE RECENT
 ULTRASONIC EXAMINATION

To: C. E. Jensen R1-56

cc: C. Defigh-Price	R2-12	D.C. Pfluger	R1-56
T. G. Goetz	R1-49	G. J. Posakony	K5-26
L. J. Julyk	R1-56	S. H. Rifaey	R1-56
J. L. Nelson	R1-30	K. V. Scott	H3-28
R. S. Nicholson	S5-05	RPA File/LB	

At your request, I completed an evaluation of the probable cause for the wall thinning of regions of primary wall that occurred in excess of the design corrosion rate in tank 241-AN-105, as determined by the recent ultrasonic examination. The results of my evaluation are described in the attached report. The report is divided into several sections, viz., executive summary, background, surface level data, corrosion and waste chemistry, and conclusions and recommendations.

The recent ultrasonic examination of Double-Shell Tank 241-AN-105 indicated wall thinning in Plates #1, and #2 of the primary wall. The attached report attributes the wall thinning to corrosion by condensed water vapor when the tank stored wastewater at low levels at the start of operations. The tank is currently operating at full capacity, and based on recent core sampling analytical data, the current waste in the tank is expected to be benign (pH > 11.5) from a corrosion standpoint. Excessive corrosion, as seen in Plate #2, could have been caused by persisting low pH (≤ 10) aqueous conditions in the pits long after the tank was filled to the current levels with benign waste. It is recommended to install an electrochemical noise probe near the locations that were observed to have experienced high corrosion damage to assure that excessive corrosion is not caused by the wastes currently stored in the tank. In addition, ultrasonic examination of tanks that received similar wastes and possess characteristics similar to tank 241-AN-105 is recommended to verify that the integrity of these tanks is not compromised.

I am happy to assist you in providing a resolution to this tank corrosion issue. If you have any questions concerning the report, please feel free to contact me on 373-0785.

R. P. Anantatmula
 Principal Engineer

rkg

Attachment

A-6002-067 (10/96) GEF397

**POSSIBLE CAUSES FOR WALL THINNING OF ISOLATED REGIONS OF
PRIMARY WALL OF TANK 241-AN-105 AS REVEALED
BY THE RECENT ULTRASONIC EXAMINATION**

Prepared By:

**R. P. Anantatmula
D. J. McCain
S. R. Wilmarth**

**LOCKHEED MARTIN HANFORD CORPORATION
for the
U.S. Department of Energy
Richland Operations Office**

**Consisting of 18 pages
including cover page**

**POSSIBLE CAUSES FOR WALL THINNING OF ISOLATED REGIONS OF
PRIMARY WALL OF TANK 241-AN-105 AS REVEALED
BY THE RECENT ULTRASONIC EXAMINATION**

EXECUTIVE SUMMARY

Recent ultrasonic examination of double-shell tank 241-AN-105 indicated wall thinning in two of the primary wall plates. The wall thinning has been attributed to corrosion by condensed water vapor when the tank stored wastewater at low levels at the start of operations. The tank is currently operating at full capacity, and based on recent core sampling analytical data, the current waste in the tank is expected to be benign from a corrosion standpoint. It is recommended to install an electrochemical noise probe near the locations that were observed to have experienced high corrosion damage to assure that excessive corrosion is not caused by the wastes currently stored in the tank. In addition, ultrasonic examination of tanks that received similar wastes and possess characteristics similar to tank 241-AN-105 is recommended to verify that the integrity of these tanks is not compromised.

2.0 BACKGROUND

As part of the integrity assessment of the double-shell tanks (DSTs), an ultrasonic (UT) examination of the primary wall of tank 241-AN-105 was performed in two vertical scans (Scan #1 and Scan #2), 15-inch wide, and spaced 6 inches apart. The vertical scans were made of all five plates of the primary wall, viz., Plates #1, #2, #3, #4 and #5, to detect the presence of wall thinning, pitting and any stress corrosion cracks that might be present. Plates #1, #2, and #3 are 8-feet high with a nominal thickness of 0.5". Plate #4 is 9-feet high with a nominal thickness of 0.75". Plate #5 is 2-feet high with a nominal thickness of 0.875". Two of the plates (Plates #1 and #2) demonstrated wall thinning. Plate #2 showed thinning to the action level or 20% thinning (0.10 inch) requiring the assembly of the Inspection Review Panel, in accordance with the engineering task plan (Pfluger 1998). The following is a summary of the UT examination results and a hypothesis of what caused the primary wall degradation indicated by the results. For more details of the UT examination results, the reader is referred to the report from Pacific Northwest National Laboratory (Posakony and Pardini 1999).

The minimum wall thickness data from Posakony and Pardini (1999) are plotted in Figure 1 as a function of distance from the top weld. The data from Scan #1 indicated that the remaining minimum wall thickness of Plate #1 to be decreasing from 0.518" at the top to 0.468" at the bottom. In Plate #2, the wall thickness decreases from 0.452" near the weld between Plates #1 and #2 to 0.413 at approximately 14.5 ft from the top weld and then increases to 0.435" near the circumferential weld between Plates #2 and #3. For Plate #3 the remaining minimum wall thickness ranges from 0.53" to 0.494", which is close to the nominal wall thickness. There appears to be minimal variation in wall thickness in Plate #4 with the remaining minimum wall thickness ranging from 0.729" to 0.777". No wall thinning was observed in Plate #5 with the data indicating a uniform wall thickness throughout of 0.874".

The data from Scan #2 indicated that at the start of the scan Plate #1 shows a wall thickness of 0.479", increases slightly to 0.497" and gradually decreases to 0.452" at the weld between Plates #1 and #2. The data indicate that the remaining minimum wall thickness of Plate #2 ranges from 0.43" at the top to 0.439" at the bottom of the plate. However, between 13 and 14 ft below the top weld, a minimum wall thickness of 0.4" was recorded with a pit-like indication. Between 14 and 15 ft level also pit-like indications were recorded with thickness values of 0.408" and 0.413". In addition, Posakony and Pardini (1999) indicate that there were other randomly spaced pit-like corrosion indications throughout the lower half of Plate #2 with thicknesses higher than those indicated above. The error in wall thickness measurement was presumed to be ± 20 mils. Ultrasonic examination data from Scan #2 indicated Plate #3 to be thicker than the nominal 0.5". The remaining minimum wall thickness values range from 0.523" to 0.518". Similar to Scan #1, Scan #2 also shows minimal variation in wall thickness in Plate #4. The thickness values range from a high of 0.751" to a low of 0.729". No wall thinning was observed in Plate #5, with a uniform wall thickness of 0.874", similar to Scan #1.

Based on the UT examination results summary above, both Scan #1 and Scan #2 indicate wall thinning of Plates #1 and #2, with Scan #2 showing the minimum of 0.4" for Plate #2. Three horizontal scans (12-in wide x 25 ft long) were run on Plate #2 to verify 0.4" is indeed the minimum wall thickness value. Although the UT equipment operators were not able to revisit the exact location of the 0.4" minimum, all the recorded values were higher than 0.4" with a minimum of 0.42". The possible causes for the observed corrosion damage of Plates #1 and #2 are discussed in the following in light of the historical surface level data of tank 241-AN-105, waste chemistry of tank 241-AN-105, data and models on carbon steel corrosion available in the literature.

3.0 SURFACE LEVEL DATA

The surface level data of the tank characterization report (TCR) for tank 241-AN-105 (Jo et al. 1997) indicate that the tank contained 11 kgal of flush water at the start of operations around September 1981. This volume of water occupied the bottom 4" of the tank. According to the waste surface level plot in the TCR (Figure 2), this water remained in the tank at that level until 1/16/83 when double-shell slurry feed (DSSF) was transferred from tank 241-AW-102 to bring the waste level up to 232". However, information supplied by the DST Engineering Group (Nicholson 1999) indicates that an interim transfer from tank 241-AW-102 was made on 12/6/82, which brought the level up to 99" and then on 1/16/83 additional slurry transfer was made to bring the level to the 232" level. Therefore, the waste level was at 99" or less for a total of approximately 1.333 years. The waste level stayed at the 232" level until 3/1/84 when waste was transferred from tank 241-AN-104 to bring the level to 402". Therefore, the waste level was at 232" or less for a total of approximately 2.5 years.

4.0 CORROSION AND WASTE CHEMISTRY

Wastewater at such low levels in tanks with an operating capacity of 420" will cause condensation of water vapor in the vapor space above the waste. Such condensation will result in uniform corrosion and pitting of the carbon steel tank wall. Pitting from condensation of water vapor from low levels of waste stored in DSTs has recently been indicated by a video examination of DSTs 241-AP-104 and 241-AP-107 (Anantatmula 1997). The condensation could occur in several regions of the tank above the waste surface depending on if the temperature decreases to the dew point in that region. Because the tanks are large, the temperature at a given altitude of the tank can be expected to be different in different regions of the tank and condensation of water vapor will occur in the regions where the dew point is reached or exceeded. The period of wetness is often much longer than the time the ambient air is at or below the dew point and varies with the section thickness of the metal structure, air currents, and relative humidity.

Personnel conducting the examination acknowledged that the UT technique does not make a distinction between uniform corrosion and pitting although Posakony and Pardini (1999) reported some pit-like indications in Plate #2. It is postulated here that the majority of the wall thinning (both uniform corrosion and pitting) in Plates #1 and #2 might have resulted from condensation of water vapor when the waste was stored at low levels, viz., 4" and 99" for the first approximately 1.333 years of tank operations. It should also be noted that although tanks 241-AN-106 and 241-AN-107 had low wastewater levels at the start of operations, UT examination of these tanks indicated low uniform corrosion with no pitting or stress corrosion cracking (SCC). It is possible that differences in air currents and relative humidity between the tanks at the start of operations might have led to differences in condensation on the walls resulting in the observed differences in wall thinning between the tanks.

Assuming a vapor space temperature at the time of low waste levels to be approximately 30°C (which is conservative) in regions where condensation might have occurred, wall thinning by pitting was calculated using aqueous corrosion models available in the literature (Lee et al. 1997). Pit depths (for 1.333 years) were calculated using Lee et al.'s average pitting factor (PF) of 4 with a standard deviation (σ) of 1. On this basis, the pit depth was only about 36 mils, which is a factor of almost 3 less than the damage depth corresponding to the 0.4" minimum wall thickness observed in Scan #2 of Plate #2. On the other hand, if one assumes that neutral/low pH (≤ 10) conditions persisted in the pits long after the tank was filled to the current levels with benign waste, better agreement between the data and the models can be obtained. This assumption is somewhat reasonable since the composition of the waste within a given pit will not change quickly to benign levels unless there is mixing with high pH waste or until the neutral/low pH (≤ 10) waste within the pits is almost totally consumed. In comparison, the maximum pitting rate indicated by the in-situ and laboratory vapor space pitting data for Hanford SSTs was 37 mils per year (Anantatmula et al. 1994), which is in reasonable agreement with the model prediction.

As mentioned before, corrosion of Plate #1 in both scans can be attributed to condensation of water vapor. However, in this case, some condensation might have occurred when the waste

level was at 232". Significant condensation is not expected near the top part of Plate #1 because the tank is ventilated with ambient air.

According to Hanlon (1999), the current tank contents are 638 kgal of supernatant, 489 kgal of sludge with drainable interstitial liquid of 53 kgal. Therefore, the top of the sludge is at approximately 15 feet above the tank bottom. The UT scans did not indicate any unusual corrosion behavior at this level in the tank, close to the interface between the supernatant and sludge. In fact, calculations of corrosivity factor (CF) (Anantatmula et al. 1994) indicate that both the supernatant and the sludge are very benign from a corrosion standpoint. These calculations were based on the measured bulk concentration of the supernatant and slurry. The hydroxide concentration from the best basis inventory estimate (Jo et al. 1997), obtained by charge balance calculations, was used in deriving the CF. This hydroxide concentration value was compared with the measured hydroxide values for drainable liquid composite and solid segments 14-22 of cores 152 and 153 and found to be in good agreement. The benign nature of the waste can be seen from the UT examination results of Plates #3, #4 and #5. In addition, no corrosion indications were noted by the UT examination of tank 241-AN-107 which has the same type waste as tank 241-AN-105.

The benign nature of the waste currently stored in tank 241-AN-105 is consistent with the DST waste specifications. On this basis, a uniform corrosion rate of 0.1 mpy has been recommended for all DSTs in compliance with the DST waste specifications (Anantatmula 1999). It should be noted here that although the waste is not aggressive, vapor space pitting could still occur above the current waste surface if conditions lead to condensation of water vapor in the dome space.

Although the bulk chemistry of the supernatant and slurry may indicate that the supernatant and slurry are benign with respect to the tank steel in the regions of Plates #1 and #2, concentration gradients of the analytes important to corrosion might have existed (and may still exist) that might have promoted (and may still promote) different corrosion rates in different regions of the tank. Recent waste chemistry analysis of tank 241-AN-105 was used to answer this important question. The analysis indicated that segment-to-segment variability in the supernatant phase of the tank waste is less than 10% for the major constituents responsible for corrosion and less than 20% for minor and trace constituents, excluding those reported at detection limits and a few apparent "flyers". Similar results were observed for the slurry phase. A comparison of the composite mean and the mean derived from the corresponding individual segments is within a 20% acceptability limit. Figures 3-6 illustrate the variation of concentration of selected analytes as a function of depth, generated from segment level data from analysis of samples from cores 152 and 153. For each of the analytes important for corrosion, the solids and supernatant data show no evidence of layering or vertical heterogeneity. The two cores were sampled through risers 12A and 7B, which are approximately 25 feet apart and Figures 3-6 do not specifically indicate any significant heterogeneity in the horizontal direction. This can be more clearly seen by an examination of data in Tables 1 and 2 for chloride, nitrate and nitrite for both cores, where the majority of the data indicate no major differences in composition of both core samples for the same segment.

5.0 TANKS WITH SIMILAR WASTE TYPES AND OTHER CHARACTERISTICS SIMILAR TO TANK 241-AN-105

5.1 TANKS CONTAINING LOW WASTE LEVELS

Several DSTs had low waste levels at the start of operations. Manual records are currently available for only the newest tank farms, viz., AW, AN, and AP farms. Based on the manual records, the majority of the AW, AN, and AP farm tanks had low waste levels for one year or more. As hypothesized in this report, the low waste levels could lead to pitting in the vapor space, which is in excess of the design corrosion allowance for uniform corrosion. Based on low waste levels, the DSTs in decreasing order of priority for UT inspection are 241-AP-108, 241-AP-107, 241-AP-106, 241-AP-101, 241-AP-103, 241-AP-105, 241-AN-106, 241-AW-101, 241-AN-103, 241-AN-101, 241-AN-104, 241-AW-105, and 241-AP-102.

5.2 TANKS CONTAINING DSSF

According to Funk et al. (1997), several tanks received DSSF from tank 241-AW-102 through the 242-A evaporator during the same time period as tank 241-AN-105. The tanks that received waste through the 242-A evaporator from tank 241-AW-102 in 1983 are: 241-AW-104, 241-AN-102, and 241-AN-106. The tanks that received waste through the 242-A evaporator from tank 241-AW-102 in 1985 are: 241-AW-106, 241-AY-101, and 241-AN-104. Tank 241-AN-105 also received waste from 241-AN-104. Other tanks containing DSSF waste are 241-AW-101 and 241-AP-105.

5.3 FLAMMABLE GAS CONTAINING TANKS

Tank 241-AN-105 is on the flammable gas watch list. Standard Hydrogen Monitoring System (SHMS) was installed in this tank in 1995 to measure the concentration of hydrogen in the dome space soon after a gas release event. There is a one-to-one correspondence between the amount of hydrogen gas released into the dome space and the surface level drop (McCain and Bauer 1998). However, the maximum surface level drop observed was 3.8 cm (1.5") in 1995, soon after the SHMS was installed. Since then the surface level drops have decreased with a corresponding decrease in gas release. It is important to note that the rise and drop of surface level of such small magnitude (maximum of 1.5") is not expected to lead to severe corrosion of a substantial portion of tank wall, as demonstrated by the UT data.

Although tank 241-SY-101 was filled during the time period 1977 to 1980 with a mixture of highly concentrated double-shell slurry, and complexant concentrate from B-Plant campaigns, tank 241-AN-105 and tank 241-SY-101 have some similarities. The addition of high concentrations of organic compounds from B-Plant campaigns led to production of flammable gases and periodic gas release in tank 241-SY-101 similar to tank 241-AN-105. Thus, both these tanks are on the flammable gas watch list although tank 241-AN-105 exhibited much smaller gas releases. Other DSTs that are on the flammable gas watch list are 241-AW-101, 241-AN-103, 241-AN-104 and 241-SY-103. Similar to tank 241-AN-105, these tanks also have a history of small gas releases.

5.4 SLUDGE CONTAINING TANKS

In addition to tank 241-AN-105, other DSTs containing sludge are tanks 241-AN-104, 241-AW-103, 241-AW-105 and 241-AW-106. The UT technique was first demonstrated at Hanford with tank 241-AW-103. The results of that examination indicated no wall thinning, pits or cracks in excess of the acceptance criteria (Scott 1996). As mentioned before, tank 241-AN-105 currently contains 489 kgal of sludge. The UT scans did not indicate any unusual corrosion behavior at the sludge level.

5.5 CONCENTRATED WASTE HOLDING TANKS

According to the Tank Integrity Assessment Program Plan (Pfluger 1994), there are 11 tanks, including tank 241-AN-105, that are categorized as concentrated waste holding tanks. They are 241-AW-101, 241-AZ-101, 241-AN-102, 241-AN-103, 241-AN-104, 241-AN-105, 241-AN-106, 241-AN-107, 241-AP-105, 241-SY-101, and 241-SY-103. Tank 241-AN-107 was previously examined in 1998 and no indications of wall thinning, pits or cracks were found.

6.0 CONCLUSIONS AND RECOMMENDATIONS

It may be concluded from the foregoing that the wall thinning recorded by the UT examination equipment in Plates #1 and #2 of tank 241-AN-105 might have been caused by uniform corrosion and pitting in the vapor space by condensed water vapor when the waste levels were lower than the current level. The maximum damage depths caused by pitting for Plate #2, as measured by the UT equipment, are more than those predicted by the existing aqueous corrosion models and those observed in the vapor space in-situ in SSTs and in simulated SST wastes investigated in the laboratory. There appears to be fair agreement between the SST vapor space pitting data and the model predictions.

It should also be pointed out that the waste that is currently stored in tank 241-AN-105 is quite benign from a corrosion standpoint with a pH > 11.5. Excessive corrosion, as seen in Plate #2, could have been caused by persisting neutral/low pH (≤ 10) aqueous conditions in the pits long after the tank was filled to the current levels with benign waste. Aggressive corrosion conditions could have also been caused by the presence of high chloride solutions (Anantamula 1996). The concentration of chloride in the supernatant and sludge is 0.3M and 0.22M respectively. The chloride concentration in the sludge is not high enough to cause any excessive corrosion problems, which is evidenced by little or no wall thinning recorded by the UT measurements in Plates #3, #4 and #5. The concentration of chloride in the supernatant may be high enough to be of some concern. However, if the pH of the supernatant is maintained at >12, excessive chloride corrosion is not expected to occur.

Therefore, based on the foregoing, it is recommended to install an electrochemical noise (ECN) probe in the supernatant areas near the locations that were observed to have experienced high corrosion damage in Plate #2 to assure that excessive corrosion is not caused by the wastes

currently stored in tank 241-AN-105. In addition, UT examination and ECN probe monitoring of tanks that received similar wastes and possess characteristics similar to 241-AN-105 (as discussed in section 5.0) is recommended to verify that the integrity of these tanks is not compromised. Based on Anantatmula (1997), the order of decreasing priority for these tanks is 241-AY-101, 241-AZ-101, 241-SY-101, 241-AN-104, 241-AW-101, 241-AN-102, 241-AN-103, 241-SY-103, 241-AP-105, 241-AW-104, 241-AW-102, 241-AN-106, 241-AW-105, 241-AW-106, 241-AN-101, 241-AP-106, 241-AP-107, 241-AP-101, 241-AP-103, 241-AP-108, and 241-AP-102.

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Figure 1

A-6002-067 (10/96) GEF397

Figure 2. Historical Surface Level Plot for Tank 241-AN-105.

Figure 3. Composition of Liquid from Cores 152 and 153 of Tank 241-AN-105.

Figure 4. Composition of Liquid from Cores 152 and 153 of Tank 241-AN-105.

Figure 5. Composition of Solid from Cores 152 and 153 of Tank 241-AN-105.

Figure 6. Composition of Solid from Cores 152 and 153 of Tank 241-AN-105.

Table 1. Concentration of Chloride, Nitrate and Nitrite from Analysis of Solid Samples from Cores 152 and 153.

Analyte	Segment #	Solids Concentration Core 152 (µg/g)	Solids Concentration Core 153 (µg/g)
Chloride	1	5485	-
	14	4800	6651.5
	15	-	5510
	16	4977.5	-
	17	-	6175
	18	5155.5	-
	19	-	6349.5
	20	5208	-
	21	-	4611.5
	22	4434.5	4266.5
Nitrate	1	153450	-
	14	85750	109850
	15	-	100750
	16	88035	-
	17	-	98850
	18	113050	-
	19	-	120500
	20	127250	-
	21	-	151100
	22	167050	123630
Nitrite	1	72900	-
	14	63450	82360
	15	-	69100
	16	62640	-
	17	-	73250
	18	65405	-
	19	-	73915
	20	64650	-
	21	-	56705
	22	52955	50185

Table 2. Concentration of Chloride, Nitrate and Nitrite from Analysis of Liquid Samples from Cores 152 and 153.

Analyte	Segment #	Liquid Concentration Core 152 (µg/mL)	Liquid Concentration Core 153 (µg/mL)
Chloride	1	9622	10520
	2	9267.5	10080
	3	10100	10020
	4	10060.5	-
	5	2885.5	10145
	6	25575	10385
	7	10040	10930
	8	9724	9556.5
	9	9508	9533.5
	10	9584	9138.5
	11	10080	9608.5
	12	9859	10036
	13	9965	9462.5
	14	10555	10145
	21	-	9227
Nitrate	1	158500	164750
	2	160600	162050
	3	173000	160800
	4	164250	-
	5	37610	169750
	6	419100	158250
	7	168900	167200
	8	161850	159350
	9	130400	154050
	10	156850	151750
	11	163950	153200
	12	153600	170200
	13	165900	159850
	14	159200	172900
	21	-	173600
Nitrite	1	126700	127800
	2	120500	123950
	3	128700	122450
	4	126300	-
	5	31530	124100
	6	329000	116050
	7	121300	120250
	8	125750	120950
	9	103100	117700
	10	123200	113000
	11	125450	123000
	12	123200	128500
	13	126150	122100
	14	119650	126300
	21	-	94325

APPENDIX B - Structural Evaluation of the 241-AN-105 Primary Tank

Consisting of 50 pages
including cover page

INTEROFFICE MEMO

LOCKHEED MARTIN

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 Phone: 376-4608 R1-56
 Date: August 9, 1999
 Subject: STRUCTURAL EVALUATION OF THE 241-AN-105 PRIMARY TANK IN
 SUPPORT OF RESOLUTION OF 1998 ULTRASONIC WALL THINNING
 MEASUREMENTS

To: C. E. Jensen R1-56

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This memo transmits the attached structural evaluation for the primary tank of the 241-AN-105 double-shell tank (DST) in support of resolution of the 1998 ultrasonic (UT) wall thinning measurements reported in Reference 1. Results from the UT examination indicated evidence of some wall thinning corrosion in Plates 1, 2, and 4 (see Figure 2 of Attachment). The most significant wall thinning was observed on Plate 2, which exceeded the screening acceptance criteria of Reference 2. The design nominal wall thickness of Plate 2 is 0.500 inches. A number of "pit-like" wall thickness indications were reported for Plate 2 (see Table 1 of Attachment). The minimum wall thickness reported for Plate 2 was a "pit-like" wall-thickness indication of 0.400 inches. The evaluation given in the Attachment conservatively treated this minimum local-wall-thickness indication as a *uniform* thickness for comparison to the allowable minimum *uniform* wall thickness at both the design and current operating conditions

C. E. Jensen
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of the tank. The allowable minimum *uniform* wall thickness was determined on the basis of the construction code-of-record allowable stress criteria (Reference 3), the predicted stress at the location of interest from the design stress analysis (Reference 4), and supplemental acceptance criteria for wall thinning from Reference 2. The remaining useful life was then estimated assuming continued operation at a constant corrosion rate until the allowable minimum *uniform* wall thickness is reached. The projected corrosion rate in this evaluation was based on the observed minimum wall thickness at the time of the UT examination relative to the initial wall thickness (nominal +/- mill tolerance of +0.030/-0.010 inches) at the service date (mid-1981) of the 241-AN-105 tank.

The results of the evaluation for Plates 1, 2, and 4 are summarized in Table 2a of the Attachment. The remaining useful life of the 241-AN-105 tank is estimated to be at least 17 additional years at the design operating conditions or 23 additional years at the current operating conditions. However, these results may be conservative by at least a factor of two if the size of the lateral extent of the "pit-like" 0.400-inch minimum wall-thickness indication is accounted for.

The greatest uncertainty in the predicted remaining useful life is in the projected corrosion rate. The estimated corrosion rates summarized in Table 2a of the Attachment are significantly greater than expected for general uniform corrosion. Under controlled chemistry conditions, the general uniform-corrosion rate is expected to be on the order of 0.1 mils/year (Reference 5). If the corrosion had initiated early in the tank operating history as a result of pitting from condensation of water vapor when the waste level was significantly lower than the current waste level (see Reference 5), the current corrosion rate would be expected to be much less than predicted in the Attachment. Hence, the remaining useful life prediction given in the Attachment would be conservative. Although this is a plausible scenario, the actual corrosion process has not been verified. If the corrosion began to accelerate more recently, though not likely for current operating conditions and waste chemistry, the remaining useful-life estimate could be unconservative. Hence, the installation of a corrosion probe in the 241-AN-105 tank is recommended, as well as, replicate UT examinations within at least one-half the minimum predicted time to reach the allowable minimum wall thickness. The replicate UT examination will help to verify the corrosion rate measured by the corrosion probe.

The remaining useful life estimate given in the Attachment is specific to the 241-AN-105 primary tank based on the current UT examination data provide in Reference 1. Because of differences in design parameters (i.e., waste volume capacity, specific gravity, temperature; primary tank wall thickness and material strength design specifications; and soil cover depth) between the DSTs in the six Hanford DST Farms, the DSTs can be grouped only into four groups with common design parameters. The four groupings are AN/AW, AP, SY, and AY/AZ. Although the methodology applied in the Attachment can be applied to all of the DSTs, the allowable minimum *uniform* wall thickness values given in Table 5 of the Attachment are applicable only to the AN/AW tank group.

L. J. Julyk
Principal Engineer

Attachment

rkg

**ATTACHMENT TO
74700-99-LJJ-015**

(Total of 48 Pages)

**STRUCTURAL EVALUATION OF THE 241-AN-105 PRIMARY
TANK IN SUPPORT OF RESOLUTION OF 1998 ULTRASONIC
WALL THINNING MEASUREMENTS**

July 1999

by

**L. J. Julyk
Lockheed Martin Hanford Corporation**

**for
the U.S. Department of Energy
Richland Operations Office, Richland, Washington**

Consisting of 48 Pages

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**STRUCTURAL EVALUATION OF THE 241-AN-105 PRIMARY
TANK IN SUPPORT OF RESOLUTION OF 1998 ULTRASONIC
WALL THINNING MEASUREMENTS**

July 1999

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Calculations contained herein were produced in Mathcad 6.0 Plus (Mathcad is a registered trademark of MathSoft, Inc., of Cambridge, Massachusetts).

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CHECKLIST FOR INDEPENDENT REVIEW

Document: Structural Evaluation of the 241-AN-105 Primary Tank in Support of Resolution of 1998 Ultrasonic Wall Thinning Measurements

Author: L. J. Julvk

Yes No N/A

☒	☐	☐	Problem completely defined.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☐	☐	☒	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☒	☐	☐	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors.
☐	☐	☒	Code run streams correct and consistent with analysis documentation.
☐	☐	☒	Code output consistent with input and with results reported in analysis documentation.
☒	☐	☐	Acceptability limits on analytical results applicable and supported limits checked against sources.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.

Harold H. Zinda
Reviewer

7-28-99
Date

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1.0 INTRODUCTION

Evaluation of ultrasonic (UT) data from the December 1998 examination of the double-shell 241-AN-105 primary tank (PNNL 1999) indicated significant wall thinning that exceeded the screening acceptance criteria (Simonen et al. 1995) for Plate (or course) No. 2 of the vertical tank wall. Some wall thinning was indicated also in Plates 1 and 4 but it did not exceed the screening criteria. See Figure 1 and Table 1 for a summary of the UT wall-thickness data reported in PNNL 1999 for the primary tank of 241-AN-105.

Figure 1. Sketch of the UT Vertical Scan Paths No. 1 and 2 (with Selected UT Results) on the Primary Tank of Double-Shell Tank 241-AN-105. (PNNL 1999)

Plate 2 is a 0.500-inch nominal wall thickness, 8-foot high, circumferential plate located vertically approximately 240 to 336 inches above the bottom of the primary tank. The minimum measured wall thickness reported in PNNL 1999 was 0.400 inches for Plate 2. This minimum wall thickness is localized over a small region less than one square inch. Other "pit-like" minimum wall thicknesses were observed for Plate 2 as indicated in Table 1. The average wall thickness for Plate 2 is estimated at approximately 0.450 inches.

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Table 1. Summary Results from the UT Vertical Scan Paths No. 1 and 2 on the Primary Tank of Tank 241-AN-105. (PNNL 1999)

Plate No.	Nominal wall thickness (in.) (90% min)	Distance from bottom of tank (ft)	Distance from top weld (ft)	Vertical UT Scan No. 1		Size of area (in. x in.) where minimum thickness was recorded	Vertical UT Scan No. 2		Size of area (in. x in.) where minimum thickness was recorded
				Wall thickness (in.) recorded within one-ft area			Wall thickness (in.) recorded within one-ft area		
				Aver.	Min.		Aver.	Min.	
1	0.500 (0.450)	36 to 35	0 to 1	0.530	0.518	Areas with thickness greater than 90% min were not sized	0.512	0.479	Areas with thickness greater than 90% min were not sized
		35 to 34	1 to 2	0.533	0.518		0.506	0.497	
		34 to 33	2 to 3	0.537	0.505		0.503	0.479	
		33 to 32	3 to 4	0.533	0.505		0.498	0.465	
		32 to 31	4 to 5	0.525	0.492		0.506	0.474	
		31 to 30	5 to 6	0.516	0.479		0.494	0.465	
		30 to 29	6 to 7	0.506	0.465		0.479	0.452	
		29 to 28	7 to 8	0.496	0.465		0.471	0.452	
		28 to 27	8 to 9	0.484	0.452		0.469	0.430	
		27 to 26	9 to 10	0.478	0.452		0.460	0.435	
2	0.500 (0.450)	26 to 25	10 to 11	0.480	0.452	Several random pit-like corrosion indications of small area were observed with local wall thickness below 90% min	0.463	0.439	not in the record
		25 to 24	11 to 12	0.477	0.448		0.464	0.426	
		24 to 23	12 to 13	0.475	0.430		0.463	0.430	
		23 to 22	13 to 14	0.472	0.430		0.461	0.400	
		22 to 21	14 to 15	0.468	0.413		0.455	0.408	
		21 to 20	15 to 16	0.468	0.435		0.455	0.413	
		20 to 19	16 to 17	0.515	0.494		0.455	0.413	
		19 to 18	17 to 18	0.514	0.498		0.454	0.439	
		18 to 17	18 to 19	0.518	0.498		0.474	0.429	
		17 to 16	19 to 20	0.530	0.498		0.480	0.429	
3	0.500 (0.450)	16 to 15	20 to 21	0.530	0.503	Areas with thickness greater than 90% min were not sized	0.560	0.523	Areas with thickness greater than 90% min were not sized
		15 to 14	21 to 22	0.529	0.498		0.551	0.518	
		14 to 13	22 to 23	0.527	0.498		0.548	0.518	
		13 to 12	23 to 24	0.530	0.503		0.545	0.518	
		12 to 11	24 to 25	0.812	0.777		0.792	0.751	
		11 to 10	25 to 26	0.796	0.764		0.767	0.751	
		10 to 9	26 to 27	0.785	0.760		0.766	0.742	
		9 to 8	27 to 28	0.772	0.747		0.766	0.742	
		8 to 7	28 to 29	0.765	0.747		0.766	0.729	
		7 to 6	29 to 30	0.759	0.738		0.764	0.738	
4	0.750 (0.675)	6 to 5	30 to 31	0.754	0.733	Areas with thickness greater than 90% min were not sized	0.759	0.738	Areas with thickness greater than 90% min were not sized
		5 to 4	31 to 32	0.750	0.729		0.755	0.729	
		4 to 3	32 to 33	0.753	0.729		0.757	0.729	
		3 to 2	33 to 34	0.914	0.874		0.909	0.874	
		2 to 1	34 to 35	0.911	0.874		0.905	0.874	
5	0.875 (0.787)	3 to 2	33 to 34	0.914	0.874		0.909	0.874	
		2 to 1	34 to 35	0.911	0.874		0.905	0.874	

To bound the evaluation of the UT data, the reported minimum wall thicknesses for Plates 1, 2, and 4 are first evaluated conservatively as uniform wall thinning extending around the entire circumference with large axial extent. The local nature of the "pit-like" indications was then investigated to provide a more realistic assessment of the wall thinning in Plate 2. The detailed evaluation of the wall thinning given herein focuses on the specific location, local morphology, and the original design and current operating conditions of tank 241-AN-105, consistent with the tank's construction code and analysis of record.

The construction code of record for the AN-Farm primary tanks is ASME, Section VIII, Division 2, 1974 with 1976 Addenda (ASME 1974). The analysis of record applicable to the AN and AW Tanks is summarized in RHO-C-60 (1981) with supplemental gravity load analysis given in WHC 1994.

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2.0 SUMMARY AND CONCLUSIONS

The minimum measured wall thicknesses from the UT examination of the 241-AN-105 primary tank were evaluated in accordance with the acceptance criteria given in Simonen et al. 1995. Figure 2 compares the measured wall thickness data from Table 1 to the ASME Code-based allowable minimum uniform wall thickness at design and current operating conditions (including seismic). This figure also shows the nominal wall thickness, mill tolerance (+0.030/-0.010 in.), and screening criteria thickness values. The minimum reported thicknesses for Plates 1, 2, and 4 were evaluated in detail. The resulting ASME Code-based allowable minimum uniform wall thicknesses and projected time to reach the allowable wall thicknesses are summarized in Table 2a for Plates 1, 2, and 4 at the design and current operating conditions (including seismic) identified in Table 2b. In determining the allowable thickness, the primary stresses as a function of wall thickness were obtained by appropriate scaling of the internal moment and force resultants from the individual load contributions (see Section 6.0) as given in RHO-C-60 (1981) adjusted for final design and current operating conditions. Only primary loads were considered, thermal induced secondary type stresses do not typically lead to a rupture type failure (see Section 5.2). However, the design and current operating maximum temperatures were considered in obtaining the ASME Code allowable stresses for determining the ASME Code-based allowable minimum uniform wall thicknesses, t_{min} . The allowable minimum uniform wall thicknesses with the primary stresses equal to 95% of the minimum material yield strength (S_y) at temperature were determined also for comparison only. The initial wall thicknesses considered for determining the average corrosion rate included the design nominal thickness (t_{nom}) and the nominal thickness plus mill tolerance. This range of thickness is used to calculate the corresponding linear corrosion rate based on the minimum measured wall thickness for the period of operation before the UT examination. See Figures 10, 11, and 16 for a graphical display of the results given in Table 2a for Plates 1, 2 and 4, respectively.

The results given in Figure 2 and Table 2a are conservative for Plate 2, in particular. The reported minimum wall thicknesses for Plate 2 (see Table 1) extend over small regions, less than one square inch, and have been characterized as "pit-like" (PNNL 1999). Hence, the application of the allowable minimum uniform wall thickness criterion (STEP 1, see Section 5.0) to these small local regions is very conservative. Even with this conservative evaluation, the primary tank wall is adequate for continued operation for at least 17 years of additional service at design conditions or 23 years at current operating conditions. The projected time to reach the Code-based minimum uniform wall thickness is based on a linear projection of the corrosion rate. This projection is believed to be conservative because much of the corrosion is likely to have occurred from pitting due to condensation of water vapor early in the tank operation history when the waste level (see Figure 9) was quite low (Anantamula 1999). Hence, the current corrosion rate with the current waste level maintained above the thinning regions of Plates 1 and 2 is likely to be more in line with a general corrosion rate of approximately 0.1 mils/year, provided that the waste pH is maintained greater than 11.5 (Anantamula 1999).

A more realistic assessment of the "pit-like" 0.400-inch minimum wall thickness indication in Plate 2 is obtained by comparing it to the allowable local wall thickness, t_{loc} , through application of STEP 2 criteria as presented in Section 5.0. In this case, the time required for the average wall thickness of Plate 2 (estimated approximately as 0.450 inches) to reach the Code-based minimum uniform wall thickness is controlling. That is, the Code-based allowable minimum uniform wall thickness is reached (based on the average thickness) before the allowable minimum local wall thickness is reached for the pit-like minimum wall thickness indication. The resulting additional useful life is extended by a factor of 2.

The results given in Table 2a are specific to Tank 241-AN-105. Additional Code-based allowable minimum uniform wall thicknesses as a function of position from the primary tank bottom are given in Section 7.0 for design and current operating conditions of 241-AN-105. These values may be used to evaluate future UT data at other locations in the primary tank vertical walls of the AN Tanks. However, results given within the one-foot radius lower knuckle region are not considered to be sufficiently reliable because of the lack of detail in the original stress analysis for this region. In addition, by design as a precautionary measure against stress-corrosion cracking (SCC), the principal stresses, including thermal and any residual stresses, at the inside surface of the primary tanks are limited to 90 percent of the minimum yield strength of the primary tank material at temperature. This SCC precautionary measure controls the minimum allowable wall thickness for the lower knuckle region (WHC 1996). All other regions of the primary tank are controlled by the Code primary stress criteria because the thermal induced stresses in the vertical wall region are not significant compared to the resulting thermal induced bending stresses in the lower knuckle region.

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Figure 2. Comparison of UT Measured Wall Thickness to Code-Based Allowable Uniform Wall Thickness for Primary Tank of Double-Shell Tank 241-AN-105.

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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.

Plate (course) number	Design thk (in.)	t_{min} UT thk (in.)	Location relative to bottom of primary tank (in.)	Estimated Corrosion rate (mils/yr)	Design Conditions				Current Conditions			
					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.

Table 2b. Load Conditions Considered in Minimum Thickness Evaluation for 241-AN-105 Primary Tank.

Load condition	Temperature (°F)	Normal Loads						Seismic		
		Waste		Vapor pressure (in. w.g.)	Soil overburden		Surcharge		Peak ground acceleration (g)	
		Specific gravity	Depth (in.)		Height (ft)	Density (lb/ft ³)	Uniform (lb/ft ²)	Concentrated (tons)	Horizontal	Vertical
Design	350	1.7	422	-6/60	7.5	125	40	100	0.25	0.167
Current	120	1.44	410	-6/60	7.5	125	40	100	0.25	0.167

Although the methodology developed herein may be applied to all of the Hanford double-shell tanks (DSTs) in evaluation of UT primary tank examination data, the results given in Section 7.0 are specific to AN and AW Tanks. Because of differences in design parameters (i.e., waste volume capacity, maximum waste specific gravity, maximum design temperature, maximum soil cover depth, and primary tank material strength) between the six DST Farms, the DSTs can at best be grouped into four groups with common design parameters. The four groups include AN/AW, AP, SY, and AY/AZ. Preliminary minimum Code-based minimum uniform wall thicknesses for each of these groups are given in WHC 1996. The WHC 1996 preliminary results were updated and expanded herein for application to the 241-AN-105 UT data. Although the results in Table 2a are conservatively based on the calculation of the Code-based minimum wall thicknesses for uniform corrosion conditions, the ASME Code Case N-480 criteria may be applied in the evaluation of more localized wall thinning conditions as observed in the UT examination of tank 241-AN-105.

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3.0 RECOMMENDATIONS

Replicate UT examinations are recommended after an appropriate time period (within half of the predicted minimum time to reach the Code-based minimum uniform wall thickness) to obtain a better estimate of the current corrosion rate. The installation of a corrosion probe in 241-AN-105 is also recommended to assess the current corrosion rate in the region of Plates 2 in the interim.

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5.0 DETAILED EVALUATION PROCEDURE

5.1 STEP 0 - SCREENING CRITERIA

The screening acceptance criteria for wall thinning from Simonen et al. 1995 are summarized in Table 3 where t_{nom} is the original design nominal wall thickness.

Table 3. Screening Criteria: Acceptable Depth of Wall Thinning Extending Around Entire Circumference.

Location	Vertical Extent (L_{me}) of Wall Thinning (in.)	Acceptable Depth of Thinning (% t_{nom})	Acceptable Measured Wall Thickness (% t_{nom})
Bottom Plates	N/A	< 20	> 80
Lower Knuckle	N/A	< 12.5	> 87.5
Vertical Tank Wall	> 18	< 12.5	> 87.5
	< 18	< 20	> 80

5.2 STEP 1 - CODE MINIMUM WALL THICKNESS

Measured wall thicknesses, t_{meas} , less than the screening criteria of Table 3 are acceptable for continued service irrespective of the circumferential and axial extent of the wall thinning provided that the minimum predicted wall thickness, t_p , projected to the next in-service examination is greater than the Code-based minimum *uniform* wall thickness, t_{ma} . The Code-based minimum wall thickness is the calculated minimum wall thickness at the location of interest as determined from the *primary* stress allowable equations of the construction code of record. The focus on primary stress is justified in that rupture of ductile materials can only occur with significant deformation which cannot typically be produced by secondary or strain-controlled thermal induced loads (Gerber et al. 1988). In addition, the ASME Code allowable stress for load combinations that include thermal stresses is twice the primary membrane stress allowable. Also, the secondary stresses due to the thermal loading are significant only in the top and bottom knuckle of the tank (RHO-C-60, 1981). This is clearly shown by comparing Figures 5-2 and 5-3 of WHC 1996. In addition, although the design temperature was 350 °F, the current operating temperature of tank 241-AN-105 is less than 120 °F (see Figure 3). Hence, since the focus of this evaluation is on the measured wall thinning in the vertical wall of the primary tank, thermal induced stresses need not be considered.

5.3 STEP 2 - ALLOWABLE LOCAL WALL THICKNESS

Predicted wall thicknesses less than t_{min} may be acceptable provided that the region of wall thinning is localized within the dimensions prescribed in ASME Code Case N-480 (ASME 1990) and t_p is less than the allowable local wall thickness, t_{loc} . The vertical (axial) and circumferential (transverse) extent (length) of the wall thickness region that is less than t_{min} is defined as L_{me} and L_{ma} , respectively (see Figure 4). Three cases for localized thinning are addressed in Code Case N-480.

5.3.1 Local Thinning Case 1

When L_{ma} [circumferential (transverse) length of the wall thickness region that is < t_{min} , see Figure 4] is less than $\sqrt{R \cdot t_{min}}$ then t_{loc} is determined from Curve 1 of Figure 5 where R is the radius of the primary tank and L_{me} (see Figure 4) is the vertical (axial) length of the wall thickness region that is < t_{min} , i.e.,

$$t_{loc} = t_{min} \left(\frac{L_{ma}}{\sqrt{R \cdot t_{min}}} \right)^2$$

Case 1 is applicable when the thinning extends *partially* around the circumference of the tank and has a limited axial extent, L_{me} .

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Figure 3. Tank 241-AN-105 Weekly High Temperature Plot. (HNF 1997a and b)

AN-105-f.mcd

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Figure 4. Schematic of Locally Thinned Region with Local Morphology Parameters Defined.
 (Figure -3621-1, ASME Code Case N-480)

Figure 5. Allowable Local Wall Thickness vs. Axial Extent for Locally Thinned Region.
 (Figure -3622-1, ASME Code Case N-480)

where

Curve 1 $C_1(\alpha) \cdot \text{interp } v_a, vC_1, \alpha$

Curve 2 $C_2(\alpha) \cdot \text{interp } v_a, vC_2, \alpha$

applicable when the thinning extends *partially* around the circumference of the tank ($L_{mt} < R - t_{min}$) and has a limited axial extent, L_{ma} .

applicable when the thinning extends around the full circumference of the tank but has a limited axial extent, L_{ma} .

AN-105-f.mcd

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α	vC_1	vC_2
0	0.3	0.3
0.2	0.3	0.3
0.25	0.3	0.3
0.26	0.3	0.375
0.32	0.3	0.477
0.38	0.3	0.551
0.45	0.3	0.616
0.5	0.3	0.651
0.6	0.3	0.703
0.7	0.3	0.742
0.83	0.3	0.778
0.85	0.315	0.782
0.9	0.349	0.794
1	0.41	0.813
1.2	0.505	0.841
1.4	0.572	0.86
1.6	0.622	0.873
1.8	0.659	0.883
2	0.687	0.891
2.25	0.714	0.897
2.5	0.734	0.902
2.75	0.75	0.907
3	0.763	0.911
3.5	0.787	0.92
4	0.811	0.929
4.5	0.834	0.938
5	0.858	0.947
5.5	0.882	0.956
6	0.905	0.964
7	0.953	0.981
8	1	1

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By: L. J. Julek
 By: C. E. Jensen

5.3.2 Local Thinning Case 2

When L_m (length of wall thickness region that is $< t_{min}$, see Figure 4) is less than $2.65 \sqrt{R t_{min}}$ and $t_{nom} > 1.13 t_{min}$, then t_{aloc} is determined by

$$t_{aloc_2}(t_{min}, t_{nom}, R, L_m, L) = \max \left[\left[\frac{1.5 \sqrt{R t_{min}}}{L} \left(1 - \frac{t_{nom}}{t_{min}} \right) + 1 \right] t_{min}, \frac{0.353 L_m}{\sqrt{R t_{min}}} t_{min} \right]$$

where L is the length of wall thinning region, see Figure 4.

5.3.3 Local Thinning Case 3

When the above conditions are not satisfied then t_{aloc} is determined from Curve 2 of Figure 5, i.e.,

$$t_{aloc_3}(t_{min}, R, L_{ma}) = C_2 \left(\frac{L_{ma}}{\sqrt{R t_{min}}} \right) t_{min}$$

Case 3 is applicable when the thinning extends around the full circumference of the tank but has a limited axial extent, L_{ma} .

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 Subject: Tank 241-AN-105 Acceptable Minimum Wall Thickness Date 7/15/99
for Local Wall Thinning Due to Corrosion Checked: 7-22-99
 Location: 200 E Area - Hanford Site, Richland, Washington Revised: By: H. H. Zieda

6.0 STRESSES FROM PRIMARY LOADS

Data = READPRN(STR_AW_{prn}) read moment and force resultants in primary steel tank wall due to design primary loads and earthquake loading from Tables 5 and 6 of RHO-C-60 (1981) on basis of original analysis with

Soil overburden: 6.5 ft Waste height: 363 in (1 Mgal)

Soil density: 110 lb/ft³ Waste specific gravity (SG): 2.0

Live load: 40 lb/ft² uniform + 50 tons concentrated

Vapor pressure: +60 to -6 in. water gauge (+60 in. w.g. included in results below as worst case)

Design basis earthquake (DBE): horizontal peak ground motion (PGA) 0.25 g with vertical 2/3 of horizontal.

Results are summarized in Table 4.

Table 4. Internal Moment and Force Resultants in Primary Tank.

z (ft.)	t _{nom} (in.)	Longitudinal (z)								Circumferential (θ)							
		Hydrostatic		Dead + Live		DBE		Hydrodynamic		Hydrostatic		Dead + Live		DBE		Hydrodynamic	
		M (kip-ft/ft)	N (kip/ft)	M (kip-ft/ft)	N (kip/ft)	M (kip-ft/ft)	N (kip/ft)	M (kip-ft/ft)	N (kip/ft)	M (kip-ft/ft)	N (kip/ft)	M (kip-ft/ft)	N (kip/ft)	M (kip-ft/ft)	N (kip/ft)	M (kip-ft/ft)	N (kip/ft)
0	0.875	-0.702	4.19	-0.53	-0.36	0.633	2.1	-0.004	1.37	-0.226	2.12	-0.175	5.06	0.212	13.29	-0.001	-8.33
2	0.875	-0.575	3.2	0.427	-2.8	0.244	4.12	-0.306	1.72	-0.193	7.91	0.115	9.32	0.058	9.04	-0.09	-8.43
6	0.875	-0.298	3.35	0.766	-2.22	0.65	3.67	-0.362	1.71	-0.104	29.87	0.226	19.92	0.189	4.32	-0.112	-5.54
12	0.875	0.184	1.59	0.527	-1.52	0.522	2.12	-0.147	1.12	0.052	62.62	0.158	24.83	0.156	13.04	-0.045	2.77
24	0.875	0.74	6.09	-0.032	-2.09	0.055	1.44	0.221	3	0.222	122.6	-0.009	15.97	0.017	12.24	0.067	24.81
37	0.875	0.778	6.21	-0.113	-3.91	0.064	2.89	0.264	4.18	0.233	143.7	-0.034	4.12	0.019	4.57	0.079	37.01
37	0.75	0.026	4.21	-0.097	-0.11	0.057	0.53	0.044	2.28	0.008	122.8	-0.028	4.27	0.017	4.5	0.013	31.34
61	0.75	0.04	4.28	-0.004	-2.34	0.014	1.71	0.015	3.58	0.012	122.7	-0.001	0.93	0.003	0.48	0.005	35.86
103	0.75	0.031	2.15	0.004	-1.91	0.005	1.26	-0.026	3.79	-0.009	105.6	0.001	0.08	0.002	0.21	0	34.41
103	0.5	-0.025	5.45	0	-1.9	0	1.02	0.004	4.47	0.007	106.6	0	0.08	0	0.27	0.001	34.61
145	0.5	-0.062	4.29	-0.001	-0.187	0.001	0.9	-0.024	4.87	-0.019	92.45	0	0.01	0	0.23	-0.007	34.79
186	0.5	-0.002	4.05	0	-1.79	0.001	0.78	0	4.88	-0.001	74.55	0	0.01	0	0.16	0	32.99
234	0.5	0.008	4.28	0	-1.71	0.001	0.27	0.005	4.84	0.002	53.92	0	0	0	0.2	0.001	31.17
294	0.5	0	3.68	0	-1.61	0	0.31	0.004	4.14	0	30.27	0	0	0	0.2	0.001	28.34
342	0.5	-0.014	3.48	0	-1.54	0.001	0.58	0.039	4	-0.005	12.94	0	-0.01	0	0.18	0.012	25.01
381	0.5	-0.021	4.94	0	-1.5	0.001	0.55	-0.051	0.78	-0.006	16.17	0	0.08	0	0.1	-0.015	0.46
381	0.375	0.014	3.44	0.001	-1.48	0.001	0.74	-0.024	2.66	0.005	12.06	0	-0.03	0	0.16	-0.007	0.97
405	0.375	0.007	4.24	-0.002	-1.56	0.001	0.92	0.005	1.99	0.002	14.82	0	-0.22	0	0.47	0.001	0.11
418	0.375	0.006	4.32	-0.022	-1.53	0.018	1.05	0.018	1.64	0.02	8.99	-0.007	1.82	0.055	1.23	0.005	-1.72
431	0.375	0.029	4.44	-0.004	-0.04	0.007	2.03	-0.005	1.27	0.008	-4.8	-0.001	6.96	0.002	5.45	-0.001	-5.75
442	0.375	-0.028	3.61	0.022	-1.17	0.021	1.56	-0.019	0.86	-0.009	-26.49	0.007	14.32	0.006	11.15	-0.006	-9.47
452	0.375	-0.124	2.99	0.043	-1.12	0.057	1.33	-0.017	0.73	-0.038	-40.24	0.013	14.88	0.017	11.89	-0.005	-9.46
461	0.375	-0.216	3.73	0.045	-1.59	0.056	3.31	-0.015	0.71	-0.062	-28.45	0.012	8.4	0.016	2.71	-0.005	-6.11
469	0.375	0.299	6.4	-0.148	-2.79	0.213	2.9	0.034	0.71	0.092	2.17	-0.004	0.34	0.064	8.79	0.011	-1.74

where z distance (in.) from bottom of primary tank
 M moment resultant (kip-ft / ft)
 N force resultant (kip / ft)

Internal moment and force resultants from secondary stresses due to thermal stress and creep of concrete are not included in the above.

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for Local Wall Thinning Due to Corrosion
 Location: 200 E Area - Hanford Site, Richland, Washington

WO/Job No. 106705/CA40
 Date: 7/15/99 By: L. J. Jolyk
 Checked: 7-27-99 By: H. H. Zinda
 Revised: _____ By: _____

Apply appropriate dimensional units to results in Table 4, i.e.,

Internal M, N from Static Loading		Longitudinal (z)	Internal M, N from Seismic Loading
$vz = \text{Data}^{<2>} \cdot \text{in}$	$vM_{z_hydrostatic} = \text{Data}^{<2>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$		$vM_{z_DBE} = \text{Data}^{<8>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$
$\delta z = 0.001 \cdot \text{in}$			
$vz_6 = vz_6 + \delta z$	$vN_{z_hydrostatic} = \text{Data}^{<3>} \cdot \frac{\text{kip}}{\text{ft}}$		$vN_{z_DBE} = \text{Data}^{<7>} \cdot \frac{\text{kip}}{\text{ft}}$
$vz_9 = vz_9 + \delta z$	$vM_{z_dead_live} = \text{Data}^{<4>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$		$vM_{z_hydrodynamic} = \text{Data}^{<9>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$
$vz_{16} = vz_{16} + \delta z$			
$vt_{nom} = \text{Data}^{<1>} \cdot \text{in}$	$vN_{z_dead_live} = \text{Data}^{<5>} \cdot \frac{\text{kip}}{\text{ft}}$		$vN_{z_hydrodynamic} = \text{Data}^{<10>} \cdot \frac{\text{kip}}{\text{ft}}$
Circumferential (θ)			
	$vM_{\theta_hydrostatic} = \text{Data}^{<10>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$		$vM_{\theta_DBE} = \text{Data}^{<14>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$
	$vN_{\theta_hydrostatic} = \text{Data}^{<11>} \cdot \frac{\text{kip}}{\text{ft}}$		$vN_{\theta_DBE} = \text{Data}^{<15>} \cdot \frac{\text{kip}}{\text{ft}}$
	$vM_{\theta_dead_live} = \text{Data}^{<12>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$		$vM_{\theta_hydrodynamic} = \text{Data}^{<16>} \cdot \frac{\text{kip} \cdot \text{ft}}{\text{ft}}$
	$vN_{\theta_dead_live} = \text{Data}^{<13>} \cdot \frac{\text{kip}}{\text{ft}}$		$vN_{\theta_hydrodynamic} = \text{Data}^{<17>} \cdot \frac{\text{kip}}{\text{ft}}$

Interpolate and scale results relative to original analysis basis

$$M_{z_hydrostatic}(h_w, SG, z) = \frac{SG}{2.0} \cdot \frac{h_w}{363 \cdot \text{in}} \cdot \text{interp}(vz, vM_{z_hydrostatic}, z)$$

$$N_{z_hydrostatic}(h_w, SG, z) = \frac{SG}{2.0} \cdot \frac{h_w}{363 \cdot \text{in}} \cdot \text{interp}(vz, vN_{z_hydrostatic}, z)$$

$$M_{\theta_hydrostatic}(h_w, SG, z) = \frac{SG}{2.0} \cdot \frac{h_w}{363 \cdot \text{in}} \cdot \text{interp}(vz, vM_{\theta_hydrostatic}, z)$$

$$N_{\theta_hydrostatic}(h_w, SG, z) = \frac{SG}{2.0} \cdot \frac{h_w}{363 \cdot \text{in}} \cdot \text{interp}(vz, vN_{\theta_hydrostatic}, z)$$

$$M_{z_dead_live}(h_{soil}, \gamma_{soil}, z) = \frac{h_{soil}}{6.5 \cdot \text{ft}} \cdot \frac{\gamma_{soil}}{110 \cdot \frac{\text{lbf}}{\text{ft}^3}} \cdot \text{interp}(vz, vM_{z_dead_live}, z)$$

$$N_{z_dead_live}(h_{soil}, \gamma_{soil}, z) = \frac{h_{soil}}{6.5 \cdot \text{ft}} \cdot \frac{\gamma_{soil}}{110 \cdot \frac{\text{lbf}}{\text{ft}^3}} \cdot \text{interp}(vz, vN_{z_dead_live}, z)$$

$$M_{\theta_dead_live}(h_{soil}, \gamma_{soil}, z) = \frac{h_{soil}}{6.5 \cdot \text{ft}} \cdot \frac{\gamma_{soil}}{110 \cdot \frac{\text{lbf}}{\text{ft}^3}} \cdot \text{interp}(vz, vM_{\theta_dead_live}, z)$$

$$N_{\theta_dead_live}(h_{soil}, \gamma_{soil}, z) = \frac{h_{soil}}{6.5 \cdot \text{ft}} \cdot \frac{\gamma_{soil}}{110 \cdot \frac{\text{lbf}}{\text{ft}^3}} \cdot \text{interp}(vz, vN_{\theta_dead_live}, z)$$

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for Local Wall Thinning Due to CorrosionDate: 7/15/99By: J. J. JubykLocation: 200 E Area - Hanford Site, Richland, WashingtonChecked: 7-28-99By: H. H. Zaida

Revised

By:

$$M_{z_hydrodynamic}(h_w, SG, PGA, z) = \frac{SG}{2.0} \frac{h_w}{363-in} \frac{PGA}{0.25} \cdot \text{interp}(vz, vM_{z_hydrodynamic}, z)$$

$$N_{z_hydrodynamic}(h_w, SG, PGA, z) = \frac{SG}{2.0} \frac{h_w}{363-in} \frac{PGA}{0.25} \cdot \text{interp}(vz, vN_{z_hydrodynamic}, z)$$

$$M_{\theta_hydrodynamic}(h_w, SG, PGA, z) = \frac{SG}{2.0} \frac{h_w}{363-in} \frac{PGA}{0.25} \cdot \text{interp}(vz, vM_{\theta_hydrodynamic}, z)$$

$$N_{\theta_hydrodynamic}(h_w, SG, PGA, z) = \frac{SG}{2.0} \frac{h_w}{363-in} \frac{PGA}{0.25} \cdot \text{interp}(vz, vN_{\theta_hydrodynamic}, z)$$

$$M_{z_DBE}(h_{soil}, \gamma_{soil}, PGA, z) = \frac{h_{soil}}{6.5-ft} \frac{\gamma_{soil}}{110 \frac{lb_f}{ft^3}} \frac{PGA}{0.25} \cdot \text{interp}(vz, vM_{z_DBE}, z)$$

$$N_{z_DBE}(h_{soil}, \gamma_{soil}, PGA, z) = \frac{h_{soil}}{6.5-ft} \frac{\gamma_{soil}}{110 \frac{lb_f}{ft^3}} \frac{PGA}{0.25} \cdot \text{interp}(vz, vN_{z_DBE}, z)$$

$$M_{\theta_DBE}(h_{soil}, \gamma_{soil}, PGA, z) = \frac{h_{soil}}{6.5-ft} \frac{\gamma_{soil}}{110 \frac{lb_f}{ft^3}} \frac{PGA}{0.25} \cdot \text{interp}(vz, vM_{\theta_DBE}, z)$$

$$N_{\theta_DBE}(h_{soil}, \gamma_{soil}, PGA, z) = \frac{h_{soil}}{6.5-ft} \frac{\gamma_{soil}}{110 \frac{lb_f}{ft^3}} \frac{PGA}{0.25} \cdot \text{interp}(vz, vN_{\theta_DBE}, z)$$

Membrane stress from normal primary loads (hydrostatic + dead + live)

$$\sigma_{z_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \frac{1}{t} \cdot (N_{z_dead_live}(h_{soil}, \gamma_{soil}, z) + N_{z_hydrostatic}(h_w, SG, z))$$

$$\sigma_{\theta_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \frac{1}{t} \cdot (N_{\theta_dead_live}(h_{soil}, \gamma_{soil}, z) + N_{\theta_hydrostatic}(h_w, SG, z))$$

Bending stress from normal primary loads

$$\sigma_{z_normal_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \frac{6}{t^2} \cdot (M_{z_dead_live}(h_{soil}, \gamma_{soil}, z) + M_{z_hydrostatic}(h_w, SG, z))$$

$$\sigma_{\theta_normal_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \frac{6}{t^2} \cdot (M_{\theta_dead_live}(h_{soil}, \gamma_{soil}, z) + M_{\theta_hydrostatic}(h_w, SG, z))$$

Membrane + bending stress from normal primary loads - outside surface

$$\sigma_{z_normal_o}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \sigma_{z_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) + \sigma_{z_normal_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, z)$$

$$\sigma_{\theta_normal_o}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \sigma_{\theta_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) + \sigma_{\theta_normal_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, z)$$

Membrane + bending stress from normal primary loads - inside surface

$$\sigma_{z_normal_i}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \sigma_{z_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) - \sigma_{z_normal_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, z)$$

$$\sigma_{\theta_normal_i}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \sigma_{\theta_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) - \sigma_{\theta_normal_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, z)$$

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By: J. J. JulykBy: H. H. Zaida

By:

Membrane stress from DBE + hydrodynamic induced loads (assume RMS combination due to large frequency difference between responses of the two motions)

$$\sigma_{z_DBE_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \frac{1}{t} \sqrt{N_{z_DBE}(h_{soil}, \gamma_{soil}, PGA, z)^2 + N_{z_hydrodynamic}(h_w, SG, PGA, z)^2}$$

$$\sigma_{\theta_DBE_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \frac{1}{t} \sqrt{N_{\theta_DBE}(h_{soil}, \gamma_{soil}, PGA, z)^2 + N_{\theta_hydrodynamic}(h_w, SG, PGA, z)^2}$$

Bending stress from DBE + hydrodynamic induced loads

$$\sigma_{z_DBE_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \frac{6}{t^2} \sqrt{M_{z_DBE}(h_{soil}, \gamma_{soil}, PGA, z)^2 + M_{z_hydrodynamic}(h_w, SG, PGA, z)^2}$$

$$\sigma_{\theta_DBE_b}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \frac{6}{t^2} \sqrt{M_{\theta_DBE}(h_{soil}, \gamma_{soil}, PGA, z)^2 + M_{\theta_hydrodynamic}(h_w, SG, PGA, z)^2}$$

Stress intensity (neglecting non-axisymmetric induced shear and torsion from horizontal seismic loading)

$$SI(\sigma_1, \sigma_2) = \max(|\sigma_1 - \sigma_2|, |\sigma_2|, |\sigma_1|)$$

Primary membrane stress intensity for normal primary loads

$$P_{m_normal}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = SI(\sigma_{\theta_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z), \sigma_{z_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z))$$

Primary membrane + bending stress intensity for normal primary loads

$$P_{m_b_normal}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) = \max \left(\left\{ \begin{array}{l} SI(\sigma_{\theta_normal_o}(t, h_w, SG, h_{soil}, \gamma_{soil}, z), \sigma_{z_normal_o}(t, h_w, SG, h_{soil}, \gamma_{soil}, z)) \\ SI(\sigma_{\theta_normal_i}(t, h_w, SG, h_{soil}, \gamma_{soil}, z), \sigma_{z_normal_i}(t, h_w, SG, h_{soil}, \gamma_{soil}, z)) \end{array} \right\} \right)$$

Primary membrane stress intensity for normal primary loads + DBE (worst case load combination)

$$P_{m_DBE}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \left\{ \begin{array}{l} \sigma_{\theta_0} \leftarrow \sigma_{\theta_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) + \sigma_{\theta_DBE_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) \\ \sigma_{\theta_1} \leftarrow \sigma_{\theta_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) - \sigma_{\theta_DBE_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) \\ \sigma_{z_0} \leftarrow \sigma_{z_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) + \sigma_{z_DBE_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) \\ \sigma_{z_1} \leftarrow \sigma_{z_normal_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, z) - \sigma_{z_DBE_m}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) \end{array} \right.$$

for $i \in 0..1$
 for $j \in 0..1$

$$P_{m_{i,j}} \leftarrow SI(\sigma_{\theta_i}, \sigma_{z_j}) \cdot ksi^{-1}$$

$$\max(P_m) \cdot ksi$$

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Primary membrane + bending stress intensity for normal primary loads + DBE (worst case load combination)

 $P_{m_b_DBE} \quad t, h, w, SG, h, soil, \gamma, soil, PGA, z$

```

 $\sigma_{\theta ni} = \sigma_{\theta\_normal\_i} \quad t, h, w, SG, h, soil, \gamma, soil, z$ 
 $\sigma_{\theta no} = \sigma_{\theta\_normal\_o} \quad t, h, w, SG, h, soil, \gamma, soil, z$ 
 $\sigma_{z ni} = \sigma_{z\_normal\_i} \quad t, h, w, SG, h, soil, \gamma, soil, z$ 
 $\sigma_{z no} = \sigma_{z\_normal\_o} \quad t, h, w, SG, h, soil, \gamma, soil, z$ 
 $\sigma_{\theta DBEm} = \sigma_{\theta\_DBE\_m} \quad t, h, w, SG, h, soil, \gamma, soil, PGA, z$ 
 $\sigma_{z DBEm} = \sigma_{z\_DBE\_m} \quad t, h, w, SG, h, soil, \gamma, soil, PGA, z$ 
 $\sigma_{\theta DBEb} = \sigma_{\theta\_DBE\_b} \quad t, h, w, SG, h, soil, \gamma, soil, PGA, z$ 
 $\sigma_{z DBEb} = \sigma_{z\_DBE\_b} \quad t, h, w, SG, h, soil, \gamma, soil, PGA, z$ 
 $\sigma_{\theta i_0} = \sigma_{\theta ni} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{\theta i_1} = \sigma_{\theta ni} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{\theta i_2} = \sigma_{\theta ni} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{\theta i_3} = \sigma_{\theta ni} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{\theta o_0} = \sigma_{\theta no} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{\theta o_1} = \sigma_{\theta no} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{\theta o_2} = \sigma_{\theta no} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{\theta o_3} = \sigma_{\theta no} - \sigma_{\theta DBEm} - \sigma_{\theta DBEb}$ 
 $\sigma_{z i_0} = \sigma_{z ni} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
 $\sigma_{z i_1} = \sigma_{z ni} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
 $\sigma_{z i_2} = \sigma_{z ni} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
 $\sigma_{z i_3} = \sigma_{z ni} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
 $\sigma_{z o_0} = \sigma_{z no} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
 $\sigma_{z o_1} = \sigma_{z no} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
 $\sigma_{z o_2} = \sigma_{z no} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
 $\sigma_{z o_3} = \sigma_{z no} - \sigma_{z DBEm} - \sigma_{z DBEb}$ 
for i in 0..3
  for j in 0..3
     $P_{m\_b\_i,j} = SI \cdot \sigma_{\theta i_j} \cdot \sigma_{z i_j} \cdot ksi$ 
     $P_{m\_b\_o,j} = SI \cdot \sigma_{\theta o_j} \cdot \sigma_{z o_j} \cdot ksi$ 
max augment /  $P_{m\_b\_i}, P_{m\_b\_o} \cdot ksi$ 

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for Local Wall Thinning Due to Corrosion
 Location: 200 E Area - Hanford Site, Richland, Washington

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By: H. H. Zinda

By:

For reference the resulting primary stress intensities in the primary steel tank for design primary loads and earthquake loading are shown in Figure 6a and 6b, respectively for the original design nominal wall thicknesses (see Figure 6c).

Figure 6. Primary Stress Intensities at Design Conditions with Original Design Nominal Wall Thicknesses for 241-AN-105 Primary Tank (RHO-C-60, 1981 and WHC 1994)

$$h_{\text{soil}} = 7.5 \text{ ft} \quad \gamma_{\text{soil}} = 125 \frac{\text{lb}}{\text{ft}^3} \quad h_w = 422 \text{ in} \quad SG = 1.7 \quad PGA = 0.25$$

Figure 6c. Original Design Nominal Wall Thicknesses for 241-AN-105 Primary Tank.

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 By: L. J. Jylk
 By: C. E. Jensen
7.0 ALLOWABLE WALL THICKNESS

 The AN-105 primary tank was constructed from ASTM A537, Class 1 material which for ASME Section VIII, Div. 2 (ASME 1974 or 1994), the allowable primary membrane stress intensity, S_m , is given by

 Temp. $t = 0..5$
 $R = 37.479\text{-ft}$ Inside radius of tank

 $(^{\circ}\text{F})$

$$vT_1 = vS_{y1} = vS_{u1}$$

 $RT = 100\text{ }^{\circ}\text{F}$

room temperature

 $S_y(T) = \text{interp}(vT, vS_y, T) \cdot \text{ksi}$ Yield strength (ksi) at temperature ($^{\circ}\text{F}$)

 $S_u(T) = \text{interp}(vT, vS_u, T) \cdot \text{ksi}$ Ultimate strength (ksi) at temperature ($^{\circ}\text{F}$)

$$S_m(T) = \min\left\{\frac{1}{3} \cdot S_u(RT), \frac{1}{3} \cdot S_u(T), \frac{2}{3} \cdot S_y(RT), \frac{2}{3} \cdot S_y(T)\right\}$$

100	50	70
200	44.1	70
250	42.3	69.3
300	40.5	68.6
350	39	68.6
400	37.5	68.6

vT_1	$S_m(vT_1)$	
100	23.3	
200	23.3	
250	23.1	
300	22.9	
350	22.9	
400	22.9	

S_m is controlled by S_u

7.1 STEP 1 - CODE MINIMUM WALL THICKNESS

 Minimum wall thickness, t_{min} on basis of ASME Code (ASME 1974 or 1994) for normal primary loads

$$k = 1$$

$$t_{min_normal}(T, h_w, SG, h_{soil}, \gamma_{soil}, z) = \max\left\{\left(\frac{\text{root}(k S_m(T) - P_{m_normal}(t, h_w, SG, h_{soil}, \gamma_{soil}, z), t)}{\text{root}(1.5 k S_m(T) - P_{m_b_normal}(t, h_w, SG, h_{soil}, \gamma_{soil}, z), t)}\right)\right\}$$

$P_m \leq k S_m$
 $P_m + P_b \leq k S_m$

 Case 1 (see Section 5.3.1) maximum circumferential (transverse) length of the wall thickness region that may be $< t_{min}$

$$L_{mt_nominal_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, z) = \sqrt{R \cdot t_{min_normal}(T, h_w, SG, h_{soil}, \gamma_{soil}, z)}$$

 Case 2 (see Section 5.3.2) maximum length of the wall thickness region that may be $< t_{min}$

$$L_{m_nominal_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, z) = 2.65 \cdot L_{mt_nominal_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, z)$$

 Minimum wall thickness, t_{min} on basis of ASME Code for normal primary loads + seismic loading

 $k_{DBE} = 1.2$ (conservatively classified seismic loading as Level C event in original design evaluation [RHO-C-60, 1981], for Level D event $k_{DBE} = 2$)

$$t_{min_DBE}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \max\left\{\left(\frac{\text{root}(k_{DBE} S_m(T) - P_{m_DBE}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z), t)}{\text{root}(1.5 k_{DBE} S_m(T) - P_{m_b_DBE}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z), t)}\right)\right\}$$

 Case 1 (see Section 5.3.1) maximum circumferential (transverse) length of the wall thickness region that may be $< t_{min}$

$$L_{mt_DBE_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \sqrt{R \cdot t_{min_DBE}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z)}$$

 Case 2 (see Section 5.3.2) maximum length of the wall thickness region that may be $< t_{min}$

$$L_{m_DBE_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = 2.65 \cdot L_{mt_DBE_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z)$$

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 By: C. E. Jensen
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Controlling minimum wall thickness, t_{min} on basis of ASME Code for normal primary loads with or without seismic loading

$$t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \max \left(\begin{array}{l} t_{min_normal}(T, h_w, SG, h_{soil}, \gamma_{soil}, z) \\ t_{min_DBE}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) \end{array} \right)$$

Case 1 (see Section 5.3.1) maximum circumferential (transverse) length of the wall thickness region that may be $< t_{min}$

$$L_{mt_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \sqrt{R \cdot t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z)}$$

Case 1 allowable local thickness

$$t_{aloc_1}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, L_{ma}) = t_{aloc_1}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z), R, L_{ma})$$

Case 2 (see Section 5.3.2) maximum length of the wall thickness region that may be $< t_{min}$

$$L_{m_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = 2.65 L_{mt_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z)$$

Case 3 (see Section 5.3.3) allowable local thickness when thinning extends around the full circumference of the tank but has a limited axial extent.

$$t_{aloc_3}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, L_{ma}) = t_{aloc_3}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z), R, L_{ma})$$

The minimum wall thickness, t_{min} , on basis of a 95% S_y criterion for normal primary loads + seismic loading is also introduced as a point of reference only.

$$t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \max \left(\begin{array}{l} \sqrt{0.95 S_y(T) - P_{m_DBE}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, t)} \\ \sqrt{1.5 \cdot 0.95 S_y(T) - P_{m_b_DBE}(t, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, t)} \end{array} \right)$$

Case 1 (see Section 5.3.1) maximum circumferential (transverse) length of the wall thickness region that may be $< t_{min}$

$$L_{mt_DBE_Sy_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = \sqrt{R \cdot t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z)}$$

Case 1 allowable local thickness

$$t_{aloc_1_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, L_{ma}) = t_{aloc_1}(t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z), R, L_{ma})$$

Case 2 (see Section 5.3.2) maximum length of the wall thickness region that may be $< t_{min}$

$$L_{m_DBE_Sy_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) = 2.65 L_{mt_DBE_Sy_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z)$$

Case 3 (see Section 5.3.3) allowable local thickness when thinning extends around the full circumference of the tank but has a limited axial extent.

$$t_{aloc_3_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, L_{ma}) = t_{aloc_3}(t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z), R, L_{ma})$$

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By: L. J. Jolyk
H. H. Zada

7.1.1 Design Conditions

The allowable minimum *uniform* wall thickness for the following *design* conditions

$$T = 350 \text{ } ^\circ\text{F (design temperature)}$$

$$h_{\text{soil}} = 7.5 \text{ ft} \quad \gamma_{\text{soil}} = 125 \frac{\text{lb}}{\text{ft}^3} \quad h_w = 422 \text{ in} \quad SG = 1.7 \quad PGA = 0.25 \quad S_m(T) = 22.9 \text{ ksi} \quad S_y(T) = 39 \text{ ksi}$$

are calculated for normal primary loads, normal primary loads + seismic loads, and the controlling Code-based allowable $t_{\min}$ is determined as the maximum minimum wall thickness between these two load conditions. In addition, the maximum circumferential extent (L_m) and resultant maximum extent (L_m) as defined in Figure 4 for evaluation of *local* wall thinning are calculated for the 241-AN-105 primary tank. For reference, the minimum wall thicknesses at the 95% S_y criterion are also calculated.

$$m = 0.39 \quad \Delta z = 12 \text{ in}$$

$$n = 0.6$$

$$t_{\text{DCM}_{m,n}} = 0 \quad z'_m = m \cdot \Delta z$$

$$t_{\text{DCM}}^{<0>} = \frac{z'}{m}$$

$$t_{\text{DCM}_{m,1}} = \frac{t_{\min_normal}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, z'_m)}{m}$$

$$t_{\text{DCM}_{m,2}} = \frac{t_{\min_DBE}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{m}$$

$$t_{\text{DCM}_{m,3}} = \frac{t_{\min}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{m}$$

$$t_{\text{DCM}_{m,4}} = \frac{L_{m_max}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{m}$$

$$t_{\text{DCM}_{m,5}} = \frac{L_{m_max}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{m}$$

$$t_{\text{DCM}_{m,6}} = \frac{t_{\min_DBE_Sy}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{m}$$

$$\text{WRITEPRN(TMINDC)} = t_{\text{DCM}} \quad (\text{write results to disk for retrieval into Table 5})$$

These results are summarized in Table 5 and in Figures 7a and 7b as a function of axial position relative to the tank bottom.

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for Local Wall Thinning Due to Corrosion Checked: 7-27-11
 Location: 200 E Area - Hanford Site, Richland, Washington Revised: _____

By: L. J. Jubyk
 By: H. H. Zaida
 By: _____

7.1.1 Design Conditions (Continued)

$T = 350$ °F (design temperature)
 $h_{\text{soil}} = 7.5$ ft $\gamma_{\text{soil}} = 125 \frac{\text{lb}}{\text{ft}^3}$ $h_w = 422$ in $SG = 1.7$ $PGA = 0.25$ $S_m(T) = 22.9$ ksi $S_y(T) = 39$ ksi

Table 5. Allowable Minimum Uniform Wall Thickness for 241-AN-105 Primary Tank at Design Conditions vs. Position from Tank Bottom.

Code-based allowable uniform wall thickness						
z (in.)	t_{min} for Normal primary loads (in.)	t_{min} for Normal primary + seismic loads (in.)	Controlling t_{min} based on Code (in.)	L_{min} (in.)	L_{min} (in.)	Controlling t_{min} based on 95% S_y (in.)
0	0.497	0.579	0.579	16.1	42.8	0.497
12	0.463	0.602	0.602	16.5	43.6	0.501
24	0.518	0.553	0.553	15.8	41.8	0.446
36	0.536	0.579	0.579	16.1	42.8	0.465
48	0.455	0.482	0.482	14.7	39.0	0.357
60	0.447	0.488	0.488	14.8	39.3	0.361
72	0.429	0.474	0.474	14.6	38.7	0.351
84	0.410	0.459	0.459	14.4	38.1	0.340
96	0.392	0.443	0.443	14.1	37.4	0.328
108	0.378	0.424	0.424	13.8	36.6	0.314
120	0.364	0.411	0.411	13.6	36.0	0.305
132	0.349	0.399	0.399	13.4	35.5	0.295
144	0.334	0.386	0.386	13.2	34.9	0.286
156	0.316	0.371	0.371	12.9	34.2	0.275
168	0.297	0.356	0.356	12.7	33.5	0.263
180	0.278	0.340	0.340	12.4	32.8	0.252
192	0.259	0.324	0.324	12.1	32.0	0.240
204	0.241	0.307	0.307	11.8	31.1	0.227
216	0.222	0.290	0.290	11.4	30.3	0.215
228	0.204	0.273	0.273	11.1	29.3	0.202
240	0.186	0.256	0.256	10.7	28.4	0.190
252	0.169	0.240	0.240	10.4	27.5	0.178
264	0.152	0.224	0.224	10.0	26.6	0.166
276	0.135	0.208	0.208	9.7	25.6	0.154
288	0.118	0.192	0.192	9.3	24.6	0.142
300	0.101	0.176	0.176	8.9	23.6	0.130
312	0.086	0.161	0.161	8.5	22.5	0.119
324	0.070	0.145	0.145	8.1	21.4	0.110
336	0.057	0.141	0.141	8.0	21.1	0.114
348	0.058	0.123	0.123	7.4	19.7	0.100
360	0.062	0.086	0.086	6.2	16.5	0.067
372	0.066	0.110	0.110	7.0	18.7	0.092
384	0.055	0.088	0.088	6.3	16.6	0.073
396	0.049	0.061	0.061	5.2	13.9	0.050
408	0.050	0.086	0.086	6.2	16.5	0.072
420	0.077	0.143	0.143	8.0	21.2	0.121
432	0.066	0.083	0.083	6.1	16.2	0.069
444	0.055	0.132	0.132	7.7	20.4	0.109
456	0.141	0.199	0.199	9.5	25.1	0.166
468	0.113	0.238	0.238	10.3	27.4	0.203

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 By: C. E. Jensen

Figure 7a. 241-AN-105 Primary Tank Code-Based Allowable Minimum Uniform Wall Thickness, t_{min} , for Design Conditions.

Figure 7b. Maximum Length (L_m - Case 2) and Maximum Circumferential Length (L_{mt} - Case 1) of the Wall Thickness Region That May be Less Than Code-Based Allowable Minimum Uniform Wall Thickness (t_{min}).

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By: J. J. Julek
 By: H. H. Ziesda
 By

7.1.2 Current Conditions (HNF 1997a and b)

The allowable minimum *uniform* wall thickness for the following *current* operating conditions

$$h_{\text{soil}} = 7.5 \text{ ft} \quad \gamma_{\text{soil}} = 125 \frac{\text{lb}}{\text{ft}^3} \quad h_w = 410 \text{ in} \quad SG = 1.44 \quad T = 120 \text{ °F} \quad PGA = 0.25 \quad S_m(T) = 23.3 \text{ ksi} \quad S_y(T) = 48.8 \text{ ksi}$$

(assume design maximum soil conditions for soil cover height and soil density)

are calculated for normal primary loads, normal primary loads + seismic loads, and the controlling Code-based allowable t_{min} is determined as the maximum minimum wall thickness between these two load conditions. In addition, the maximum circumferential extent (L_m) and resultant maximum extent (L_m) as defined in Figure 4 for evaluation of *local* wall thinning are calculated for the 241-AN-105 primary tank. For reference, the minimum wall thicknesses at the 95% S_y criterion are also calculated.

$$t_{\text{CCM}_{m,0}} = 0$$

$$t_{\text{CCM}}^{<0>} = \frac{z'}{\text{in}}$$

$$t_{\text{CCM}_{m,1}} = \frac{t_{\text{min_normal}}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, z'_m)}{\text{in}}$$

$$t_{\text{CCM}_{m,2}} = \frac{t_{\text{min_DBE}}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{\text{in}}$$

$$t_{\text{CCM}_{m,3}} = \frac{t_{\text{min}}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{\text{in}}$$

$$t_{\text{CCM}_{m,4}} = \frac{L_{m_max}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{\text{in}}$$

$$t_{\text{CCM}_{m,5}} = \frac{L_{m_max}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{\text{in}}$$

$$t_{\text{CCM}_{m,6}} = \frac{t_{\text{min_DBE_Sy}}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z'_m)}{\text{in}}$$

WRITEPRN(TMINCC) = t_{CCM} (write results to disk for retrieval into Table 6)

These results are summarized in Table 6 and in Figures 8a and 8b as a function of axial position relative to the tank bottom.

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By: L. J. JulekBy: J. H. Zinda

By: _____

7.1.2 Current Conditions (Continued)

$$h_{\text{soil}} = 7.5 \text{ ft} \quad \gamma_{\text{soil}} = 125 \frac{\text{lb}}{\text{ft}^3} \quad T = 120 \text{ °F} \quad h_w = 410 \text{ in} \quad SG = 1.44 \quad PGA = 0.25 \quad S_m(T) = 23.3 \text{ ksi} \quad S_y(T) = 48.8 \text{ ksi}$$

Table 6. Allowable Minimum Uniform Wall Thickness for 241-AN-105 Primary Tank at Current Operating Conditions vs. Position from Tank Bottom.

Code-based allowable uniform wall thickness						
z (in.)	t _{min} for Normal primary loads (in.)	t _{min} for Normal primary + seismic loads (in.)	Controlling t _{min} based on Code (in.)	L _{min} mm (in.)	L _{min} mm (in.)	Controlling t _{min} based on 95% S _y (in.)
0	0.469	0.560	0.560	15.9	42.1	0.431
12	0.434	0.577	0.577	16.1	42.7	0.427
24	0.436	0.483	0.483	14.7	39.1	0.340
36	0.436	0.496	0.496	14.9	39.6	0.347
48	0.369	0.392	0.392	13.3	35.2	0.236
60	0.361	0.397	0.397	13.4	35.4	0.239
72	0.347	0.385	0.385	13.2	34.9	0.233
84	0.332	0.372	0.372	12.9	34.3	0.225
96	0.318	0.359	0.359	12.7	33.7	0.217
108	0.305	0.343	0.343	12.4	32.9	0.207
120	0.293	0.333	0.333	12.2	32.4	0.201
132	0.281	0.322	0.322	12.0	31.9	0.195
144	0.270	0.312	0.312	11.8	31.4	0.188
156	0.255	0.300	0.300	11.6	30.8	0.181
168	0.239	0.288	0.288	11.4	30.1	0.174
180	0.224	0.276	0.276	11.1	29.5	0.166
192	0.209	0.263	0.263	10.9	28.8	0.159
204	0.194	0.249	0.249	10.6	28.0	0.150
216	0.179	0.235	0.235	10.3	27.2	0.142
228	0.164	0.221	0.221	10.0	26.4	0.133
240	0.150	0.208	0.208	9.7	25.6	0.125
252	0.136	0.195	0.195	9.4	24.8	0.118
264	0.122	0.182	0.182	9.0	24.0	0.110
276	0.109	0.169	0.169	8.7	23.1	0.102
288	0.095	0.156	0.156	8.4	22.2	0.094
300	0.082	0.143	0.143	8.0	21.3	0.086
312	0.069	0.131	0.131	7.7	20.3	0.079
324	0.056	0.118	0.118	7.3	19.3	0.081
336	0.049	0.121	0.121	7.4	19.6	0.086
348	0.051	0.107	0.107	6.9	18.4	0.076
360	0.055	0.072	0.072	5.7	15.1	0.050
372	0.058	0.097	0.097	6.6	17.5	0.072
384	0.049	0.078	0.078	5.9	15.7	0.058
396	0.041	0.054	0.054	4.9	13.0	0.039
408	0.046	0.081	0.081	6.0	16.0	0.061
420	0.074	0.138	0.138	7.9	20.9	0.105
432	0.058	0.077	0.077	5.9	15.6	0.057
444	0.030	0.116	0.116	7.2	19.2	0.085
456	0.116	0.178	0.178	8.9	23.7	0.133
468	0.099	0.243	0.243	10.4	27.7	0.186

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Figure 8a. 241-AN-105 Primary Tank Code-Based Allowable Minimum Uniform Wall Thickness, t_{min} , for Current Conditions.

Assume design maximum soil conditions for soil cover height and soil density.

$h_{soil} = 7.5 \text{ ft}$ $h_w = 410 \text{ in}$ $T = 120 \text{ °F}$

$\gamma_{soil} = 125 \frac{\text{lb}}{\text{ft}^3}$

$SG = 1.44$
 $PGA = 0.25$

$S_m(T) = 23.3 \text{ ksi}$

$S_y(T) = 48.8 \text{ ksi}$

Figure 8b. Maximum Length (L_{max} - Case 2) and Maximum Circumferential Length (L_{mt} - Case 1) of the Wall Thickness Region That May be Less Than Code-Based Allowable Minimum Uniform Wall Thickness (t_{min}).

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7.2 PREDICTED WALL THICKNESS

A predication of the of wall thickness into the future requires an estimate of the expected corrosion rate. However, only limited direct data is available since the initial wall thickness of the plates is only known within its mill tolerance and the rate of corrosion may or may not have been constant over the operating period.

Assuming a linear corrosion rate, the predicted wall thickness becomes

$$t_p(\text{time}, t_{\text{start}}, t_{\text{meas}}) = \frac{t_{\text{meas}} - t_{\text{start}}}{\text{time}_{\text{exam}} - \text{time}_{\text{start}}} (\text{time} - \text{time}_{\text{start}}) + t_{\text{start}}$$

where
 $\text{time}_{\text{start}} = 1983\text{-yr}$ Water was initially added (11 kgal) to tank AN-105 in the second quarter of 1982 (HNF 1997a and b). During the fourth quarter of 1982 through the first quarter of 1983, the tank received double-shell slurry feed waste (628 kgal) from tank 241-AW-102. The current waste volume of 971 kgal (less than 410 inches) was maintained from 1984 to the present except for a brief period in the first quarter of 1985 for the evaporator campaign, leaving approximately 154 kgal of waste (see Figure 9). Hence, assume start of corrosion in beginning of 1983.
 $\text{time}_{\text{exam}} = 1999\text{-yr}$ approximate time of exam (December 1998 to beginning of 1999)
 t_{start} initial wall thickness, t_{nom} or t_{min} +/- mill plate tolerance
 $\text{tol}_{\text{high}} = 0.030\text{-in}$ Mill plate tolerance
 $\text{tol}_{\text{low}} = -0.010\text{-in}$
 t_{meas} measure wall thickness at $\text{time}_{\text{exam}}$

Corrosion period prior to UT examination

$$\Delta \text{time}_{\text{corrosion_period}} = \text{time}_{\text{exam}} - \text{time}_{\text{start}} \quad \Delta \text{time}_{\text{corrosion_period}} = 16\text{-yr}$$

Predicted linear corrosion rate

$$r_{\text{corrosion}}(t_{\text{start}}, t_{\text{meas}}) = \frac{t_{\text{meas}} - t_{\text{start}}}{\text{time}_{\text{exam}} - \text{time}_{\text{start}}}$$

Critical time on exceeding t_{min}

$$\text{time}_{\text{cr}}(t_{\text{min}}, t_{\text{start}}, t_{\text{meas}}) = \text{root}(t_p(\text{time}, t_{\text{start}}, t_{\text{meas}}) - t_{\text{min}}, \text{time})$$

Delta time to exceed t_{min} after UT examination

$$\Delta \text{time}_{\text{cr}}(t_{\text{min}}, t_{\text{start}}, t_{\text{meas}}) = \text{time}_{\text{cr}}(t_{\text{min}}, t_{\text{start}}, t_{\text{meas}}) - \text{time}_{\text{exam}}$$

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Figure 9. Waste Surface Level History for Tank 241-AN-105. (HNF 1997a and b)

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7.3 PLATE 1 EVALUATION

Nominal wall thickness Measured min wall thk Location relative to bottom of primary tank mils 10³·in
 t_{nom} 0.5·in $t_{meas_Plate_1}$ 0.452·in z_{Plate_1} 28·ft z_{Plate_1} = 336·in

Predicted corrosion rate (assuming linear rate)

 $r_{corrosion} t_{nom} \text{ to } \text{high } t_{meas_Plate_1} = 4.875 \frac{\text{mils}}{\text{yr}}$ high

Design Conditions

 h_{soil} 7.5·ft γ_{soil} 125 $\frac{\text{lb}}{\text{ft}^3}$ h_w 422·in

 $r_{corrosion} t_{nom} \text{ to } t_{meas_Plate_1} = 3 \frac{\text{mils}}{\text{yr}}$ nominal

T 350 °F (design temperature)

SG 1.7 PGA 0.25 $S_m(T) = 22.9 \cdot \text{ksi}$
 $r_{corrosion} t_{nom} \text{ to } \text{low } t_{meas_Plate_1} = 2.375 \frac{\text{mils}}{\text{yr}}$ low
 $S_y(T) = 39 \cdot \text{ksi}$

Figure 10. STEP 1 - 214-AN-105 Primary Tank Predicted Minimum Wall Thickness, t_p , of Plate 1 vs. Time, Compared to Code-Based Allowable Minimum Uniform Wall Thickness, t_{min} .

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7.3 PLATE 1 EVALUATION (Continued)

Design Conditions

t_{min} T, h w, SG, h soil, γ soil, PGA, z Plate_1 = 0.141 in Code t_{min} Δ time to reach t_{min}

Δ time_{cr} t_{min} T, h w, SG, h soil, γ soil, PGA, z Plate_1, t_{nom} tol high, $t_{meas_Plate_1}$ = 63.8 yr min

Δ time_{cr} t_{min} T, h w, SG, h soil, γ soil, PGA, z Plate_1, t_{nom} $t_{meas_Plate_1}$ = 103.8 yr nom

Δ time_{cr} t_{min} T, h w, SG, h soil, γ soil, PGA, z Plate_1, t_{nom} tol low, $t_{meas_Plate_1}$ = 131.1 yr max

$t_{min_DBE_Sy}$ T, h w, SG, h soil, γ soil, PGA, z Plate_1 = 0.114 in 95% S_y t_{min}

Δ time_{cr} $t_{min_DBE_Sy}$ T, h w, SG, h soil, γ soil, PGA, z Plate_1, t_{nom} tol high, $t_{meas_Plate_1}$ = 69.4 yr min

Δ time_{cr} $t_{min_DBE_Sy}$ T, h w, SG, h soil, γ soil, PGA, z Plate_1, t_{nom} $t_{meas_Plate_1}$ = 112.7 yr nom

Δ time_{cr} $t_{min_DBE_Sy}$ T, h w, SG, h soil, γ soil, PGA, z Plate_1, t_{nom} tol low, $t_{meas_Plate_1}$ = 142.4 yr max

Current Conditions

t_{min} 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1 = 0.121 in Code t_{min} Δ time to reach t_{min}

Δ time_{cr} t_{min} 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1, t_{nom} tol high, $t_{meas_Plate_1}$ = 67.8 yr min

Δ time_{cr} t_{min} 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1, t_{nom} $t_{meas_Plate_1}$ = 110.2 yr nom

Δ time_{cr} t_{min} 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1, t_{nom} tol low, $t_{meas_Plate_1}$ = 139.2 yr max

$t_{min_DBE_Sy}$ 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1 = 0.086 in 95% S_y t_{min}

Δ time_{cr} $t_{min_DBE_Sy}$ 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1, t_{nom} tol high, $t_{meas_Plate_1}$ = 75.1 yr min

Δ time_{cr} $t_{min_DBE_Sy}$ 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1, t_{nom} $t_{meas_Plate_1}$ = 122 yr nom

Δ time_{cr} $t_{min_DBE_Sy}$ 120,410-in, 1.44, h soil, γ soil, PGA, z Plate_1, t_{nom} tol low, $t_{meas_Plate_1}$ = 154.1 yr max

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7.4 PLATE 2 EVALUATION

Nominal wall thickness Measured min wall thk Location of minimum wall thickness relative to bottom of primary tank
 $t_{nom} = 0.5$ -in $t_{meas_Plate_2} = 0.40$ -in Actual Conservatively assume at bottom of Plate 2
 $z_{Plate_2} = 22.5$ ft $z_{Plate_2} = 20$ ft $z_{Plate_2} = 240$ -in

Predicted corrosion rate (assuming linear rate)

$$r_{corrosion}(t_{nom} + t_{high}, t_{meas_Plate_2}) = 8.125 \frac{\text{mils}}{\text{yr}} \text{ high}$$

$$r_{corrosion}(t_{nom}, t_{meas_Plate_2}) = 6.25 \frac{\text{mils}}{\text{yr}} \text{ nominal}$$

$$r_{corrosion}(t_{nom} + t_{low}, t_{meas_Plate_2}) = 5.625 \frac{\text{mils}}{\text{yr}} \text{ low}$$

Design Conditions

$$h_{soil} = 7.5 \text{ ft} \quad \gamma_{soil} = 125 \frac{\text{lb}}{\text{ft}^3} \quad h_w = 422 \text{ in}$$

$$T = 350 \text{ } ^\circ\text{F (design temperature)}$$

$$SG = 1.7 \quad PGA = 0.25$$

$$S_m(T) = 22.9 \text{ ksi}$$

$$S_y(T) = 39 \text{ ksi}$$

Figure 11. STEP 1 - 241-AN-105 Primary Tank Predicted Minimum Wall Thickness, t_p , of Plate 2 vs. Time Compared to Code-Based Allowable Minimum Uniform Wall Thickness, t_{min}

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7.4 PLATE 2 EVALUATION (Continued)

Design Conditions

$t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}) = 0.256 \text{ in}$	Code t_{min}	Δt_{min} to reach t_{min}	
$\Delta t_{min_cr}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{high}, t_{meas_Plate_2}) = 17.7 \text{ yr}$			min
$\Delta t_{min_cr}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom}, t_{meas_Plate_2}) = 23.1 \text{ yr}$			nom
$\Delta t_{min_cr}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{low}, t_{meas_Plate_2}) = 25.6 \text{ yr}$			max
$t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}) = 0.19 \text{ in}$	95% S_y t_{min}		
$\Delta t_{min_cr}(t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{high}, t_{meas_Plate_2}) = 25.9 \text{ yr}$			min
$\Delta t_{min_cr}(t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom}, t_{meas_Plate_2}) = 33.7 \text{ yr}$			nom
$\Delta t_{min_cr}(t_{min_DBE_Sy}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{low}, t_{meas_Plate_2}) = 37.4 \text{ yr}$			max

Current Conditions

$t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}) = 0.208 \text{ in}$	Code t_{min}	Δt_{min} to reach t_{min}	
$\Delta t_{min_cr}(t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{high}, t_{meas_Plate_2}) = 23.7 \text{ yr}$			min
$\Delta t_{min_cr}(t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom}, t_{meas_Plate_2}) = 30.8 \text{ yr}$			nom
$\Delta t_{min_cr}(t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{low}, t_{meas_Plate_2}) = 34.2 \text{ yr}$			max
$t_{min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}) = 0.125 \text{ in}$	95% S_y t_{min}		
$\Delta t_{min_cr}(t_{min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{high}, t_{meas_Plate_2}) = 33.8 \text{ yr}$			min
$\Delta t_{min_cr}(t_{min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom}, t_{meas_Plate_2}) = 44 \text{ yr}$			nom
$\Delta t_{min_cr}(t_{min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + tol_{low}, t_{meas_Plate_2}) = 48.8 \text{ yr}$			max

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Note that the measured minimum wall thickness indicated above extends over a small region, less than one square inch as can be seen from Figure 12 (PNNL 1999) which shows the thickness profile along the vertical axis of the tank near the "pit-like" 0.400-inch minimum wall thickness indication. A similar profile was given in PNNL 1999 for the circumferential direction.

Figure 12. Local UT-Measured Wall Thickness Profile of Plate 2 Along Vertical Axis of 241-AN-105 Primary Tank Near Pit-Like/Corrosion 0.400-inch Minimum Wall Thickness Indication. (PNNL 1999)

Hence, the application of STEP 1 evaluation criterion to this small local region is very conservative. Because of the "pit-like" wall thinning data observed for Plate 2, the wall thinning may be the result of aggressive pitting rather than uniform corrosion (Anantatmula 1999). A sizing of the extent of local wall thinning in the axial and circumferential direction allows a better assessment of the allowable wall thickness through application of STEP 2 criteria.

7.4.1 Plate 2 Evaluation of Local Wall Thinning

As a better estimate of the allowable continued operation time, STEP 2 criteria from Section 5.3 are applied to the local "pit-like" minimum wall thickness indication data. Figure 13 shows the resulting allowable local wall thickness near the bottom of Plate 2 as a function of the extent of the wall thickness that is $< t_{min}$ in the axial (L_{ax}) and circumferential (L_{cm}) directions as defined in Figure 4.

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Figure 13. STEP 2 - AN-105 Primary Tank Allowable Local Thickness, t_{loc} , for Plate 2 vs. Axial Extent, L_{ma} , of the Wall Thickness Region That is Less Than Code t_{min} .

For the 0.400-inch *local* minimum wall thickness indication, assuming the shape of the pit-like indication remains constant as the corrosion continues with time, take

$$L_{ma} = 0.192 \text{ in} \quad (\text{PNNL 1999})$$

$$L_{mt} = 0.266 \text{ in}$$

when the *average* wall thickness is just equal to t_{min} , provided that the *local* corrosion rate is equal to the *average* corrosion rate. However, this is not likely to be true and hence L_{ma} and L_{mt} may also increase.

With the current estimated *average* wall thickness for Plate 2 taken approximately as (see Figure 12)

$$t_{meas_Plate_2_aver} = 0.450 \text{ in}$$

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the time for the measured *average* wall thickness to reach t_{min} becomes

Design Conditions

$$t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}) = 0.256 \text{ in} \quad \text{Code } t_{min} \quad \Delta \text{time to reach } t_{min}$$

$$\Delta \text{time}_{cr}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + \text{tol}_{high}, t_{meas_Plate_2_aver}) = 38.8 \text{ yr} \quad \text{min}$$

$$\Delta \text{time}_{cr}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom}, t_{meas_Plate_2_aver}) = 62.1 \text{ yr} \quad \text{nom}$$

$$\Delta \text{time}_{cr}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + \text{tol}_{low}, t_{meas_Plate_2_aver}) = 77.7 \text{ yr} \quad \text{max}$$

Current Conditions

$$t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}) = 0.208 \text{ in} \quad \text{Code } t_{min} \quad \Delta \text{time to reach } t_{min}$$

$$\Delta \text{time}_{cr}(t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + \text{tol}_{high}, t_{meas_Plate_2_aver}) = 48.5 \text{ yr} \quad \text{min}$$

$$\Delta \text{time}_{cr}(t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom}, t_{meas_Plate_2_aver}) = 77.6 \text{ yr} \quad \text{nom}$$

$$\Delta \text{time}_{cr}(t_{min}(120, 410 \text{ in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + \text{tol}_{low}, t_{meas_Plate_2_aver}) = 97 \text{ yr} \quad \text{max}$$

At the time the *average* wall thickness is equal to t_{min} , the *local* minimum wall thickness will be less than t_{min} . The predicted local wall thickness is given by

$$t_{loc_p}(t_{min}, t_{start}, t_{meas_aver}, t_{meas_loc}) = t_p(\text{time}_{cr}(t_{min}, t_{start}, t_{meas_aver}), t_{start}, t_{meas_loc})$$

Hence, for the design conditions, the predicted *local* minimum wall thickness when the average wall thickness is equal to t_{min} is

$$t_{loc_p}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} - \text{tol}_{high}, t_{meas_Plate_2_aver}, t_{meas_Plate_2}) = 0.085 \text{ in} \quad \text{min}$$

$$t_{loc_p}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom}, t_{meas_Plate_2_aver}, t_{meas_Plate_2}) = 0.012 \text{ in} \quad \text{nom}$$

$$t_{loc_p}(t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}), t_{nom} + \text{tol}_{low}, t_{meas_Plate_2_aver}, t_{meas_Plate_2}) = -0.037 \text{ in} \quad \text{max}$$

The above is clearly unacceptable since a negative local wall thickness is predicted. Hence, we need to predict when the measured *local* minimum wall thickness reaches the allowable *local* wall thickness, t_{loc} .

In evaluating the *local* wall thinning assume that L_{me} and L_{mt} increases by a factor of 10 (Case 1 applies since $10 \cdot L_{mt} = 2.66 \text{ in}$ is less than L_{mt_max} , see Figure 13). The factor of 10 increase in the axial and circumferential extent of the measured local wall thinning was selected to conservatively bound uncertainties in the UT results as well as uncertainties in the local corrosion rate. The time for the measured *local* minimum wall thickness (0.400 in.) for Plate 2 to reach the allowable *local* wall thickness, t_{loc} , is

Design Conditions

$$t_{aloc_1}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 \cdot L_{me}) = 0.077 \text{ in} \quad \Delta \text{time to reach } t_{aloc}$$

$$\Delta \text{time}_{cr}(t_{aloc_1}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 \cdot L_{me}), t_{nom} + \text{tol}_{high}, t_{meas_Plate_2}) = 39.8 \text{ yr} \quad \text{min}$$

$$\Delta \text{time}_{cr}(t_{aloc_1}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 \cdot L_{me}), t_{nom}, t_{meas_Plate_2}) = 51.7 \text{ yr} \quad \text{nom}$$

$$\Delta \text{time}_{cr}(t_{aloc_1}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 \cdot L_{me}), t_{nom} + \text{tol}_{low}, t_{meas_Plate_2}) = 57.5 \text{ yr} \quad \text{max}$$

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Current Conditions

$$t_{aloc_1}(120, 410\text{-in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 L_{ma}) = 0.062\text{-in}$$

$$\Delta t_{time_cr}(t_{aloc_1}(120, 410\text{-in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 L_{ma}), t_{nom} - tol_{high}, t_{meas_Plate_2}) = 41.6\text{-yr} \quad \text{min}$$

$$\Delta t_{time_cr}(t_{aloc_1}(120, 410\text{-in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 L_{ma}), t_{nom}, t_{meas_Plate_2}) = 54\text{-yr} \quad \text{nom}$$

$$\Delta t_{time_cr}(t_{aloc_1}(120, 410\text{-in}, 1.44, h_{soil}, \gamma_{soil}, PGA, z_{Plate_2}, 10 L_{ma}), t_{nom} + tol_{low}, t_{meas_Plate_2}) = 60\text{-yr} \quad \text{max}$$

Since the time for the *average* wall thickness to reach t_{min} is less than the time for the *local* "pit-like" 0.400-inch minimum wall thickness to reach t_{aloc} , in this case, the time for the *average* wall thickness to reach the allowable *uniform* wall thickness is controlling. The results from the controlling condition may be compared to the results summarized in Table 2a for Plate 2 in which the *local* minimum wall thickness was evaluated conservatively against the Code-based allowable minimum *uniform* wall thickness, t_{min} . In this case, the results in Table 2a are conservative by a factor of approximately two in the prediction of the remaining useful life of the 241-AN-105 tank.

Figures 14 and 15 show the sensitivity of the axial and circumferential extent of the minimum local wall thickness for Plate 2 on the predicted remaining useful life for design and current operating conditions, respectively. These figures were obtained from application of the following relation for the remaining useful life on the basis of the structural integrity Code-based criteria summarized in Section 5.0.

$$\Delta t_{time_cr}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, L_{ma}, L_{mt}, t_{start}, t_{meas}) = \begin{cases} t_{min} - t_{min}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) \\ \alpha \frac{L_{ma}}{\sqrt{R \cdot t_{min}}} \\ L_{mt_max} - L_{mt_max}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z) \\ t_{aloc_1} - t_{aloc_1}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, L_{ma}) \\ t_{aloc_3} - t_{aloc_3}(T, h_w, SG, h_{soil}, \gamma_{soil}, PGA, z, L_{ma}) \\ t_{allow} - t_{aloc_1} \quad \text{if } (L_{mt} \leq L_{mt_max}) (\alpha < 8) \\ t_{allow} - t_{aloc_3} \quad \text{if } (L_{mt} > L_{mt_max}) (\alpha < 8) \\ t_{allow} - t_{min} \quad \text{otherwise} \\ \Delta t_{time_cr}(t_{allow}, t_{start}, t_{meas}) \end{cases}$$

Lockheed Martin Hanford Corporation
EVALUATION ANALYSIS

Client: Lockheed Martin Hanford Corporation
 Subject: Tank 241-AN-105 Acceptable Minimum Wall Thickness
for Local Wall Thinning Due to Corrosion
 Location: 200 E Area - Hanford Site, Richland, Washington

WO/Job No. 106705/CA40
 Date: 7/15/99
 Checked: 8/5/99
 Revised: _____

Calc. No. RPP-LJJ-001
 Revision 0
 Page No. 35 of 38

By: J. J. Jubyk
 By: C. E. Jensen

Figure 14. 241-AN-105 Primary Tank Remaining Useful Life at Design Operating Conditions Based on Measured Minimum Local Wall Thickness for Plate 2 vs. Axial (L_{ax}) and Circumferential (L_{cm}) Extent of the Local Wall Thickness Region That is Less Than Code t_{min} .

Lockheed Martin Hanford Corporation
EVALUATION ANALYSIS

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 Revision 0
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Client: Lockheed Martin Hanford Corporation
 Subject: Tank 241-AN-105 Acceptable Minimum Wall Thickness
for Local Wall Thinning Due to Corrosion
 Location: 200 E Area - Hanford Site, Richland, Washington

WO/Job No. 106705/CA40

Date: 7/15/99

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Revised: _____

By: L. J. Julyk

By: C. E. Jensen

By: _____

Figure 15. 241-AN-105 Primary Tank Remaining Useful Life at Current Operating Conditions Based on Measured Minimum Local Wall Thickness for Plate 2 vs. Axial (L_{mt}) and Circumferential (L_{mc}) Extent of the Local Wall Thickness Region That is Less Than Code t_{min}

Lockheed Martin Hanford Corporation
EVALUATION ANALYSIS

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Client: Lockheed Martin Hanford Corporation
 Subject: Tank 241-AN-105 Acceptable Minimum Wall Thickness
for Local Wall Thinning Due to Corrosion
 Location: 200 E Area - Hanford Site, Richland, Washington

WO/Job No. 106705/CA40Date 7/15/99Checked: 7-28-99

Revised:

By: L. J. JolykBy: H. H. Zinda H.H. Zinda

By:

7.5 PLATE 4 EVALUATION

Nominal wall thickness Measured min wall thk Location relative to bottom of primary tank mils = 10^{-3} in
 $t_{nom} = 0.75$ in $t_{meas_Plate_4} = 0.729$ in $z_{Plate_4} = 3$ ft $z_{Plate_4} = 36$ in

Predicted corrosion rate (assuming linear rate)

$$r_{corrosion}(t_{nom} - t_{high}, t_{meas_Plate_4}) = 3.188 \frac{\text{mils}}{\text{yr}} \text{ high}$$

$$r_{corrosion}(t_{nom} - t_{meas_Plate_4}) = 1.313 \frac{\text{mils}}{\text{yr}} \text{ nominal}$$

$$r_{corrosion}(t_{nom} - t_{low}, t_{meas_Plate_4}) = 0.687 \frac{\text{mils}}{\text{yr}} \text{ low}$$

Design Conditions

$$h_{soil} = 7.5 \text{ ft} \quad \gamma_{soil} = 125 \frac{\text{lb}}{\text{ft}^3} \quad h_w = 422 \text{ in}$$

$$T = 350 \text{ } ^\circ\text{F} \text{ (design temperature)}$$

$$SG = 1.7 \quad PGA = 0.25 \quad S_m(T) = 22.9 \text{ ksi}$$

$$S_y(T) = 39 \text{ ksi}$$

Figure 16. STEP 1 - 241-AN-105 Primary Tank Predicted Minimum Wall Thickness, t_p , of Plate 4 vs. Time, Compared to Code-Based Allowable Minimum Uniform Wall Thickness, t_{min}

AN-105-F.MCD

37

Lockheed Martin Hanford Corporation
EVALUATION ANALYSIS

Calc. No. RPP-111-001
 Revision 0
 Page No 38 of 38

Client: Lockheed Martin Hanford Corporation
 Subject: Tank 241-AN-105 Acceptable Minimum Wall Thickness
for Local Wall Thinning Due to Corrosion
 Location: 200 E Area - Hanford Site, Richland, Washington

WO/Job No. 106705/CA40
 Date: 7/15/99
 Checked: 7-28-99
 Revised: _____

By: L. J. Jubyk
H. H. Zuck
H. H. Zuck

7.5 PLATE 4 EVALUATION (Continued)

Design Conditions

$$t_{\min}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}) = 0.579 \text{ in} \quad \text{Code } t_{\min} \quad \Delta \text{time to reach } t_{\min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{high}}, t_{\text{meas_Plate}_4}) = 47.2 \text{ yr} \quad \text{min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}}, t_{\text{meas_Plate}_4}) = 114.5 \text{ yr} \quad \text{nom}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{low}}, t_{\text{meas_Plate}_4}) = 218.7 \text{ yr} \quad \text{max}$$

$$t_{\min_DBE_Sy}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}) = 0.465 \text{ in} \quad 95\% S_y \quad t_{\min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min_DBE_Sy}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{high}}, t_{\text{meas_Plate}_4}) = 82.9 \text{ yr} \quad \text{min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min_DBE_Sy}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}}, t_{\text{meas_Plate}_4}) = 201.4 \text{ yr} \quad \text{nom}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min_DBE_Sy}(T, h_w, SG, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{low}}, t_{\text{meas_Plate}_4}) = 384.4 \text{ yr} \quad \text{max}$$

Current Conditions

$$t_{\min}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}) = 0.496 \text{ in} \quad \text{Code } t_{\min} \quad \Delta \text{time to reach } t_{\min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{high}}, t_{\text{meas_Plate}_4}) = 73.2 \text{ yr} \quad \text{min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}}, t_{\text{meas_Plate}_4}) = 177.7 \text{ yr} \quad \text{nom}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{low}}, t_{\text{meas_Plate}_4}) = 339.2 \text{ yr} \quad \text{max}$$

$$t_{\min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}) = 0.347 \text{ in} \quad 95\% S_y \quad t_{\min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{high}}, t_{\text{meas_Plate}_4}) = 119.8 \text{ yr} \quad \text{min}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}}, t_{\text{meas_Plate}_4}) = 291 \text{ yr} \quad \text{nom}$$

$$\Delta \text{time}_{\text{cr}}(t_{\min_DBE_Sy}(120, 410 \text{ in}, 1.44, h_{\text{soil}}, \gamma_{\text{soil}}, PGA, z_{\text{Plate}_4}), t_{\text{nom}} + \text{tol}_{\text{low}}, t_{\text{meas_Plate}_4}) = 555.6 \text{ yr} \quad \text{max}$$

8.0 UNCERTAINTIES

There are uncertainties in this evaluation process. Among the uncertainties are uncertainties in the actual stress state which affects the prediction of the allowable $t_{\min}$ and t_{allow} ; uncertainties in the predicted current corrosion rate which affects the prediction of the wall thickness into the future; and uncertainties in the UT results, both in term of the uncertainties in the measurement process and with respect to the limited sampling as being representative of the complete primary tank wall. The greatest uncertainty is perhaps in the prediction of the current corrosion rate in that most of the wall thinning could have occurred early in the tanks operating history and the current corrosion rate may be less benign or the opposite may be true. To help resolve the uncertainty in the current corrosion rate, the installation of a corrosion probe in Tank 241-AN-105 and a repeat UT examination of the 241-AN-105 primary tank at some future point in time are recommended. The corrosion probe should provide an early estimate of the current corrosion rate from the bulk waste material near the wall. However, the corrosion probe is not expected to be able to determine the local corrosion rate at the wall which may or may not be affected by local chemistry at the wall. The repeat UT exam will help to confirm the corrosion rate estimate from the probe but requires a sufficiently long time between UT examinations in order to be able to discriminate from the initial UT results within the accuracy of the UT equipment.

APPENDIX C - Fabrication Drawings

Consisting of 4 Drawings

NOTES:

1. ALL FIELD WELDS IN BOTTOM PLATES AND KNUCKLE TO BE 100% RADIOGRAPHED AND LIQUID PENETRANT INSPECTED BEFORE THE BOTTOMS ARE SET IN PLACE. PER CUST. SPEC. B-130-C4 PART 3 SECT. 3.03
2. AFTER SETTING BOTTOM IN PLACE ALL WELDS IN BOTTOM PLATES AND KNUCKLE SHALL BE INSPECTED ON THE INSIDE SURFACE BY THE MAGNETIC PARTICLE METHOD PER CUST. SPEC. B-130-C4 PART 3 SECTION 3.03
3. AFTER FIELD STRESS RELIEVING OF THE PRIMARY TANK ALL WELDS IN THE BOTTOM PLATES AND KNUCKLE SHALL BE INSPECTED ON THE INSIDE SURFACE BY THE MAGNETIC PARTICLE METHOD PER CUST. SPEC. B-130-C4 PART 3 SECT. 3.03
4. ALL ELECTION AND TESTING PER CUST. SPEC. B-130-C4
5. FOR PLATE AND WELDER IDENTIFICATION SEE DRAWINGS - E202 - THRU - E207
6. CONSULT DEPT. TO FURNISH BACKUP FOR THOSE WELDS WHICH REQUIRE IT. (REMOVE AFTER WELDING)
7. FOR PLATE IDENTIFICATION AND MARKING SEE MATERIAL CONTROL PROCEDURE.
8. WELDER IDENTIFICATION SHALL BE PER CUST. SPEC. B-130-C4

PRIMARY BOTTOM KNUCKLE PLATES

J.A. JONES CONSTRUCTION CO.
HANFORD WORKS - RICHLAND, WASHINGTON
6' DBL. WALL WASTE STORAGE TANK
N°S 101 102 103 104 105
TANK FARM NS 24-AN, 22- ESE AREA
REF DWG. NR H-2-71975

REVIEWED AS INDICATED BY B BELOW	DATE	BY
APPROVED WITH EXCEPTIONS NOTED		
REVISOR'S NAME AND RESUBMIT		
NOT APPROVED		
DATE: 8-11-70 (1000-1-30)		
CHECKED BY: JNL		
DATE: 2/23/73		

REVISIONS	DATE	BY	REVISIONS
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PRIMARY TANK BOTTOM PLATES
AND KNUCKLE LAYOUT

SECTION (A)

REVIEWED AS INDICATED BY ☒ BELOW

☒ APPROVED.

☒ APPROVED WITH EXCEPTIONS NOTED.

☐ SERVICE AND RESUBMIT.

☐ REJECTED.

J. A. JONES CONSTRUCTION CO.
HANFORD WORKS - RICHLAND WASH.
6 DEL. WALL WASTE STORAGE TANKS
N°S 101, 102, 103, 104, 105, 106
TANK FAR A N° 241-AH, 200 EAST AHEAD
REF DWG. N° H-2-71975

USS American Bridge
Division of United States Steel Corporation

F 12					
E					
D 12-7A	10C				
C 12-7B	15C				
B 12-7	2-22				
A 12-7	2-12				
REVIEWS					

PREPARED BY: SA S.F.
 APPROVED BY: SA L.A.
 DATE: 1/1 BY: SA J. H. GILBERT
 IN CHARGE OF: FOWLER (389)
 ORDER NO. E301
K9263

NOTES:

- * 1. LOCATION OF PIECE 30IM2 MAY CHANGE AT FIELD OPTION, FIELD DEPARTMENT TO CHANGE PIECE MARKS SHOWN AS REQD.
- 2. FIELD DEPARTMENT TO FURNISH APPROPRIATE DASH NUMBER 30IM1 - X, 30IM2 - X AS REQD.
- 3. FOR SHOP WELD AND PLATE IDENTIFICATION RECORDS ON PRIMARY TANK TOP KNUCKLE SECTIONS 30IM1 & 30IM2 - SEE SK 30IM1-1 THRU 24 AND 30IM2-1 THRU 72 (SELECT CORRECT SHEETS PERTAINING TO PIECE MARK & DASH NUMBERS USED ON THIS TANK)

PRIMARY TANK
SHELL STRETCH-OUT FOR HEAT SLAB NO'S
AND WELDERS I.D. FOR TANK NO 105

- △ WELD JOINT VISUAL INSP
- WELDERS STAMP NO OUTSIDE
- WELDERS STAMP NO INSIDE
- ◇ WELDING PROCEDURE
- HEAT NO
- SLAB NO

HEAT SLAB AND WELDERS I.D. FOR
PRIMARY TANK SHELL PLATE
TANK NO 105

J.A. JONES CONST. CO.
HAWFORD WORKS - RICHMOND, VA.
G. DEL. WAIL WASTE STORAGE TANKS
NO 101 102 103 104 105 & 106
TANK FARM NO 241-A, 200 EAST AREA
REF. DWG. NO. H-2-71976

REVISIONS	
NO.	DESCRIPTION
1	ISSUED
2	REVISED
3	REVISED
4	REVISED
5	REVISED
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7	REVISED
8	REVISED
9	REVISED
10	REVISED

PROJECT NO. K9263
SHEET NO. E310AB
DATE: 11-1-77
BY: J.A.J.
CHECKED BY: J.A.J.
APPROVED BY: J.A.J.

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C. E. Jensen	R1-56	x			
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D. B. Smet	R1-56	x			
T. B. Veneziano	S7-40	x			
K. A. White	S5-13	x			
M. L. Ramsay	S7-54	x			