Hanford Double-Shell Tank Extent-of-Condition Construction Review – 15498

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ABSTRACT

During routine visual inspections of Hanford double-shell waste tank 241-AY-102 (AY-102), anomalies were identified on the annulus floor which resulted in further evaluations. Following a formal leak assessment in October 2012, Washington River Protection Solutions, LLC (WRPS) determined that the primary tank of AY-102 was leaking. A formal leak assessment, documented in RPP-ASMT-53793, *Tank 241-AY-102 Leak Assessment Report*, identified first-of-a-kind construction difficulties and trial-and-error repairs as major contributing factors to tank failure.[1] To determine if improvements in double-shell tank (DST) construction occurred after construction of tank AY-102, a detailed review and evaluation of historical construction records was performed for Hanford's remaining twenty-seven DSTs. Review involved research of 241 boxes of historical project documentation to better understand the condition of the Hanford DST farms, noting similarities in construction difficulties/issues to tank AY-102. Information gathered provides valuable insight regarding construction difficulties, future tank operations decisions, and guidance of the current tank inspection program. Should new waste storage tanks be constructed in the future, these reviews also provide valuable lessons-learned.

INTRODUCTION

This document provides an overview of the construction history of the six double-shell tank farms constructed at Hanford, noting any difficulties encountered. On November 7, 2012, it was determined that the primary tank of double-shell tank AY-102 was leaking. It was stated in the leak assessment report for tank AY-102 that bulges in the secondary liner, deterioration of refractory during post-weld stress relieving (post-weld heat treatment), and primary tank floor plate welding rework during construction left residual stresses in the tank that may have accelerated corrosion and contributed to the primary tank failure.

Following identification of the tank AY-102 probable leak cause, other DSTs with construction, waste storage, or thermal histories similar to that of tank AY-102 were identified for review. The evaluation identified six tanks with similar construction for additional evaluation. These tanks were those located in Hanford's 241-AY, 241-AZ, and 241-SY tank farms. One of the evaluations was to identify any similarities in construction that could be precursors for accelerated corrosion and premature failure.

The construction histories of these first three tank farms were reviewed to identify issues similar to those experienced during tank AY-102 construction. Three comprehensive assessments of the construction issues were prepared.[2,3,4] Following this initial review phase, a decision was made to continue evaluation efforts for the remaining three tank farms at Hanford; 241-AW, 241-AN, and 241-AP tank farms. These second phase reviews were documented in similar comprehensive assessments.[5,6,7] In total, the construction history for each of Hanford's 28 double-shell nuclear waste tanks has been evaluated. In this paper, the issues impacting integrity are presented based on information found in available construction records, using tank AY-102 as the comparison benchmark.

Overview of Hanford Double-Shell Tanks

Six double-shell tank farms were constructed over a period of approximately 18 years (from 1968 to 1986), with a design life of 20 to 50 years. Table 1 provides the construction dates, the year of initial service, and the expected service life for all of the DSTs.

Table 1
Double-Shell Tank Construction and Age as of 2014

Tank Farm	Number of Tanks	Construction Period	Construction Project	Initial Operation	Service Life	Current Age
241-AY	2	1968 – 1970	IAP-614	1971	40	43
241-AZ	2	1970 – 1974	HAP-647	1976	20	38
241-SY	3	1974 – 1976	B-101	1977	50	37
241-AW	6	1976 – 1979	B-120	1980	50	34
241-AN	7	1977 – 1980	B-130, B-170	1981	50	33
241-AP	8	1982 – 1986	B-340	1986	50	28
Total	28					

Each DST consists of a primary carbon steel tank, ~23 m (75 ft) in diameter, inside of a secondary carbon steel liner, which is surrounded by a reinforced-concrete shell. Both the primary tank and secondary liner are constructed in four courses. The primary steel tank rests atop a 229 mm (8 in) insulating concrete slab (also called refractory), separating it from the secondary steel liner, and providing for air circulation/leak detection channels under the primary tank bottom plate. An annular space of 0.8 m (2.5 ft) exists between the secondary liner and primary tank, allowing for visual examination of the tank wall and secondary liner annular surfaces and ultrasonic volumetric inspections of the primary tank walls and secondary liners, as well as other activities. See Figure 1 for a simplified depiction.

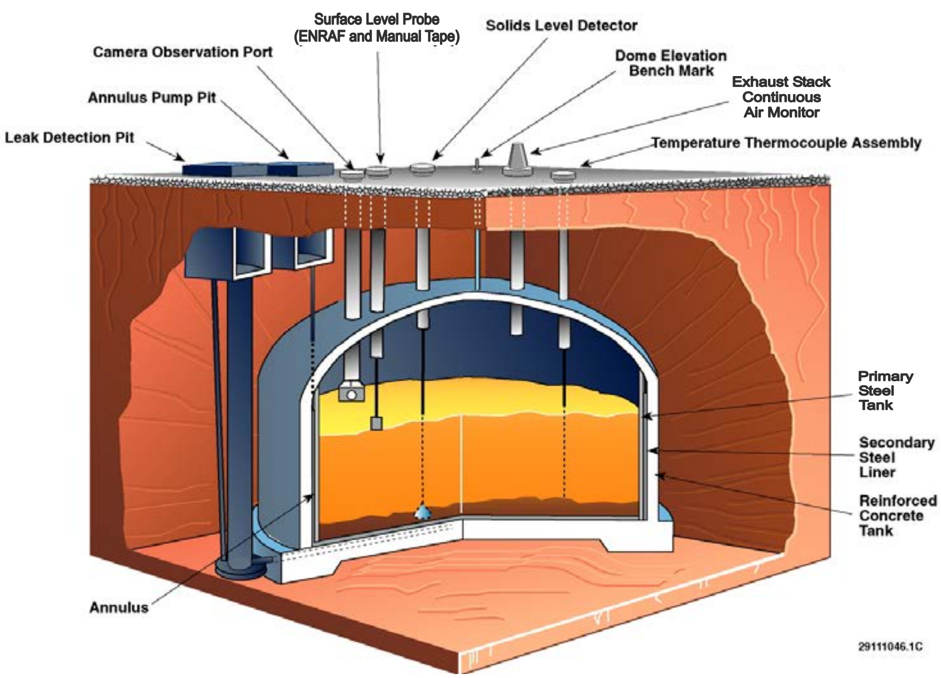


Figure 1: General Double-Shell Tank Depiction

METHODS/TASK DESCRIPTION

The review of the construction records required the retrieval of historical project documents from Federal Records Storage. These records included specifications, letters, quality assurance (QA) inspection logs, status reports, weld inspection records, material test reports, photographs, and other project documents.

Review focused on those areas of deficiencies and problems identified in the leak assessment of tank AY-102. These include a high weld rework rate for the steel liners, bulges in the tank bottoms, refractory damage, and ineffectiveness of post-weld heat treatment operations. From the information collected, the resulting quality of construction of the other tanks was assessed. Any issues or difficulties similar to those seen in tank AY-102 were noted and discussed as well as issues perceived to be unique to each individual tank or tank farm. Additionally, these reviews included a comparative analysis of the tanks within all of the farms.

General Double-Shell Tank Construction Sequence

The general sequence of construction for each underground double-shell tank farm was examined. The exact sequence can vary between farms as changes were made to facilitate construction or avoid difficulties encountered. The sequence of construction for the 241-AY and 241-AZ tank farms proceeded differently than for the remaining other farms. Table 2 explains the variations and Figure 2 provides a photo gallery of the SY/AW/AN/AP sequence.

Table 2
General Construction Sequence for Each Tank Farm

AY/AZ	SY/AW/AN/AP
1. Concrete Foundation	1. Concrete Foundation
2. Secondary Liner Bottom	2. Secondary Liner Bottom
3. Secondary Liner Walls	3. Castable Refractory
4. Castable Refractory	4. Primary Tank Bottom
5. Primary Tank Bottom	5. Primary Tank Walls
6. Concrete Shell	6. Secondary Liner Walls
7. Primary Tank Walls	7. Primary Tank Dome and Risers
8. Primary Tank Dome and Risers	8. Primary Tank Stress Relief
9. Primary Tank Stress Relief	9. Primary Tank Hydrostatic Test
10. Primary Tank Hydrostatic Test	10. Secondary Liner Top Knuckle
11. Secondary Liner Top Knuckle	11. Concrete Shell
12. Concrete Dome	12. Concrete Dome

Changes to the construction sequence seen in other farms typically involved the sequence of liner fabrication, concrete wall construction, and backfill. Completing the secondary liner first created challenges in welding the more important primary tank liner by restricting primary tank access to the annular space. Subsequent tank farms were built by simultaneously building the primary and secondary liners or completing primary liner fabrication first.

1

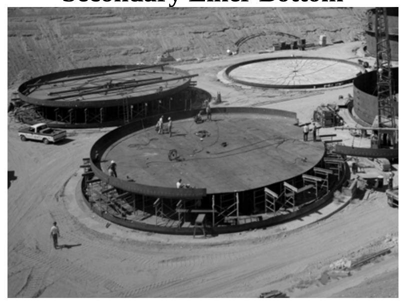
Concrete Foundation

Secondary Liner Bottom

2

3

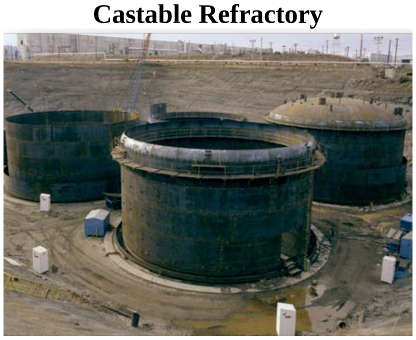
Castable Refractory



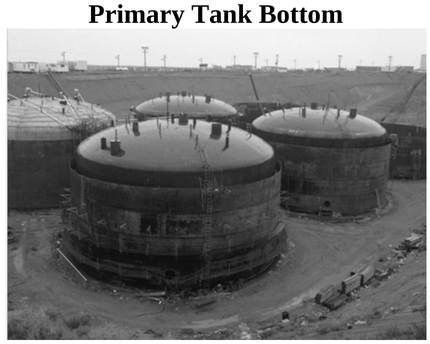
Primary Tank Bottom

4

5



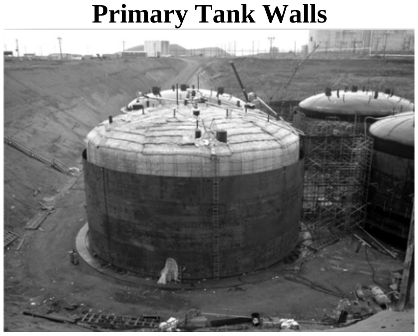
Primary Tank Walls



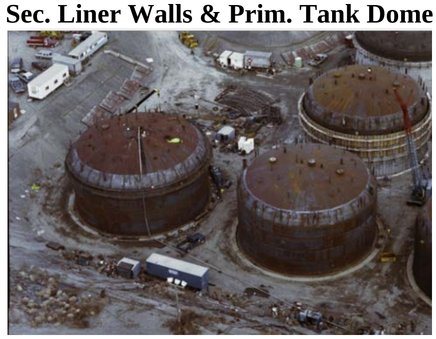
Sec. Liner Walls & Prim. Tank Dome

6 & 7

8



Primary Tank Stress Relief

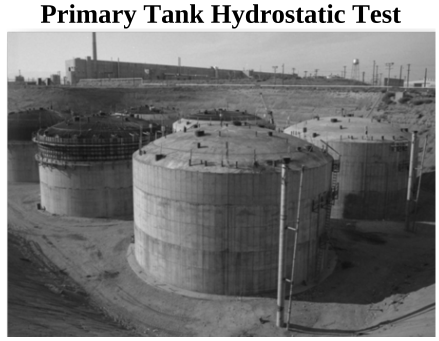


Primary Tank Hydrostatic Test

9

10

Secondary Liner Top Knuckle



Concrete Shell and Dome

11 & 12

Figure 2: Double-Shell Tank Construction Sequence Gallery

REVIEW FINDINGS

Construction Order

The order of construction and the principal construction contractor are shown in Table 3. During the review, it became evident that following completion of the first DST farm, the 241-AY tank farm, design evaluations and "lessons-learned" meetings occurred to remedy some of the issues encountered during construction and were incorporated into the design and fabrication of the subsequent tank farms. When a new contractor was chosen in the cases of the 241-SY and 241-AW tank farms, some construction issues re-emerged, as will be described in later sections.

Table 3
Construction Completion Order

241-AY Tank Farm		**Contractor**	**241-AN Tank Farm**		**Contractor**
1st	AY-102	Pittsburgh-Des Moines (PDM) Steel Company	14th	AN-106	American Bridge (AB) Company
2nd	AY-101		15th	AN-107	
241-AZ Tank Farm			16th	AN-102	
3rd	AZ-101		17th	AN-103	
4th	AZ-102		18th	AN-105	
241-SY Tank Farm		Chicago Bridge and Iron (CBI) Company	19th	AN-104	
5th	SY-102		20th	AN-101	
6th	SY-101		**241-AP Tank Farm**		
7th	SY-103		21st	AP-108	
241-AW Tank Farm		American Bridge (AB) Company	22nd	AP-107	
8th	AW-101		23rd	AP-102	
9th	AW-102		24th	AP-101	
10th	AW-103		25th	AP-106	
11th	AW-104		26th	AP-104	
12th	AW-105		27th	AP-103	
13th	AW-106		28th	AP-105	

Secondary Liner

<u>Material and Bottom Plate Thickness.</u>

The materials of secondary liner construction and the bottom plate thicknesses are shown in Table 4. After excessive bulging, as seen with the 241-AY secondary bottom fabrication, the plate thickness was increased for both the primary tank and secondary liner bottoms. The sheet steel used in the 241-AY and 241-AZ tank farms, which were designed to be high-temperature aging waste tanks, was UNS K02401. In the 241-SY tank farm, the sheet steel was changed to UNS K02403. The UNS K02403 is a fine-grain-size metal produced for moderate and lower temperature service, while UNS K02401 is a coarse-grain-size metal produced for moderate and higher temperature service. The smaller grain size in K02403 increases the notch toughness and resistance to stress corrosion cracking over UNS K02401. UNS K12437 was utilized in the remaining tank farms and is a fine austenitic grain size metal. This change represented and increase to the notch toughness and increased resistance to stress corrosion cracking.

Table 4
Secondary Liner Material and Bottom Plate Thickness

Tank Farm	Material Type	Bottom Plate Thickness
241-AY	UNS K02401 (ASTM A515, Gr 60)	6mm (1/4 in)
241-AZ	UNS K02401 (ASTM A515, Gr 60)	10mm (3/8 in)
241-SY	UNS K02403 (ASTM A516, Gr 65)	10mm (3/8 in)
241-AW	UNS K12437 (ASTM A537, Class 1)	10mm (3/8 in)
241-AN	UNS K12437 (ASTM A537, Class 1)	10mm (3/8 in)
241-AP	UNS K12437 (ASTM A537, Class 1)	10mm (3/8 in)

Bottom Bulges.

Extensive problems with bulges in the secondary liner of tank AY-102 were identified in a leak assessment. They contributed to problems with refractory placement and may have led to refractory cracking and damage when the tank was loaded during hydrostatic testing. Secondary liner bulge issues identified during extent of condition investigation are summarized in Table 5. Only those tanks with documented secondary liner bottom bulging are included within the table. In tank AY-101, only slightly less bulging was noted. In the 241-AZ tank farm, few problems were noted with secondary bulges, although some minor issues were noted during later refractory placement. In the 241-SY tank farm, excessive secondary liner bottom bulging was noted in each tank and efforts to resolve the issue were unsuccessful. In the 241-AW tank farm, only two tanks had indications of bottom bulging challenges and those were accepted as is based upon engineering assessment. In all cases, bulges were ultimately accepted on the basis of liquid penetrant examination and the statement that areas out of tolerance were localized and would not affect the tank function and integrity.

Table 5
Secondary Liner Bottom Bulge Instances

Tank	Detail
AY-101	Excessive distortion and bulges were noted throughout. Maximum slope of bulges was as being as much as 83 mm per m (1 in per ft). The specified maximum slope was 31 mm per m (3/8 in per ft). Six places exceeded a 51mm (2 in) peak-to-valley tolerance.
AY-102	Excessive distortion and bulges were noted throughout. Maximum slope of bulge was noted as being as much as 83 mm per m (1 in per ft). Twenty-two places exceed 51 mm (2 in) peak-to-valley tolerance.
AZ-101	Only minor notation, no deficiencies or non-conformance reports (NCRs) found. It was noted that refractory thickness was increased due to an irregular secondary liner bottom.
AZ-102	Only minor notation, no deficiencies or NCRs found. The log noted that the plate dropped 10 mm (3/8 in) when refractory was poured.
SY-101	Out of tolerance in several areas, up to 52 mm per m (5/8 in per ft) and an NCR was generated.
SY-102	Out of tolerance in several areas, up to 68 mm per m (13/16 in per ft) and an NCR was generated. Flattening attempts were unsuccessful.
SY-103	Weld pattern was changed, liner was still out of tolerance, up to 83 mm per m (1 in per ft), NCR generated. Flattening attempts, including using a 26690 Newton (6000 lb.) weight, were unsuccessful.
AW-102	Four bulges identified. All slopes less than 62 mm per m (3/4 in per ft). All 241-AW tank farm bulges were accepted based on an engineering evaluation of the 241-SY Bottom Flatness Study authored by Battelle Northwest.

Tank	Detail
AW-106	19 bulges identified and all less than 62 mm per m (3/4 in per ft) and accepted as is. All 241-AW tank farm bulges were accepted based on an engineering evaluation of the 241-SY Bottom Flatness Study authored by Battelle Northwest.

Refractory

The refractory material in each tank was varied slightly, but all were high alumina castable refractory concretes. The types of refractory used are shown in Table 6. The primary function of the refractory was to protect the tank foundation from the high heat experienced during the primary tank stress relief process. Additionally, the refractory pad contains air channels either cast or cut into the top that facilitate forced ventilation cooling of the primary tank bottom. Compressive strength requirements were modest, with an initial requirement of 1379 kPa (200 psi) for the 241-AY tank farm, later being relaxed to 896 kPa (130 psi) all later tank farms. As tank farm construction progressed, changes were also made in the air channel pattern and the refractory pour pattern that simplified installation and assured a more level installation.

Table 6
Refractory Material Utilized By Farm

Tank Farm	Refractory Material
241-AY	Kaolite 2200-LI
241-AZ	Kaolite 2000
241-SY	Lite Wate 50
241-AW	Lite Wate 50 and Enriched Lite Wate 50 in AW-101. Lite Wate 70 in AW-102 through AW-106.
241-AN	Lite Wate 70
241-AP	Litecrete 60M

Castable refractories are typically poured or “gunned” into place. After air drying or “curing,” the refractory is then “fired” or heated to high temperatures to convert hydrated compounds into a more durable, de-hydrated, ceramic structure. During the initial air-drying and until the firing is completed, protection from freezing and water saturation is important. During construction of the 241-AY tank farm, there were problems with both of these protections. After heat treatment and hydrostatic testing, the refractory material in both tanks was found to be badly cracked and degraded, caused in some part by poor weather protection. Concerns about lack of support in the high-stress knuckle region led to the decision to remove ~533 mm (21 in) of the refractory and replace it with structural concrete in both tanks. Given the location and access constraints, the effectiveness of this repair and proper concrete placement was identified as a concern during the leak assessment of tank AY-102. As previously mentioned, voids from primary bottom bulging that were beyond the ~533 mm (21 in) perimeter were filled with foam prior to placement of the structural concrete repair. See Figure 3 for pictures of the refractory repair in progress in the 241-AY tank farm.

Figure 3: Refractory Repair Operations in 241-AY Tank Farm

In comparison, refractory protection and condition in the later tanks were much better. In the 241-AZ tank farm, specific measures were taken to keep the refractory above 10°C (50˚F) using heaters and to keep water from rain and snow out by using tarps. There were some failures noted, but protection was generally good. In the 241-SY tank farm, a temporary heating grid and insulating panels were used for tanks SY-101 and SY-102. For tank SY-103, refractory placement was postponed until spring to avoid freezing weather conditions. The practice warm weather installation of refractory was continued for the 241-AW, 241-AN, and 241-AP tank farms. In instances where cool temperatures were expected overnight, temporary heating infrastructure was deployed. Inspection of these tanks after hydrostatic testing showed little or no damage to the refractory and no refractory repairs after hydrostatic testing were required in any of the double-shell tanks outside of the 241-AY tank farm.

Primary Tank

Material and Bottom Plate Thickness.

The materials of primary tank construction and the bottom plate thicknesses are shown in Table 7. After excessive bulging, as seen with the 241-AY bottom fabrication, the plate thickness was increased for both the primary and secondary liner bottoms.

Table 7
Primary Tank Material and Bottom Plate Thickness

Tank Farm	Material Type	Bottom Plate Thickness
241-AY	UNS K02401 (ASTM A515, Gr 60)	10mm (3/8 in)
241-AZ	UNS K02401 (ASTM A515, Gr 60)	13mm (1/2 in)
241-SY	UNS K02403 (ASTM A516, Gr 65)	13mm (1/2 in)
241-AW	UNS K12437 (ASTM A537, Class 1)	13mm (1/2 in)
241-AN	UNS K12437 (ASTM A537, Class 1)	13mm (1/2 in)
241-AP	UNS K12437 (ASTM A537, Class 1)	13mm (1/2 in)

Bottom Weld Rework.

The weld rework rate for the primary tank bottom in tank AY-102 was noted in the leak assessment as excessive and in excess of 33%. The primary bottom weld rework rate was determined from radiography records and is shown in Table 8. As tank construction progressed, the weld reject rate was lowered considerably throughout construction of the 241-AZ farm. When a new contractor was selected for both the 241-SY and 241-AW tank farms, a return to high weld reject rates was seen. This suggests some correlation between past experience and aptitude.

It is important to note that eventually all welds were reworked, passed inspection, and were stress relieved. Nonetheless, as the leak in tank AY-102 is in the primary tank bottom, the primary bottom weld reject rate is an important statistic, reflective of overall construction quality.

Table 8
Primary Tank Bottom Weld Rework Rates

241-AY Tank Farm	
AY-101	10.2%
AY-102	33.8%
241-AZ Tank Farm	
AZ-101	14.5%
AZ-102	6.3%
241-SY Tank Farm	
SY-101	30.1%
SY-102	21.9%
SY-103	25.7%
241-AW Tank Farm	
AW-101	30%
AW-102	31%
AW-103	27%
AW-104	34%
AW-105	31%
AW-106	24%

241-AN Tank Farm	
AN-101	13%
AN-102	13%
AN-103	9%
AN-104	9%
AN-105	15%
AN-106	10%
AN-107	20%
241-AP Tank Farm	
AP-101	6%
AP-102	9%
AP-103	10%
AP-104	9%
AP-105	12%
AP-106	6%
AP-107	7%
AP-108	5%

Bottom Bulges.

Although project documents for the 241-AY farm commonly described primary tank bottom flatness as "generally good," it was noted that during refractory repairs the primary bottom had pulled up from the refractory in places. These voids were filled with foam during the refractory replacement and repair described later. The bottom plate thickness was increased in the 241-AZ tank farm and bottom flatness was described as "acceptable without flattening." In the 241-SY farm, the new contractor used a different plate layout for the bottoms and bulging problems were seen in all of the tanks. In tank SY-101, out-of-tolerance areas were noted and plate repair was attempted, which caused new out-of-tolerance areas to appear. A maximum bump height of 79 mm (3 in) was measured in the primary tank bottom and the decision was made to support the bottom by filling the bulges with grout. After gaining access through the annulus, two 0.6 m by 2.4 m (2 ft by 8 ft) deep sections of the refractory were cut out and refilled with grout. In tank SY-103, out-of-tolerance bulging in several areas was found, up to 68 mm per m (13/16 in per ft). Computer modeling of the bulge indicated that excessive stresses might be seen in the lower knuckle. Eventually an empirical solution was used which included strain gage monitoring and acoustic testing during the hydrostatic test. These tests determined that stresses from flattening the bulges were acceptable.

Additional non-destructive testing was conducted on the primary tank during and after hydrostatic testing such as liquid penetrant examination, magnetic particle testing, and visual examinations. As was previously noted with secondary liner bottom bulging, minimal evidence of primary tank bulging issues exists for the tanks in the 241-

AW, 241-AN, and 241-AP tank farms. The extensive record review shows little indication for concern regarding out-of-tollerance bottom conditions in these farms.

Stress Relief Process.

The stress relief process for tank AY-102 was very difficult, requiring long heat-up times to drive excessive moisture out of the refractory. There was some uncertainty about whether all portions of the primary tank bottoms of AY-101 and AY-102 reached the desired annealing temperature. This uncertainty was rooted in inconsistency and unreliability of thermocouple readings. During attempts to heat up, large amounts of steam were observed leaving the annulus for several hours. Caused by excess moisture being driven out of the refractory, this likely contributed to damage of the refractory as identified following stress relief and discussed previously. By comparison, the heat treatment of all the other tanks went well.

Not all tanks reached the desired 593°C (1100˚F) for one hour per 25 mm (1 in) thickness hold time and temperature, but instead met alternate code requirements for stress relieving (typically 538°C (1000°F) for a 3 hour hold). Details for each tank are summarized in Table 9.

Table 9
Primary Tank Stress Relief Parameters

241-AY Tank Farm		
AY-101	538°C (1000°F)	3 hours
AY-102	538°C (1000°F)	3 hours
241-AZ Tank Farm		
AZ-101	565°C (1050°F)	2 hours
AZ-102	538°C (1000°F)	3 hours
241-SY Tank Farm		
SY-101	538°C (1000°F)	3 hours
SY-102	593°C (1100°F)	1 hour
SY-103	593°C (1100°F)	1 hour
241-AW Tank Farm		
AW-101	593°C (1100°F)	1 hour
AW-102	538°C (1000°F)	3 hours
AW-103	538°C (1000°F)	3 hours
AW-104	538°C (1000°F)	3 hours
AW-105	538°C (1000°F)	3 hours
AW-106	538°C (1000°F)	3 hours

241-AN Tank Farm		
AN-101	538°C (1000°F)	3 hours
AN-102	538°C (1000°F)	3 hours
AN-103	538°C (1000°F)	3 hours
AN-104	538°C (1000°F)	3 hours
AN-105	538°C (1000°F)	3 hours
AN-106	538°C (1000°F)	3 hours
AN-107	538°C (1000°F)	3 hours
241-AP Tank Farm		
AP-101	538°C (1000°F)	3 hours
AP-102	538°C (1000°F)	3 hours
AP-103	538°C (1000°F)	3 hours
AP-104	538°C (1000°F)	3 hours
AP-105	538°C (1000°F)	3 hours
AP-106	538°C (1000°F)	3 hours
AP-107	538°C (1000°F)	3 hours
AP-108	510°C (950°F)	5 hours

Other Unique Findings

During the review, other issues were noted that were unique to the tanks examined and may have an impact on tank integrity. In the 241-AZ tank farm, laminations in the liner steel plates were found, with provision made to remove surface laminations from the primary tank bottom of tank AZ-101 by surface grinding up to 1.6 mm (1/16 in) in depth. Several mid-wall laminations were found in the upper shell ring plate of the tank AZ-102 primary tank, which required the replacement of four plates. Ultrasonic thickness inspection was used as the basis for acceptance of two other plates that were within the code allowable.

Both tanks AZ-101 and AZ-102 had leaks found during hydrostatic leak testing in the upper knuckle section above the maximum waste level. As the tank had already been subject to stress relieving, these weld repairs were performed without additional stress relief. An unrepaired weld grind-out was found in the lower knuckle weld seam in tank AZ-101 during final inspection. The groove, sized at approximately 140 mm long by 5 mm wide by 2 mm deep (5-1/2 in long by 3/16 in wide by 3/32 in deep), was accepted based on expert opinion. The logs also mentioned that two fires occurred during construction in the annulus of tank AZ-102 and in the bottom of the primary tank in tank AZ-102, but the job logs did not indicate that any significant damage was caused by these two fires. The fire issues are not expected to significantly affect the tank integrity.

In the 241-SY tank farms, there were relatively minor unique issues identified. For tanks SY-101 and SY-103, the primary bottom had four plates meet at a weld junction when the construction specification called for no more than three. These were accepted based on the ASME(1) Boiler and Pressure Vessel Code (which allowed four) and weld nondestructive examination. For tank SY-102, lack of control during lowering of the secondary liner bottom led to temporary distortions of up to 457 mm (18 in). This was accepted based on actions identified for secondary bulges seen during welding (liquid penetrant examination, and refractory examination and repair, if necessary after partial loading).

In the 241-AW tank farm, various surface defects discovered during receipt of material were noted and dispositioned to be repaired. These defects were assumed to have likely occurred during shipment to the field or fit-up of the material in the field. Challenges with tank bottom lifting and transport occurred early on during construction activities, but modifications to the method were made and success was later achieved. Following post-weld stress relief, tank dome distortions were observed around the risers that had housed the burners. This condition presented itself in tanks AW-101, AW-102, AW-103, and AW-104 and was accepted-as-is in all cases. Also related to stress relieving, three of the four deflector tubes fell from their suspended location and impacted the bottom of tank AW-102 during stress relief. Discovered documentation indicates that no damage was done as a result of the impact and any induced residual stress would have been subsequently relieved during the remainder of the stress relief operation. Following hydrostatic testing of the tanks in the 241-AW tank farm, the uninhibited test water was stored in the tanks for extended durations, between 6 to 9 months. Later inspection of tank AW-104 led to the discovery of pitting corrosion. This same condition is likely present in the all tanks within the farm, since similar conditions were experienced. This corrosion was analyzed and the tank was determined to be capable of meeting the criteria to which it was designed and fabricated.

In the 241-AN tank farm, various surface defects and plate damage discovered during inspection of the material were noted and dispositioned to be repaired. These defects included laminations and transverse cracking near a weld seam. Minor pitting (508μm (20 mils) to 762μm (30 mils) in depth) as a result of extended raw water storage was found in tank AN-107 and is expected in all tanks in the 241-AN tank farm. Tank dome distortions were observed on the dome of tanks AN-101, AN-102, AN-103, and AN-104. The distortions were not considered critical enough to cause structural problems during construction and operational loading conditions, and were accepted as is. Contaminated backfill was introduced to the 241-AN tank farm accidentally and the majority of it was later removed; however, some of the contaminated backfill remains. The remaining contamination should not affect the integrity of the tanks, but it could impact future tank leak investigations.

In the 241-AP tan farm, surface defects and plate damage were discovered during inspection of the material. This damage was directed to be repaired per approved procedures. These defects included laminations, scabbing, and pitting. Tank dome distortions were observed and noted on the domes of tanks AP-103, AP-104, AP-105, and AN-107 following stress relief. Additional anchor studs were added to adequately support the dome and the conditions were accepted as is.

(1) The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990.

SUMMARY OF FINDINGS

Tank 241-AY-101

During review of the construction history of the 241-AY tank farm, the most significant deficiency found in the review was the degradation and repair of the refractory in tanks AY-101 and AY-102. Both refractories were exposed to similar conditions of moisture and freezing temperatures during the curing stage, which is believed to have contributed to their friable nature and reduced vertical compressive strength. The refractory repairs required the outer 533 mm (21 in) of the periphery refractory to be chipped out all the way around the tank and replaced with reinforced structural concrete.

Significant problems arose with welding of the secondary liner and primary tank bottoms of tank AY-102, with a weld rejection rate of 33.8%. Welding improved with fabrication of tank AY-101, with a weld rejection of 10.2%. Regarding tank bottom flatness, tank AY-101 had a total of six instances of secondary liner bottom bulging as compared to tank AY-102 with 22 instances. QA inspections indicated that bulging of the primary tank bottom had not occurred in tank AY-101 and the information discovered substantiates that it met specification. Despite this documentation, photos from refractory repair after stress relief indicate that voids existed between the primary tank and refractory surface. These voids could be attributed to primary tank bottom bulges, which would indicate that unsupported areas of the primary tank exist in tank AY-101. This lack of support was identified as a contributing factor to primary tank failure in tank AY-102.

The post-weld stress relieving of tank AY-101 was more successful when compared to tank AY-102. Tank AY-101 was stress relieved at 538°C (1000°F) for four hours, which did not meet the specification of 593°C (1100°F) for one hour. This reduced-temperature, longer-duration stress relief method was deemed to be an acceptable alternative per provisions of the ASME Boiler and Pressure Vessel Code, which indicated that it would still produce a suitable stress relief and resistance to stress corrosion cracking.

Although some improvement was seen in the construction of tank AY-101 following tank AY-102, many of the same issues found in tank AY-102 also existed in tank AY-101.

241-AZ Tank Farm

During construction of the 241-AZ tank farm, the second double-shell tank farm built fewer welding problems of the secondary liner and primary tank bottoms were noted compared to the 241-AY tank farm. The secondary liner bottom thickness in the 241-AZ tank farm was increased to ~10 mm (3/8 in) from ~6 mm (1/4 in) in the 241-AY tank farm, and only a minor mention of secondary liner irregularities was noted, requiring the refractory thickness to be increased to ensure a thickness of at least 203 mm (8 in) in all locations. The thickness of the primary tank bottom was also increased from 10 mm (3/8 in) in the 241-AY tank farm to 13 mm (1/2 in) in the 241-AZ tank farm. The overall primary liner weld rejection rates were much lower in the 241-AZ tank farm. Refractory installation and weather protection were improved and, although issues with this protection were noted, no significant refractory repairs were required. The post-weld stress relieving process required modifications, but the changes allowed for more efficient and effective heat treatment in the 241-AZ tank farm compared to the tanks in the 241-AY tank farm.

The most significant deficiency found was the presence of plate laminations. Some surface grinding on the bottom plate of the primary tank AZ-101 occurred. In tank AZ-102, six plates in the upper shell ring were found to have laminations, with four of them severe enough to require replacement prior to heat treatment.

Both primary tanks had leaks found during the hydrostatic test. They were above the normal waste level and repaired without additional stress relieving. A square groove was discovered to have been ground into one weld in the lower knuckle in the tank AZ-101 primary side wall after heat treatment, but this condition was evaluated and accepted as-is.

Following completion of the 241-AY tank farm, design evaluations and "lessons-learned" meetings occurred to remedy issues encountered during construction and resulting changes were incorporated into the 241-AZ tank farm. Although there were improvements in the construction of the 241-AZ tank farm, issues were still noted, some unique to tanks AZ-101 and AZ-102.

241-SY Tank Farm

During construction of the 241-SY tank farm, the third double-shell tank farm built, a new contractor was used. Weld rework rates for all of the 241-SY tank farm tanks were similar to the weld rework rate for tank AY-102. The secondary liner bottom thickness was increased to 10 mm (3/8 in) from 6 mm (1/4 in) and the primary tank bottom was increased from 10 mm (3/8 in) to 13 mm (1/2 in). The plate material was also changed from UNS K02401 carbon steel in the 241-AY tank farm to UNS K02403 carbon steel in the 241-SY tank farm.

Minor issues were noted for refractory installation and weather protection, but no significant refractory repairs were required. The post-weld stress relieving process was more disciplined and effective in the 241-SY tank farm. All tanks were successfully post-weld stress relieved with no deficiencies noted.

The most significant deficiency found in the 241-SY tank farm was the presence of bulging in the primary and secondary bottoms. The maximum root-to-crown slope was found in the tank SY-103 secondary tank bottom and had a slope of 83 mm per m (1 in per ft) or almost three times the allowable specification. Structural analysis and strain gage testing of the bulge was conducted and results indicated the stresses in the tank to be less than the yield strength of the material. Bulging in tank SY-101 was similar in size, shape, and location to the bulge in tank SY-103. However, it was decided to grout the area underneath two bulges to support the primary tank in those locations.

Various other issues related to difficulties in liner fabrication were noted. All of these issues were evaluated and accepted as-is with no stated impact on structural tank integrity.

The 241-SY tank farm had improved construction practices in some areas as compared to tank AY-102, yet many of the construction issues experienced by tank AY-102 re-emerged. Overall, the conditions of the tank liners in the 241-SY tank farm are considered to be similar to tank AY-102. Factors thought to have caused unsupported areas in the primary tank bottom and the potential for areas of high residual stress in tank AY-102 are also present in all of the 241-SY tank farm tanks.

241-AW Tank Farm

During construction of the 241-AW tank farm, weld rejection rates for the tanks were similar to those for tank AY-102. High weld rework rates and subsequent repairs are thought to be a contributor to out-of-tolerance distortions, or bulges. Tanks AW-102 and AW-106 had bulging in the secondary liner bottom that was similar to the bulging noted for tank AY-102. In the 241-AW tank farm, each secondary liner was accepted as is, following engineering evaluation to determine any risk to tank structural integrity. No indication of bulging in any of the primary tank bottoms was found. All 241-AW tanks were accepted as successfully post-weld stress relieved. No post-weld stress relieving deficiencies similar to those that occurred during construction of the 241-AY tank farm were noted.

While Lite Wate 50 (LW50) was initially chosen as the castable refractory product to be used in the 241-AW tank farm, extensive out-of-specification low compressive strength tests of the first several refractory pads led to a material change to Lite Wate 70 (LW70). Tank AW-101 is the only tank in the 241-AW tank farm that utilized

LW50 refractory material, with only Section D being composed of an enriched LW50, containing one additional bag of calcium aluminate binder. No issues were noted with refractory following the change to LW70.

As a result of refractory removal and replacement, scratches and gouges were inflicted upon the secondary liner bottom of several tanks. The construction specification provided direction for repair of such defects and it was applied satisfactorily in the discovered, documented instances.

While tank bottom bulging, refractory material quality and post-weld stress relieving were improved, primary tank bottom weld rejection in the 241-AW tank farm experienced similar challenges when compared to tank AY-102. While these issues, along with others that were judged to be minor (e.g. surface defects and pitting), leave room for uncertainty of long-term tank integrity, the overall condition of the 241-AW tank farm following construction is judged to be better than that of tank AY-102.

241-AN Tank Farm

During construction of the 241-AN tank farm, there was approximately 50% less weld rework when compared to tank AY-102. However, 9% to 20% weld rework rates leave cause for concern. While high weld rework rates and subsequent repairs are thought to be a contributor to out-of-tolerance distortions, or bulges, there were no out-of-specification bulges found in the 241-AN tank farm primary tank or secondary liner bottoms. All 241-AN tank stress relief processes were completed successfully using the alternate requirement of 538°C (1000°F) for three hours per inch and were accepted. No post-weld stress relieving deficiencies similar to those that occurred during construction of the 241-AY tank farm were noted.

Lite Wate 70 (LW70) was the refractory material utilized in the 241-AN tank farm tanks. A void between the secondary liner bottom and refractory was found near the center of tank AN-104. Holes were drilled in the refractory and pourable grout was used to fill the void. The holes were then filled with LW70, and the refractory was accepted.

Tank bottom bulging, refractory material quality, post-weld stress relieving, and primary tank bottom weld rejection in the 241-AN tank farm were improved when compared to tank AY-102. While these issues, along with others that were judged to be minor (e.g., tank dome deformations and pitting), leave room for uncertainty of long-term tank integrity, the overall condition of the 241-AN tank farm following construction is judged to be better than that of tank AY-102.

241-AP Tank Farm

During construction of the 241-AP tank farm, primary tank bottom weld rework was significantly improved over that seen during 241-AY-102 tank construction. A weld rework of 5% to 12% was noted in the 241-AP tank farm, while tank AY-102 primary bottom saw a 34% weld rejection. There were two out-of-specification bulges in primary tank AP-104. Dead weight was placed on the bulges, which brought the primary bottom into specification. No bulges were found in any of the secondary liner bottoms. All 241-AP tank farm stress relief processes were completed successfully using alternate code requirements (1000°F for three hours per inch or 510°C (950°F) for 5 hours for AP-108 only) and were accepted. There is a higher certainty of proper stress relief in the 241-AP tank farm than was noted for tank AY-102.

Litecrete 60M was the castable refractory material utilized in the 241-AP tank farm tanks. For tanks AP-101 through AP-107, no indication of out-of-specification refractory was found. Plastic shrinkage cracks were found in tank AP-108 refractory, caused by curing too quickly. These cracks were filled with refractory material and the refractory was accepted.

Tank bottom bulging, refractory material quality, post-weld stress relieving, and primary tank bottom weld rejection in the 241-AP tank farm were improved when compared to tank AY-102. These issues, along with others (e.g. concrete foundation and encasement repairs and weld joint preparation), are judged to be minor. Overall condition of the 241-AP tank farm following construction is judged to be better than that of tank AY-102.

Conclusions

The formal leak assessment for Tank 241-AY-102 identified first-of-a-kind construction difficulties and trial and-error repairs as major contributing factors to tank failure (1). To determine if improvements in double-shell tank (DST) construction occurred after construction of tank AY-102, a detailed review and evaluation of historical construction records was performed for Hanford's remaining twenty-seven DSTs. Review involved research of 241 boxes of historical project documentation to better understand the condition of the Hanford DST farms, noting similarities in construction difficulties/issues compared to those seen during construction of tank AY- 102.

The reviews revealed that most of the problems seen in construction of the first DST were not repeated in later DSTs. Although some issues were noted with the refractory in other DST farms, none were damaged to the point of the requiring repair as seen in the AY tank farm. Stress relief operations were also improved but only 3 DSTs were stress relieved at the desired temperature of 1100°F; all other met alternate code provisions of lower temperature and longer soak times. Bottom plate thickness was increased after 241-AY tank farm but bottom plate bulges were still an issue in 241-SY tank farm. Problems with high weld rework returned in the 241-SY and 241-AW tank farm when each time a new contractor was selected for construction.

Information gathered provides valuable insight regarding construction difficulties, future tank operations decisions, and guidance of the current tank inspection program. Should new waste storage tanks be constructed in the future, these reviews also provide valuable lessons-learned.

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