Forensic Investigation of Hanford Double-Shell Tank AY-102 Radioactive Waste Leak – 14178

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ABSTRACT

Tank 241-AY-102 was the first of 28 double-shell radioactive waste storage tanks constructed at the U. S. Department of Energy's Hanford Site, near Richland, WA. The tank was completed in 1970, and entered service in 1971. In August 2012, an accumulation of material was discovered at two locations on the floor of the annulus that separates the primary tank from the secondary liner. A formal leak assessment team was established to review Tank AY-102 construction and operating histories, and determine whether the material found on the annulus floor resulted from a primary tank leak. The leak assessment concluded that a leak had occurred at the bottom of the primary tank. The probable cause was identified as corrosion at high temperatures in a tank whose waste containment margins had been reduced by construction difficulties. The conclusion initiated critical assessments of the construction histories of the other 27 double-shell tanks, as well as all elements of the existing Hanford double-shell tank integrity program.

INTRODUCTION

The U. S. Department of Energy's Hanford Site, near Richland, WA contains twenty-eight 3785 m^3 (1 million gal) capacity double-shell underground waste storage tanks. The tanks are grouped in tank farms, containing from two to eight tanks. The earliest tank farm, 241-AY Tank Farm, located in the southeast portion of the 200 East Area, was completed in 1970.
Tank AY-102 is one of two tanks in the 241-AY Tank Farm, and the first double-shell waste tank constructed at the Hanford Site.

The double-shell tank structure consists of a carbon steel primary tank enclosed by a carbon steel secondary liner, inside a concrete shell. The primary tank rests inside the secondary steel liner on an insulating refractory pad on top of the secondary liner and structural foundation. An annular space 0.75 m wide (2.5 ft) is formed between the primary tank and the wall of the secondary liner. The primary tank and annulus have separate ventilation systems, designed to maintain the internal pressures negative with respect to ambient pressure (Refer to Figure 1).

The primary tank is a fully enclosed structure with the only penetrations being side fill lines and dome risers that extend to grade. The secondary liner provides containment up to a height of 11.7 m (38 ft-4 in) above the floor of the primary tank to where the secondary liner meets the top knuckle of the primary tank. The annulus has 22 risers that allow for the insertion of inspection equipment and placement of instruments. Six additional risers act as annulus ventilation outlets.

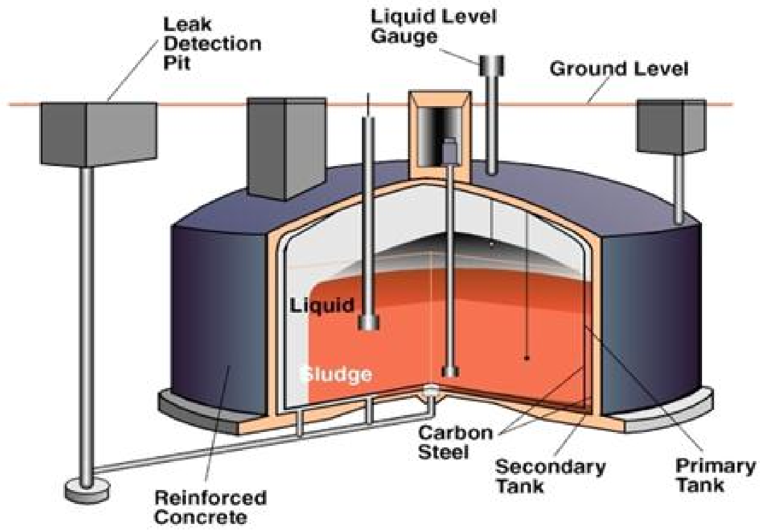

Fig. 1. Hanford Double-Shell Waste Storage Tank Features

The primary tank sidewall and visible portions of dome are routinely inspected for structural and leak integrity, using guidelines developed by Brookhaven National Laboratory on behalf of the U. S. Department of Energy. Key elements of the guidelines were later incorporated in DOE M 435.1-1, *Radioactive Waste Management Manual*, and the accompanying guide, DOE G 435.1-1, *Implementation Guide for Use with DOE M 435.1-1* [1, 2, 3]. The annulus space receives a video inspection once every 5-7 years; the primary tank wall is inspected ultrasonically once every 8-10 years for wall thinning and cracking. The primary tank bottom resting on the refractory pad is not accessible for inspection (Refer to Figure 2). Waste chemistry is monitored and controlled to minimize pitting corrosion and prevent the initiation of stress corrosion cracking. The double-shell tanks have completed several video inspection cycles, and most have completed at least two rounds of ultrasonic inspections. Until the Tank AY-102 video inspection in 2012, none of the inspections had identified an anomaly indicative of tank failure.

In August 2012, an accumulation of material was discovered at two locations on the annulus floor of Tank AY-102 (Refer to Figures 3, 4 and 5). None of the material was present during video inspections completed in December 2006 and January 2007. A formal leak assessment panel was established to review Tank AY-102 and determine whether the material found on the annulus floor resulted from a primary tank leak.

DESCRIPTION

A formal, structured leak assessment process has been applied to the Hanford radioactive waste tanks since 1998. The process is useful for investigations where evidence of a leak is ambiguous. A panel of experts reviews the evidence, performs analyses and supplementary investigations in order to determine the probability that the observed data would be presented if the tank was leaking, and formulates “Leak” and “Non-Leak” hypotheses to explain the aggregated evidence. As an illustration of the assessment process, consider the following: data show that the liquid waste level in a tank is steadily decreasing. If the tank was leaking, then the probability of a decreasing waste level would be high. If the liquid waste in the tank is also thermally hot, a situation commonly found in Hanford’s underground waste storage tanks, then the probability that the observed decrease is due to evaporation is high if the tank is sound;

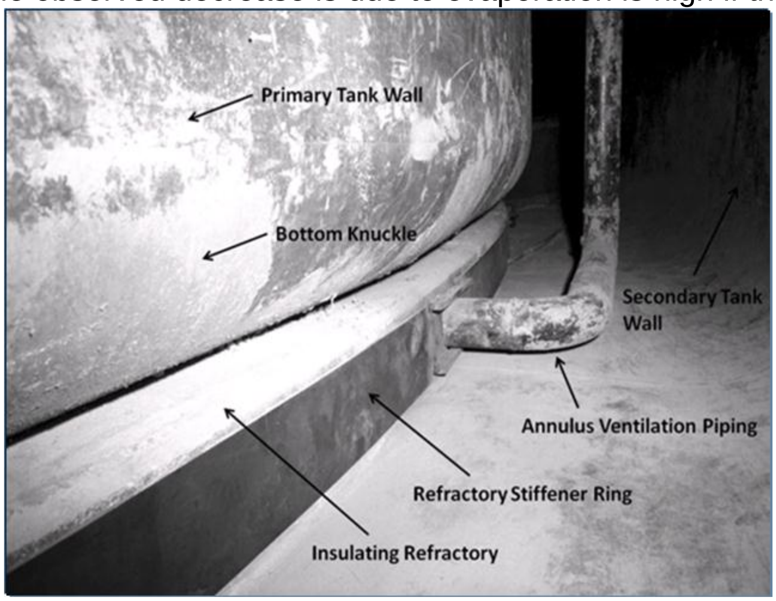

Fig. 2. Tank AY-102 Primary Tank and Annulus Features

however, a small leak could be present within the observed level decrease. A calculation shows that evaporation could account for the waste level decrease. Therefore, the probability that the tank is leaking may be small, but it is not necessarily zero.

The expert panel considers the decrease in the context of the tank’s thermal and operating history, waste characteristics, and the leak integrity of other tanks with similar histories. Additional forensic data are acquired from the historical records maintained at the Hanford Site, and from the National Archives Regional Archives Center in Seattle, WA. As the assessment proceeds and additional information is accumulated, a clearer understanding of the leak risk emerges. The panel considers all of the evidence, and using a structured mathematical decision process, reaches consensus on the tank’s leak status [4]. The structured methodology is intended to ensure that two independent panels of experts, presented with the same data, will reach the same leak assessment conclusion.

The panel’s assessment and the leak integrity recommendation are presented to the Tank Operating Contractor’s Executive Safety Review Board for review and concurrence. Board concurrence is required to change the leak integrity assignment of a tank. The information is subsequently reviewed with the U. S. Department of Energy, and the State of Washington, Department of Ecology. To date the process has been successfully applied to six single-shell tanks, and Tank AY-102. Of the seven tanks assessed, five were determined to be misclassified as “assumed leakers”, and two classified as “sound” were determined to be leaking, including Tank AY-102.

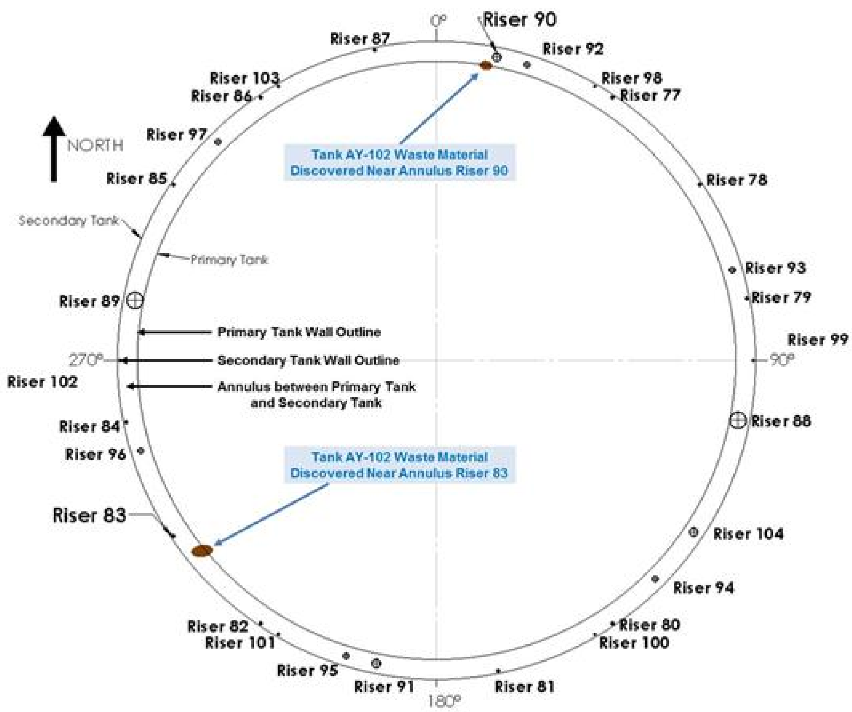

Fig. 3. Tank AY-102 Leak Accumulation Sites

Fig. 4. Tank AY-102 Waste Material Discovered
Near Annulus Riser 90

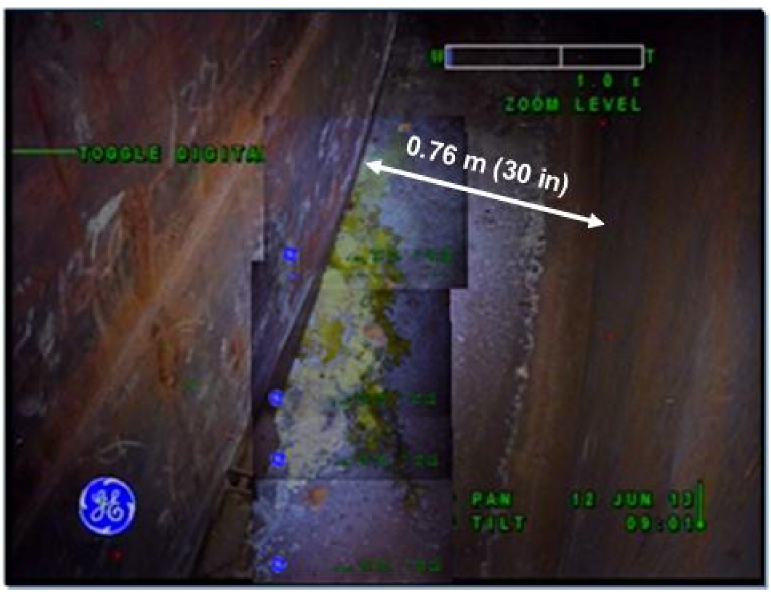

Fig. 5. Tank AY-102 Waste Material Discovered
Near Annulus Riser 83

Because similar materials, fabrication techniques, and operating controls were used for all 28 double-shell tanks, and because previous tank inspections had not predicted incipient leakage, the Tank AY-102 formal leak assessment was expanded to identify the leak cause in addition to determining a possible change in the tank's leak integrity. Multiple Lines of Inquiry were explored, including chemical and rheological analysis of the tank waste material accumulating in the annulus, additional annulus video inspections, and exhaustive re-creation of the tank's construction, operating, thermal, and corrosion-control histories.

In many cases, the Lines of Inquiry did not establish a meaningful link to the tank's leak status. However, there were three Lines of Inquiry that made significant contributions to understanding the tank's leak integrity status: tank construction history; tank thermal and operating history; and composition of samples collected from the annulus floor material.

The leak assessment team completed its evaluation in October 2012, and recommended that the Tank AY-102 leak classification be changed from "Sound" to "Assumed Leaker – Primary Tank". The panel concluded that the probability was $p = > 0.75$ that the material discovered on the floor of the annulus was waste from a leak in the bottom of the primary tank [5].

DISCUSSION

Tank AY-102 was the first double-shell radioactive waste storage tank constructed at the Hanford Site. The design of its primary tank shared many similarities with the last single-shell tanks constructed at the site, just three years before ground was broken for the 241-AY Tank Farm. Higher yield strength steel alloy was used, and the practice of post-weld stress relief was introduced (Refer to Figure 6). However, difficulties that had plagued even the earliest single-shell tank construction at Hanford were again present during the new tank farm's construction.[1] Details of these, as well as the thermal and operating history of the tank contributed to the leak failure. The most significant elements are discussed below:

Tank Construction History

Tank AY-102 construction records detail a tank plagued by first-of-a-kind construction difficulties and trial-and-error repairs. The result was a tank whose as-constructed robustness was much less than foreseen by the tank designers.

The use of thin 0.6 cm (0.25 in) metal plate for the secondary liner, complicated by welding in the open in extreme cold temperatures (-29^{o} C to -23^{o} C [-20^{o} F to -10^{o} F]) caused floor liner warpage. As the floor plates were preheated and welded, convex bulges and wrinkles appeared. Flame heating and water fast quench partially eliminated the wrinkles; however when the assembled floor plates were later heated by the sun new wrinkles appeared. These did not disappear as temperatures chilled. A February 1969 survey found 22 liner locations exceeding the allowable 5 cm (2 in) convexity. Root-to-crown slopes up to 2.5 cm per 30 cm (1 in per ft) were present, exceeding the allowable 0.95 cm per 30 cm (3/8 in per ft) specification. The bulges and wrinkles created in the secondary liner floor by welding the thin floor plates and by reworking rejected welds were eventually accepted so construction could proceed.

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[1] Extensive floor liner buckling in the first twelve single-shell waste storage tanks constructed at the Hanford caused the floors to be replaced according to the May, 1944 Hanford Engineer Works Monthly Report [Declassified] [6].

The rigid refractory insulation cast on top of the secondary liner cracked as the bulges moved, leaving the pad bridged in places. Cracks 2.5 cm to 5 cm (1 to 2-in) deep and up to 2 m (7 ft) long appeared in the cured refractory as pours continued. These were blamed on flexing of the secondary liner from movement of the bulges.

Weld quality during primary tank floor fabrication was a continuing concern. The floor plate weld rejection rate was 36 %. Weld maps show welds being reworked as many as four times before passing radiography examination. Eventually all of the floor plate welds passed radiography examination and were accepted.

Rainwater saturated the insulating refractory pad in the weeks before the primary tank was scheduled for post-weld stress relief, that required the tank to be heated to 593^{o}C (1100^{o}F) and held at that temperature for one hour. During stress relief the tank bottom temperature could not be raised above 99^{o}C (210°F) for two days, while steam escaped from the water-soaked refractory. The tank temperature eventually reached the required stress relief temperature and was held at temperature for the required time.

After post-weld stress relief and the hydrostatic leak check, part of the insulating refractory pad was found to be too damaged to be used. Full depth cracks 0.6 cm (0.25 in) wide extending several feet from the outer lip of the insulating refractory pad back underneath the primary tank were evident. The top surface was spongy (“punky”), had no compressive strength, and the affected depth increased as the outer lip was approached. The air channels cast in the top surface of the pad intended to pass cooling air under the bottom of the primary tank, were blocked with spalled refractory material. The damage was thought to result from alkali hydrolysis, skin friction as primary tank expanded and contracted across surface of refractory pad during stress-relief, and “oil-canning” of the tank on the outside perimeter of the pad.

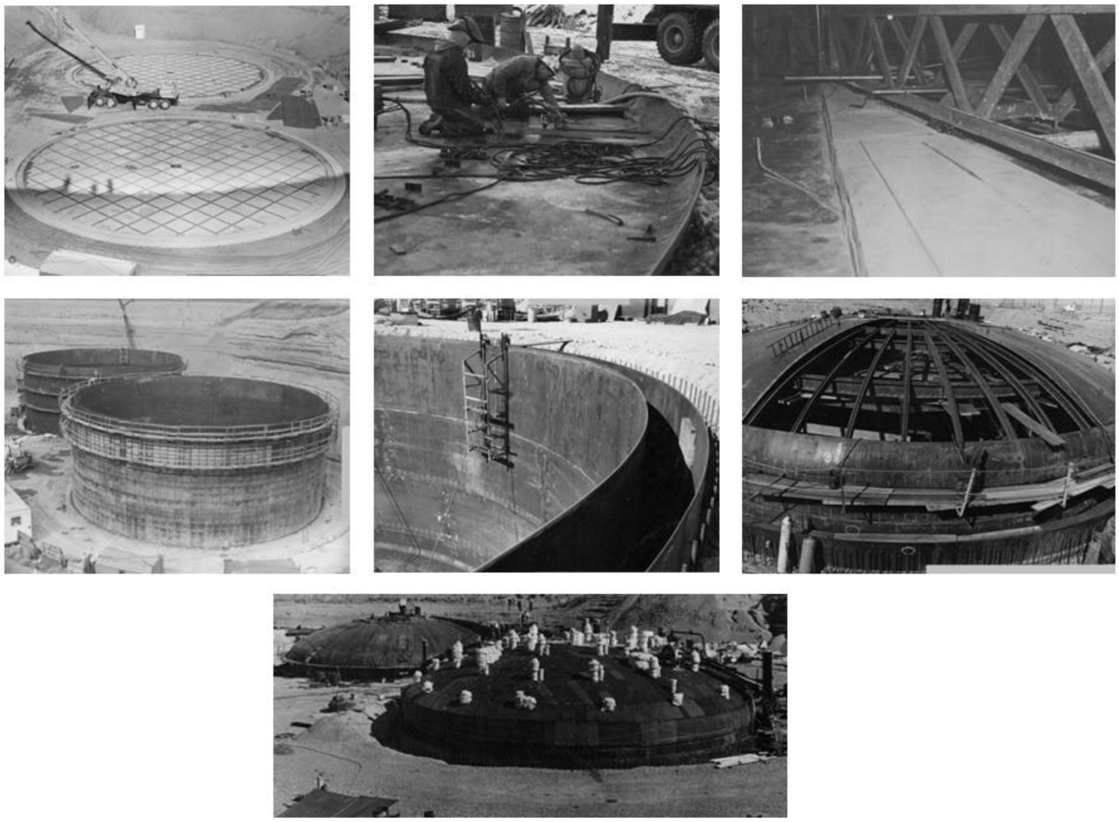

Fig 6. Tank AY-102 Construction Sequence: Left to Right from Top: Concrete Foundation, Tank AY-102 in Foreground; Secondary Liner Lower Knuckle Fabrication; Insulating Refractory Placement; Primary and Secondary Tank Steel Erection and Concrete Sidewall Shell; Backfill to Height of Secondary Tank Steel; Placement of Primary Tank Dome Plates; Preparation for Primary Tank Post-Weld Stress Relief.

Eventually the outside 50 cm (21 in) of the refractory were excavated from beneath the primary tank and replaced with structural concrete (Refer to Figure 7). Inspections following insulating refractory removal found gaps between the refractory surface and the primary tank bottom as large as 3.8 cm (1.5 in). The gaps were filled with polyurethane foam when they were found. The initial pours of the structural concrete filled the excavated area beneath the primary tank knuckle, but did not flow to the back of the excavation. The slump was increased on later pours to ensure that the primary tank bottom was supported once the concrete cured.

Fig. 7. Tank AY-102 Insulating Refractory Repair:
Preparation for Placement of Reinforced Concrete

Tank Thermal and Operating History

After completion Tank AY-102 was partially filled with untreated water in 1971 and held between 71^{o}C and 82^{o}C (160^{o}F and 180^{o}F) as an aging waste spare tank for six years. Between 1977 and 1984, the tank received a variety of supernatant wastes. A thin layer of sludge formed on the tank bottom from 1977 to 1979, and probably 1982 to 1984. The interstitial liquid associated with the sludge may have been mildly corrosive based on derivation of its composition from the limited number of sample analyses that are available from that period. It is possible that the interstitial liquid began to incrementally corrode the tank bottom during this time.

During 1998 and 1999 Tank AY-102 received about 708 m^3 (187,000 gal) of high-temperature sludge from Tank C-106. The sludge formed a 1.7 m (68 in) layer over the existing sludge. The waste temperature increased from 21^{o}C (70^{o}F) to about 54^{o}C (130^{o}F). It is likely that the corrosion rate accelerated after the temperature increase.

Annulus Floor Material Sample Composition

Samples of the annulus floor material were collected from the Riser 83 and Riser 90 locations during September and October 2012. The materials were radioactive, and their compositions were consistent with Tank AY-102 waste (Refer to Figure 8).

The sample radiation dose rates were much lower than predicted by the tank contents – about 1.3E-04 mSv/sec (~ 45 mrem/hr) for the Riser 83 sample. The principal fission products remaining in the Tank AY-102 waste are Sr-90 and Cs-137. The Cs-137 is soluble and typically found in Hanford tank waste supernatant. The Sr-90 is insoluble and typically associated with tank waste sludge. If supernatant had leaked from the tank, then the sample radiation dose rate would be expected to be much higher than measured.

In 2000 the results of laboratory sludge washing tests using Tank AY-102 samples were published. The tests concluded the Tank AY-102 sludge had an unusually high affinity for retraining Cs-137 – 81% of the Cs-137 inventory in the tank was associated with the solids. This was thought to result from the presence of aluminosilicates in the sludge.

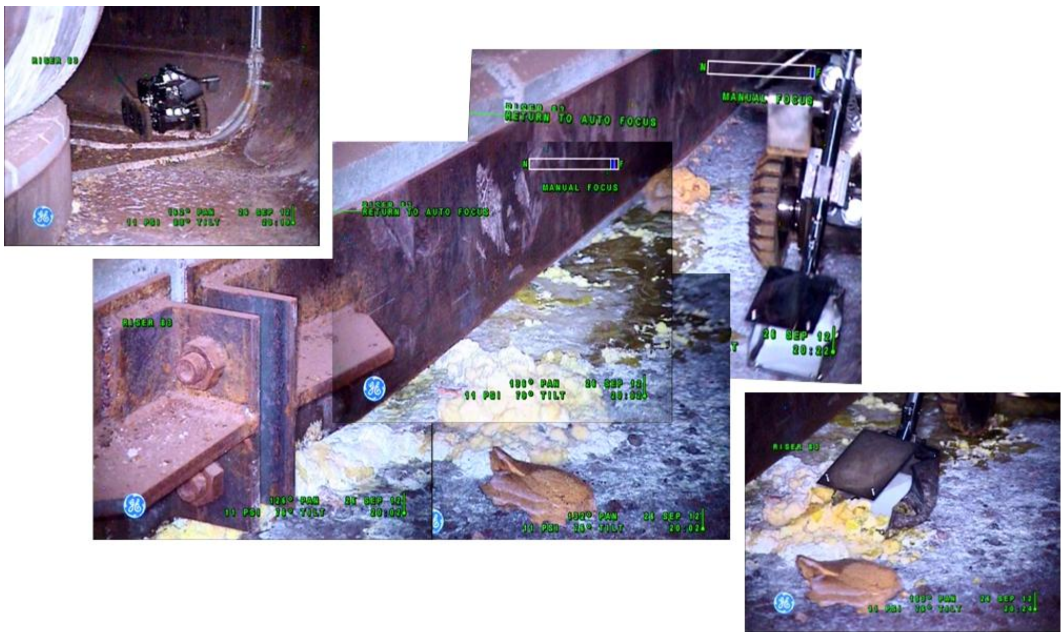

Fig. 8. Tank AY-102 Floor Material Sampling, September 2012: Left to Right from Top: Wheeled Robot Traveling to Sample Site; Sample Site; Sample Collection.

The composition of the Kaolite 2200-LI insulating refractory pad under the primary tank is about 77 weight % aluminum and silicon, suggesting that Cs-137 may be preferentially adsorbed by the refractory as well. The sludge and the insulating refractory pad were acting like a two column tandem ion exchange system, effectively stripping much of the Cs-137 from any supernatant that might have leaked from the primary tank. This behavior was thought to explain the low radiation dose rate.

Laboratory tests of the Riser 83 floor material also showed an unusually high concentration of potassium. Potassium is a unique chemical marker because it exists in significant quantities in only a few Hanford waste tanks. In 1994, 15 m^3 (4,000 gal) of KOH, containing about 1,200 kg (2,600 lbs) of potassium, were added to Tank AY-102 to increase the pH. The Tank AP-101 supernatant transferred into Tank AY-102 during 2007 contained a significant potassium inventory as well. Tank AY-102 has second highest potassium inventory of any Hanford waste tank.

Laboratory results from material collected near Riser 90 in October 2012 were consistent with the results obtained from the Riser 83 sample

CONCLUSIONS

A forensic leak investigation was initiated in August 2012 when unexplained material was discovered on the annulus floor of Tank AY-102. The investigators created detailed construction and thermal and operating histories for Tank AY-102 in order to determine the plausible causes of the material discoveries. Laboratory analyses confirmed the material to be tank waste.

There was consensus agreement among the leak assessment panel members that the radioactive material was the result of waste leaking from a breach in the bottom of the primary tank. The probable leak cause was identified as corrosion at high temperatures in a tank whose waste containment margins had been reduced by construction difficulties.

Implications of Tank AY-102 Leak

The implications of the Tank AY-102 primary tank leak are far-reaching, well beyond the loss of use of a 3785 m^3 (1 million gal) double-shell tank. All 28 Hanford double-shell tanks have the same general design, similar materials of construction, and used similar fabrication techniques during construction. These common factors suggest the other double-shell tanks could be at risk for leaks as well.

Figure 9 illustrates the impacts and changes to the Double-Shell Tank Integrity Program caused by the Tank AY-102 primary tank leak. The changes have all been implemented or are in progress as this paper is being written. They are summarized below:

- The number of annulus risers entered in each double-shell tank for video inspections has been tripled in order to cover > 95% of the annulus floor area and the adjacent primary tank sidewall. An increase in video inspection frequency from the once every 5-7 years to once every three years is being considered.

- Construction records for Tank AY-101, and the other five Hanford double-shell tank farms have been recalled from the Seattle, WA Regional Archives Center to develop construction histories similar to the history prepared for Tank AY-102. The construction histories use Tank-AY-102 as the comparison benchmark to determine whether similar difficulties were encountered in later double-shell tank construction.

- Experimental work to understand the corrosion mechanism responsible for the primary tank leak and the implications for continued leak integrity of the annulus liner in contact with the tank waste is in progress. Heat-treated, “As-Received”, and “Flame Heated-Water Fast Quenched” vintage steel test specimens with microstructure and composition variation similar to Tank AY-102 steel, and representing the primary tank, annulus liner, and the annulus liner bulges present during construction, respectively, are being tested.

- Robotic inspections will determine the location of the primary tank bottom leak site and the condition of the bottom surface of the secondary liner. If the leak site can be reached, then a repair will be attempted if it is determined to be practical.

- A Tank Integrity Panel consisting of nationally-recognized materials, corrosion, and industrial storage tank experts is evaluating the existing elements of Hanford’s Double-Shell Tank Integrity Program. The Panel’s objectives are to: determine why previous inspections did not predict the primary tank failure or provide early warning of the pending failure; to recommend activities to either predict a primary tank failure or increase the probability of early warning; to enhance the existing tank integrity program elements to prevent or minimize degradation of double shell tanks; and to validate that double-shell tanks are capable of supporting the extended Hanford cleanup mission.

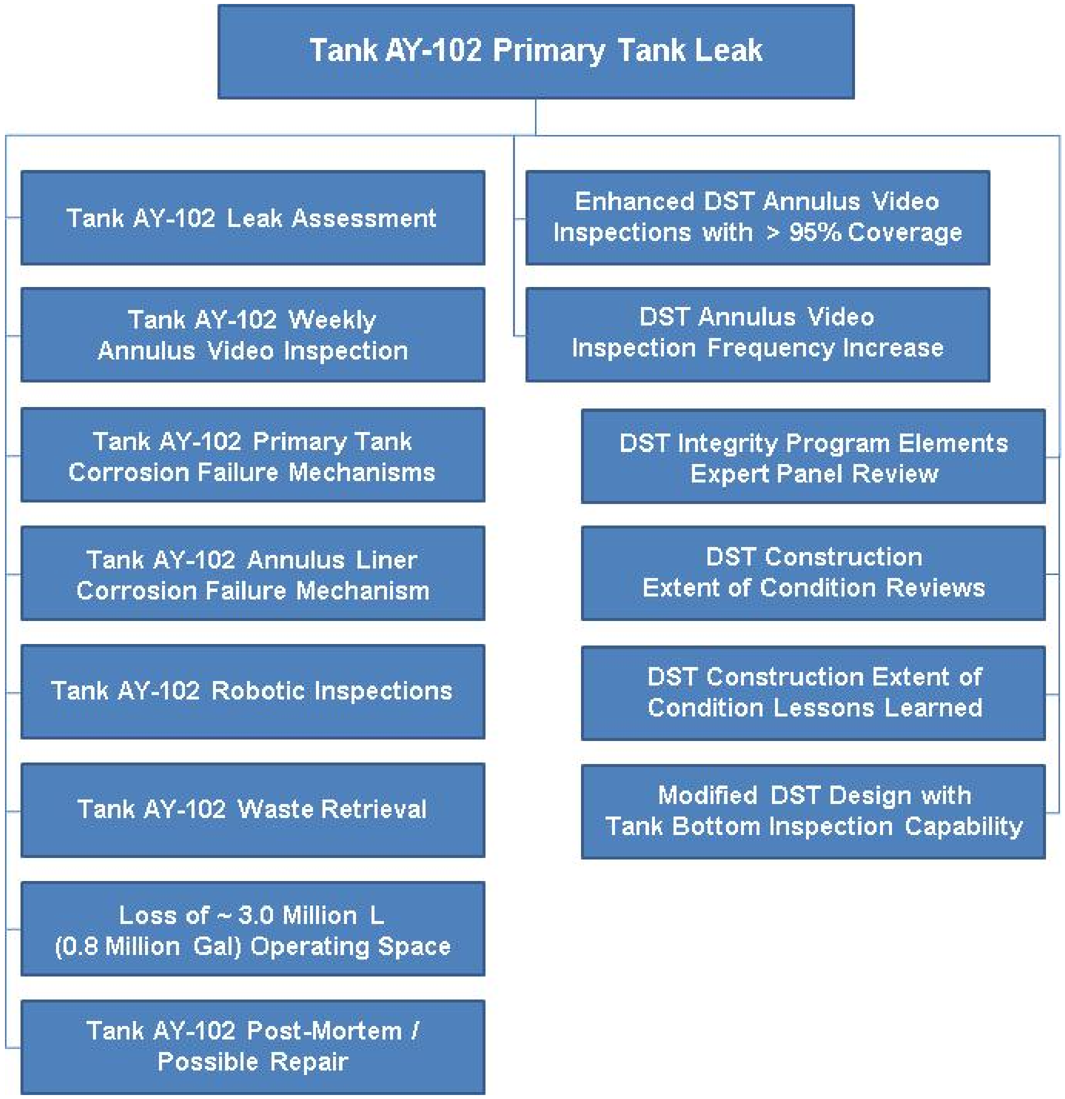

Fig. 9. Hanford Double-Shell Tank Integrity Program Impacts Resulting from the Tank AY-102 Leak

Finally, it must be recognized, that regardless of changes in inspection frequency, or improvements in inspection techniques, the existing double-shell tank design limits inspection access to the primary tank sidewall, and upper and lower knuckles. A significant part of the Hanford double-shell tanks' primary tank bottom is likely to remain inaccessible for inspection. Based on the loss of Tank AY-102, any future double-shell tank design will necessarily have to address this inspection shortcoming.

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ACKNOWLEDGEMENTS

The Leak Assessment Panel consisted of six Hanford tank farm experts with significant inspection, leak assessment, operating, and environmental compliance experience. The panel's deliberations were, in turn, supported by almost two dozen technical staff and independent consultants. This paper cannot adequately describe the intensive effort expended by these groups between August and October 2012 to investigate and logically explain the failure of Tank AY-102.

Significant portions of this paper were adapted from RPP-ASMT-53793, *Tank 241-AY-102 Leak Assessment Report*, Revision 0.