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FITNESS-FOR-SERVICE ASSESSMENT FOR A RADIOACTIVE WASTE TANK THAT CONTAINS STRESS CORROSION CRACKS

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ABSTRACT

Radioactive wastes are confined in 49 underground storage tanks at the Savannah River Site. The tanks are examined by ultrasonic (UT) methods for thinning, pitting, and stress corrosion cracking in order to assess fitness-for-service. During an inspection in 2002, ten cracks were identified on one of the tanks. Given the location of the cracks (i.e., adjacent to welds, weld attachments, and weld repairs), fabrication details (e.g., this tank was not stress-relieved), and the service history the degradation mechanism was stress corrosion cracking. Crack instability calculations utilizing API-579 guidance were performed to show that the combination of expected future service condition hydrostatic and weld residual stresses do not drive any of the identified cracks to instability.

The cracks were re-inspected in 2007 to determine if crack growth had occurred. During this re-examination, one indication that was initially reported as a “possible perpendicular crack <25% through wall” in 2002, was clearly shown not to be a crack. Additionally, examination of a new area immediately adjacent to other cracks along a vertical weld revealed three new cracks. It is not known when these new cracks formed as they could very well have been present in 2002 as well. Therefore, a total of twelve cracks were evaluated during the re-examination.

Comparison of the crack lengths measured in 2002 and 2007 revealed that crack growth had occurred in four of the nine previously measured cracks. The crack length extension ranged from 0.25 to 1.8 inches. However, in all cases the cracks still remained within the residual stress zone (i.e., within two to three inches of the weld). The impact of the cracks that grew on the future service of Tank 15 was re-assessed. API-579 crack instability calculations were again performed, based on expected future service conditions and trended crack growth rates for the future tank service cycle. The analysis showed that the combined hydrostatic and weld residual stresses do not drive the identified cracks to instability.

This tank expected to be decommissioned in the near future. However, if these plans are delayed, it was recommended that a third examination of selected cracks in the tank be performed in 2014.

INTRODUCTION

High level radioactive waste is stored in large underground carbon steel tanks (approximately 1,000,000 gallons each) at the SRS (see Figure 1). The primary tank is contained within a secondary tank that is separated by a 30 inch wide annulus. The secondary tank serves as a liner for a concrete vault. The tanks have been in service for between 25 to 50 years.

The wastes generated at SRS are typically by-products of plutonium and uranium recovery processes. The wastes are present in three forms:

1. Supernate – an alkaline sodium salt solution.

2. Sludge – a gel containing insoluble metal oxides that settle to the tank bottom with some trapped supernate.
3. Salt Cake – salt crystals formed by evaporation of water from the supernate.

The primary species of the salt solution are nitrate, nitrite, hydroxide and aluminate. In addition, the tank interior walls are exposed to a potentially humid environment above the wastes.

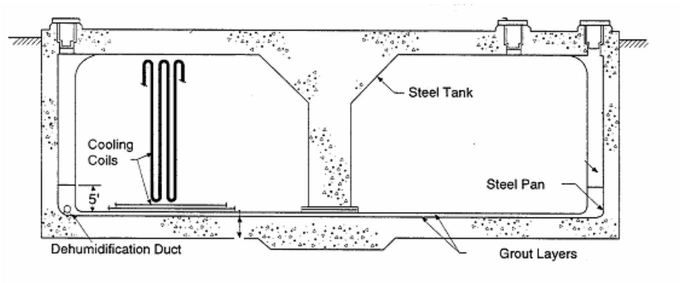

Figure 1. Cut-away drawing of SRS high-level radioactive waste tank.

The oldest waste tanks were not stress-relieved following welding. Therefore, the carbon steel in these tanks is susceptible to nitrate stress corrosion cracking in the region near welds [1]. In the past, SRS has relied upon laboratory testing, visual examinations, and residual stress modeling to characterize these flaws. Recently however, magnetic wall crawlers have been developed to transport ultrasonic (UT) inspection equipment into the annulus region so that crack sizing and characterization may be performed. In 2002, UT was utilized to characterize ten cracks in one of the tanks [2]. The cracks were re-inspected in 2007 to determine if crack growth had occurred. This paper will compare the previous data on stress corrosion cracks with the new information gathered from the 2007 UT inspection in an effort to verify the current understanding of nitrate stress corrosion cracking in carbon steel tanks. Additionally the potential impact of each crack on the structural stability of the tank structure was evaluated.

NON-DESTRUCTIVE EXAMINATION OF CRACKS

UT inspection was performed with the FORCE Technology, P-scan, PS4-Lite, automated system. This system is capable of operating 2 angle beam and 1 thickness mapping transducer or 4 angle beam probes simultaneously. The PS4-Lite also controls the wall crawler that carries the probes across the tank surface. The crawler was also built by FORCE Technology and attaches to the steel tank wall by strong permanent magnetic wheels (see Figure 2). The crawler is capable of being installed through a five inch carbon steel riser. The crawler is also outfitted with a remote control pan and tilt camera system with auxiliary lighting.

Figure 2. Wall crawler utilized for UT inspections.

Crack detection was performed utilizing single element, 45 degree shear wave transducers (Krautkramer MWB-45-4E) operating at 4 MHz. The system was operated to detect stress corrosion cracking (SCC) oriented parallel and/or perpendicular to welds and vertically oriented SCC in the base metal. Crack lengths were reported to the point(s) where the indication was no longer discernable from the noise (See Figure 3). If a crack was branched, the crack tips that resulted in the maximum length in the vertical or horizontal orientation were utilized. No attempt was made to estimate the length along an arc. Crack depths were determined utilizing planar flaw sizing techniques. For indications less than 100% through-wall, the Absolute Arrival Time Technique (AATT) was used to measure the remaining metal ligament. AATT is a planar flaw sizing technique to provide a direct reading of depth the crack tip. The UT equipment was qualified to detect the crack depth within 0.1 inches for a crack between 0.5 and 6 inches long. The personnel performing the UT inspections were certified Level II or Level III in the method utilized.

Cracks were also detected utilizing a technique termed through-wall bleed-out. The technique is a field implemented variation of a liquid penetrant surface inspection technique. It was observed that water used as the UT couplant would penetrate via capillary action the surface cracks. Due to the elevated temperature of the tanks wall, the wetted surface would dry after a few minutes. If a crack was open to the exterior surface, the water drawn into the crack would bleed out providing a high contrast image of an open crack (see Figure 4). Video cameras were utilized to view these indications and make approximate estimates of the crack length as the crawler was being drawn along the tank wall.

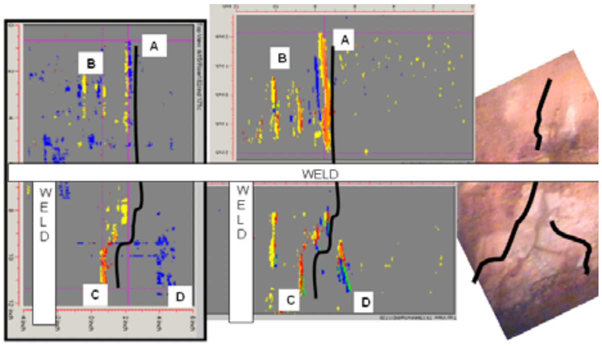

Figure 3. UT scan of stress corrosion crack.

Figure 4. Example of through-wall bleedout.

Although the techniques and the transducers used to size the crack in 2002 and 2007 were the same, there was a significant mechanical improvement to the fixtures that held the probes. This improvement allowed for better contact between the probe and the tank wall surface and a closer approach to the seam weld bead. As a result, better scan resolution, and hence more accurate sizing, was achieved.

To determine whether growth had occurred, all available scan data was utilized to look for reference points on the interior surface of the tank (e.g., weld beads). Typically there were at least two sets of data for each indication from each examination period. Crack extension was then determined by a comparison between the distance between this reference point and the tip of the crack in 2002 and 2007.

DISCUSSION

Crack Analysis

The ten cracks that were identified during a UT inspection performed in 2002 were re-examined in 2007. During this re-examination, one indication that was initially reported as a "possible perpendicular crack <25% through wall", was clearly shown not to be a crack. Additionally, examination of a new area immediately adjacent to other cracks along a vertical weld revealed three new cracks. It is not known when these new cracks formed as they could very well have been present in 2002 as well. Therefore, a total of twelve cracks were evaluated during the re-examination in 2007.

Of these twelve cracks, nine were located in the vapor space above a layer of solids, including the three new cracks. Comparison of the crack lengths measured in 2002 and 2007 revealed that crack growth had occurred in four of the six previously measured vapor space cracks. None of the three cracks beneath the sludge showed evidence of growth.

An example of a crack that grew is shown in Figure 5. The crack was first observed in 1994 and had only a limited amount of leakage. During the first 21 years of service the crack was exposed to nitrate-rich liquid, while for the past 25 years it has been in the vapor space. Though the exact date is unknown, visual inspection results and the limited amount of leakage indicate that through-wall penetration occurred during the past 25 years of vapor exposure. However, initiation of the crack may have occurred during the exposure to liquid phase.

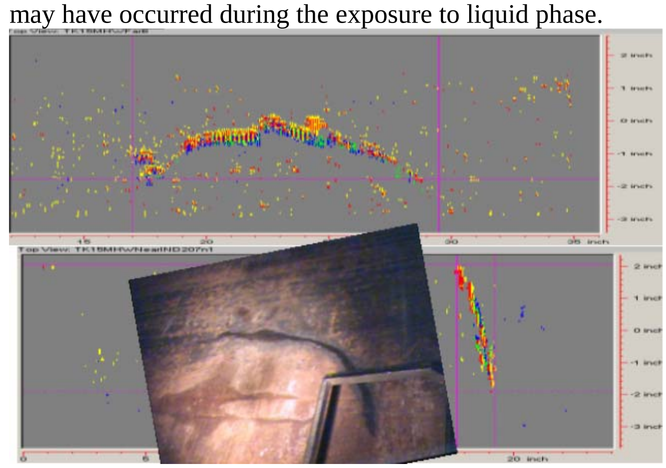

Figure 5. Stress corrosion crack near repair weld in tank.

The crack is located near a repair weld in the middle horizontal weld. In 2007, it was determined that the length of the crack was approximately 19 inches. The visible portion of the crack begins at the left edge of the repair weld and then arcs so that it becomes parallel to the horizontal weld. According to the residual stress modeling, the maximum transverse tensile stress occurs at this location [3-5]. The distance of the parallel portion of the arc is approximately 6 inches from the center of the weld. This distance is further than that observed for other cracks in the tank, however, the effect of a nearby vertical weld may influence the residual stress pattern as well. The through wall portion of the crack is approximately 14.4 inches. At each end of the through-wall section of the crack are part through-wall sections (see Figure 5 for UT scan of crack). In the plate above the weld, a primarily vertical branched crack extends tangentially from the repair weld approximately 3.7 inches above the middle horizontal weld. Approximately 1 inch of this segment is through-wall, whereas in 2002, all of this segment was part through-wall. There has been approximately

1.7 inches of crack extension into the base plate since 2002. The segment that has extended is part through-wall. The part through-wall crack in the plate beneath the weld arcs back toward the middle horizontal weld. The arc-like pattern of the crack adjacent to the weld repair is consistent with laboratory results [6]. The behavior also agrees with the residual stress model for a narrow weld repair in that the crack is located a short distance from the weld repair fusion line [5].

Due to a lack of significant driving forces, either hydrostatic or residual stresses, the crack currently does not impact either the structural stability or the leak tightness of the tank. This statement is confirmed by the finite element fracture analysis previously performed on the crack (assuming that it was 15 inches) [7]. The analysis showed that the hydrostatic stresses were not sufficient to drive the crack to instability. The horizontal orientation of the crack means that hydrostatic stresses in the hoop direction will not have a significant impact on further crack growth. Therefore, from a structural stability perspective the crack is not anticipated to be significant to facility operations.

Crack growth rates were estimated based on the change in length between the 2002 and the 2007 measurements divided by the time between the measurements. The results of this calculation are shown in Table 1 for each of the growing cracks. The first observation is that the crack growth rates are approximately 1 to 2 orders of magnitude lower than the crack growth rate observed in a 5 M nitrate solution on a laboratory sample at approximately the same temperature as the Tank 15 wall [1]. The second observation is that the crack growth rate appears to decrease as the distance from the edge of the weld increases. For example, for Crack #1 in 2002 the distance from the weld was 3.76 inches, whereas for Crack #3 the distance was 2.2 inches (Note: These are not the total crack length, but the length on one side of the weld). The growth rate for Crack #3 appears to be approximately 4 times greater than Crack #1. Both of these observations suggest that the stress intensity at the crack tip is decreasing and approaching K_{Iscc} as the crack tip approaches the edge of the residual stress zone. The observation that the cracks are only part through-wall at the end also suggests that the cracks are nearing the edge of the residual stress zone.

Fitness-For-Service Evaluation of Flaws

Crack specific evaluations were performed to determine the possibility of unstable crack growth. The Fitness-For-Service fracture methodology outlined in API-579 (i.e., the Failure Assessment Diagram) was used for this evaluation [8]. The analysis provided a critical crack length for a given stress level. If the measured crack length is less than the critical crack length, the flaw will continue to propagate at a sub-critical rate. On the other hand, if the measured crack length is greater than the critical crack length uncontrolled, rapid crack growth would occur. The stresses anticipated for waste removal conditions in Tank 15 were utilized. These conditions would certainly bound the current stresses in the tank (i.e., no hydrostatic loads). Crack lengths and locations from the UT inspection were utilized in the analysis.

Table 1. Crack growth rates estimated from UT measurements.

Crack #	Crack Growth Rate (inches/yr)	Total length of crack from edge of the weld in 2002 (inches)	Total Length of crack from edge of the weld in 2007 (inches)
1	0.098	3.76	4.22
2	0.054	3.84	4.1
3	0.367	2.2	3.9
4	0.381	1.5	3.2
5 M Nitrate solution at 50 °C	4.380		

The stresses considered in the analysis were: hydrostatic, residual, dead load, seismic and loads due to the operation of a submersible mixer pump. The primary stresses, particularly outside the residual stress zone, will be hydrostatic. The fill level and specific gravity of the waste determine the hydrostatic stress. For the current conditions, the hydrostatic stresses are minimal since only small volume of dry solids is present in the tank.

In the future, the solids layer will be removed from the tank for further processing and to facilitate tank closure. For waste removal, water is added to slurry the solids layer for transfer. The specific gravity of the solids slurry is dependent on the soluble salt and insoluble solids concentration of the sludge. The most recent solids slurry operation produced a sludge slurry with a soluble salt concentration of approximately 5 to 7 wt.% and a 14 wt.% insoluble solid concentration. The resulting specific gravity of this slurry was 1.16. For the analysis a bounding value of 1.2 was assumed for the SpG of the slurry.

Each of the cracks that exhibited growth was evaluated against the critical crack length at that location and at the specific orientation of the crack (i.e., either horizontal or vertical). It was assumed in the analysis that the cracks were completely through-wall. For a horizontal crack, the worst case was the crack that measured 6.7 inches at the 128” elevation. The critical flaw size at this elevation and in this orientation was > 200 inches, which means that a margin of greater than 30 exists on the measured crack length. For the worst case vertical cracks that exhibited growth (all at elevations greater than 128”), the critical crack length was greater than 50 inches. The longest vertical crack was measured at 10.5 inches, which means that a margin of greater than 5 exists on the measured crack length.

Since the cracks exhibited sub-critical growth, the growth rate for each crack was utilized to estimate the time to reach the critical crack length. For the calculations it was assumed that the growth rate is constant, even at distances that are clearly outside the area affected by the residual stresses from the weld. For the worst case horizontal crack, the growth rate was 0.38 inches/yr. The crack exhibited growth on one side, therefore only extension on one side of the crack will be considered. Given a critical crack length of 200 inches and a current crack length of 6.7 inches the crack will grow to the critical flaw size in approximately 500 years. Likewise, the growth rate for the worst case vertical crack was only 0.05 inches. The crack exhibited growth on one side, therefore only extension on one side of the crack will be considered. Given a critical crack length of 50 inches and a current crack length of 10.5 inches the crack will grow to the critical crack length in approximately 800 years. Therefore, these particular cracks do not represent a threat to the structural stability of the tank.

A “worst” case situation was considered to bound conditions in this tank and other tanks of similar construction where cracks exist. A vertical crack 10.5 inches long was located at the 30 inch elevation (i.e., the highest stress area) and it was assumed to grow at a rate of 0.38 inches per year. These assumptions are extremely conservative since only cracks in the vapor space have been observed to grow and in most cases the 30 inch level in the other tanks are covered with salt or sludge The critical crack length under these conditions was 24 inches. The time to critical crack length in this instance is approximately 36 years. Although the time to the critical crack length is shorter in this case, there would be plenty of time to either respond by re-inspecting the cracks or to complete waste removal in the tank. It was recommended that re-inspection of the cracks that exhibited growth be performed again in 2014 (i.e., 7 years after the most recent inspection) to confirm that crack growth is indeed dissipating.

CONCLUSIONS

Ultrasonic inspection of radioactive high level waste tank was performed in 2007. This was a re-inspection of the tank, the previous one was performed in 2002. Ten cracks were characterized in the previous examination. The re-inspection was performed to verify the present models and understanding for stress corrosion cracking.

Each crack was evaluated for service exposure history, consistency of the crack behavior with the current understanding of stress corrosion cracking, and present and future impact to the structural integrity of the tank. Crack instability calculations were performed on each crack for a bounding waste removal loading condition in Tank 15.

In all cases, the crack behavior was determined to be consistent with the previous understanding of stress corrosion cracking in a waste tank environment. The length of the cracks was limited due to the short-range nature of the residual stresses near seam, repair and attachment welds. A comparison of the 2002 UT results with the 2007 UT results indicated crack growth on four of the cracks in the vapor space. However, the growth remained within the residual stress zone.

The impact of the cracks that grew on the future service of the tank was assessed by the Fitness-For-Service fracture methodology outlined in API-579. A bounding loading condition for waste removal of the solids from this tank was considered for this analysis. The analysis showed that the combination of hydrostatic, seismic, pump and weld residual stresses are not expected to drive any of the cracks identified during the UT inspection to instability.

It was recommended that a third examination of selected cracks be performed in 2014. This examination would provide information to determine whether any additional detectable degradation is occurring in the tank and to supplement the basis for characterization of conditions that are non-aggressive to tank corrosion damage.

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