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Remote Inspection of a 46 Year Old Buried High Level Waste Storage Tank

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ABSTRACT

This paper provides a description of the remote ultrasonic (UT) examinations of a high level radioactive waste (HLW) storage tank at the Savannah River Site. The inspections were performed from the contaminated, annular space of the 46 year old, inactive, 1.03 million gallon waste storage tank. A steerable, magnetic wheel wall crawler was inserted into the annular space through small (6" diameter) holes/risers in the tank top. The crawler carried the equipment used to simultaneously collect data with up to 4 UT transducers and 2 cameras.

The purpose of this inspection was to verify corrosion models and to investigate the possibility of previously unidentified corrosion sites or mechanisms. The inspections included evaluation of previously identified leak sites thickness mapping and crack detection scans on specified areas of the tank. No indications of reportable wall loss or pitting were detected. All thickness readings were above minimum, design tank-wall thickness although several small indications of thinning were noted. The crack detection and sizing examinations revealed five previously undetected indications, four of which were only partially through wall. The cracks that were examined were found to be slightly longer than expected, but are still well within the flaw size criteria used to evaluate tank structural integrity.

BACKGROUND AND REQUIREMENTS

The Savannah River Site (SRS) uses large, water-cooled, carbon steel tanks to store alkaline high-level radioactive solutions that arise from the production of nuclear materials. Three types, or designs, of tanks have been used over the fifty plus years since operations began at SRS. Each primary tank sits in a secondary tank or pan that is surrounded by reinforced concrete. The concrete, except for the tank top, is surrounded by dirt so that the tank is essentially a buried structure. The early, Type I and II, tanks experience nitrate induced stress corrosion cracking. The cracks were associated with fabrication welds and were driven by the residual stresses in the weld heat affected zones. Later tank designs included a post fabrication stress relief anneal and no cracking has been observed in the new tanks. The residual stress pattern in the Type I and II tanks is such that the typical crack is less than six inches long. Operating experience has demonstrated that through wall cracks can cause minimal leakage from the primary tank into the annular space between the primary and secondary tank walls. The leak rate from any crack decreases with time because the leak site becomes salt encrusted as water evaporated from the leaking nitrate solution. Analysis, based on measured material properties, has demonstrated that the crack lengths required for structural instability greatly exceed the observed crack sizes. Additionally tank-operating procedures require that the liquid levels be maintained below any known crack site. These observations, coupled with concern over unidentified corrosion mechanisms, has resulted in a in-service inspection program to identify sites of potential thinning, cracking and/or pitting in the primary tank walls.

The in-service inspection program (ISI) stipulates the frequency and extent of tank examinations, as well as the damage mechanism(s) to be detected. The ISI Program for HLW Tanks stipulates that Tank 15 (a Type II tank) shall be inspected two times within each five-year time span to validate current degradation models. Known leak sites will be characterized and if leakage occurs or previously unidentified degradation mechanisms are suspected, additional inspections will be performed.

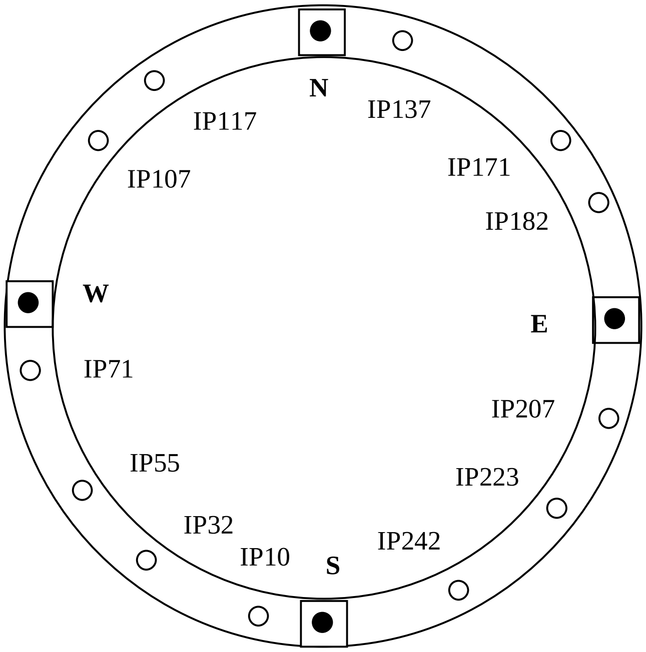
The ISI Program for HLW Tanks calls for the following regions to be inspected:
- Liquid Vapor Interface
- Liquid Sludge Interface
- Upper Weld of Lower Knuckle (the transition from the tank wall to the tank bottom) of Primary Tank (5% of accessible circumference)
- Lower Knuckle Base Material
- External surface of primary tank (including vapor space above the liquid)
- Vertical and horizontal welds other than the lower knuckle weld (one vertical course section and 5% of middle horizontal weld)

These general requirements are further delineated in an inspection plan for a specific tank. The plan for Tank 15 was to conduct the following inspections specific to the primary wall.

1) Four vertical strips for the entire accessible height of the tank; one each under riser IP55, IP107, IP182 and the East riser (see Figure 1),
2) Thirty feet of middle horizontal weld between riser IP171 and IP207 (10% of circumference - additional 5% in lieu of 5% of upper weld of lower knuckle that was inaccessible due to tank geometry.)
3) Lower primary shell plate vertical weld below riser IP182
4) Five previously identified leak sites:
    - vertical weld at 53 feet, 200 inches above tank bottom
    - lower primary shell plate at 115 feet, 88 inches above tank bottom
    - middle horizontal weld at 172 feet
    - middle horizontal weld at 192 feet
    - middle horizontal weld at 207 feet

The approximate radial locations of annulus access risers are illustrated in Figure 1. Locations are in feet from the South riser. The North, South, East and West risers are 5 inch diameter carbon steel pipe. The other inspection ports (IP) were added using a 6 inch diameter core drill to penetrate the tank top.

Figure 1: Tank 15 Riser Layout Sketch



NDE TECHNIQUES AND STRATEGIES

The NDE inspection of tank 15 included remote automated ultrasonic inspection supplemented by remote visual inspection. The inspection system provided the following capabilities:

1) Thickness Mapping
2) Weld Inspection
3) Crack Detection
4) Flaw Sizing
5) Through Wall Bleed-out
6) Visual/Photography

Inspection Equipment

All ultrasonic inspections were performed utilizing the P-scan, automated ultrasonic system and remotely operated magnetic wheel scanner known as the wall crawler. The prescribed regions were inspected utilizing two basic data collection techniques:

1) Vertical Strips – base material thickness mapping and crack detection scans, and
2) Weld Inspection - scans of weld and heat affected zones to detect and characterize any crack indications oriented parallel and/or perpendicular to the weld seam.

Ultrasonic System

The FORCE Technology, P-scan, PS4-Lite, automated, ultrasonic system was used for these inspections. This system (Figure 2) is capable of performing inspections with multiple transducers and can apply several UT techniques. The PS4-Lite can simultaneously perform thickness mapping, weld inspection and A-scan recording. During tank inspections 2 angle beams and 1 thickness mapping transducer or 4 angle beam probes were operated simultaneously. The PS4Lite is operated through a laptop computer as the user interface. The computer also controls the wall crawler that moves and positions the inspection system.

Figure 2: Inspection Equipment

Wall Crawler

The wall crawler is a commercially available, FORCE Technology, P-scan, AMS-1T crawler (Figure 3). The crawler is attached to the steel tank wall by the strong, permanent magnetic wheels. The crawler is small enough to be installed on the tank wall by moving it through a five inch carbon steel riser. The wall crawler is typically outfitted with a remote control pan and tilt camera system and auxiliary lighting for visual inspection of the tank walls. The wall crawler included a pneumatically activated camera boom arm to lift the pan and tilt camera about 10 inches off the surface. It also has pneumatic lifting feet to de-couple it from the tank wall to allow removal from the annulus.

Figure 3: P-scan AMS-1T Wall Crawler

Procedure and Equipment Qualification

The NDE procedures and equipment used for thickness mapping and weld inspection were qualified to the following detection limits at a ½ inch nominal tank wall thickness:

1) General corrosion or localized wall thinning greater than 0.020 inch.
2) Pits exceeding 0.050 inch depth. (elliptical or hemispherical)
3) Cracks deeper than 0.100 inch and $\geq$ 0.5 inch long, < 6 inches long.

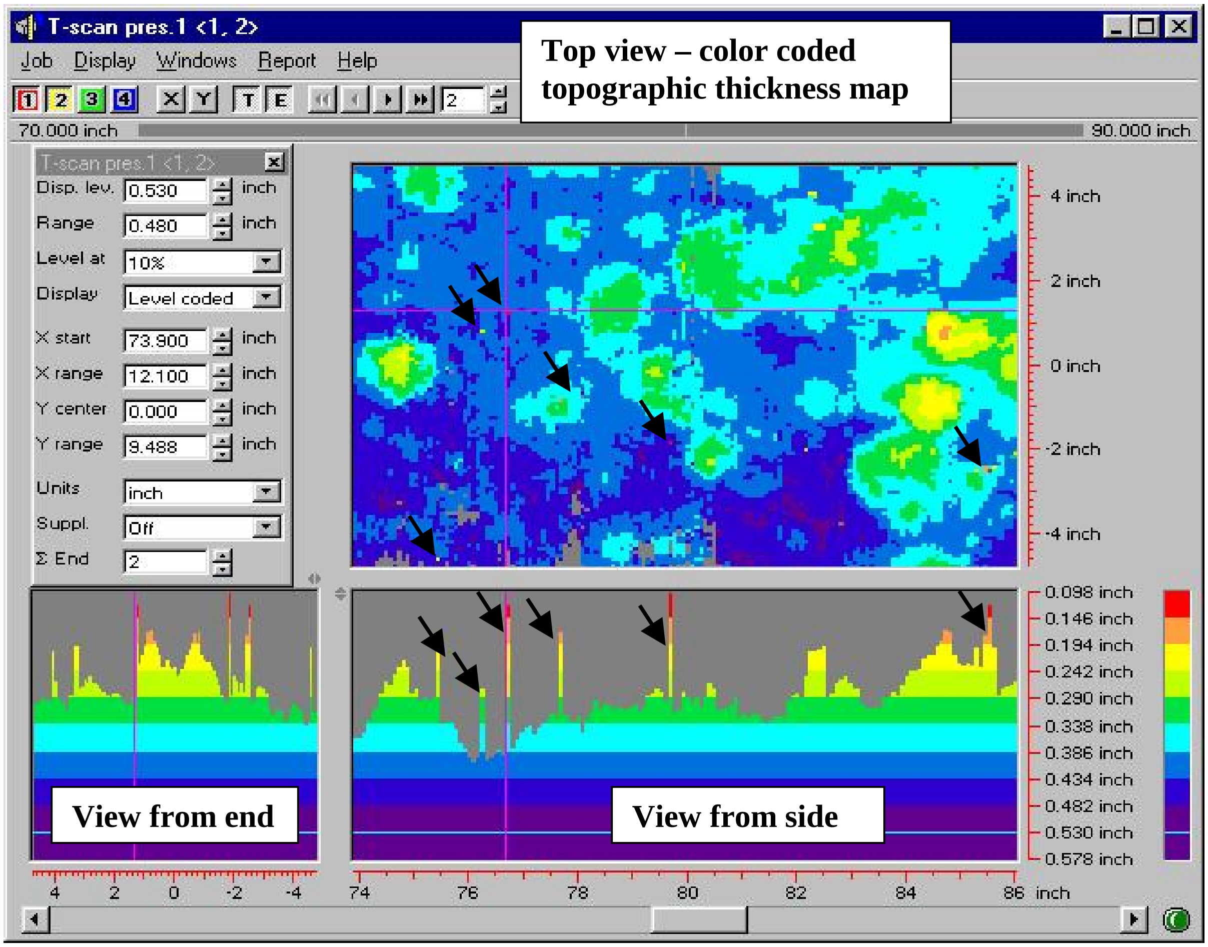
The procedures and equipment easily met the qualification requirements and detection capabilities were demonstrated prior to performing the tank inspections.

Thickness Mapping

The ultrasonic techniques used to map wall thickness also detect and size corrosion, pitting, and attack at the liquid/air interface. Thickness mapping was performed in four vertical strips. Individual vertical strips were 8.5 inches wide so the combined width of all 4 strips provided coverage of 1% of the circumference of the tank. Thickness mapping data was collected over the entire accessible height of the tank to ensure coverage of all areas and environments in the tank. By collecting data in a continuous strip from top to bottom, all present and historic interface levels were examined. Additionally, collecting data in a continuous strip from top to bottom also assessed the tank wall exposed to vapor space above the supernate (liquid).

Thickness data was collected using the FORCE Institutes, P-scan PS4 (Lite) automated ultrasonic system. The "T-scan" thickness mapping program provided color-coded thickness plots from the top, side and end views. This data, collected using a dual element, 0 degree, longitudinal wave transducer (Krautkramer DA301) operating at 5 MHz. The sensitivity of the instrument to various simulated corrosion processes is summarized in Figure 4.

Figure 4: Explanation of Thickness Mapping Images



T-scan pres.1 <1, 2>

Disp. lev. 0.530 inch

Range 0.480 inch

Level at 10%

Display Level coded

X start 73.900 inch

X range 12.100 inch

Y center 0.000 inch

Y range 9.488 inch

Units inch

Suppl. Off

Σ End 2

Figure 4 shows actual thickness mapping data collected on a carbon steel pipe sample fabricated to duplicate potential in-tank corrosion processes. This sample data shows the detection of pitting corrosion in a carbon at the liquid vapor interface. The image also shows pitting and corrosion patterns typical of actual wall loss as well as noise spikes (also known as data dropout). The noise spikes are noted with arrows in the top and side views.

Weld Inspection and Crack Detection

Weld inspection and crack detection were performed with the same ultrasonic system using the "P-scan" amplitude based weld inspection software. Crack detection was performed using single element, 45 degree shear wave transducers (Krautkramer MWB-45-4E) operating at 4 MHz. This technique was incorporated into the thickness mapping vertical strips and was used to examine welds for cracking oriented parallel and perpendicular to the weld seam.

Ultrasonic Flaw Sizing

When indications were detected with ultrasonic techniques, the extent of the indications was measured or "sized". The location and length/width in the X and Y directions were determined based on where the indication was discernable from the background and/or thickness noise.

Pit indications are sized based on remaining, sound, metal (ligament) above the pit. The depth of any pit indications was determined by subtracting the minimum thickness reading obtained from the pit from the thickness of the area adjacent to the pit.

Cracking lengths were reported to the point(s) where the indication was no longer discernable from the noise. Crack depths were determined using planar flaw sizing techniques. Utilizing the same transducer(s) that were used for detection, the amplitude was adjusted to locate the deepest point on the crack. When indications were less than 100 percent through wall, a measurement of the remaining metal (ligament) was made utilizing the Absolute Arrival Time Technique (AATT). AATT is a planar flaw sizing technique used throughout industry to provide a direct reading of depth at the crack tip.

Through-Wall Bleed-Out

Through-wall bleed-out is the term used to describe a field implemented variation of the liquid penetrant surface inspection technique. It was noted that the water being used as the UT couplant, would penetrate (through capillary action) into cracks that were open to the external surface. The tank wall was ~120 degrees F because of the radioactive decay of radioisotopes contained in the tank, thus the wetted surface would dry rapidly as the UT inspection crawler moved away. However, where there was a crack open to the exterior surface, the water drawn into the crack would bleed out continuously wetting the near crack surface and providing a high contrast image of the open crack. Video cameras were used to view these indications (Figure 5) and make crude measurements of length as the crawler was driven along the indication(s).

Figure 5: Example of Through-Wall Bleed-Out

TANK DESIGN AND NDE DATA COLLECTION

Tank Design

Tank 15 is a Type II tankshown schematically in Figure 6 and having the following specifics

- Constructed – 1955 through 1956
- Entered service in 1960
- Capacity – 1,030,000 gallons

- Material – ASTM A285, Grade B Carbon Steel (Not stress relieved)
- Construction Code – ASME-52
- Five foot steel secondary containment pan. Material is A285, Grade B carbon steel
- Annulus Ventilation – Normally positive pressure (changed to negative during inspection)
- Annulus Access – Constructed with five inch carbon steel risers at the South, West, North and East annulus risers.

Additional access provided through 6 inch diameter drilled inspection ports (IP). There are 12 IP's plus the four 5 inch risers spaced around the 267 foot circumference of the tank. The IP's are identified by the distance in feet from the South riser (see Figure 1)

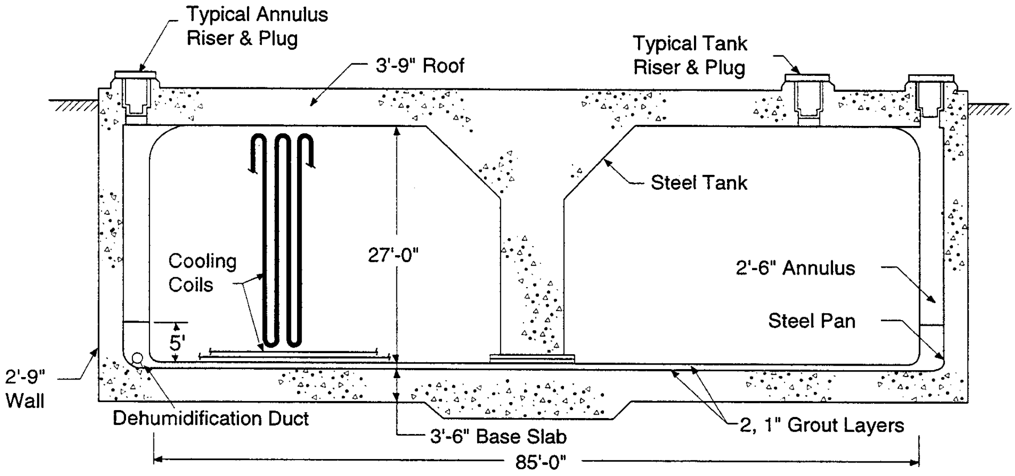


Figure 6: Type II High Level Waste Tank

Inspection Personnel

Nondestructive examination data was collected and analyzed by certified NDE personnel including an ASNT Level III UT inspector and two Level II UT inspectors. All inspection data were analyzed by certified NDE Level III personnel.

Field Tank Inspections

Inspections were performed from the annular space of the high level waste tank. The wall crawler and cameras were installed in the annulus and operated from the NDE control trailer (see Figure 7) which was up to 200 feet from the riser. Access to the annulus was through inspection ports or risers (see Figure 8) inside contamination control huts. These risers are approximately four feet long and are either five inch carbon steel pipe or six inch diameter holes in the tank top. All UT inspections were performed by inserting the wall crawler through the six inch risers. Remote pan & tilt cameras were also inserted into the annulus to monitor crawler movement. Tank 15 has a history of through wall leaks, therefore the annulus is contaminated, thus the tank ventilation was shut down and auxiliary ventilation (MAC-21) was installed to provide negative pressure during the inspections. Containment huts were set up around each riser that was used for crawler access to provide contamination control. In addition to the huts and ventilation, respiratory protection was typically required for the inspectors during crawler installation, removal and maintenance activities. All of the inspections were performed through risers IP55, IP 107 and IP 182.

Figure 7: NDE Control Trailer and Generator

Figure 8: Typical Inspection Port / 5- 6 Inch Riser

INSPECTION RESULTS

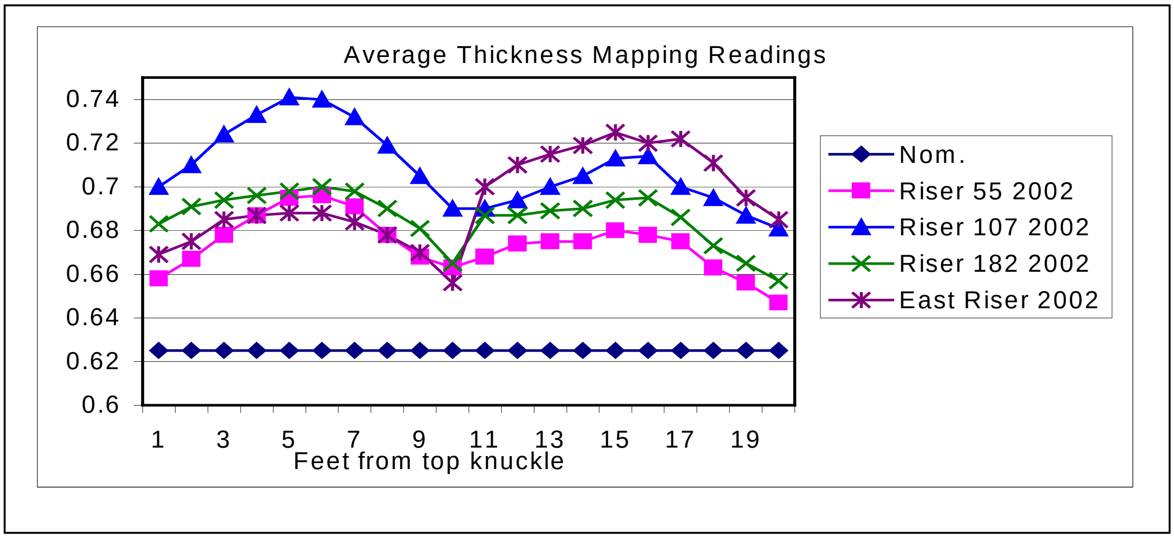
Summary

Tank 15 is an inactive Type II High Level Waste storage tank. This type of tank was not stress relieved and has a history of stress corrosion cracking (SCC). There were eighteen previously identified leak sites in the tank and partially because of this corrosion history the tank was used to demonstrate the remote UT technology.

Several leak sites were ultrasonically evaluated to demonstrate capabilities and to determine the length, depth and factors (weld attachments, weld beads, etc.) that may have contributed to the cracking susceptibility. These indications are scheduled for re-inspection in five years to look for any changes and to evaluate crack growth. Maximum crack lengths were determined and used as input for structural integrity assessments.

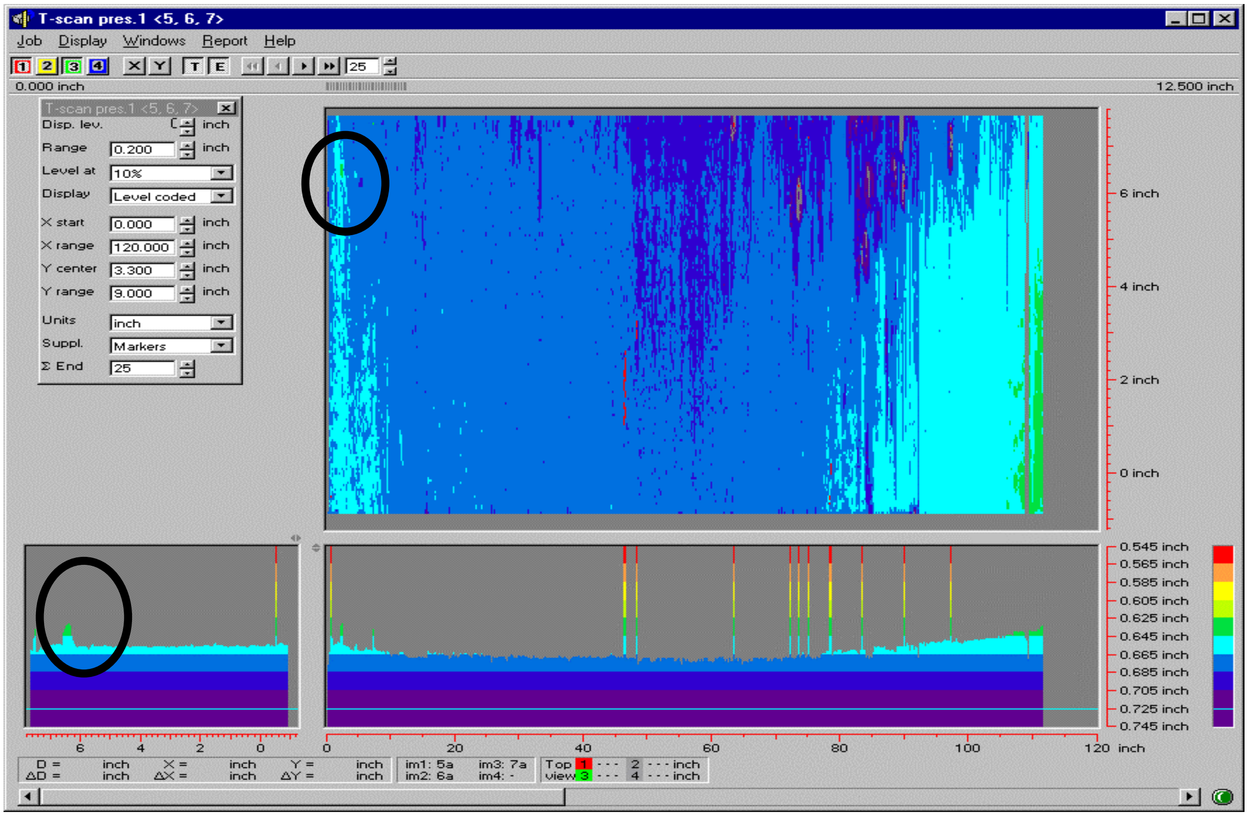
Thickness mapping was performed on 1% of the circumference of the tank for the entire accessible height of the tank (see Figure 9). These thickness mapping examinations were performed to detect and measure any general wall loss, pitting or interface attack in all regions of the tank including the vapor space. The measurements demonstrate the variability in plate thickness and show that most plates were thinner at the edges than at the interior. However, in-spite of the obvious variations in thickness, no reportable wall loss or pitting was detected.

Figure 9: Average Thickness Summary Plot



Inspections of Tank 15 through riser IP 55 included one vertical strip for the entire accessible height of the tank. No reportable losses in thickness or pit indications were detected in the vertical strip. The minimum thickness detected in the upper and lower plates was above nominal plate thickness. The minimum thickness detected in the upper plate was 0.639 inch and is near the edge of the plate toward the middle weld. The minimum thickness detected in the lower plate was 0.632 inch. This minimum thickness was detected over an area that was a 0.25 x 0.40 inch and provided an indication approximately 2.5 inches from the middle weld. The minimum thickness at the bottom of the same plate was 0.634 inch. The indication, inside the black circles on Figure 10, was approximately 0.030 inch deep. The image in Figure 10 also shows the plate is thinner at the edges. There are several noise spikes shown in the side and end views. These noise indications were evaluated and determined to be non-relevant. No crack-like indications were detected in this strip.

Figure 10: Thickness Mapping Image of Lower Plate, Riser 55



T-scan pres.1 <5, 6, 7>

Disp. lev. inch
Range 0.200 inch
Level at 10%
Display Level coded
X start 0.000 inch
X range 120.000 inch
Y center 3.300 inch
Y range 9.000 inch
Units inch
Suppl. Markers
Σ End 25

D = inch X = inch Y = inch
ΔD = inch ΔX = inch ΔY = inch
im1: 5a im3: 7a
im2: 6a im4: -
Top 1 - - - 2 - - - inch
view 3 - - - 4 - - - inch

A previously identified leak site in the upper plate vertical weld under riser IP55 was examined. The leak site was 200 inches above the tank bottom and is illustrated in Figure 11 and UT examinations were performed on the side of the weld opposite the riser. The UT examination demonstrated the leakage had been from a through wall crack and further showed a partially through wall crack segment. The through wall portion on the right side of the weld was 1.4 inches long and the total length on that side of the weld was 3.7 inches. Figure 12 shows some of the UT data from this indication.

Figure 11: Visual Image of Crack in Upper Plate Vertical Weld, Riser 55

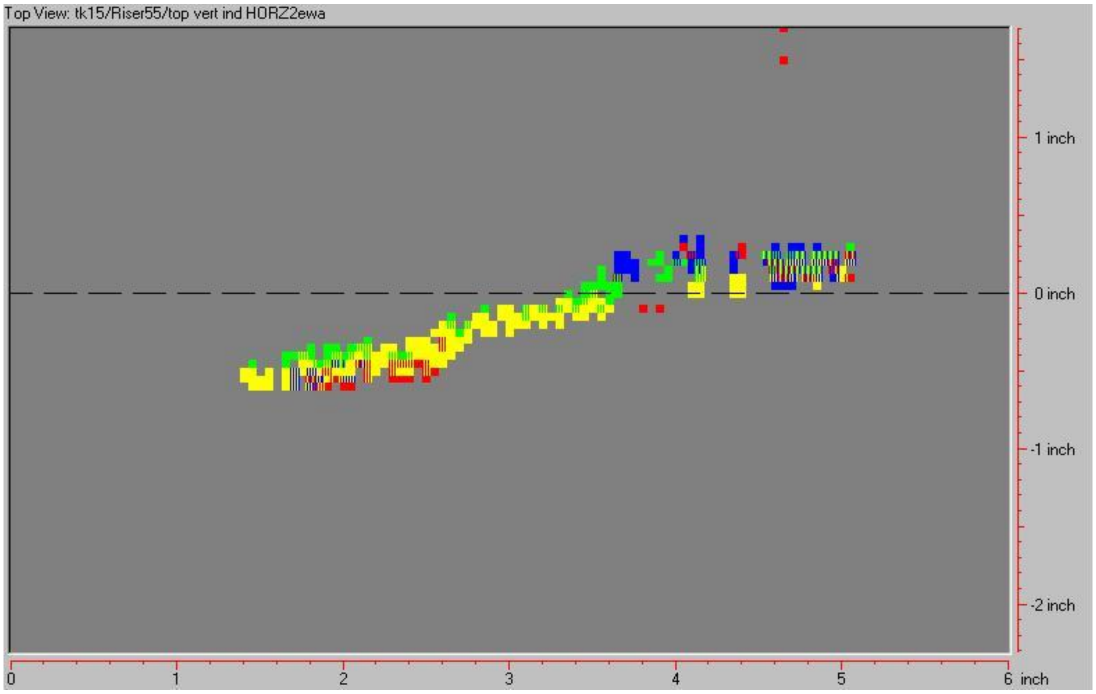
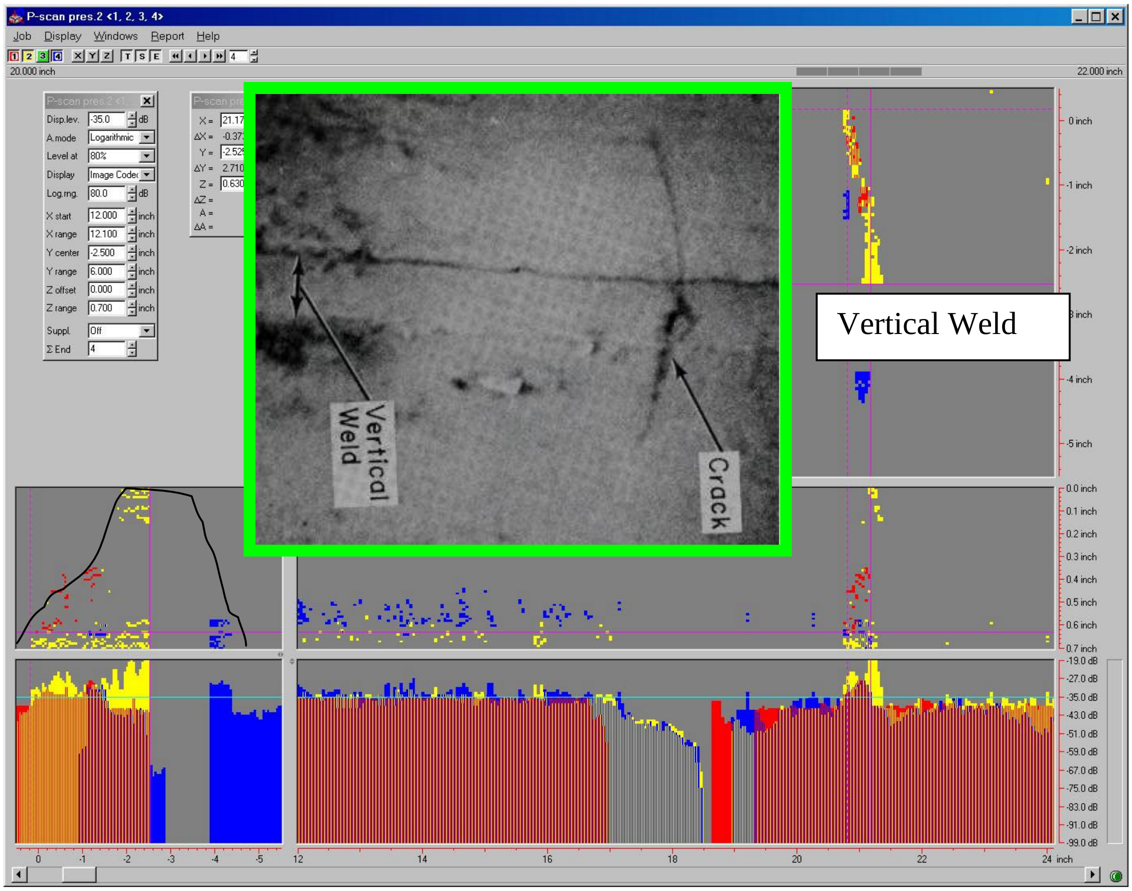


Figure 12 The UT for the Crack Shown in Figure 11

A photograph in Figure 11 is rotated to the same orientation as the P-scan data is shown in Figure 12. The photograph is rotated 180 degrees (up-side down) and the vertical weld edges are marked. Only the part of the indication on the left side of the picture was scanned during the UT examination. The through wall portion of the crack is visible in the photograph and is represented by the blue portion of the P-scan data in Figure 12. The yellow and green portions of the P-scan image indicate the part of the crack that is only partially through the tank wall. The scales on the P-scan data allow measurement of the crack length. These crack lengths (through wall and/or total crack length) are used in tank structural integrity assessments. The difference between the information gained from the visual image and the P-scan data illustrate the valuse of the UT inspection.

The UT inspection also revealed previously undetected indications in the lower plate vertical weld. The through wall indication (see Figure 13) measured 4.5 inches total length and was very similar to stress corrosion crack sites that had been previously identified. The photograph overlay in Figure 13 is from a liquid penetrant inspection that identified stress corrosion cracking in a similar tank in 1962. The recently detected crack is nearly identical to the crack from 1962.

Figure 13: Image of Perpendicular Crack With Liquid Penetrant Results Overlay



Disp.lev. -35.0 dB
A.mode Logarithmic
Level at 80%
Display Image Codec
Log.rng. 80.0 dB
X start 12.000 inch
X range 12.100 inch
Y center -2.500 inch
Y range 6.000 inch
Z offset 0.000 inch
Z range 0.700 inch
Suppl. Off
Σ End 4

X = 21.17
ΔX = -0.37
Y = -2.52
ΔY = 2.710
Z = 0.630
ΔZ =
A =
ΔA =

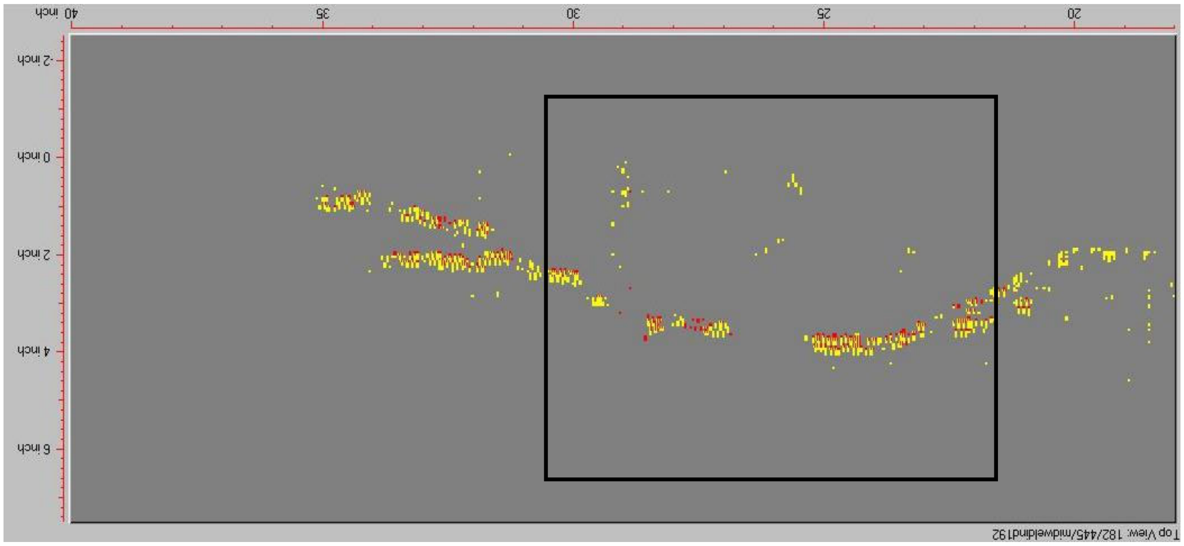
Approximately 33 feet of the middle horizontal weld was also examined for crack indications. The weld was examined in three sections:

- From 171 to 180 feet
- From 183 to 195 feet
- From 196 to 208 feet

The previously leak site at 192 feet is a horizontal/arched crack in lower plate. The UT examination showed that this crack was associated with a weld repair. The through-wall portion (verified visually with bleed-out technique) of this crack was 10.2 inches long, arch shaped and curved around a significant weld repair to the horizontal weld. The weld repair area appears to be approximately 8 inches long and centered on the through-wall portion of the crack. The total length of the indication was 18.1 inches. As shown in Figures 14 and 15, the indication is longer at the inside surface than on the outside and the ends of the indication are multiple, shallow (partial through-wall) crack branches. This condition was also noted on the indication at 207 feet.

Figure 14: As-Found and Bleed-out Image of Crack at 192 feet, Middle Horizontal Weld

Figure 15: P-scan Image of Crack at 192 feet, Middle Horizontal Weld



Through wall part of crack (shown in Figure 14) inside boxed area. P-scan image rotated to same orientation as visual image.

CONCLUSION

The technology, data and analysis presented in this paper demonstrate that remote UT examination can be successfully applied to large, inaccessible structures. An inactive, high level radioactive waste storage tank successfully examined for wall thinning, corrosion at liquid/vapor interfaces, stress corrosion cracking and pitting. Previously identified leak sites were examined and the associated stress corrosion cracks were sized. Additionally, new (previously unidentified) crack indications were located and sized. Wall thickness measurements demonstrated that little or no wall thinning had occurred during the fifty plus years of service. Although neither liquid/vapor interface nor pitting corrosion was identified the technology to identify these degradation modes was also demonstrated. This technology is now being used to evaluate active waste storage tanks.