PNNL-16646 Rev.1

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Ultrasonic Examination of double-shell tank 241-AY-101 Examination Completed October 2007

AF Pardini
DR Weier

January 2008

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

AREVA NC Inc., under a contract from CH2M Hill Hanford Group, has performed an ultrasonic examination of selected portions of Double-Shell Tank 241-AY-101. The purpose of this examination was to provide information that could be used to evaluate the integrity of the wall of the primary tank. The requirements for the ultrasonic examination of Tank 241-AY-101 were to detect, characterize (identify, size, and locate), and record measurements made of any wall thinning, pitting, or cracks that might be present in the wall of the primary tank. Any measurements that exceed the requirements set forth in the Engineering Task Plan, RPP-Plan-27202 (Jensen 2005) and summarized on page 1 of this document, are to be reported to CH2M Hill Hanford Group and the Pacific Northwest National Laboratory for further evaluation. Under the contract with CH2M Hill Hanford Group, all data is to be recorded on electronic media and paper copies of all measurements are provided to Pacific Northwest National Laboratory for third-party evaluation. Pacific Northwest National Laboratory is responsible for preparing a report(s) that describes the results of the AREVA NC Inc. ultrasonic examinations.

Examination Results

The results of the examination of Tank 241-AY-101 have been evaluated by Pacific Northwest National Laboratory personnel. The primary tank ultrasonic examination consisted of scans completed in March 2007 and October 2007. The scan sequence is as follows:

March 2007

- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 88.
- Heat-affected zone of five vertical welds and one horizontal weld from Riser 88.
- Three horizontal scan paths in the liquid-air interface region on Plate #2 from Riser 88.
- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 89.

October 2007

- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 88 (this scan was done directly over the scan that was competed in March 2007). All data was considered when listing the minimum value for a plate.
- One vertical 15-in.-wide scan path adjacent to the scan under Riser 88 but only on Plates #1, #2, #3, and #4.
- One horizontal scan path in the liquid-air interface region on Plate #4 from Riser 88.
- One vertical 15-in.-wide scan path on Plate #5 adjacent to the region scanned from Riser 89 in March 2007.

All examinations were performed to detect any wall thinning, pitting, or cracking in the primary tank wall.

Primary Tank Wall Vertical Scan Paths

The two 15-in.-wide vertical scan paths under Riser 88 yielded the following results. The plates were examined for wall thinning, pitting, and cracks oriented vertically on the primary tank wall.

- Plate #1 results indicate two areas with minimum thickness of 0.326-in. and 0.326-in. that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #1.
- Plate #2 results indicate one area with minimum thickness of 0.434-in. exceeds the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #2.
- Plate #3 results indicate ten areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. However, these ten areas (with remaining ligament of 0.427-in., 0.439-in., 0.439-in., 0.440-in., 0.440-in., 0.440-in., 0.441-in., 0.442-in., 0.447-in., and 0.449-in.) were analyzed by the ultrasonic testing (UT) Level III and were considered pit-like and therefore do not exceed the reportable pitting level of 25% of the nominal thickness. No vertical crack-like indications were detected in Plate #3.
- Plate #4 results indicate two areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. However, these two areas (with remaining ligament of 0.665-in., and 0.667-in.) were analyzed by the Ultrasonic Level III and were considered pit-like and therefore do not exceed the reportable pitting level of 25% of the nominal thickness. No vertical crack-like indications were detected in Plate #4.
- Plate #5 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #5.

The two 15-in.-wide vertical scan paths under Riser 89 yielded the following results. The plates were examined for wall thinning, pitting, and cracks oriented vertically on the primary tank wall.

- Plate #1 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #1.
- Plate #2 results indicate two areas with minimum thickness of 0.397-in. and 0.444-in. that exceed the minimum thinning reportable level of 10% of the nominal thickness. The 0.397-in. area exceeded the acceptance criteria of 20% and will require the tank owner to take special action. No pitting or vertical crack-like indications were detected in Plate #2.
- Plate #3 results indicate eight areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. However, these eight areas (with remaining ligament of 0.431-in., 0.437-in., 0.437-in., 0.439-in., 0.439-in., 0.446-in., 0.446-in., and 0.448-in.) were analyzed by the Ultrasonic Level III and were considered pit-like and therefore do not exceed the reportable pitting level of 25% of the nominal thickness. No vertical crack-like indications were detected in Plate #3.

- Plate #4 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #4.
- Plate #5 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #5.

Primary Tank Wall Horizontal Scan Paths

Three 15-in.-wide horizontal scan paths were performed in the liquid-air interface region on Plate #2 from Riser 88. The plate was examined for wall thinning, pitting, and cracks oriented in a circumferential direction on the primary tank wall.

- Liquid-air interface scan #1 results indicated seven areas (with remaining ligament of 0.423-in., 0.431-in., 0.438-in., 0.440-in., 0.445-in., 0.446-in., and 0.449-in. exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or circumferentially oriented crack-like indications were detected in liquid-air interface scan #1.
- Liquid-air interface scan #2 results indicated nine areas (with remaining ligament of 0.388-in., 0.419-in., 0.430-in., 0.430-in., 0.439-in., 0.440-in., 0.444-in., 0.445-in., and 0.448-in. exceed the minimum thinning reportable level of 10% of the nominal thickness. However, one of these areas (0.388-in.) was analyzed by the Ultrasonic Level III and was considered pit-like and therefore does not exceed the reportable pitting level of 25% of the nominal thickness. No circumferentially oriented crack-like indications were detected in liquid-air interface scan #2.
- Liquid-air interface scan #3 results indicated two areas (with remaining ligament of 0.436-in., and 0.446-in. exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or circumferentially oriented crack-like indications were detected in liquid-air interface scan #3.

One 15-in.-wide horizontal scan path was performed in the liquid-air interface region on Plate #4 from Riser 88. The plate was examined for wall thinning and pitting on the primary tank wall.

- Liquid-air interface scan results indicated one area (with remaining ligament of 0.671-in.) that exceeded the minimum thinning reportable level of 10% of the nominal thickness. No pitting was detected in liquid-air interface scan on Plate #4.

Primary Tank Wall Weld Scan Paths

The heat-affected zone of vertical welds in Plates #1, #2, #3, #4, and #5 from Riser 88 were examined for wall thinning, pitting and cracks oriented either perpendicular or parallel to the weld.

- Plate #1 indicates one area with a minimum thickness of 0.329-in. that exceeded the minimum thinning reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #1.
- Plate #2 indicates two areas with a minimum thickness of 0.434-in. and 0.443-in. that exceeded the minimum thinning reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #2.

- Plate #3 indicates no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #3.
- Plate #4 indicates no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #4.
- Plate #5 indicates no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #5.

The heat-affected zone of the horizontal weld between Plate #3 and Plate #4 from Riser 88 was examined for wall thinning, pitting and cracks oriented either perpendicular or parallel to the weld. The results indicated no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas on Plate #3 side or on Plate #4 side of the horizontal weld.

Extreme Value Analysis

Extreme value measured wall thickness losses were estimated. Since current remaining wall thickness typically still exceeds drawing nominal, thereby generating negative losses, UT image maximum values were instead used to determine estimated nominal wall thickness per plate/riser combination. These thicknesses tended to run up to about 0.020-in. greater than drawing nominal. They in turn were used with each UT image minimum value to determine estimated wall thickness losses, which then were combined for a plate course over the two risers (88 and 89). In converting to such losses, instead of using remaining wall thickness, measurements could potentially be combined for distribution fitting across plates of differing nominal thicknesses.

Measurements from March 2007, and October 2007, inspections were combined in these analyses. However, since a same Riser 88 path was measured during each inspection, with very minimal measurement differences resulting, only one of these replicate paths was used in the extreme value analysis. This was because the same tank wall area was measured, apparently with little measurement error relative to the actual variability in wall thickness. Such replicate data are very useful for characterization of measurement error, and its occasional generation is recommended. Better understanding of the measurement system performance is needed to determine if the values from different measurement campaigns, separated by several years, can be used in estimating corrosion rates.

Three parameter Weibull distributions were fit to suitable combinations of plate course measurements as well as to the measurements for a liquid air interface (LAI). If two Plate 1 outlying values are omitted from Plates 1&2 combined, a worst case measured wall thickness loss of 0.076-in. results. It might be expected if the entire surface area of the tank wall in these plates, but outside the LAI in Plate 2, were UT inspected. A 95% confidence bound for this case is computed based on the uncertainty in the Weibull parameters caused by the relatively minimal amounts of data for distribution fitting and the quality of the Weibull fit; this bound on measured wall thickness loss is 0.093-in. Note that such losses should be considered relative to the larger "estimated" nominal wall thicknesses and not relative to the drawing nominal.

The corresponding estimated worst case loss and bound when the two outlying values are included for Plates 1&2 (no LAI) are respectively 0.102-in. and 0.130-in.; for Plates 3, 4, &5, they are 0.117-in. and 0.131-in., and for the LAI, 0.138-in. and 0.170-in. These larger values result from generally larger measured losses, their greater variability, and rather poor Weibull distribution fits.

Contents

Figures

1.0 Introduction

AREVA NC Inc. (AREVA), under a contract from CH2M Hill Hanford Group (CH2M Hill), has performed an ultrasonic (UT) examination of selected portions of Double-Shell Tank (DST) 241-AY-101. The purpose of this examination was to provide information that could be used to evaluate the integrity of the DST. The requirements for the ultrasonic examination of Tank 241-AY-101 were to detect, characterize (identify, size, and locate), and record measurements made of any wall thinning, pitting, or cracks that might be present in the wall of the primary tank. Any measurements that exceed the requirements set forth in the Engineering Task Plan (ETP), RPP-Plan-27202 (Jensen 2005), are to be reported to CH2M Hill and the Pacific Northwest National Laboratory (PNNL) for further evaluation. Specific measurements that are reported include the following:

- Wall thinning that exceeds 10% of the nominal thickness of the plate.
- Pits with depths that exceed 25% of the nominal plate thickness.
- Stress-corrosion cracks (SCC) that exceed 0.10 in. (through-wall) and are detected in the inner wall of the tank, the heat-affected-zone (HAZ) of welds, or in the tank knuckle.

The accuracy requirements for ultrasonic measurements for the different types of defects are as follows:

- Wall thinning – measure thickness within ±0.020 in.
- Pits – size depths within ±0.050 in.
- Cracks – size the depth of cracks on the inner wall surfaces within ±0.1 in.
- Location – locate all reportable indications within ±1.0 in.

Under the contract with CH2M Hill, all data is to be recorded on electronic media and paper copies of all measurements are provided to PNNL for third-party evaluation. PNNL is responsible for preparing a report(s) that describes the results of the AREVA UT.

2.0 Qualified Personnel, Procedures, and Equipment

Under contract from CH2M Hill, qualification of personnel participating in the DST inspection program, the UT equipment (instrument and mechanical scanning fixture), and the UT procedure that will be used in the examination of the current DST is required. Personnel participating in the examinations are to be certified in accordance with American Society for Nondestructive Testing (ASNT) Recommended Practice SNT-TC-1A, 1992 Edition, and associated documentation is to be provided. The capability of the UT system is to be validated through a performance demonstration test (PDT) on a mock-up simulating the actual DST. The current procedure for the UT is to be based on requirements listed in the American Society for Mechanical Engineers (ASME), Boiler and Pressure Vessel Code Section V, Article 4, *Ultrasonic Examination Methods for Inservice Inspection*.

2.1 Personnel Qualifications

The following individuals were qualified and certified to perform UT of the Hanford DST 241-AY-101:

- **Mr. Wesley Nelson**, ASNT Level III (#LM-1874) in UT, has been identified as AREVA's UT Level III authority for this project. Mr. Nelson has been certified by AREVA as a UT Level III in accordance with AREVA procedure COGEMA-SVCP-PRC-014, latest revision which conforms to the requirements of ASNT SNT-TC-1A, 1992. Further documentation has been provided to establish his qualifications (Pardini 2000).

- **Mr. James B. Elder**, ASNT Level III (#JM-1891) in UT, has been contracted by AREVA to provide peer review of all DST UT data. Mr. Elder has been certified by JBNDT as a UT Level III in accordance with JBNDT written practice JBNDT-WP-1, latest revision. Further documentation has been provided to establish his qualifications (Posakony and Pardini 1998).

- **Mr. William D. Purdy**, AREVA UT Level II limited (for P-Scan data acquisition only). Mr. Purdy has been certified in accordance with AREVA procedure COGEMA-SVCP-PRC-014, latest revision. Further documentation has been provided to establish his qualifications (Posakony 2001).

- **Mr. Jeffery S. Pintler**, AREVA UT Level II limited (for P-Scan data acquisition only). Mr. Pintler has been certified in accordance with AREVA procedure COGEMA-SVCP-PRC-014, latest revision. Further documentation has been provided to establish his qualifications (Pardini 2006).

The following individual participated in this examination and is a trainee and therefore not qualified or certified to perform independent UT of the Hanford DST 241-AY-101:

- **Ms. Laura A. Sepich**, AREVA UT trainee in accordance with AREVA procedure COGEMA-SVCP-PRC-014, latest revision.

2.2 Ultrasonic Examination Equipment

CH2M Hill has provided the UT equipment for the examination of Tank 241-AY-101. This equipment consists of a Force Technology P-Scan ultrasonic test instrument and Force Technology AWS-5D remote-controlled, magnetic-wheel crawler for examining the primary tank wall. Ultrasonic transducers used for the examinations are commercially available. The P-Scan ultrasonic system has been qualified through a PDT administered by PNNL. (Posakony and Pardini 1998)

2.3 Ultrasonic Examination Procedure

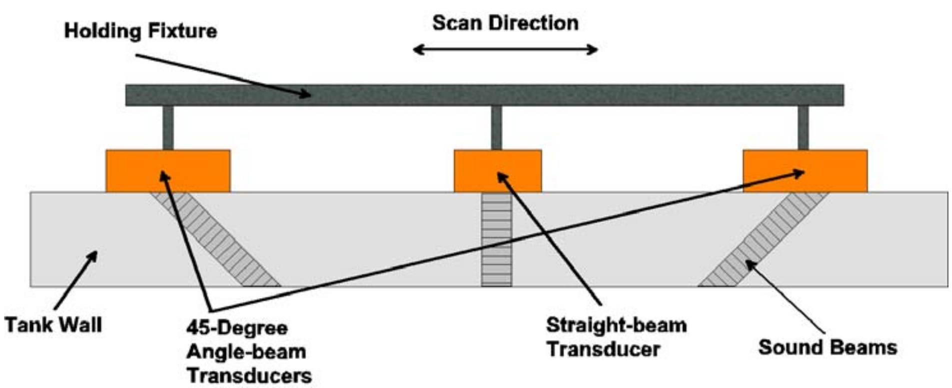
AREVA has provided the UT procedure for the examination of Tank 241-AY-101. This procedure, COGEMA-SVUT-INS-007.3, Revision 3, outlines the type of UT and mechanical equipment that are to be used as well as the types of transducers. Both straight-beam and angle-beam transducers are used for the examination of the primary tank wall. The examination procedures include full documentation on methods for calibration, examination, and reporting. Hard copies of the T-Scan (thickness) and P-Scan (projection or angle beam) views of all areas scanned are made available for analysis. The UT procedure requires the use of specific UT transducers for the different examinations. A calibration performed before and after the examinations identifies the specific transducers used and the sensitivity adjustments needed to perform the inspection. The AREVA UT procedure has been qualified through a PDT (Posakony and Pardini 1998).

3.0 Ultrasonic Examination Configuration

AREVA is required to inspect selected portions of the DSTs which may include the primary and secondary tank walls, the HAZ of the primary tank vertical and horizontal welds, and the tank knuckle and bottoms. The P-Scan system has been configured to perform these examinations and has been performance tested. The examination of Tank 241-AY-101 included UT of the primary tank wall and the HAZ of selected welds in the primary tank wall.

3.1 Primary Tank Wall Transducer Configuration

Figure 3.1 provides an example of the scanning configuration generally used during an examination of the primary tank wall. However, other configurations can be used at the discretion of the AREVA UT Level III (i.e., 45-degree transducers can be removed for simple wall thickness measurements). The functional diagram in Figure 3.1 shows one straight-beam and two angle-beam transducers ganged together for examining the primary tank wall. The straight beam is designed to detect and record wall thinning and pits, and the angle beams are designed to detect and record any cracking that may be present. These transducers are attached to the scanning bridge and they all move together. Information is captured every 0.035-in. (or as set by the UT inspector) as the assembly is scanned across a line. At the end of each scan line the fixture is indexed 0.035-in. (or as set by the UT inspector) and the scan is repeated. The mechanical scanning fixture is designed to scan a maximum of approximately 15-in. and then index for the next scan. The hard copy provides a permanent record that is used for the subsequent analysis.



Transducer Specifications:

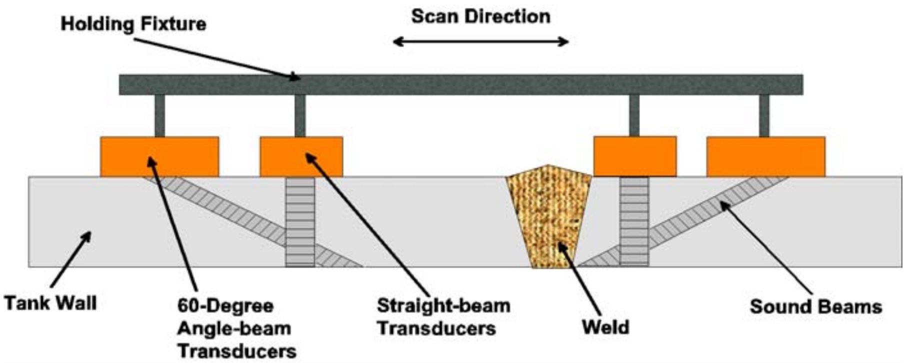
Angle-Beam
Type: MWB-45 04E
Frequency: 4 MHz
Size: 8 X 9 mm
Manufacturer: Krautkramer

Straight-Beam
Type: MSEB 5B
Frequency: 5 MHz
Size: Dual - 9 X 2 mm
Manufacturer: Krautkramer

Figure 3.1. Transducer Configuration for Examining the Primary Tank Wall

3.2 Weld Zone Transducer Configuration

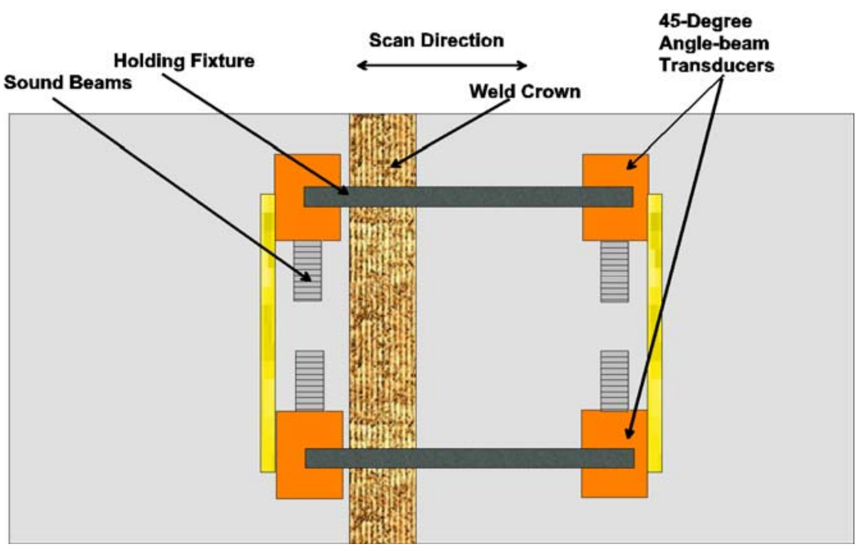
Figure 3.2 is a functional sketch that shows the configurations for examination of the weld zone. The area of interest (HAZ of the weld) is shown as lying adjacent to the weld. Both cracks and pitting may occur in this region. The "A" portion of this sketch shows the 60-degree angle-beam transducers used for detecting cracks parallel to the weld. The straight-beam transducers in this sketch are used for detecting and recording any pitting or wall thinning that may be present. All transducers are ganged together. The scanning distance traveled is limited to a total of approximately 5.0-in. The sketch titled "B" shows the arrangement for detecting cracks that may lie perpendicular to the weld. Four 45-degree, angle-beam transducers are used for this inspection. Again the transducers are ganged together but the scan is limited to a total of approximately 4.0-in. The weld zone requirements are shown in Figure 3.3. The scan protocol, data capture, and index parameters are the same for examining other weld areas in the tank.



A. Configuration for pitting and cracks parallel to weld

Transducer Specifications:
Angle-Beam
Type: MWB-60 04E
Frequency: 4 MHz
Size: 8 X 9 mm
Manufacturer: Krautkramer

Straight-Beam
Type: MSEB 5B
Frequency: 5 MHz
Size: Dual - 9 X 2 mm
Manufacturer: Krautkramer



Transducer Specifications:
Angle-Beam
Type: MWB-45 04E
Frequency: 4 MHz
Size: 8 X 9 mm
Manufacturer: Krautkramer

B. Configuration for cracks perpendicular to weld

Figure 3.2. Transducer Configurations for Examination of Weld Zone in the Primary Tank Wall

In the HAZ, the requirement for characterizing cracks that lie perpendicular or parallel to welds in the primary tank wall is described in Figure 3.3. The HAZs are located on either side of the weld and defined as being within 1-in. of the toe of the weld and on the inner three-quarters of the thickness (3/4T) of the plate. These zones are considered most likely to experience stress-corrosion cracking.

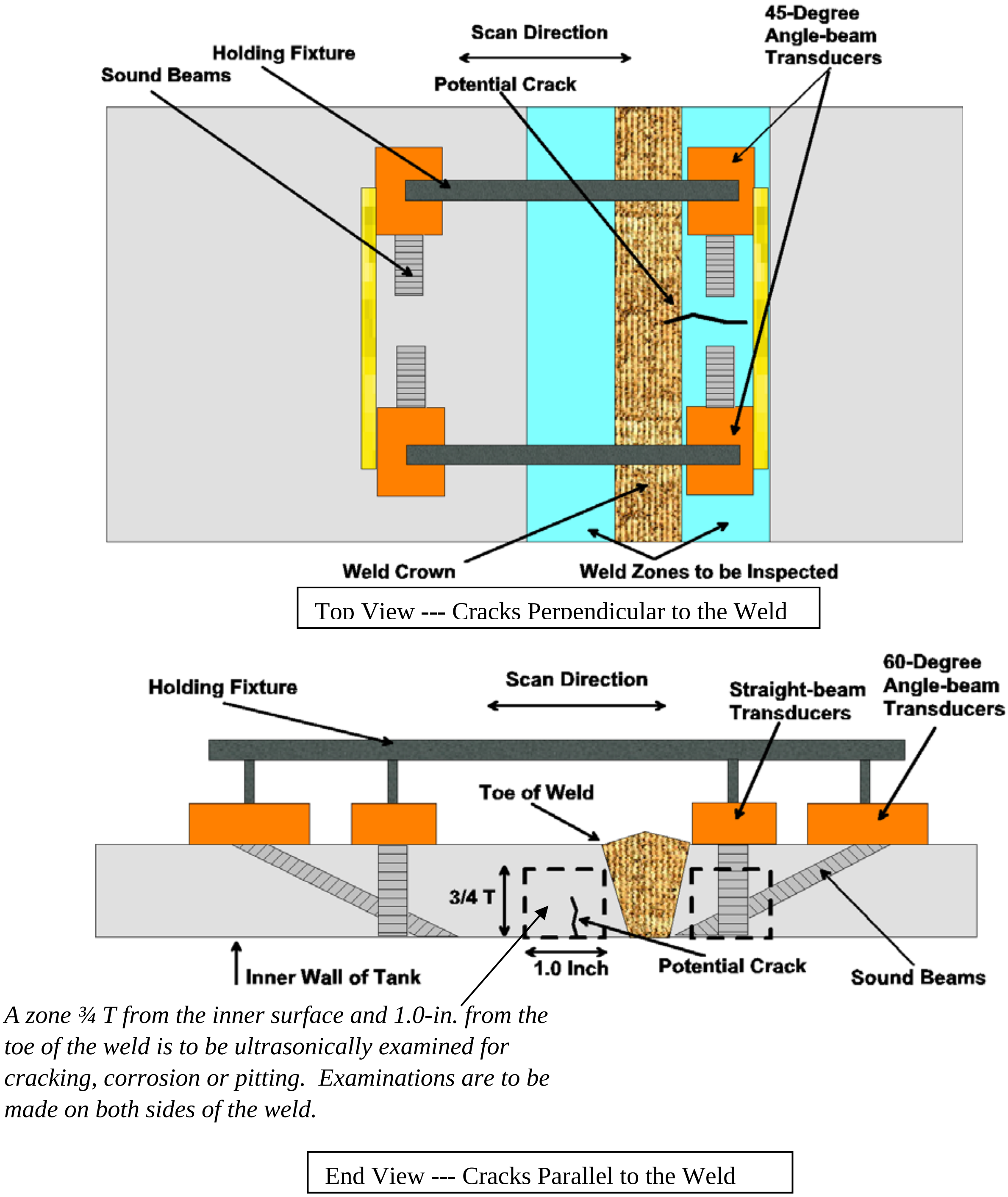


Figure 3.3. Views of the Weld Zone to be Ultrasonically Examined in the Primary Tank Wall

4.0 Ultrasonic Examination Location

Tank 241-AY-101 is located in the Hanford 200 East area in AY Tank Farm. The crawler and associated scanner that hold the transducers were lowered into the 24-in. risers located on the east side (Riser 88) and on the west side (Riser 89) of 241-AY-101. Figure 4.1 provides a graphic of the location of the risers.

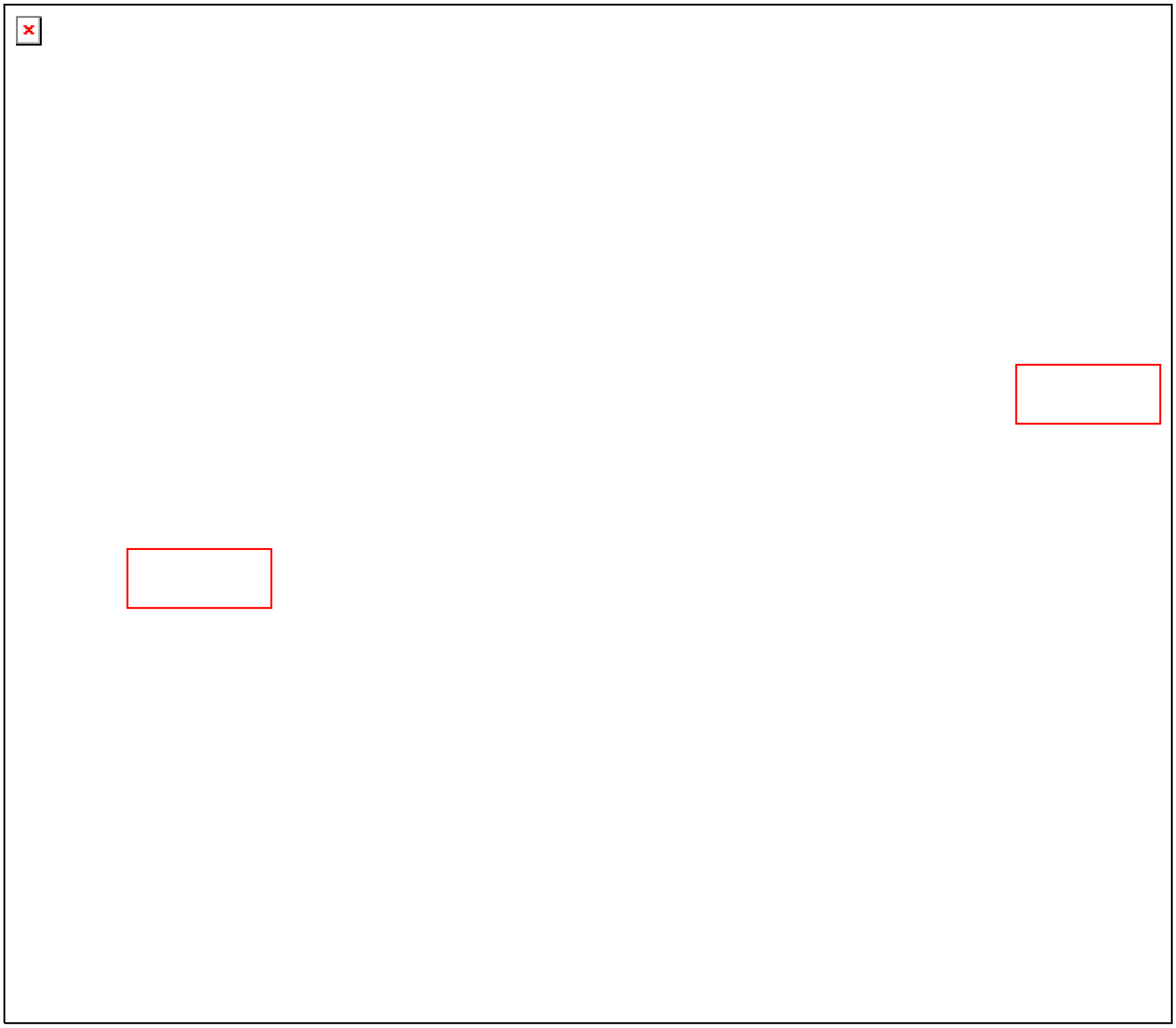


Figure 4.1. UT of Tank 241-AY-101 Riser 88 and Riser 89

Figure 4.2 (from Riser 88) and 4.3 (from Riser 89) describe the areas on the primary wall of Tank 241-AY-101 that were ultrasonically examined in March 2007 and October 2007. The scan sequence is as follows:

March 2007

- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 88.
- Heat-affected zone of five vertical welds and one horizontal weld from Riser 88.
- Three horizontal scan paths in the liquid-air interface (LAI) region on Plate #2 from Riser 88.
- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 89.

October 2007

- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 88 (this scan was done directly over the scan that was competed in March 2007). All data was considered when listing the minimum value for a plate.
- One vertical 15-in.-wide scan path adjacent to the scan under Riser 88 but only on Plates #1, #2, #3, and #4.
- One horizontal scan path in the LAI region on Plate #4 from Riser 88.
- One vertical 15-in.-wide scan path on Plate #5 adjacent to the region scanned from Riser 89 in March 2007.

All examinations were performed to detect any wall thinning, pitting, or cracking in the primary tank wall.

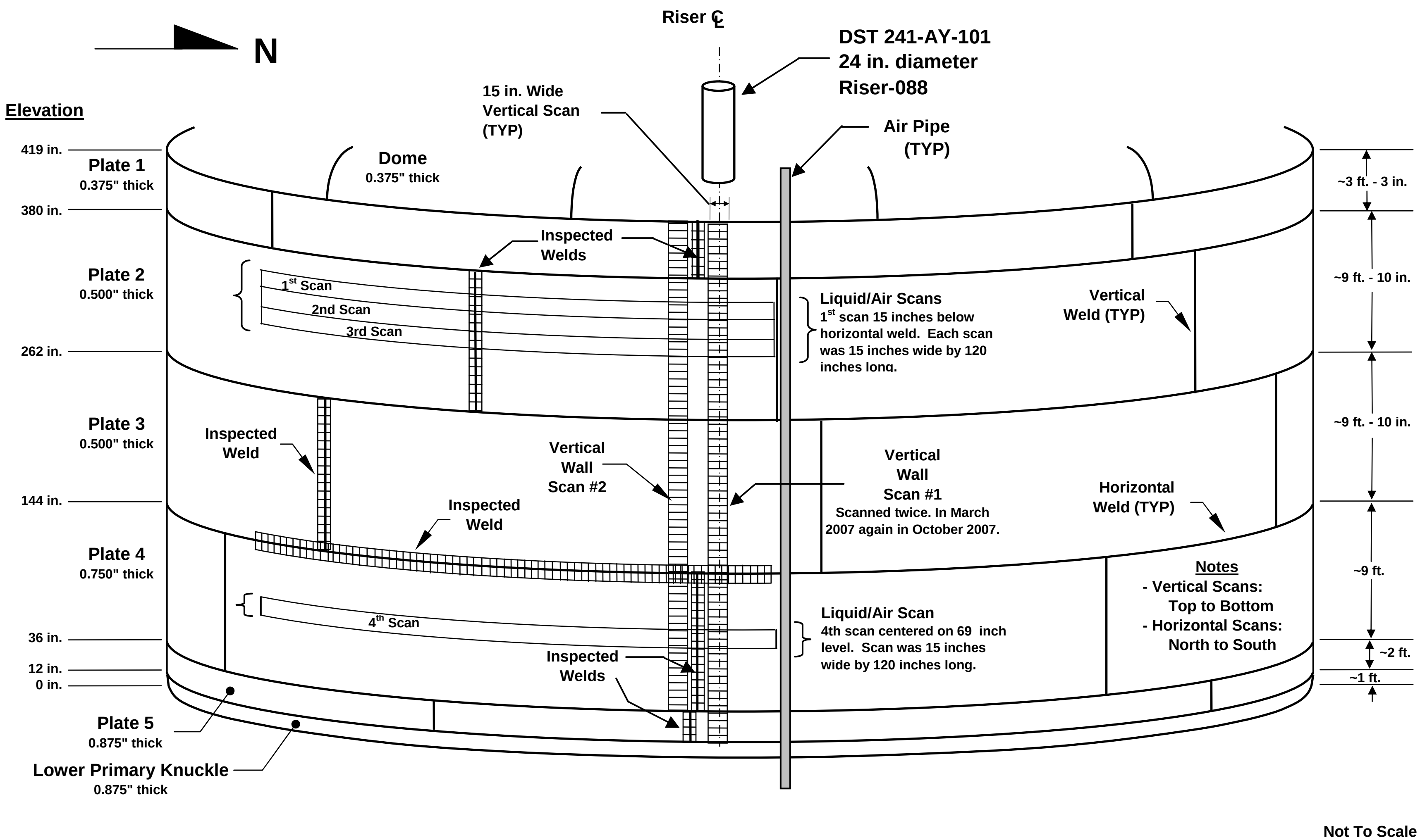


Figure 4.2. Sketch of Scan Paths on 241-AY-101 Primary Tank from Riser 88

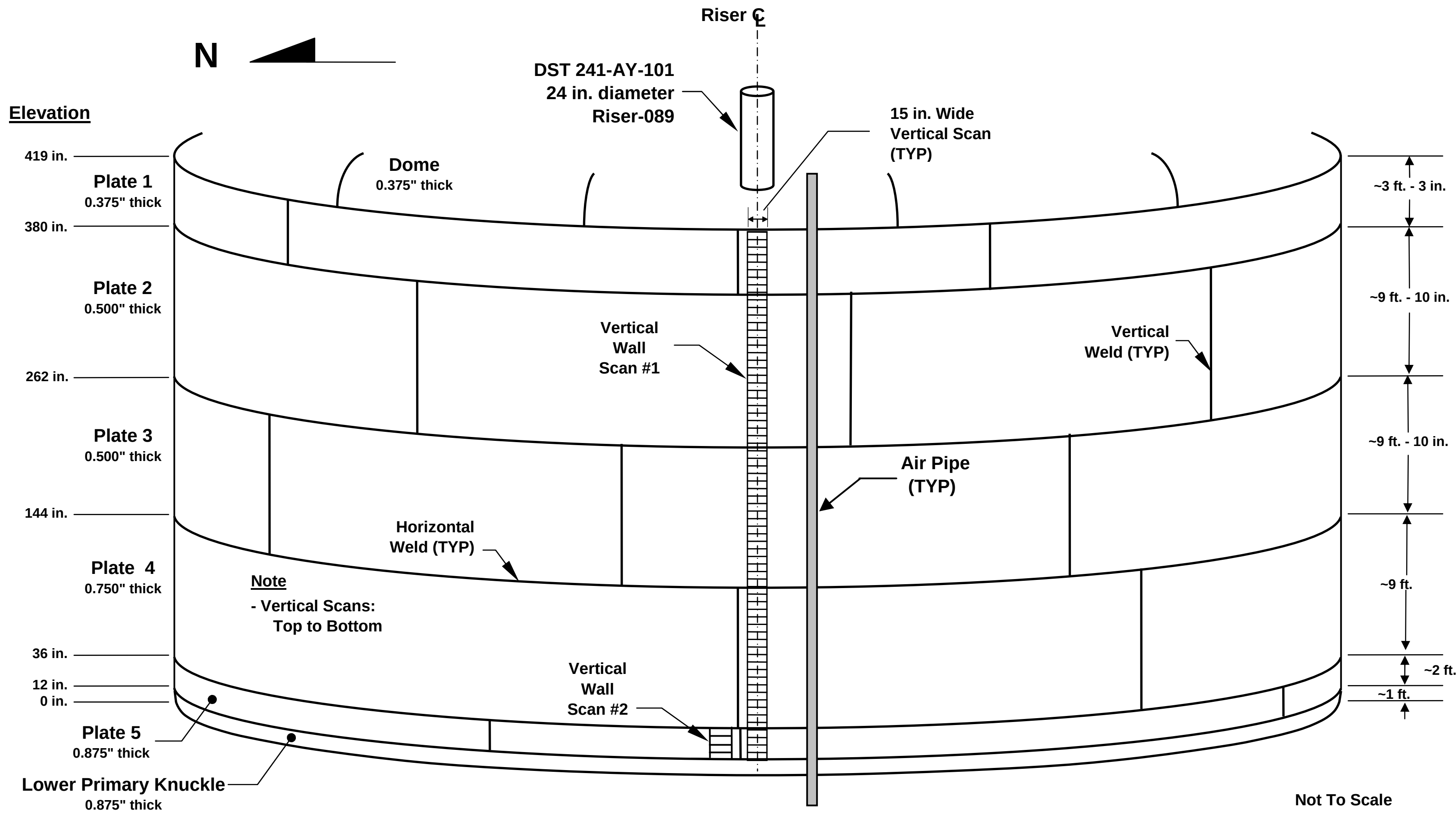


Figure 4.3. Sketch of Scan Paths on Tank 241-AY-101 Primary Tank from Riser 89

5.0 Ultrasonic Examination Results

AREVA has provided detailed reports including T-Scan and P-Scan hard copies of all areas that were ultrasonically examined to PNNL for third-party review. The data was analyzed by AREVA UT Level III Mr. Wes Nelson, and peer reviewed by JBNDT UT Level III Mr. Jim Elder. The results of the examination of Tank 241-AY-101 are presented in Figures 5.1 through 5.4.

Figures 5.1 and 5.2 show the wall thickness examination results for the primary tank wall and the HAZs of both vertical and horizontal welds from Riser 88. The examination consisted of one 15-in.-wide vertical path beneath the centerline of the 24-in. diameter riser on Plates #1, #2, #3, #4, and #5 and one 15-in.-wide vertical path adjacent to scan path 1 on Plates #1, #2, #3, and #4. Vertical scans were conducted in the downward direction. Note that an additional scan which was competed in March 2007 and is shown on the right side of the graphic. Since the exact same area was rescanned in October 2007, the latest data is shown on the tank wall and the older data is shown on the side for reference. Three horizontal scans were performed in the LAI region on Plate #2 and one horizontal scan was performed in the LAI region on Plate #4. Figures 5.1 and 5.2 display the minimum readings taken in each 15-in.-wide by 12-in.-long area of the scan. The HAZs of vertical welds in Plates #1, #2, #3, #4, and #5 were examined and the HAZ in the horizontal weld between Plate #3 and Plate #4 was also examined. Weld area exams include approximately 5-in. on each side of the weld. Areas in the figures that show two measurements in the same box are the result of the vertical scan paths overlapping the horizontal scan paths. In the overlapping areas, both minimum readings from each vertical and horizontal scan paths are given. The gray highlighted areas indicate that the minimum wall thickness exceeded the reportable level of 10% of the nominal wall thickness. The green highlighted areas indicate that the minimum wall thickness exceeded the 10% level, but the UT Level III has characterized these as pit-like indications. None of these pit-like indications exceed the pitting criteria of 25% of nominal thickness and are therefore not reportable.

Figures 5.3 and 5.4 show the wall thickness examination results for the primary tank wall from Riser 89. The examination consisted of one vertical path beneath the centerline of the 24-in. diameter riser on Plates #1, #2, #3, #4, and #5 and one 15-in.-wide vertical path adjacent to scan path 1 on Plates #5. Vertical scans were conducted in the downward direction. Figures 5.3 and 5.4 display the minimum readings taken in each 15-in.-wide by 12-in.-long area of the scan. The gray highlighted areas indicate that the minimum wall thickness exceeded the reportable level of 10% of the nominal wall thickness. The 0.397-in. shown as a gray highlighted area exceeded the acceptance criteria of 20% and will require the tank owner to take special action. The green highlighted areas indicate that the minimum wall thickness exceeded the 10% level, but the UT Level III has characterized these as pit-like indications. None of these pit-like indications exceed the pitting criteria of 25% of nominal thickness and are therefore not reportable.

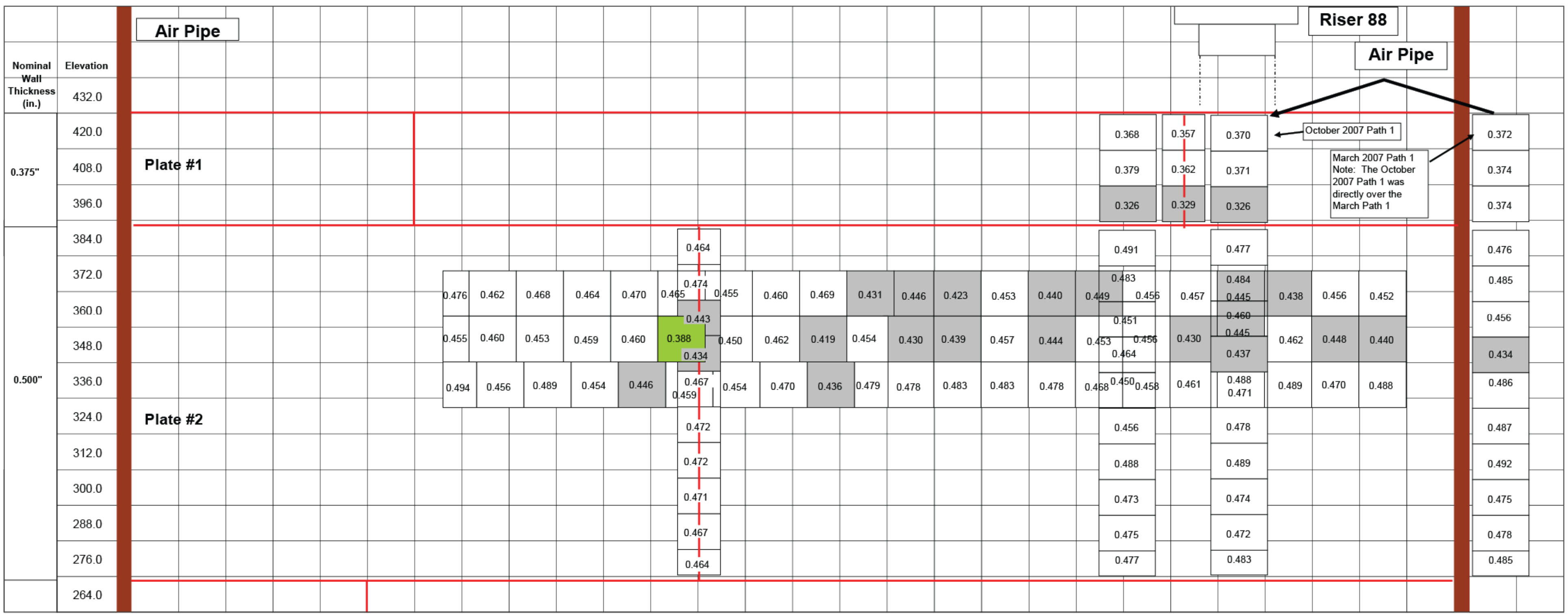


Figure 5.1. UT Data from Tank 241-AY-101 Primary Tank Riser 88

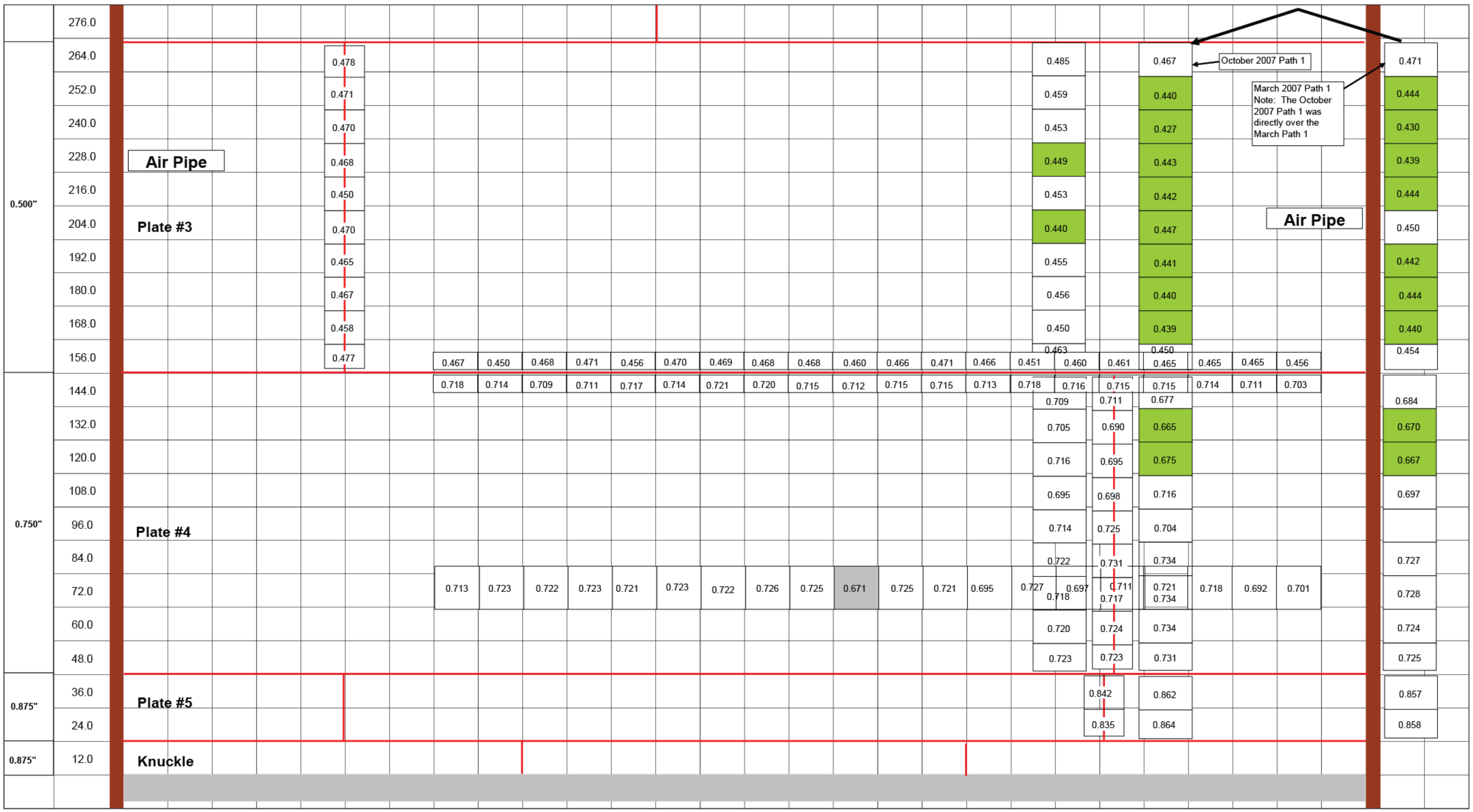


Figure 5.2. UT Data from Tank 241-AY-101 Primary Tank Riser 88 cont.

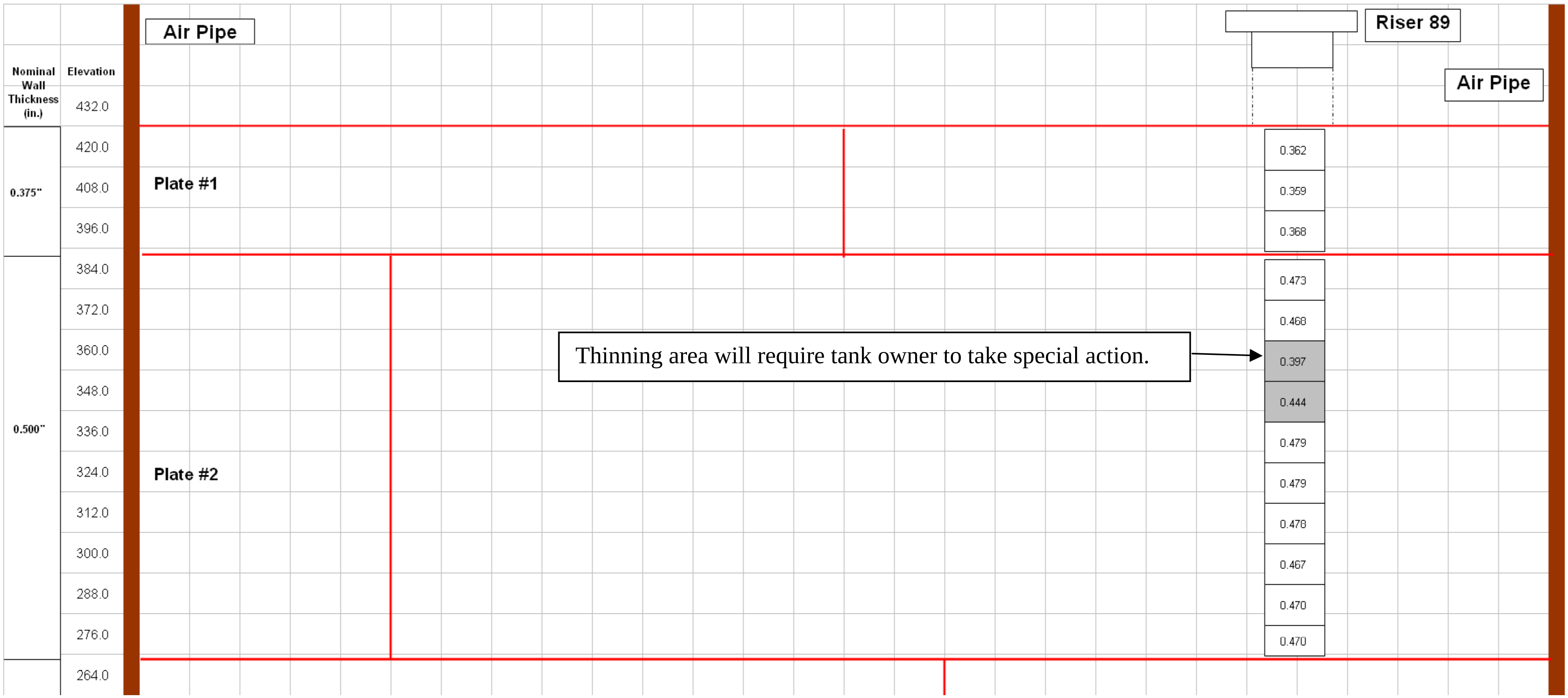


Figure 5.3. UT Data from Tank 241-AY-101 Primary Tank Riser 89

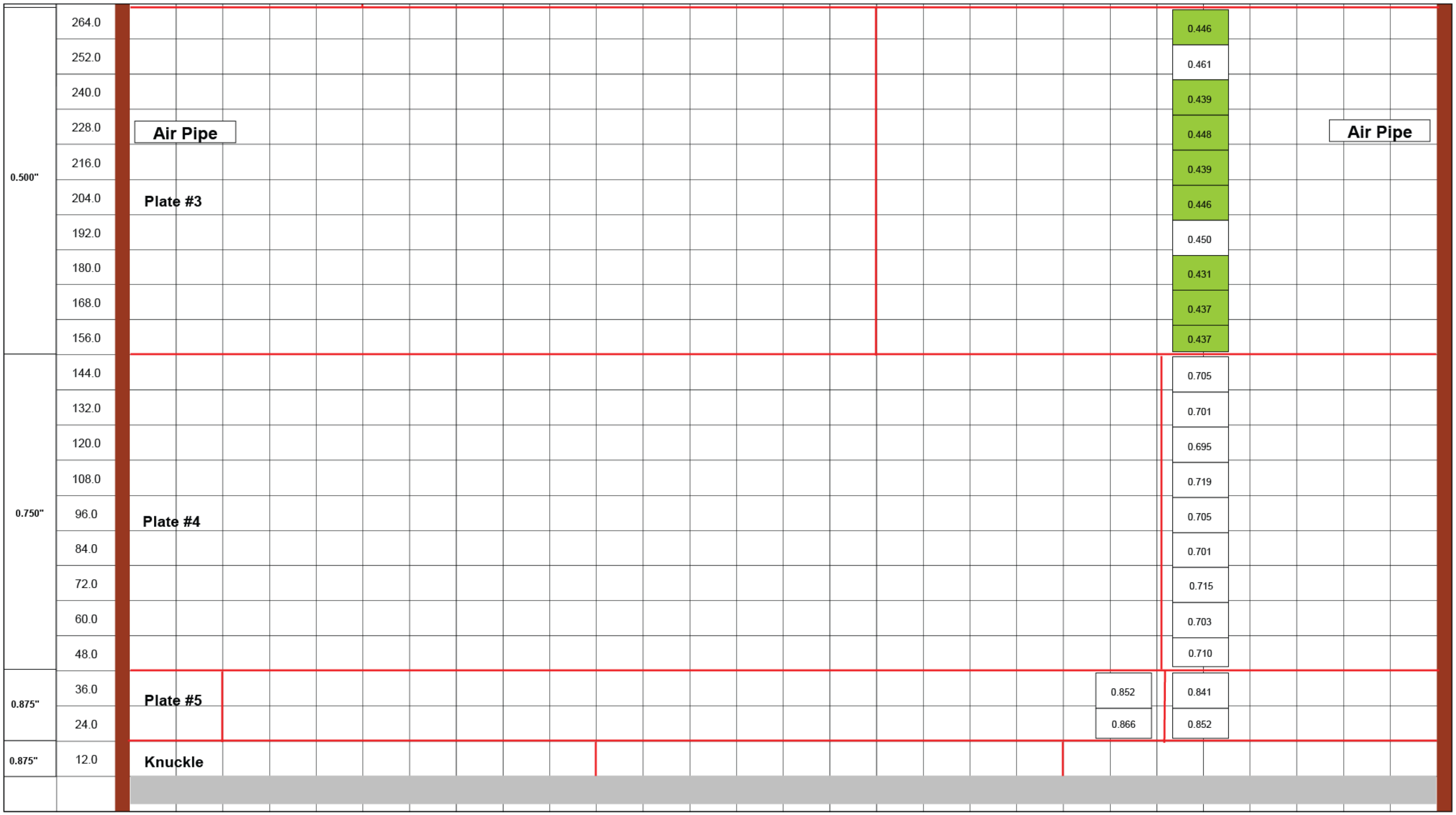


Figure 5.4. UT Data from Tank 241-AY-101 Primary Tank Riser 89 cont.

6.0 Extreme Value Analysis

The objective of this section of the report is to estimate a worst case wall condition with respect to thinning (see Weier, Anderson, 2005, for a description of the methodology). If remaining wall thickness were used to estimate such a worst case condition, wall thickness measurements from plates with differing nominal thicknesses could not be combined to fit a common distribution. Extreme value distribution fitting will benefit from having more measurements to fit, so if results can be reasonably combined across plates, this approach is preferred. For this reason, extreme value plate loss is computed instead of using remaining wall thickness. However if the original nominal values for tank wall thicknesses of 0.375-in., 0.500-in., 0.750-in., and 0.875-in. are used, negative losses are often obtained since remaining wall thickness still exceeds drawing nominal. For this reason UT image maximum values were used to provide a better estimate of original wall thickness than the drawing nominal values. This assumes some areas of plates are in near pristine condition. But of course such maximum values would not be used if they were less than the original drawing nominal thickness.

Note that measurement error and its variability has not been separated from the actual wall thickness variability here. Therefore when an extreme value is generated using the following methodologies, a worst case "measured wall thickness loss" is being estimated. That is, both the measurement variability and the actual wall thickness variability contribute to the overall uncertainty. When we obtain a worst case value, we are then deriving a worst case "measured result" that would be expected if the entire tank were inspected using UT methodology. This is a more extreme value than would be obtained estimating only a worst case wall condition; to do that, measurement error would have to be adequately characterized and removed from consideration. That has not yet been undertaken since appropriate data are not generally available to do so, but it is a topic of ongoing analyses.

For UT measurements used in this report, Tank 241-AY-101 had initial inspection performed in March 2007. This included a single path down each of two risers (88 and 89). For example, in a ~10-ft. plate (vertical dimension) for one riser, this generates about 9 maximum measured wall thickness values (it actually varies from plate to plate depending on plate dimensions). These values were considered for each riser/plate combination. The alternative "nominal thickness" selected in this manner then depended somewhat on the pattern of these maximum values, but generally it could be described as approximately the 90th percentile of such measurements. It was considered too extreme to use the largest of the 9 or so maximum values due to potential measurement error then grossly over-estimating the true nominal thickness. In this manner the Figure 6.1 maximum remaining thicknesses were obtained for Tank 241-AY-101.

AY-101	**Plate Estimated Nominal**				
	1	**2**	**3**	**4**	**5**
Riser 88	0.400	0.515	0.500	0.760	0.890
Riser 89	0.400	0.505	0.520	0.760	0.900

Figure 6.1. Table of Estimated Nominal Thickness from UT Maxima

In the March 2007 inspection, additional measurements were made along the LAI in Plate #2. Three horizontal paths about 20 feet long were measured generating about 20 images per path. But since the paths were "stacked" vertically, the minimum value for each linear foot from the three paths was used to represent the minimum wall thickness at that point of the LAI. The resulting values are the vertical set of black points at an elevation of about 355-in. subsequently given in Figure 6.2, which shows all measurements, including those from additional inspection performed in October 2007

In October 2007, the Riser 88 Path 1 was re-inspected, and then a second adjacent path was inspected. This second path did not include Plate #5. A second path was started for Riser 89, but only Plate 5 was completed. A potential second LAI in Plate #4 under Riser 88 was also inspected more thoroughly with a horizontal scan. It can be seen in Figure 6.2 as the vertical set of points at about elevation 69-in.

For both the March 2007 and October 2007 results, all the individual UT image minimum values for a plate/riser combination were then subtracted from the estimated maximum value for that plate/riser from Figure 6.1. In this manner estimated maximum wall thickness losses could be obtained for such a plate/riser combination, and then these were combined across the two risers, so a compiled set of such losses were available for the entire plate course. Note however that this gives a fairly minimal amount of data for distribution fitting as performed in this work.

Since two risers are used with the plate course wall losses combined over the risers, the riser variability within the tank does contribute to the overall variability in the results. For this reason an added one-sigma uncertainty, to accommodate riser variability if only a single riser were used, is not added here (see Weier, Anderson, Berman 2005).

The maximum estimated wall thickness loss per UT image obtained in the manner described above is shown for each path in Figure 6.2. For example consider the green curve in the figure and in the legend below the figure. The "Mar, 2007_88_1" label indicates the March 2007 inspection, Riser 88, Path 1. The top of the tank and Plate #1 are located on the right of the figure with the horizontal axis representing tank elevation. Numbered sections of the graphs represent the different plate courses.

The blue path on the figure is the re-inspection of the same Riser 88 Path 1; its label includes the "rep" designation indicating it constitutes replicated measurements. Recall that it was discussed how these measurements vary both due to measurement error and to the actual physical variability of tank wall thickness. Now if measurement error dominated, then the two replicate measurement paths on the figure would not look particularly like each other regardless of the physical condition of the wall. On the other hand, if the measurement paths tracked each other well, then minimal measurement error would be indicated with most of the variability more likely due to differing tank wall thickness. The latter case applies here since the two sets of path measurements track very closely to each other.

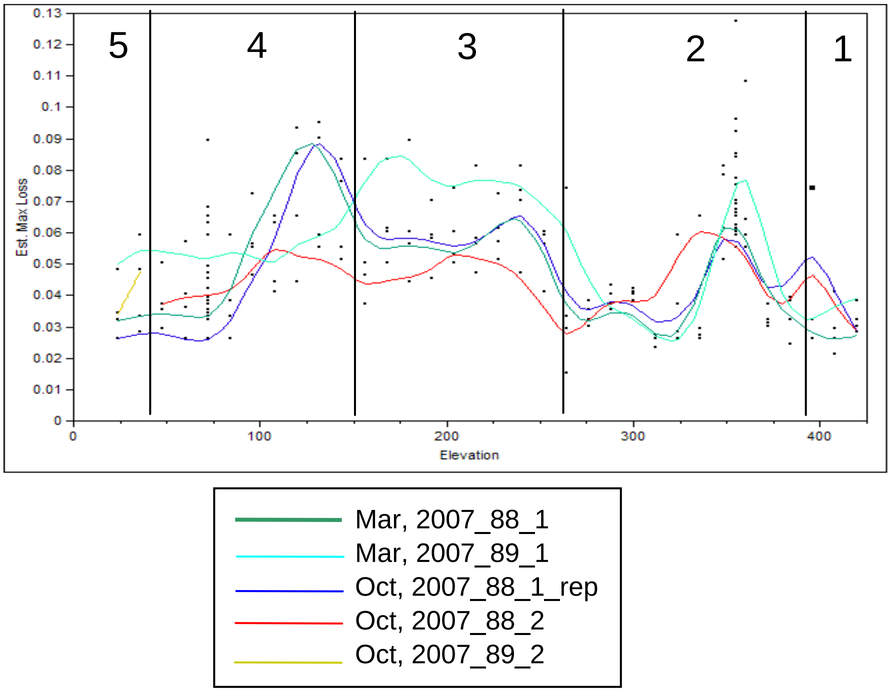


Figure 6.2. Estimated Maximum Wall Thickness Loss by Riser Path

The only exception is an outlying result from a wall condition indicated at the lowest elevation of Plate #1. The darkened point on the figure at this elevation represents a thinned wall on the October 2007 inspection that was not similarly observed in the March 2007 inspection. It is obviously quite a substantial outlier relative to the rest of Plate #1. But it does appear to be a legitimate measurement since the same result was attained from the second, and new, Riser 88 path as well; in fact that darkened point is actually two points, one from each path. And surprisingly these two points are on opposite sides of a vertical weld and therefore on different steel plates. Review of the March data does show similar thinning at that elevation in the weld inspection done at that point even though it didn't show up in the original Riser 88, Path 1.

Since so little measurement error is indicated between the two Riser 88, Path 1 inspections, we likely are getting true indications there of the varying wall thickness. Thus we really can't take credit for measuring more of the surface tank area, which appears to dominate the variability. If measurement error instead dominated, then we could take more credit for additional measurements characterizing this source of certainty. But we in fact re-inspected the same area, getting substantially the same results, so only one of the replicate paths is used in the extreme value analysis. Since the outlying value occurs in both new paths, the October 2007 Path 1 that includes it is used as well to see the combined impact of the two outlying values.

The greater corrosion in the original Plate #2 LAI was addressed in Weier, Anderson, Berman 2005 where LAI measurements were treated separately for extreme value estimation. That is again done here. Additional UT inspection was done along this LAI in the March 2007 inspection; it gives the elevated vertical line of points in Plate #2 on the figure at about elevation 355-in. Three horizontal paths about 20 feet long were measured generating about 20 images per path. But since the paths were "stacked" vertically, the minimum value for each linear foot from the three paths was used to represent the minimum wall thickness at that point horizontally on the LAI. Other than at those particular elevations within the new inspection paths, no additional Plate #2 LAI inspection was done in the October 2007 inspection.

As in the earlier work, Plate #2 areas, within and outside the LAI, are considered separately. In the October 2007 inspection of a second LAI in Plate #4, indicated by the vertical set of points at elevation 69-in., no difference is noted between this potential LAI and the remainder of the Plate #4 measurements. For this reason, this second LAI is not treated separately and is simply grouped with the other Plate #4 measurements. Subsequent references to the LAI in this report therefore refer only to the Plate #2 LAI.

While all points combined, except for the LAI, were considered as a single group with a single Weibull distribution fit, the results were not representative due to the considerable variability between the plates. For this reason the plates were instead grouped based on Figure 6.2. Plate #1 and #2 measurements (outside the LAI) were combined into one group since they tend to be considerably consistently less than those for the other plates; but note that the two new outlying values in Plate #1 will have considerable impact here. The analysis will be done with and without these two points to see their impact on results. Plates #3, #4, and #5 were combined into a second group. Plate #5 really could have gone into either grouping, but with so few measurements it has minimal impact. The LAI measurements formed the third group.

The histograms in Figure 6.3 show the wall thickness loss data for the indicated plate groupings. Three parameter Weibull distributions are fit to these histograms and are shown as the smooth curves. For Plates #1 & #2, the analysis is done with and without the two outlying values indicated by the bar on the right; the fitted curve shown is the distribution that results when those points are omitted. The curve with those two points included would reach considerably further to the right.

The total surface area of a plate course combination, and thus the number of 15-in. by 12-in. UT images needed to 100% inspect the entire plate course combination, is computed. The percentile of the distribution that then corresponds to the maximum expected loss among this many UT images, based on the distribution fit to the histogram, is considered as the estimated worst case loss. For the Plate #2 LAI, the linear feet inspected were used analogously with the required worst case percentile based on the total circumference of the tank at the LAI.

The number of measurements available and the quality of the fit of the Weibull distribution affect the uncertainty in the estimated Weibull parameters, and in turn, the uncertainty in the estimated worst case losses. Therefore 95% confidence bounds on the worst case values are also computed using these uncertainties.

The shift between the Figure 6.3 histograms indicates the basis for the plate groupings selected. Note however, that such shifts and differences between plates may result as much from the UT maxima that were used to estimate original nominal thicknesses as from wall thickness loss. It is indeed unfortunate that the true original thicknesses are not available.

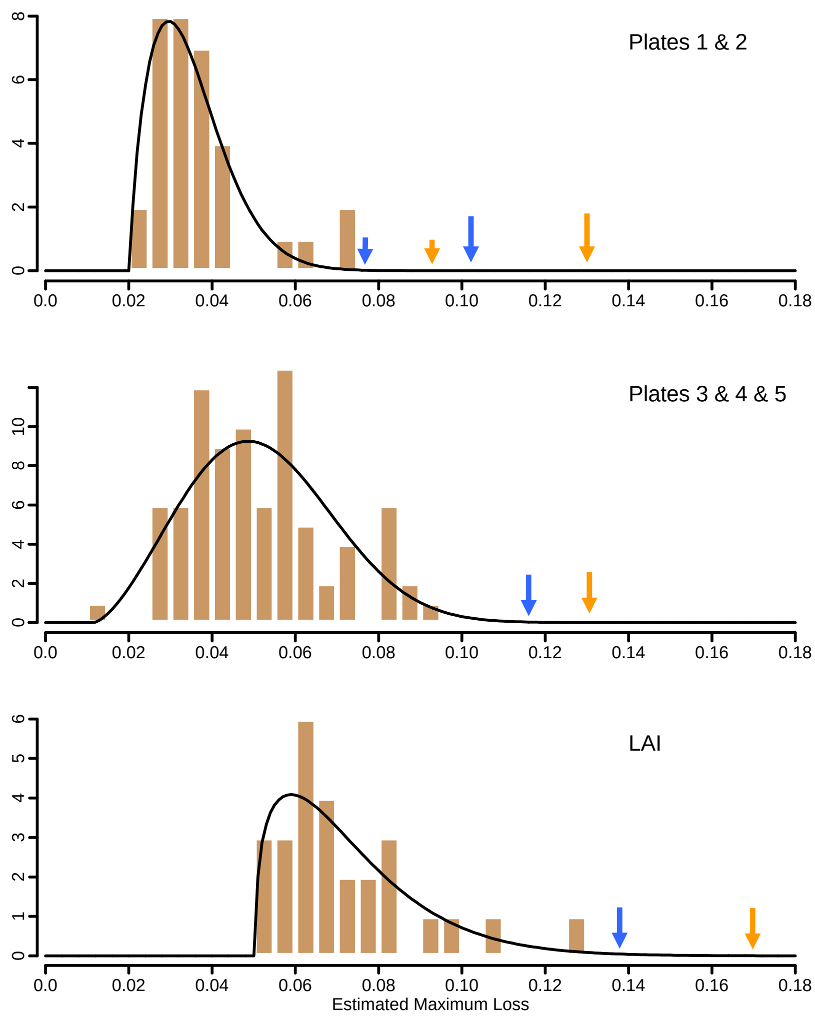


Figure 6.3. Weibull Distribution Fits to UT Maximum Wall Thickness Loss

The values indicated by the arrows on the histograms are the estimated worst case losses per plate course combination (colored blue and to the left) and their associated 95% confidence bounds (colored orange and to the right). For the Plate #1 & #2 combination, the short arrows are those associated with the indicated curve that results from deleting the two large outlying values. The taller arrows result if the curve were refit to include the two outliers. The corresponding extreme value estimates and bounds are given in the table shown in Figure 6.4. Included in the table are: 1) the number of measurements, 2) the estimated extreme value loss expected for the plate course combination around the entire circumference of the tank, and 3) the 95% confidence bound for the extreme loss.

AY-101 Extreme Values	Plates			
	1,2 Combined	3,4,5 Combined	LAI	1,2 Combined (no outliers)
Estimate	0.102	0.117	0.138	0.076
95% Bound	0.130	0.131	0.170	0.093
Measurements	33	83	27	31

Figure 6.4. Table of Tank 241-AY-101 Wall Thickness Extreme Value Loss Estimates and Bounds

The impact of the Plate #1 & #2 outliers can be seen both on Figure 6.3 and in the Figure 6.4 table. The Weibull distribution fit is quite reasonable without the outliers, and the resulting extreme value estimate and bound are reasonably tight giving the smallest worst case loss and bound respectively as 0.076-in. and 0.093-in. The greater variability, generally larger losses, and somewhat poorer fits of the Weibull distribution for Plates #1 & #2 with the outlying two values, for Plates #3, #4, & #5, and for the LAI result in the considerably larger estimated losses and bounds indicated in the table.

7.0 Conclusions

The results of the examination of Tank 241-AY-101 have been evaluated by Pacific Northwest National Laboratory personnel. The primary tank ultrasonic examination consisted of scans completed in March 2007 and October 2007. The scan sequence is as follows:

March 2007

- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 88.
- Heat-affected zone of five vertical welds and one horizontal weld from Riser 88.
- Three horizontal scan paths in the LAI region on Plate #2 from Riser 88.
- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 89.

October 2007

- One vertical 15-in.-wide scan path over the entire height of the tank directly under Riser 88 (this scan was done directly over the scan that was competed in March 2007). All data was considered when listing the minimum value for a plate.
- One vertical 15-in.-wide scan path adjacent to the scan under Riser 88 but only on Plates #1, #2, #3, and #4.
- One horizontal scan path in the LAI region on Plate #4 from Riser 88.
- One vertical 15-in.-wide scan path on Plate #5 adjacent to the region scanned from Riser 89 in March 2007.

All examinations were performed to detect any wall thinning, pitting, or cracking in the primary tank wall.

7.1 Primary Tank Wall Vertical Scan Paths

The two 15-in.-wide vertical scan paths under Riser 88 yielded the following results. The plates were examined for wall thinning, pitting, and cracks oriented vertically on the primary tank wall.

- The nominal thickness of Plate #1 is 0.375-in. Plate #1 results indicate two areas with minimum thickness of 0.326-in. and 0.326-in. that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #1.
- The nominal thickness of Plate #2 is 0.500-in. Plate #2 results indicate one area with minimum thickness of 0.434-in. exceeds the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #2.
- The nominal thickness of Plate #3 is 0.500-in. Plate #3 results indicate ten areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. However, these ten areas (with remaining ligament of 0.427-in., 0.439-in., 0.439-in., 0.440-in., 0.440-in., 0.440-in., 0.441-in., 0.442-in., 0.447-in., and 0.449-in.) were analyzed by the ultrasonic testing (UT) Level III and were considered pit-like and therefore do not exceed the reportable pitting level of 25% of the nominal thickness. No vertical crack-like indications were detected in Plate #3.

- The nominal thickness of Plate #4 is 0.750-in. Plate #4 results indicate two areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. However, these two areas (with remaining ligament of 0.665-in., and 0.667-in.) were analyzed by the Ultrasonic Level III and were considered pit-like and therefore do not exceed the reportable pitting level of 25% of the nominal thickness. No vertical crack-like indications were detected in Plate #4.
- The nominal thickness of Plate #5 is 0.875-in. and the minimum thickness in this area was 0.857-in. Plate #5 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #5.

The two 15-in.-wide vertical scan paths under Riser 89 yielded the following results. The plates were examined for wall thinning, pitting, and cracks oriented vertically on the primary tank wall.

- The nominal thickness of Plate #1 is 0.375-in. and the minimum thickness in this area was 0.359-in. Plate #1 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #1.
- The nominal thickness of Plate #2 is 0.500-in. Plate #2 results indicate two areas with minimum thickness of 0.397-in. and 0.444-in. that exceed the minimum thinning reportable level of 10% of the nominal thickness. The 0.397-in. area exceeded the acceptance criteria of 20% and will require the tank owner to take special action. No pitting or vertical crack-like indications were detected in Plate #2.
- The nominal thickness of Plate #3 is 0.500-in. Plate #3 results indicate eight areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. However, these eight areas (with remaining ligament of 0.431-in., 0.437-in., 0.437-in., 0.439-in., 0.439-in., 0.446-in., 0.446-in., and 0.448-in.) were analyzed by the Ultrasonic Level III and were considered pit-like and therefore do not exceed the reportable pitting level of 25% of the nominal thickness. No vertical crack-like indications were detected in Plate #3.
- The nominal thickness of Plate #4 is 0.750-in. and the minimum thickness in this area was 0.695-in. Plate #4 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #4.
- The nominal thickness of Plate #5 is 0.875-in. and the minimum thickness in this area was 0.841-in. Plate #5 results indicate no areas that exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or vertical crack-like indications were detected in Plate #5.

7.2 Primary Tank Wall Horizontal Scan Paths

Three 15-in.-wide horizontal scan paths were performed in the liquid-air interface region on Plate #2 from Riser 88. The plate was examined for wall thinning, pitting, and cracks oriented in a circumferential direction on the primary tank wall.

- LAI scan #1 results indicated seven areas (with remaining ligament of 0.423-in., 0.431-in., 0.438-in., 0.440-in., 0.445-in., 0.446-in., and 0.449-in. exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or circumferentially oriented crack-like indications were detected in LAI scan #1.

- LAI scan #2 results indicated nine areas (with remaining ligament of 0.388-in., 0.419-in., 0.430-in., 0.430-in., 0.439-in., 0.440-in., 0.444-in., 0.445-in., and 0.448-in. exceed the minimum thinning reportable level of 10% of the nominal thickness. However, one of these areas (0.388-in.) was analyzed by the Ultrasonic Level III and was considered pit-like and therefore does not exceed the reportable pitting level of 25% of the nominal thickness. No circumferentially oriented crack-like indications were detected in LAI scan #2.
- LAI scan #3 results indicated two areas (with remaining ligament of 0.436-in., and 0.446-in. exceed the minimum thinning reportable level of 10% of the nominal thickness. No pitting or circumferentially oriented crack-like indications were detected in LAI scan #3.

One 15-in.-wide horizontal scan path was performed in the liquid-air interface region on Plate #4 from Riser 88. The plate was examined for wall thinning and pitting on the primary tank wall.

- Liquid-air interface scan results indicated one area (with remaining ligament of 0.671-in.) that exceeded the minimum thinning reportable level of 10% of the nominal thickness. No pitting was detected in liquid-air interface scan on Plate #4.

7.3 Primary Tank Wall Weld Scan Paths

The HAZ of vertical welds in Plates #1, #2, #3, #4, and #5 from Riser 88 were examined for wall thinning, pitting and cracks oriented either perpendicular or parallel to the weld.

- The nominal thickness in Plate #1 is 0.375-in. Plate 1 indicates one area with a minimum thickness of 0.329-in. that exceeded the minimum thinning reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #1.
- The nominal thickness in Plate #2 is 0.500-in. Plate 2 indicates two areas with a minimum thickness of 0.434-in. and 0.443-in. that exceeded the minimum thinning reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #2.
- The nominal thickness in Plate #3 is 0.500-in. and the minimum thickness in this weld area was 0.450-in. There were no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #3.
- The nominal thickness in Plate #4 is 0.750-in. and the minimum thickness in this weld area was 0.690-in. There were no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #4.
- The nominal thickness in Plate #5 is 0.875-in. and the minimum thickness in this weld area was 0.835-in. There were no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas in Plate #5.

The HAZ of the horizontal weld between Plate #3 and Plate #4 from Riser 88 was examined for wall thinning, pitting and cracks oriented either perpendicular or parallel to the weld. The results indicated that the minimum thickness in the weld area with nominal thickness of 0.500-in. on Plate #3 was 0.450-in. The minimum thickness in the weld area with nominal thickness of 0.750-in. on Plate #4 was 0.703-in. There were no areas of wall thinning that exceeded the reportable level of 10% of the nominal thickness. No pitting or crack-like indications were detected in the weld areas on Plate #3 side or on Plate #4 side of the horizontal weld.

7.4 Extreme Value Analysis

Extreme value measured wall thickness losses were estimated. Since current remaining wall thickness typically still exceeds drawing nominal, thereby generating negative losses, UT image maximum values were instead used to determine estimated nominal wall thickness per plate/riser combination. These thicknesses tended to run up to about 0.020-in. greater than drawing nominal. They in turn were used with each UT image minimum value to determine estimated wall thickness losses, which then were combined for a plate course over the two risers (88 and 89). In converting to such losses, instead of using remaining wall thickness, measurements could potentially be combined for distribution fitting across plates of differing nominal thicknesses.

Measurements from March 2007, and October 2007, inspections were combined in these analyses. However, since a same Riser 88 path was measured during each inspection, with very minimal measurement differences resulting, only one of these replicate paths was used in the extreme value analysis. This was because the same tank wall area was measured, apparently with little measurement error relative to the actual variability in wall thickness. Such replicate data are very useful for characterization of measurement error, and its occasional generation is recommended. Better understanding of the measurement system performance is needed to determine if the values from different measurement campaigns, separated by several years, can be used in estimating corrosion rates.

Three parameter Weibull distributions were fit to suitable combinations of plate course measurements as well as to the measurements for a liquid air interface (LAI). If two Plate 1 outlying values are omitted from Plates 1&2 combined, a worst case <u>measured</u> wall thickness loss of 0.076-in. results. It might be expected if the entire surface area of the tank wall in these plates, but outside the LAI in Plate 2, were UT inspected. A 95% confidence bound for this case is computed based on the uncertainty in the Weibull parameters caused by the relatively minimal amounts of data for distribution fitting and the quality of the Weibull fit; this bound on measured wall thickness loss is 0.093-in. Note that such losses should be considered relative to the larger "estimated" nominal wall thicknesses and not relative to the drawing nominal.

The corresponding estimated worst case loss and bound when the two outlying values are included for Plates 1&2 (no LAI) are respectively 0.102-in. and 0.130-in.; for Plates 3, 4, &5, they are 0.117-in. and 0.131-in., and for the LAI, 0.138-in. and 0.170-in. These larger values result from generally larger measured losses, their greater variability, and rather poor Weibull distribution fits.

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