# Inspection Technology Advancements for Hanford Double Shell Tank Integrity Verification – 16150

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## ABSTRACT

The Hanford double-shell tanks (DSTs) were constructed in southeastern Washington State between 1968 and 1986 to store nuclear waste. Most of the tank waste came from the Hanford nuclear weapons program, which has been stopped for more than 25 years. The tanks will be needed for many years to come until suitable vitrification and permanent storage solutions are developed. These tanks are nominally 45 ft. deep from the dome peak to the floor. The inner tank is nominally 75 ft. dia. and the outer tank is nominally 80 ft. dia., leaving a 2.5 ft. annulus between the two side tank walls. The waste management program (under direction of Washington River Protection Solutions, WRPS) manages inspections of these DSTs from the annulus to justify their continued safe service and to avoid the high cost of new replacement tanks.

Over time, the Hanford Tank Farm contractors, currently WRPS, have increased their ultrasound inspections of these tanks. Pacific Northwest National Laboratory has worked with the Hanford Tank Farm contractors for more than 15 years to advance applicable tank nondestructive inspection technology for improved performance and cost reduction. Past, present, and planned technology advancements are addressed in this paper, including tank wall ultrasonic testing examination, extreme value statistical analysis, phased array for the tank wall, transmit/receive tandem synthetic aperture focusing technique knuckle examination, and electromagnetic acoustic transducer screening of the tank wall including mill-scale compensation.

## INTRODUCTION

The Hanford double-shell tanks (DSTs) serve an important role in managing nuclear weapons production legacy waste until ultimate disposition and burial. Although not particularly easy to access, the annulus between the two tanks with a 43.2 cm (17 in.) to 61 cm (24 in.) riser (depending on the tank) offers a viable inspection approach that allows access to a great deal of the primary tank's outer wall and the secondary tank's inner wall [1] (Fig. 1). The inspection program has evolved and continues to evolve to take advantage of advancements in inspection technology and to manage the inspection costs where justified [2].

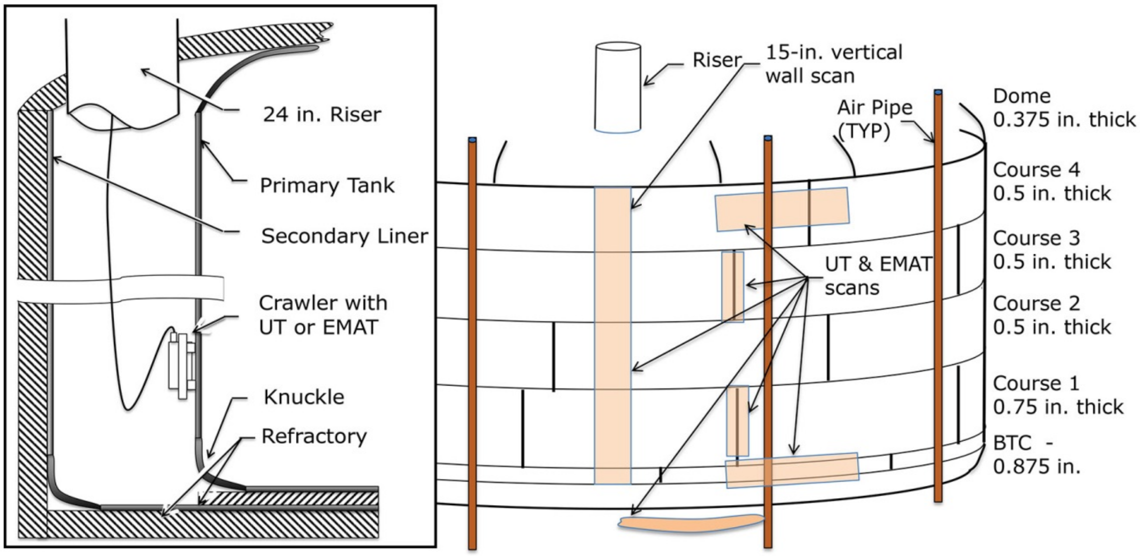


Fig. 1. Typical Scan Plan Regions in DST and (inset) Representation of UT/EMAT Crawler in Annulus between Primary and Secondary Tanks.

## MAGNETIC CRAWLERS, ZERO DEGREE, AND ANGLE BEAM UT MEASUREMENTS

The ultrasonic testing (UT) program began in 1997 with selection of remote crawler UT technology for examination of these tanks and a rigorous procedure and personnel qualification program consistent with American Society for Nondestructive Testing (ASNT) guidelines to ensure quality inspections. Over the years, equipment and techniques have been refined such that this is a relatively efficient and predictable operation. Typically, the inspections require 40 shifts with a crew of approximately 10 personnel including UT technicians plus health, safety, and support staff to perform the examination. The equipment is based on a FORCE P-Scan system that can accommodate various UT transducers. Prior to each inspection, scan plans are developed including specific transducers for each targeted area. Zero-degree 5 MHz units are used for corrosion and pitting [3]. For welds and the heat-affected zones, 45° and 60° angle beam 4 MHz transducers are used (Fig. 2). Target areas include regions near the access risers of a complete vertical strip encompassing all vertical course plates, inspection patches bridging vertical and horizontal welds, the air/liquid interface elevation on the wall, the knuckle area (as much as can be accessed from the vertical wall), and the secondary tank floor within the annulus. This general system has been used for more than 10 years; however, new equipment has been developed by the UT vendor (FORCE Technology’s PA 64 Phased Array Stack) and acquired by WRPS for phased array examinations. Qualifications are planned to support this upgrade. This is expected to improve the imaging resolution, inspection speed, volume coverage, and overall data quality when qualified and fully implemented.

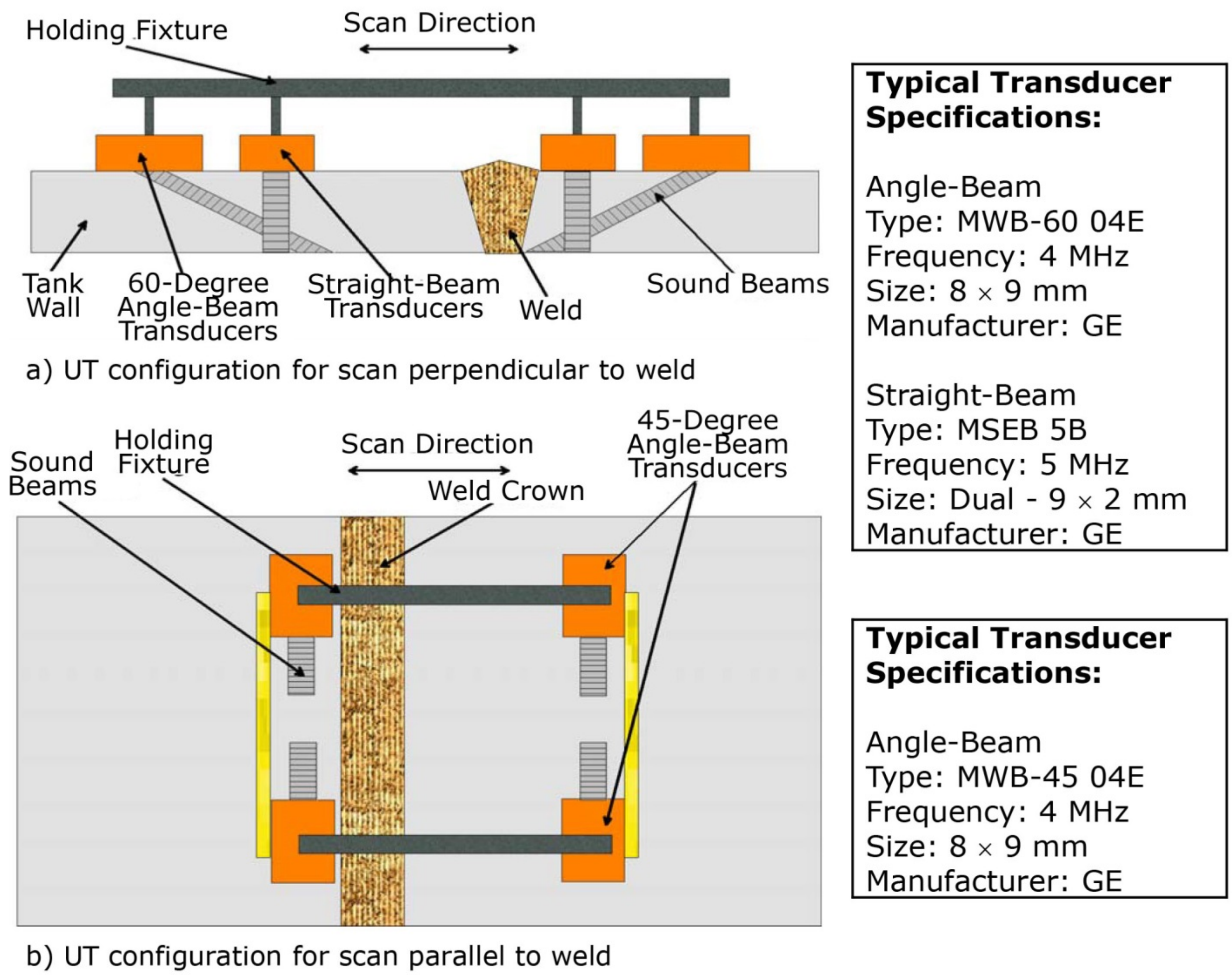


Fig. 2. Transducer Configuration for Examination of Weld Zone in Primary Tank Wall for Scans Perpendicular to and Parallel to the Weld.

Multiple examinations (approximately every 10 years) of these tanks coupled with careful scrutiny of data trends revealed some variation and even wall thickening from one examination to the next. This prompted a detailed investigation of factors influencing the measurements [4]. The conclusion was that the UT precision is repeatable to about ± 5 mills (0.13 mm). Liftoff in one scanner direction can cause over-estimation of wall thickness based on the raw data, but multiple-echo analysis approaches could minimize such errors. Temperature variations between the tank wall and the calibration block can also have a small effect on measurements and should be controlled to no more than 25°F (14°C). Adjustment of the acquisition and analysis procedure is anticipated for the next procedure and qualification revision.

## STATISTICAL EXTREME VALUE ANALYSIS

The limited data from the remote crawlers' wall examinations has been subjected to a statistical extreme value analysis to justify the full tank integrity based on a very limited (but more cost-effective) examination [3, 5]. Based on the UT measured data, the nominal plate thicknesses are assessed. Note that these values are usually slightly more than the original manufacturer's specified minimum wall thickness. Moreover, the typical plate thickness profile is a curved bow profile with the thickest portion in the middle and the thinnest portion at the edges consistent with typical plate roll-fabrication methods. This nominal profile is fit to the average measurements and then actual measured thickness values are subtracted from this nominal value to yield an improved estimate of wall thinning both in the measured area and extrapolated to the extreme tails of the histogram to encompass the entire tank. This approach limits the total amount of time, dose, and dollars required to acquire data while providing a scientific basis to justify expectation of acceptable remaining tank wall over the entire tank. A representative histogram by tank-wall course is shown in Fig. 3.

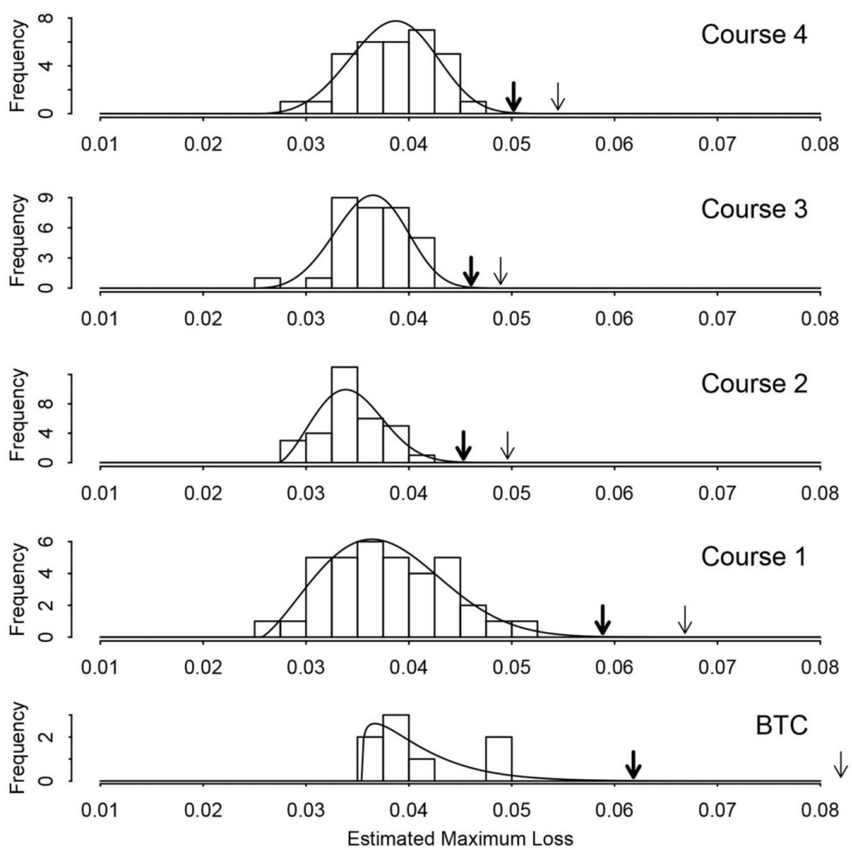


Fig. 3. Histogram Distribution of Wall Thinning by Course from Bottom to Top of Tank Wall.

## REMOTE T-SAFT INSPECTION OF THE TANK KNUCKLES

The more complex geometry and thicker walls of the tank knuckle cannot easily be examined with a simple zero-degree thickness gage as discussed above. The curved geometry of the upper portion of the knuckle would require adaptation of the scanner to hold a transducer against the surface, and access is blocked as the knuckle transitions to the horizontal floor by the refractory layer separating the primary and secondary tank bottoms (Fig. 4). A tandem synthetic aperture focusing technique (T-SAFT) was developed and qualified for this examination to project a 70° 3.5-MHz shear wave from the vertical tank wall more than 1 m around the curved knuckle and part way into the flat portion of the tank bottom [6]. The SAFT signal processing approach uses the known position of the transducers coupled with the well-characterized beam-spread transducer behavior to coherently sum and effectively average and sharpen the blurred reflector images, thereby facilitating detection and sizing inspection capability. The system was qualified to reliably detect and size flaws as small as 20% by 25 mm sawcuts transverse to the UT beam path up to 1 m away from the transducers. The system was adapted for remote delivery using an adaptation of the crawler discussed above for the wall thickness measurement, and an ASNT-compliant blind qualification program was developed to certify personnel for detection and sizing in this regions.

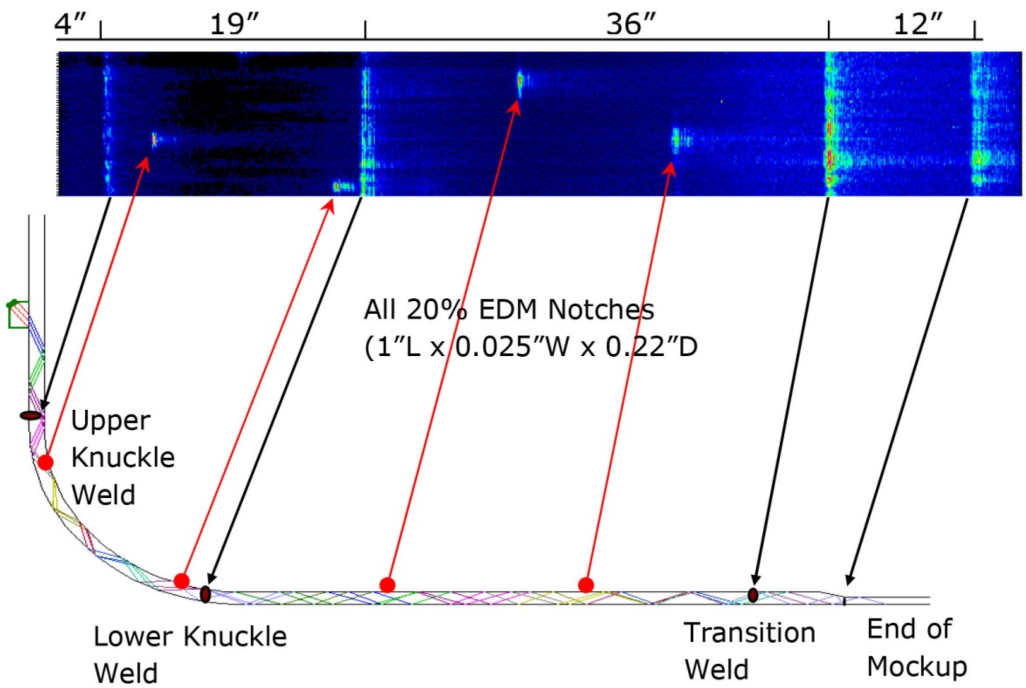


Fig. 4. T-SAFT Image of 70° Shear Wave Imaging the Entire Knuckle and Beyond Covering more than 1 m from the Transducer Location.

## ELECTROMAGNETIC ACOUSTIC TECHNIQUE

Electromagnetic acoustic transducer (EMAT) technology leverages the magnetostrictive forces generated in accordance with Lorenz laws within the steel when eddy-currents interact with a strong magnetic field (Fig. 5). When configured as a transmit/receive EMAT (T/R EMAT), the transmitter and receiver are separated by approximately 250 mm. The acoustic wave traverses the steel beneath the two transducers and any reduction in amplitude would be indicative of an acoustic reflector in the sound-path. This enables inspection of a wide swath of material with a single degree-of-freedom scan (no raster scan required). Overall scan speeds are increased more than 10-fold compared to conventional UT. This approach is being developed as a screening approach to reduce inspection costs and enable the conventional UT to focus on the most interesting areas within the screened area.

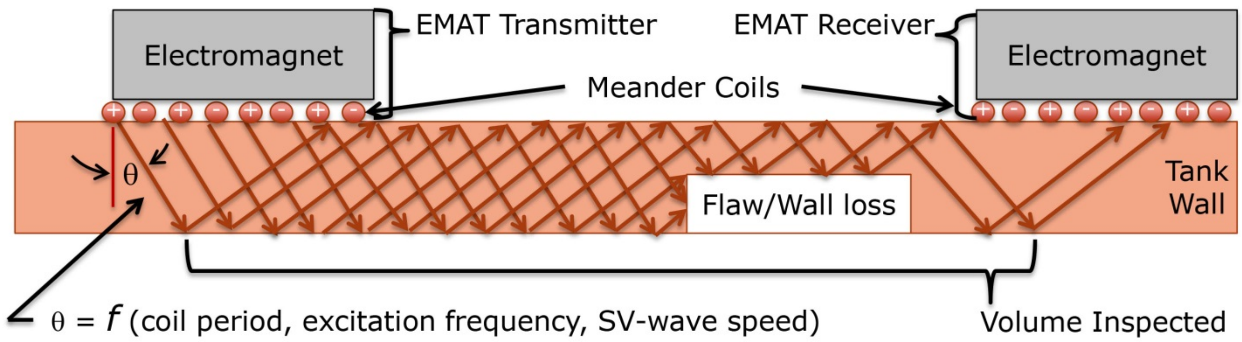


Fig. 5. With the T/R EMAT Concept for SV Wave Generation, Flaws Alter and Attenuate Receive Signal.

The EMAT transmitter generates an acoustic wave when the meander coil between the steel and the magnet is pulsed, thereby generating eddy currents within the steel that interact with the magnetic field of a permanent magnet or electromagnet. The direction of the acoustic wave is a function of the coil spacing, the pulse frequency, and the speed of sound within the material. When the UT wave arrives below the receive EMAT, the reciprocal behavior is observed. The motion of the steel within the magnetic field produces a current that can be sensed by the receive coils between the steel and the magnet. Such a transmit-receive approach allows rapid screening of the tank wall to quickly detect any indication of pitting, transverse cracking, or wall thinning that may require a more thorough and more accurate wall thickness measurement.

An EMAT qualification was performed on relatively clean carbon steel plates and good sensitivity to wall-thinning as small as 10% and pits as shallow as 25% through-wall was demonstrated [7]. The initial in-tank deployment, however, showed noise levels quite similar to or in some cases above the signal changes associated with target flaws of interest where corroborating UT data showed no thinning, pitting, or cracks [8]. Close examination of the EMAT performance on different mockup plates plus careful review of video of the tank walls suggested the cause of the noise to be a combination of FeO, $Fe_2O_3$, and $Fe_3O_4$ commonly referred to as mill-scale. This irregular splotchy mill-scale layer has a high permeability that interacts with the magnetic field and affects the amplitude of the EMAT transmit and receive signal.

Based on understanding of the noise cause, several mill-scale compensation approaches were developed and assessed. The preferred approach was an envelope correlation method whereby a reference signal from an unflawed plate of nominally the same thickness as the plate to be inspected is correlated with the scanned measured waveforms [8]. A drop in the correlation coefficient is indicative of a waveform distortion that may be associated with wall loss, thinning, cracks, or other anomalies. Without this compensation approach, neither wall thinning nor pit surrogate flaws could be reliably detected. After compensation, however, wall thinning down to 10% through wall (TW) and pitting to 25%TW were sometimes detectable (Fig. 6). The location of the flaws, however, (closer to the transmit or closer to the receive transducer) and the specific character of the mill-scale influenced the signal. On three separate runs of the mockup shown in Fig. 7—first with the surrogates centered between the transmit and receive transducer, then with the surrogates 50 mm closer to the transmit transducer, then with the surrogates 50 mm closer to the receive transducer—all wall thinning indications were detected. Pit indications down to 25% could be seen in the data, but only the 50% pit indication crossed the detection threshold for all three runs.

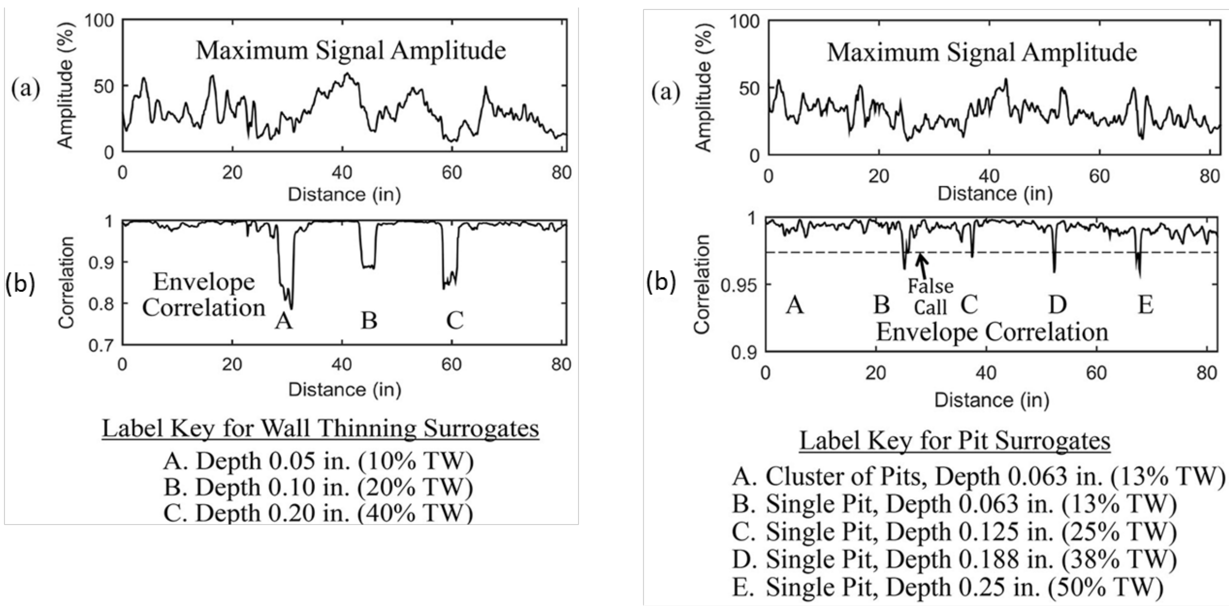


Fig. 6. Uncompensated (top) and Envelope Correlation Compensated (bottom) Responses for Wall-Thinning (left) and Pit (right) Surrogate Flaws.

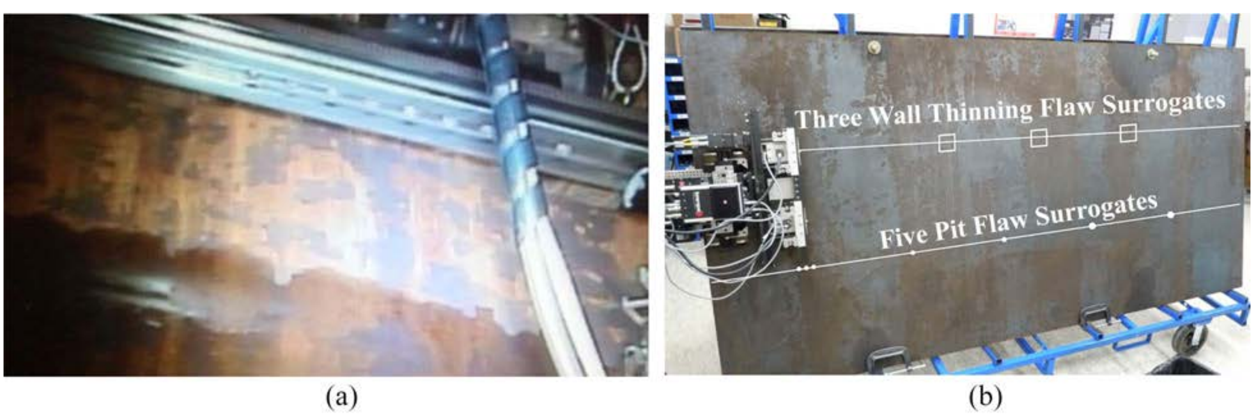


Fig. 7. (a) Splotchy Mill-Scale Observed on the Tank Wall and (b) also Observed on Large Test Plates. Note the white drawn-in wall thinning and pit surrogate flaws that were machined into the back of this plate.

The EMAT compensation approach was also applied to data taken in the tank (Fig. 8). Although there were no large damage indications, the conventional UT inspection indicated two distinct regions in Course 3: a region of uniform thickness and a region where a cluster of pitting precursors was apparently present. Note how well the algorithm response compared to the conventional UT data. The envelope correlation technique was stable over the region of uniform thickness and sensitive to what appears to be the cluster of pitting precursors.

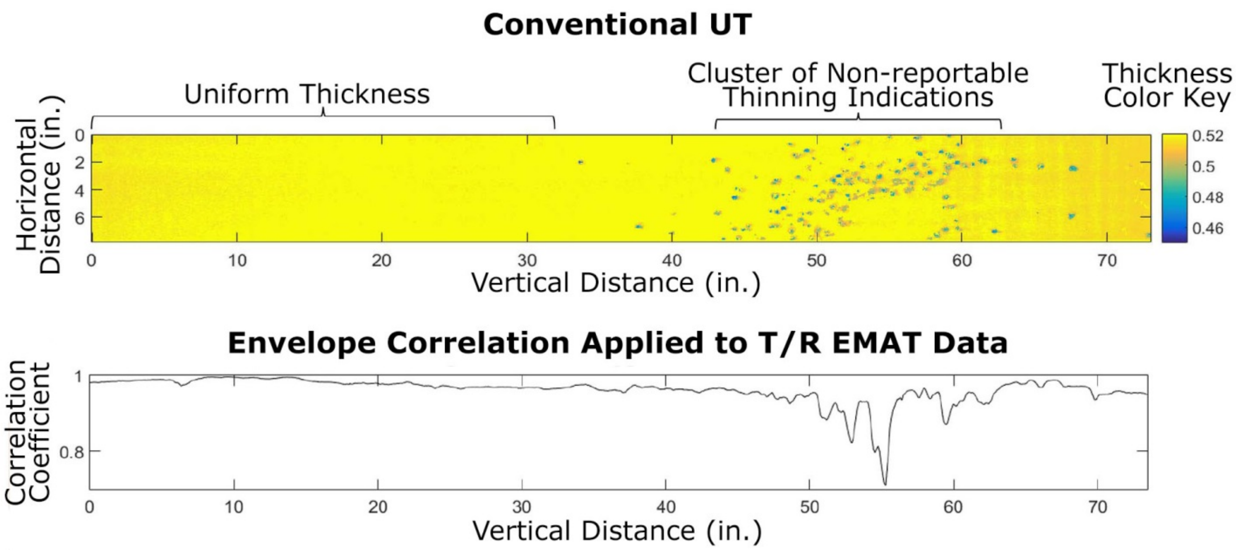


Fig. 8. Conventional UT (top) and the T/R EMAT with Envelope Correlation Compensation (bottom) Applied to Identical Scan Regions of One of the DST Tanks.

The T/R EMAT screening technique does not ensure remaining wall thicknesses but can serve to indicate where follow-up UT scanning should be directed. Because this approach allows the scan to be conducted more than 10 times as fast as the traditional UT scan, the overall result allows more tank wall to be checked; and there is a higher assurance that UT to confirm wall thickness or detect cracks, pits, and thinning is being performed on the most interesting areas among the total screened area. In addition to traditional laboratory qualifications of inspection sensitivity to known flaw surrogates, the overall qualification of the screening EMAT is planned based on several tank examinations where both traditional UT and T/R EMAT are performed. It is expected that the EMAT screening approach will be confirmed to be sensitive enough to real flaws and degradation, thereby supporting revising and optimizing the actual tank scan sequences to take advantage of the EMAT screening methodology [9]. This is an ongoing development program.

## CONCLUSIONS

PNNL has worked with Hanford's Tank Farm contractor, currently WRPS, for more than 15 years to advance applicable tank nondestructive inspection technology for improved performance and cost reduction. Technologies include traditional UT with advanced data analysis and data management approaches that have been and are continuing to be applied to the tank inspections that are repeated approximately every 10 years. In addition, advanced approaches have been developed; demonstrated; and, in some cases, fully qualified for use to improve performance, coverage, and control cost. These techniques include 1) T-SAFT technology for tank knuckle inspection beyond the reach of traditional UT methods and 2) EMAT rapid screening technology to focus the traditional UT examinations on regions that are most likely to have indications of interest. Plans for continued work include 1) qualification and implementation of phased array techniques to improve visualization, coverage, and efficiency of the tank wall examination; and 2) optimization of the mill-scale compensation for EMAT screening on all plate thicknesses.

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