Testing and Recommended Practices to Improve Nurse Tank Safety, Phase III

This brief documents findings from the third phase of a multi-year research effort related to nurse tank safety. Reports detailing findings from the first two phases of this research were published in 2013. Phase III of this research (this study) was designed to:

- Re-examine ultrasonic indications of stress corrosion cracks (SCCs) and other weld discontinuities that were previously found during the Phase II study.
- Measure the tank wall thickness of the examined pressure vessels.

Phase II of this research was conducted in 2012. Phase III was conducted in 2015.

BACKGROUND

Anhydrous ammonia (NH_3), used in agriculture as a nitrogen-rich fertilizer, is a hazardous material that may cause chemical burns, frostbite, and suffocation. Steel nurse tanks, which are used to transport this fertilizer locally on public roads and farm fields, hold NH_3 at multiple times atmospheric pressure. Tank failures can release this pressure with catastrophic force, additionally posing the risk of impact injury to workers and bystanders. Tank failures can be caused by a variety of factors, including misuse. In this study, researchers focused on the initiation and growth of SCCs. Stress corrosion cracking occurs by a process involving a corrosive material, such as NH_3, and steel with residual or mechanically applied tensile stresses. Greater stresses mean more stress corrosion cracking is likely to occur.

STUDY APPROACH

In Phase III, researchers re-examined 411 nurse tanks (previously studied in Phase II) using single-beam ultrasonic nondestructive testing methods. Student examiners received more extensive training than those in Phase II. Thus, the study was better able to make judgements about whether parallel indications were likely SCC or likely caused by weld geometry issues.

The inspections used the same basic ultrasonic testing instruments used in the Phase II study, but the probes that were attached to the instruments were upgraded. The ultrasound equipment was configured the same way in both studies to keep SCC detection thresholds the same.

A typical field inspection involved locating and inspecting a tank that was part of the Phase II study and recording the Phase III results for comparison. This study included recording the tank thickness measurements. If any new indications were located and determined to be relevant, they were also recorded.

STUDY FINDINGS

Table 1 shows key statistics from the Phase III study.

Table 1. Statistics of Phase III (2015) Study.

Topic	Statistics
Indication count for Phase III study	• Total indications found in Phase III study: 2,755 • 1,148 new indications were found. – 1,039 found in tanks manufactured beginning in 1999 and later without post-weld heat treatment (PWHT) • 1,719 indications from Phase II either not located in Phase III or eliminated as likely non-SCC indications.
Previous indications/ indication growth	• 1,174 indications showed essentially no change in length (±0.25-inch change). • 433 indications were recorded as existing indications that had grown – 422 were in tanks manufactured beginning in 1999 and later without PWHT
Indication locations	• Axial welds in shell region: 40 • Leg welds: 3 (likely not actually SCC) • Circumferential welds: 2,712 – 2,691 were in head-to-shell circumferential welds – 21 were found in shell-to-shell circumferential welds.
Tank Thickness	• 10 tanks (2.4 percent of the 411 examined) were determined to be within 0.01 inch of the Nurse Tank Inspection Program (NTIP) required minimum thickness. • 10 other tanks were below the required minimum in at least one location.

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The average change in lengths of indications clearly identified in Phases II and III seemed to indicate an impossible average decrease of −0.12 inches. The explanation is that the equipment used in both phases could have measurement errors of up to 0.25 inches for each indication. (The width of the probes in both studies were 0.5 inches.) Thus, a final difference of ±0.12 inches on average is well within the noise range of the ability to estimate indication length with that technology.

The higher number of indications in the head-to-shell circumferential welds (2,691 compared to only 40 in axial welds in the shell region, or 21 in shell-to-shell welds) is due to the shape of the head constraining the steel of the welded cylinder from expanding/contracting during welding. That creates considerably more post-welding residual stress than occurs in welding that is entirely within the shell.

The perpendicular indication growth rates appear to be small, but growth rate of existing perpendicular indications is only one important measure for indications. Of the 1,148 new indications found, 1,039 (90.5 percent) were found in tanks manufactured in 1999 or later, the year when post-weld heat treatment (PWHT) was no longer performed by any nurse tank manufacturer. Plus, the 1997 American Society of Mechanical Engineers (ASME) change in guidance to allow thinner steel was also in effect. Further, of the 433 indications analyzed that did show growth, 422 (97.5 percent) were found in tanks manufactured in 1999 or later with no PWHT. The testing technology could not measure the possibly more dangerous parallel indications in the weld zone.

Most tanks still measured above the thickness listed on their ASME data plates. If a tank has a legible ASME data plate, it is currently not subject to periodic testing; however, if 10 of these 411 re-examined tanks (2.4 percent) were tested, they would not meet the thickness requirements.

RECOMMENDATIONS

The research findings suggest that lack of PWHT and possibly thinner steel in tank shells contribute to decreased nurse tank safety. Hoop stress in a tank increases as wall thickness decreases, and more stress produces more SCCs. Regardless of changes in thickness regulation, it is critical that full-body PWHT of tanks be required to remove residual stresses introduced during the manufacturing and welding processes. This is even more critical if manufacturers continue to be permitted to produce nurse tanks with thinner steel shells.

The current method (also used in the Phase II study) of recording indication location is not precise enough to reliably locate the indications in follow-up non-destructive examination (NDE) tests. A more precise two- or three-point measurement system to record location would be useful.

It is recommended that all future NDE work in this area use trained and supervised examiners to reduce the number of potential SCC indications that can be clearly attributed to weld design and geometry.

Phased-array ultrasonic testing (PAUT) represents a substantial technological increase in resolution performance and discriminatory capabilities over the cheaper, simple single-beam technology used in the Phase II and Phase III studies. PAUT would be able to determine extent (depth) of indication and may be able to discriminate between a long parallel indication and weld discontinuities. A study to determine the applicability and performance of PAUT for use in imaging of parallel indications located in the heat-affected zone of a weld is highly recommended.

Acoustic emission (AE) monitoring has the potential to locate cracks if they form or grow due to over-pressurization in pressure testing. If coupled with PAUT, the severity of these crack formations or expansions could be determined. (Both AE and phased-array techniques were mentioned by the Phase II report as recommendations for future study.) AE and PAUT would have applicability for testing for all pressurized cargo tanks requiring pressure testing, not simply nurse tanks. Such a combined study could also result in significant improvements in the location and monitoring of possible crack growth.

If PAUT is found to be an effective NDE technology, in the future, PAUT could allow a tank to be tested while full of product.

To read the complete report, please visit: [insert link to published report once available.]