Study of Improving Nurse Tank Safety

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Nurse Tank Safety Project

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U.S. Department of Transportation

Pipeline and Hazardous Materials Safety Administration

Virginia Tech
TRANSPORTATION INSTITUTE

Nurse Tank Safety Project

Phase 1 Tasks: Dec., 2008 - May, 2011

- Literature review of prior research
- Examine 20 used tanks: ultrasound, metallography, tensile tests, neutron diffraction, glow discharge spectroscopy, and fluorescent dye penetrant
- Stress corrosion crack growth rate study
  (56 specimens, liquid & vapor ammonia, 4 months)
- Computer modeling , best practices recommendations

Nurse Tank Safety Project

Phase 2: Oct., 2010 - Aug., 2013

- Pinhole leaks
- Stress-relief annealing
- Ultrasound survey of 500+ in-service tanks
- Stress corrosion crack growth rate study (200 specimens, liquid & vapor, 3 conditions, 12 months)
- Computer modeling , best practices recommendations

The Problem

Photo courtesy of Terry Pollard

Many tanks in use are 40+ years old. Anhydrous ammonia is a corrosive that can cause *stress corrosion cracking* in steel.

If cracks become large enough, the pressurized tank can burst. Several ruptures have occurred, causing injuries and one death from inhalation of the ammonia.

Pinhole Leaks Task Findings

A very small fraction of the U.S. nurse tank fleet develops leaks in welds that slowly vent NH_3 into the atmosphere.

Objectives:
This study sought to answer two questions:

1. What causes pinhole leaks?
2. Can pinhole leaks lead to sudden, large NH_3 releases?

Pinhole Conclusions

1. What causes pinhole leaks?

   Weld porosity.

2. Can pinhole leaks lead to sudden, large NH_3 releases?

   Very Unlikely. Pinhole flaw sizes are much smaller than critical flaw sizes in these steels, even when the steel is chilled by rapidly expanding NH_3. There was no indication of pinholes being connected to crack networks.

The Phase II Study

Three 450-550 gallon tanks were manufactured or modified to have manways. Each tank contained:

- 33 samples in the liquid space
- 33 samples in the vapor space

Stress intensity distribution was the same for each set of 33 samples. Stresses varied from 45 to 95 MPa√m.

The Phase II Study

Three different anhydrous ammonia environments in tanks were studied to see if they influenced SCC:

1. Anhydrous ammonia (0.2% water)
2. Anhydrous ammonia (0.2% water) plus N-Serve
3. Vacuum pumped tank to -15psi and backfilled with 99.95% pure N_2 before being filled with anhydrous ammonia (0.2% water)

SCC Findings

- As predicted by theory, samples in vapor spaces without water tend to have more cracks and worse cracking than samples in liquid spaces with water.
- The N_2 purge did not lower the incidence of cracking.
- N-Serve additions did not cause more cracking.
- N-Serve caused more corrosion and presumably some tank wall thinning.
- Safe lifetimes can be calculated.
- Recommended inspection times can be calculated.

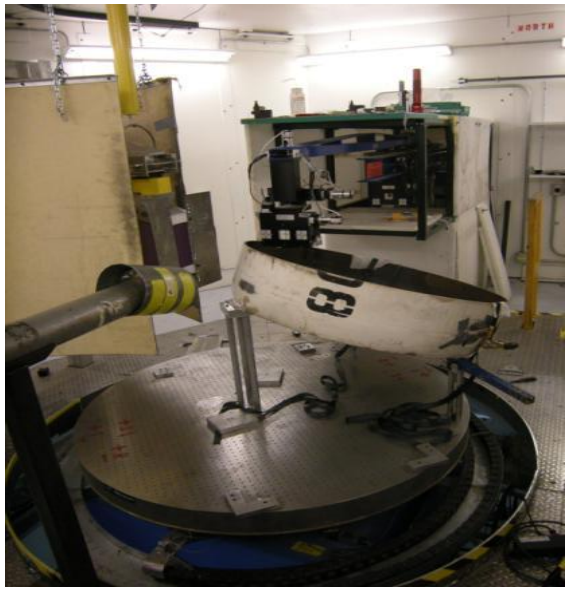
Stress Relief Annealing Study: Calculating Residual Stress

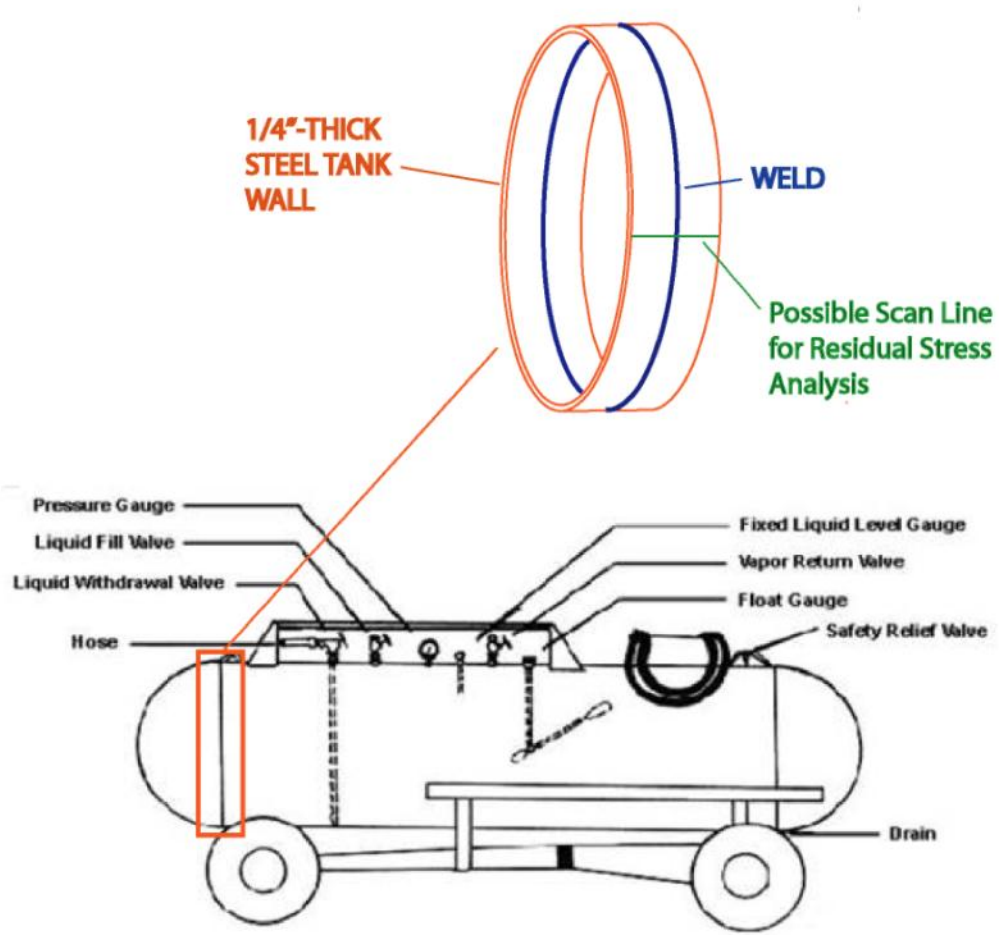
- Most important stress for SCC is stress near the inner tank wall surface
- Prior to this project the inner tank wall stress had never been measured in a nurse tank
- Residual stress (s) measured by measuring strain (e). s = Elastic modulus(e)
- Accuracy depends on measuring strain in three orientations

From Phase 1 of the Project

Findings:

- Residual stresses around unannealed welds were found to be very high.





Residual Stress Conclusions

FINDING:

Residual stress in unannealed nurse tanks is very high – near the yield point of steel.

This high residual stress results from welding.

IMPLICATION:

Residual stress can cause cracks to initiate and grow.

FINDING:

Residual stresses are much lower (30-66%) in the example strain-relieved tank.

IMPLICATION:

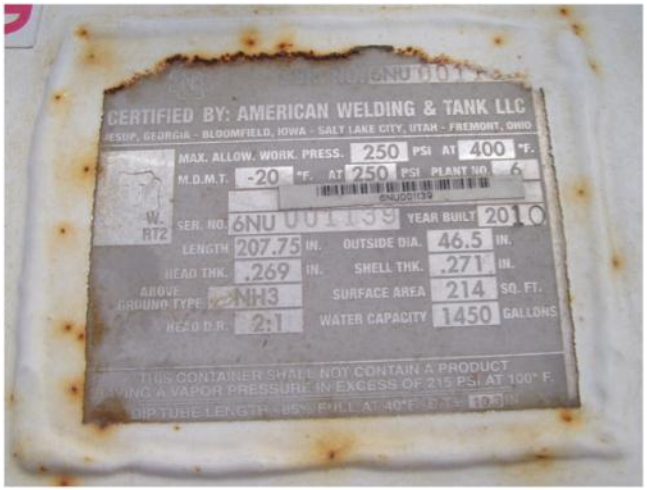
Fully strain relieved tanks should have fewer cracks.

Survey of 532 In-Service Nurse Tanks

The survey was conducted in summer, 2012 by ISU undergraduate students trained in NDE methods. The goal was to acquire as much data as possible on distribution of stress corrosion cracking in nurse tanks.

From May through August 532 tanks were surveyed using side-angle ultrasonic inspection methods.

Typical Survey



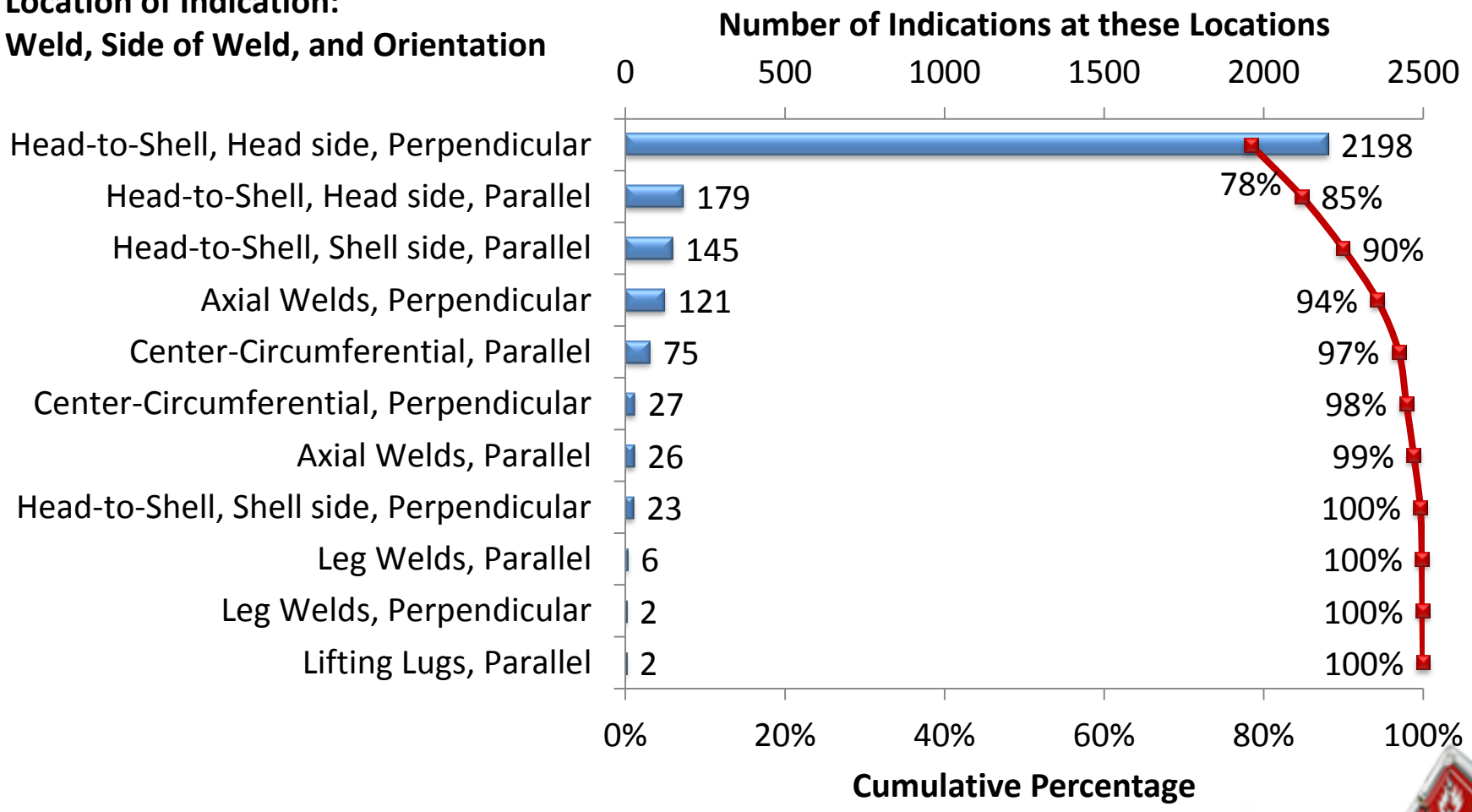
Only tanks bearing legible data plates were surveyed.

1000 gal > 50’ of welds > two orientations > both sides = 200’ of inspection. (264’ for 1450 gal)

One inspector could typically examine a tank in 2-4 hours (depending upon number of indications)

Drawing Conclusions

Location of Indication:
Weld, Side of Weld, and Orientation



Conclusions

- Pinhole leaks in nurse tanks result from porosity and wormholes that form when wet, rusted, or contaminated surfaces are welded.
- Pinhole leaks in nurse tanks are much smaller than the critical crack size and don't connect with other cracks, so catastrophic tank rupture is unlikely.
- SCC samples tested in the vapor space above the liquid formed more cracks and longer cracks than SCC samples immersed in liquid NH_3. The vapor space contains NH_3 vapor with little or no H_2O vapor. This is a more aggressive SCC corrosive medium than liquid NH_3 containing the required 0.2% H_2O.

Conclusion Cont'd

- A N_2 gas purge during tank re-filling did not reduce SCC cracking; thus, N_2 gas purging during nurse tank loading won't reduce SCC risk in nurse tanks. This is because tanks routinely get air purged by venting a little ammonia.
- N-Serve additions to ammonia did not change SCC rates; however, N-Serve did increase the uniform corrosion rate (rusting) of the tank's interior wall.
- The particular Post-Weld Heat Treatment (PWHT) (annealing) tested by this study, reduced residual tensile hoop stress near welds by two thirds and reduced the residual axial tensile stress by one third. Hoop and axial tensile stresses are the primary drivers of SCC in nurse tanks.

Conclusion Cont'd

- Ultrasonic testing is an effective method for determining the location and size (but not the depth) of cracks.
- The 532 in-service nurse tanks examined by side-angle ultrasound contained 3326 total indications (2788 in the HAZ and 538 in the weld). (Most indications are cracks, but some may result from weld geometry or non-crack internal flaws.)
- As noted, about 84% of indications were located in the HAZ beside the weld, but a significant minority (16%) were found in the weld fusion zone. About three fourths of the indications were perpendicular to the weld line; one fourth lay parallel to the weld line. More than ¾ of indications were located in the tank heads; only about 1/5 of indications found in the tank shell.

Conclusion Cont'd

- The circumferential welds that join the heads to the shell accounted for the great majority of indications, and most of those indications were located in the vapor space above the 80% fill line.
- The 168 tanks examined that were manufactured on or after 1999 with no annealing and thinner steel accounted for 74% of the indications found in the HAZ, even though those tanks comprised only 32% of the tanks examined.