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- Automated phased array UT of weld fabrication indication in DMW at U.S. BWR/4

Automated Phased Array UT of Transverse Weld Fabrication Indication in DMW

Background Information

- Planar weld fabrication flaw reported during the 2017 manual phased array UT examination of an N2 nozzle–to–safe-end DMW
  - Reported as being an embedded, transverse oriented weld fabrication flaw 0.70” [18 mm] in length and wholly contained within the Alloy 82/182 weld and butter material
- Examination data sheets reviewed prior to 2024 RFO
  - Characterization of indication deemed suspect due to transverse nature combined with reported length and included screenshot

Flaw Evaluation

Planar Flaw Comparison to Acceptance Standards - ASME Section XI - 2001 Edition with Addenda Through 2003

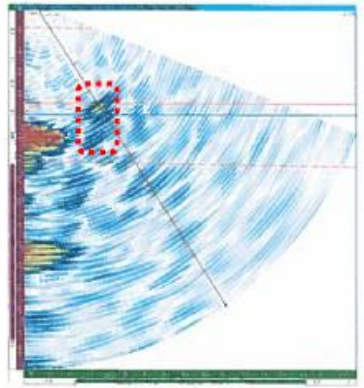
J.A. Fitzpatrick

Component ID: N-2F-SE

Flaw No.	Flaw Start	Flaw End	Flaw Length	(S) Depth OD to Top of Flaw	Depth OD to Bottom of Flaw	Flaw Through Wall	Component Thickness	Flaw a	Flaw af	Flaw a/t%	Flaw Type	Material Type	Flaw a/t	Subsurface Flaw Only Y=s/a	Subsurface Flaw a/t%	Subsurface Code Allowable Table	Subsurface Code Allowable a/t%	Results
1	0.69	0.70	0.70	0.86	0.97	0.11	1.20	0.06	0.08	4.58%	Subsurface	Austenitic	0.08	1	4.58%	10.76%	10.76%	Acceptable

Flaw #1 is an axially oriented fabrication flaw, which is located 6.5° clockwise from TDC when looking toward nozzle. The flaw is totally contained within the butter / butt weld material.

Flaw #1 - Volume-Corrected Sectorial Data Image



N2 Safe-End Weld Fabrication Process

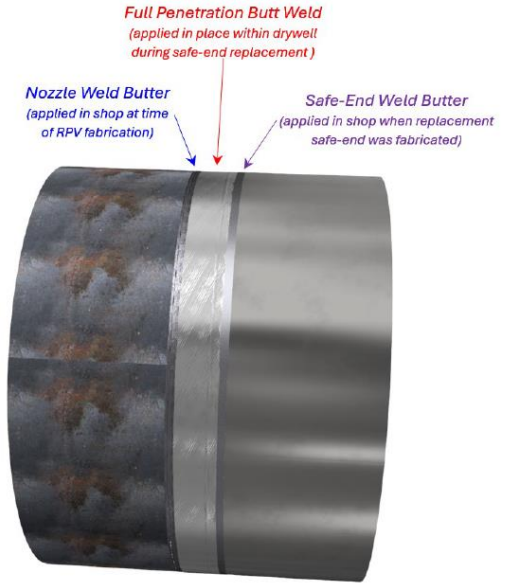
1. Nozzle buttering welded to RPV in the RPV fabrication facility
   - 1G (laying flat) position
2. Safe-end removed at some point
3. Safe-end weld buttering applied long after RPV fabrication
   - 1G (laying flat) position
4. New safe-end mated to RPV nozzle inside drywell
5. New DMW completed inside drywell
   - 5G (fixed horizontal pipe) position

1:

3:

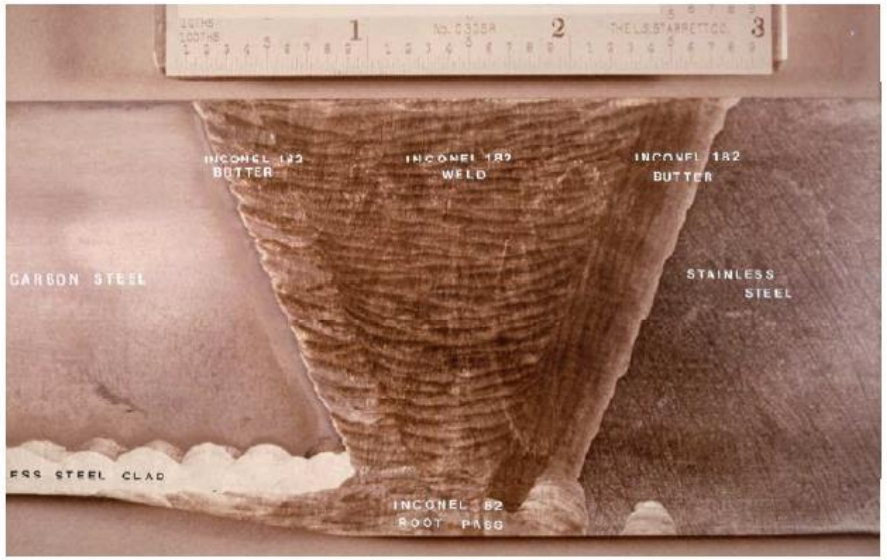
4:

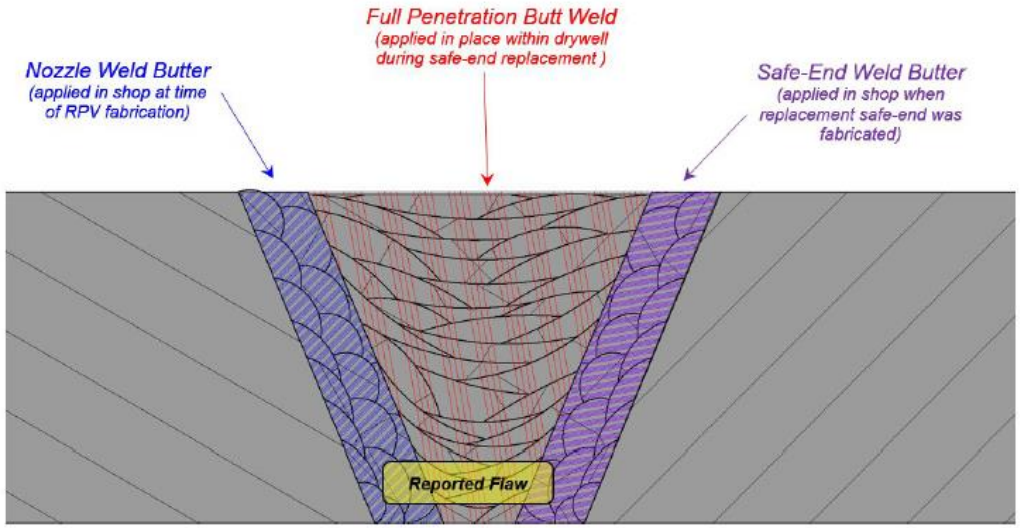
5:



What's the Worry?

- As recorded, the "weld fabrication flaw" would have to:
  - be oriented transverse to the direction in which welding was performed
    - This is a possible, but unlikely orientation for weld fabrication flaws
  - extend through the RPV butter, across several DMW weld beads, and into the safe-end butter…all of which were applied at different times, at different locations, and using different weld orientations
- A common attribute of transverse SCC flaws within DMWs is they tend to span across the entire width of SC- susceptible Alloy 82/182 weld and butter material

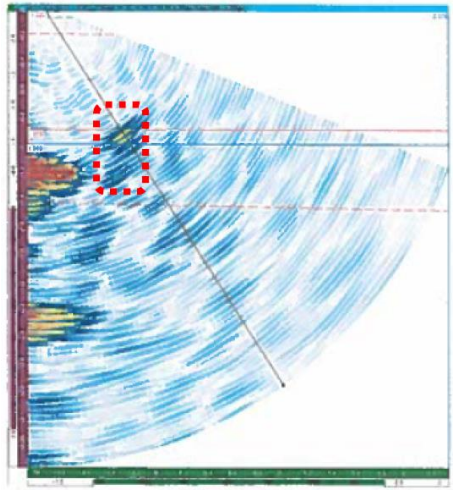




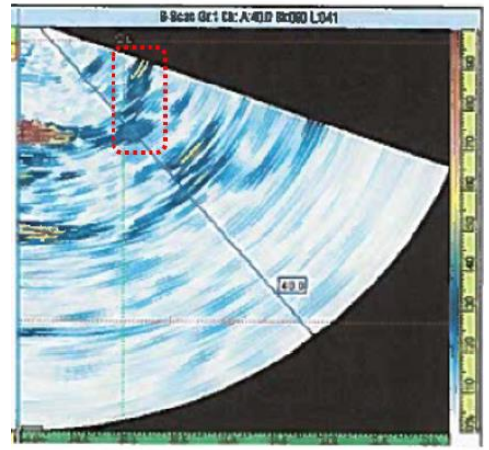
Comparative Review of Available Information

- The screenshot of the fabrication flaw was compared against screenshots of:
  - Mockup flaw responses included in the final report from site specific mockup scans for the “ditch weld” configuration
    - Scans utilized the same examination procedure, UT instrument, probe, wedge, & the DMW was of the same thickness as the N2
    - Screenshots displayed similar characteristics to shallow, inside surface connected planar cracks in the mockup. The characterization as an embedded flaw was brought into question.
  - Flaw response included in the data sheet for a reported SCC flaw that leaked during application of the weld overlay
    - A similar, but much larger stacked pattern of responses was present. The characterization as a fabrication related reflector was brought into question.

Fabrication flaw:

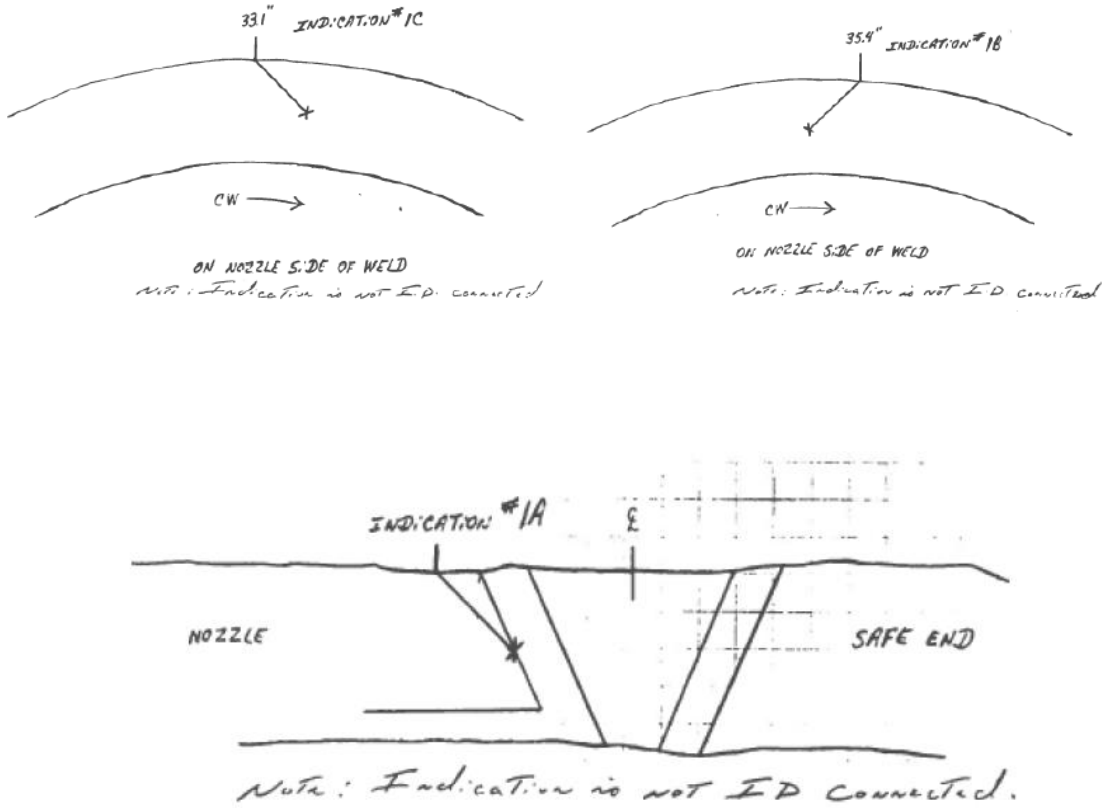


Confirmed SCC flaw:



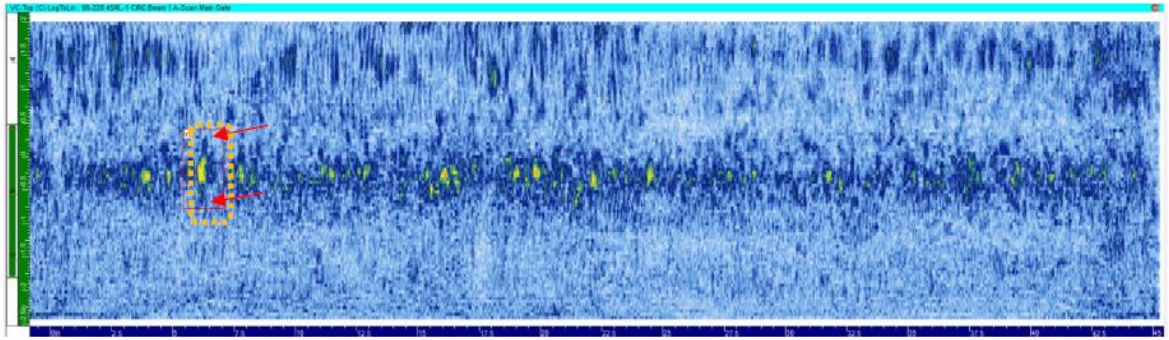
Comparative Review of Available Information

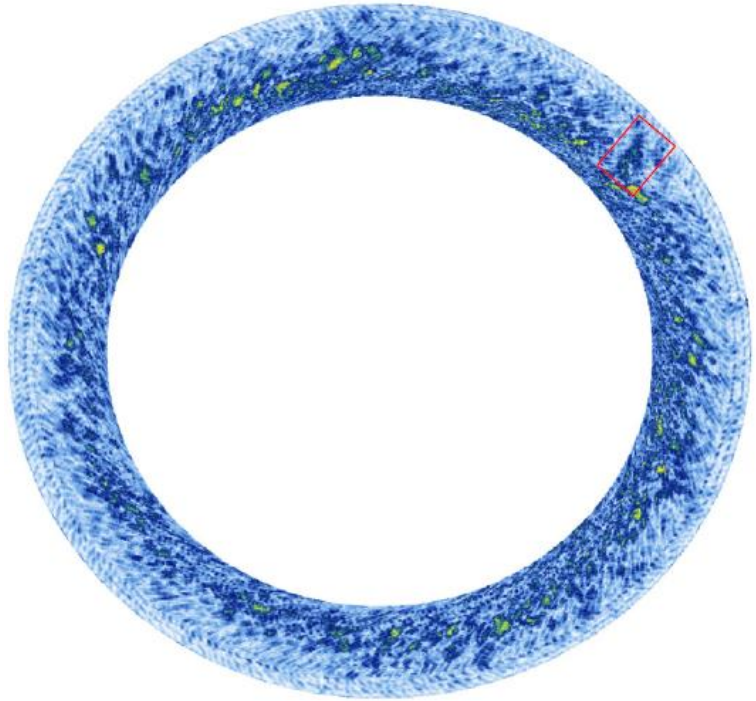
- Embedded slag inclusion recorded during 1988 examination
  - Indication detected from both circumferential scan directions, from the axial scan direction, and during a supplemental 0° scan
    - Recorded circumferential location does not match 2017 indication
    - Recorded depth position does not match 2017 indication
  - Indication characterized as a slag inclusion; datasheet states a review of construction-era radiographic film confirmed a slag inclusion was present in the area
  - Indication not likely associated with 2017 indication and appeared to be thoroughly and properly characterized



Comparative Review of Available Information

- Review of 2008 automated UT examination data showed no clear evidence of a flaw in the area of the 2017 indication
  - A faint pattern exhibiting unique characteristics was present in the area
    - Transverse orientation and approximate length as reported in 2017
- Could this indicate a transverse flaw was beginning to develop ~2008 and didn't become detectable until ~2017?





Results From Review of Available Information

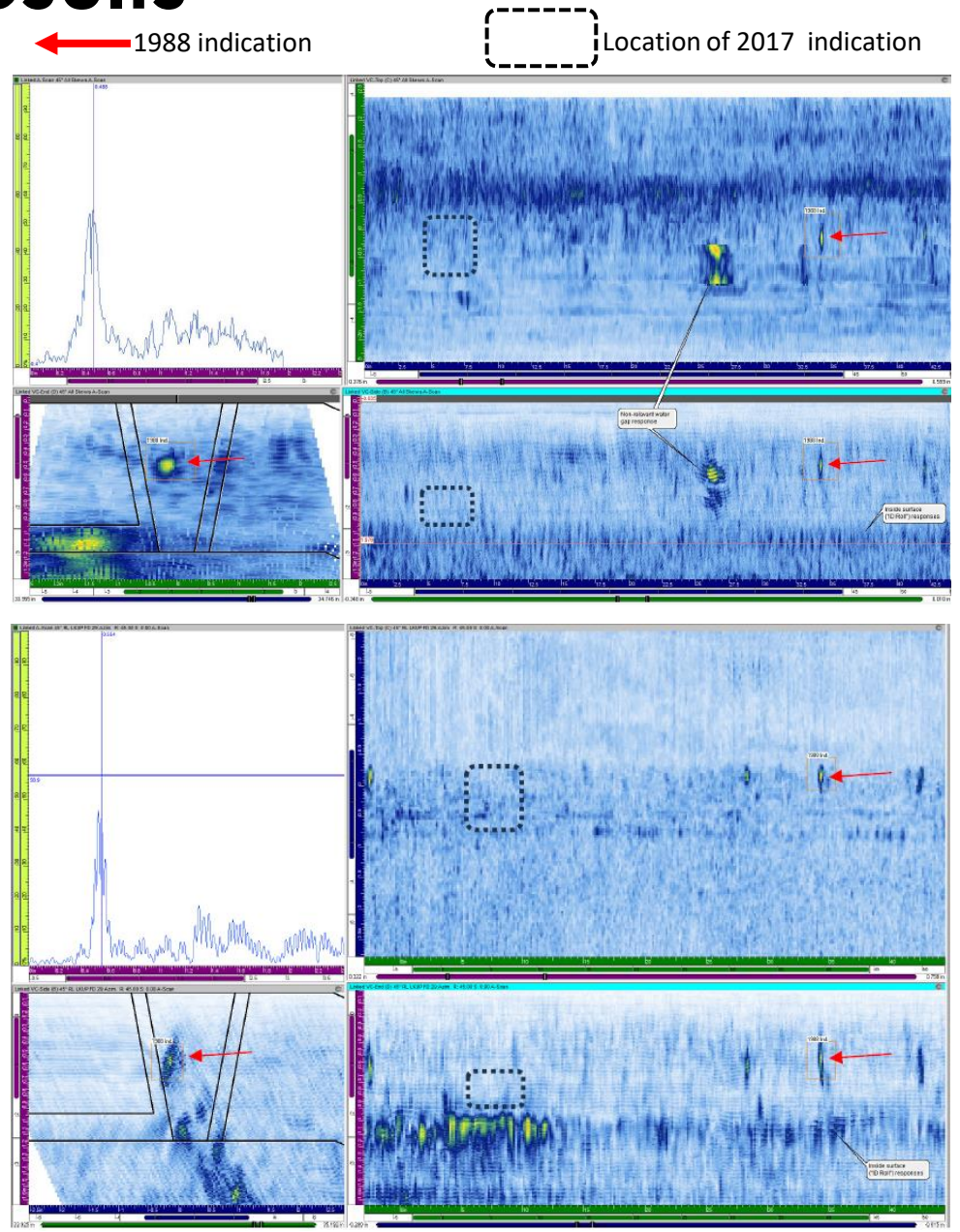
- 2017 characterization as a 0.70” [18 mm] long, transverse weld fabrication flaw deemed to be non-credible
  - One of two possibilities are most likely outcomes:
    - A service induced SCC flaw grew to detectable size between 2008 and 2017 and was mischaracterized as a transverse, embedded weld fabrication flaw in 2017
    - A non-relevant indication “e.g., spot indication” was mischaracterized as a reportable weld fabrication flaw in 2017
      - The manual phased array examination data provides little opportunity for independent review
        - Review limited to a screenshot and the examiner’s written notes
        - Don’t know if response was clearly evident for the entire reported length or if it was seen for only a small spot and measuring to noise level extended it out for 0.70” [18 mm]

Preparations for 2024 UT examination

- Long before the 2024 outage, the 2017 indication was evaluated as an inside surface connected planar flaw in accordance with IWB-3600
  - Determined the scheduled 2024 automated UT would be performed before the flaw grew to rejectable size
- Contingency plans to apply full-structural weld overlay during RFO
  - Automated phased array UT of weld overlay mockup performed pre-outage to verify weld parameters capable of welding an acceptable FSWOL
- Scope expansion pre-selected with necessary resources in place
- Experienced manual phased array UT team deployed to take immediate first look at flaw
  - Get in and out quicker than automated UT, use information to initiate scope expansion
- Automated phased array UT mobilized to site to perform definitive characterization of the indication

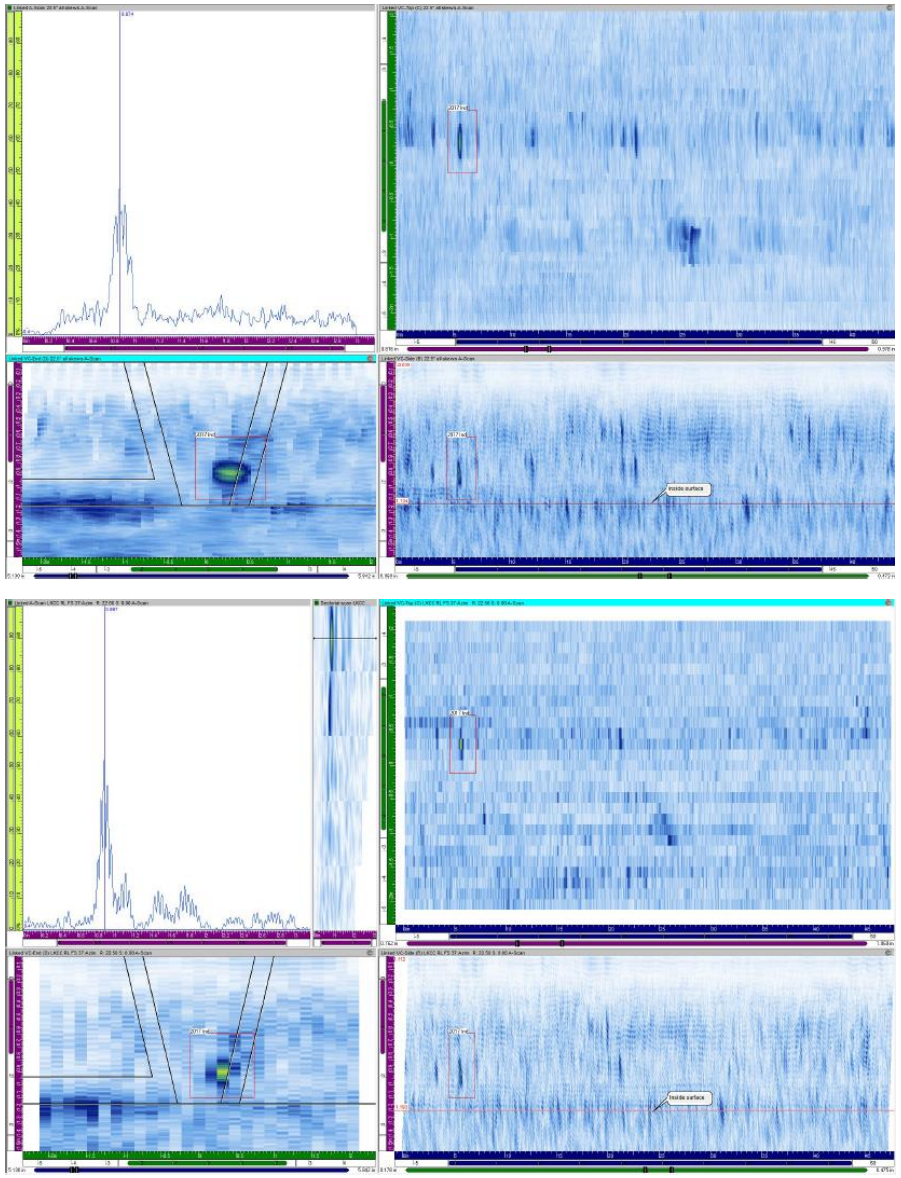
2024 Phased Array Examination Results

- Manual UT team reported flaw indication located only after a very meticulous manipulation of the UT probe
  - Indication difficult to repeat
  - Indication extremely short, response disappears with very little lateral movement of the probe
  - Advised automated UT team to tighten scan and index increments as reflector likely to be very small
- No immediate action taken to initiate scope expansion based on results of manual phased array UT examination
- Automated phased array UT results:
  - 1988 UT indication confirmed; same characteristics as documented by prior examiners
  - 2017 UT indication identified but much smaller than reported; recharacterized as a non-recordable indication
- Scope expansion and weld overlay not needed



2024 Phased Array Examination Results

- Reflector reported as a flaw in 2017 was identified
  - Highest amplitude of all the responses which comprise the 360° weld pattern
  - A single hot-spot present along weld fusion line
    - Detected only with the counterclockwise probe orientation
    - Detected only with 22.5°, 30°, and 37.5° examination angles
      - Previous conventional UT exams utilized 45° and 60° search units – this is why it was detected for the first time in 2017
    - Discernable from weld noise pattern only along a single scan line
    - Clearly not connected to the inside surface
- 2017 indication recharacterized as a non-recordable weld discontinuity typical of the 360° weld pattern responses



Recommendations

- UT indications recorded as a transverse/axially oriented weld fabrication flaw should always be treated with suspicion
  - Transverse / axially oriented indications which are reported to extend across the full-width of the DMW and weld butter material are likely to originate from an SCC flaw
    - Based on 20+ years of DMW OE
- Characterization of such indications should be well documented for subsequent review
  - Characterization of the indication in 1998 was well documented, and did not cause concern
  - Documentation of the indication in 2017 lacked a lot of key information, which prompted concern that a relevant SCC flaw was mischaracterized
    - Clockwise or counterclockwise probe orientation was not documented
    - Range of examination angles which detected the indication was not documented
      - It is now known the indication was likely detectable using examination angles below 40°, the 2017 examination was the first time these examination angles were used to interrogate the weld

Applicable OE of confirmed transverse SCC flaws extending across full-width of weld and butter

DMW location (year)	Flaw Details and Confirmation
V.C. Summer RPV outlet nozzle DMW (2000) [4]	Flaw identified via operational leakage. Metallurgical evaluation confirmed a ~2" long axial SCC flaw which spanned the full width of weld and butter.
Davis Besse decay heat nozzle DMW (2008) [6]	Flaw identified via leakage after a preemptive weld overlay, applied over the unknown flaw, melted through the thin layer of unflawed material which separated the flaw tip from the OD surface. An axial flaw spanning the full width of the DMW confirmed during the excavation to peen the flaw shut before subsequent repair operations.
Kernkraftwerk Leibstadt RPV feedwater nozzle DMW (2012) [7]	Significant axial flaw identified during planned UT examination. Outside surface eddy current examination also detected the flaw, confirming the flaw was nearly 100% through-wall when detected by UT.
North Anna steam generator inlet nozzle DMW (2012) [9]	Three leaking, axial flaws which spanned the full width of the Alloy 182 weld joint were identified when the outside surface of the nozzle was machined prior to application of a pre-emptive weld overlay. Five significant, axial SCC flaws were *not* identified during the pre-machining UT examinations.
Hatch RPV N2 nozzle DMW (2016) [11]	During the 2016 removal and upgrade of an Alloy 182 design overlay installed in 1988 over a reported axial crack, an outside surface liquid penetrant examination revealed an SCC-like indication which extended across nearly the full width of the DMW.
FitzPatrick RHR Tee-to-valve DMW (2017) [13] & [14]	An axial flaw was reported during the scheduled manual phased array UT examination of the DMW. As the weld overlay was applied, welding along the edge of the DMW, near the base material, melted through the thin layer of unflawed material separating the flaw tip from the OD surface creating a leak.

Conclusions

- The indication reported as a weld fabrication flaw in 2017 was recharacterized as a non-recordable weld discontinuity
- The station was very well prepared to:
  - definitively characterize the indication in 2024
  - respond as necessary to all potential outcomes during the 2024 RFO
- If the 2017 indication were first identified today, the Licensees current standard practice would have led them to mobilize encoded UT during the same outage to definitively characterize the indication
- EPRI's on-site field trial of the DMW AI application discovered system requires modification to interpret very large data files
  - Enhanced resolution of automated phased array circumferential scans exceeded capabilities of AI box
- Axial scan AI model performed as expected