NDE and DE of PWSCC found in the J-Groove Weld of a Removed-From-Service Control Rod Drive Mechanism

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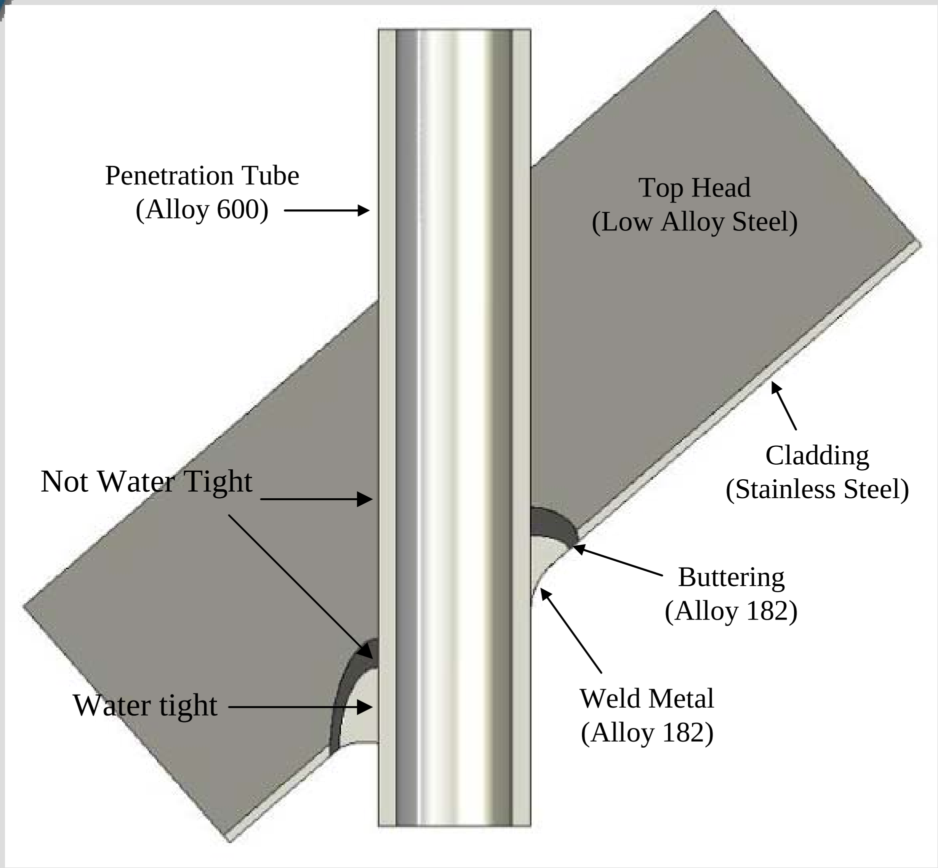
CRDM Nozzle Description

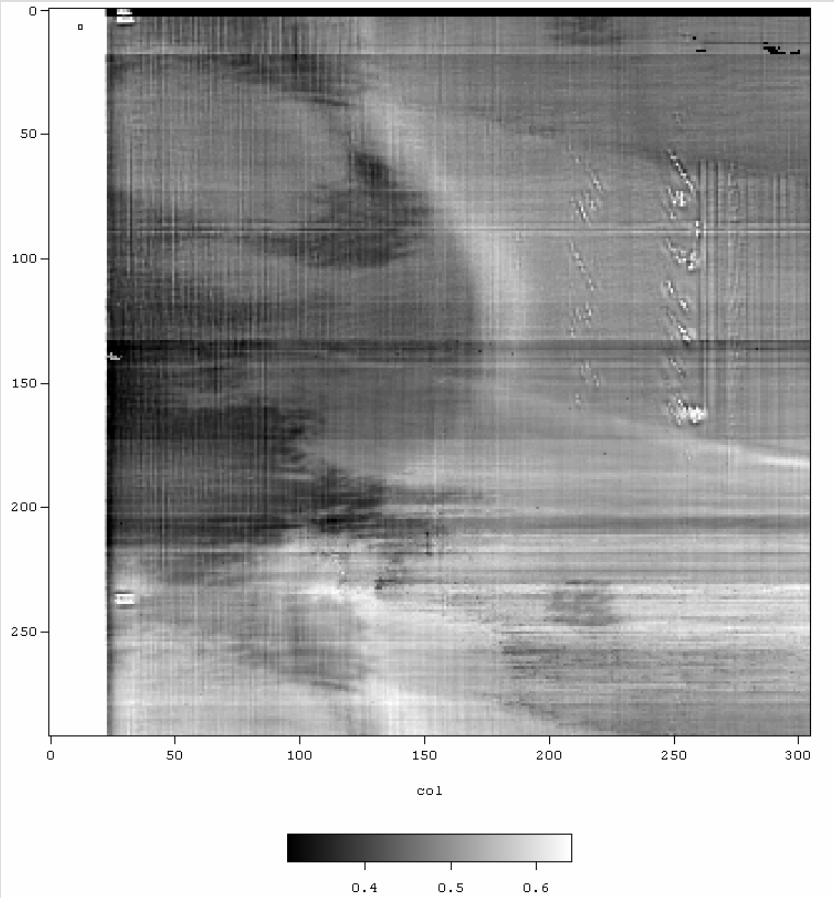


Laboratory NDE Examination of NA2 CRDM Nozzles at PNNL

- The penetration tube interior surface was first examined with eddy current (ET) as it requires no coupling fluid.
- The penetration tube interior surface was then examined using time of flight diffraction ultrasound (TOFD).
- After the TOFD was completed the penetration tube was filled with water to conduct the immersion UT testing of the J-groove weld and buttering.
- The J-groove weld was covered in Microset and the replica was removed and set aside for later visual testing.
- The J-groove weld was then examined using penetrant testing.
- Finally, the J-groove weld was examined using eddy current testing.

Nozzle #31- Penetration Tube ID ET exam

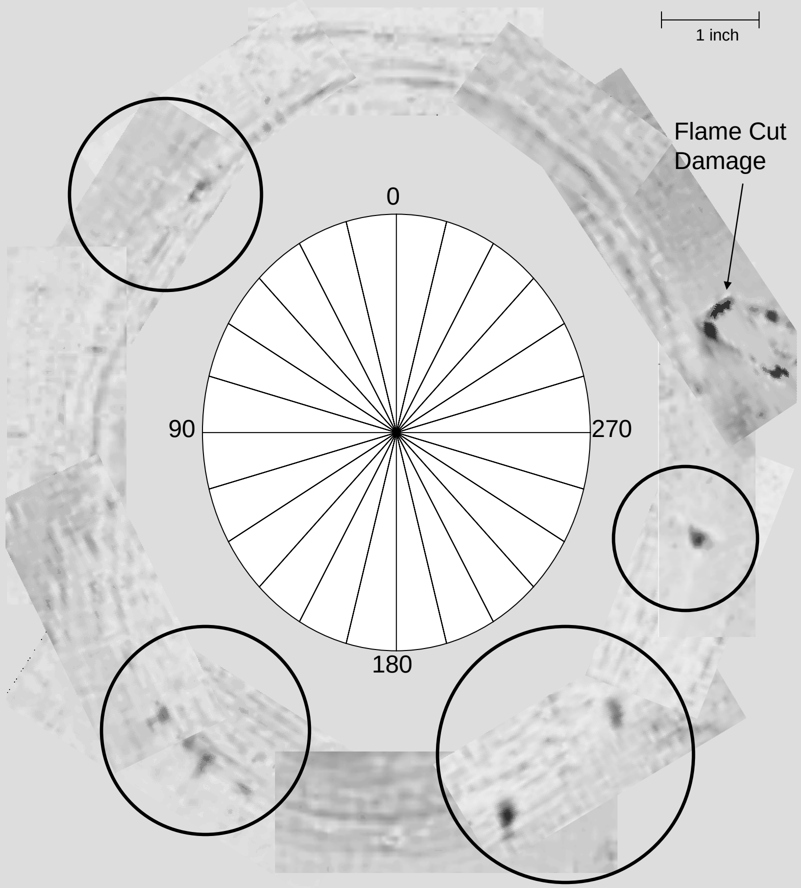
Eddy Current Testing



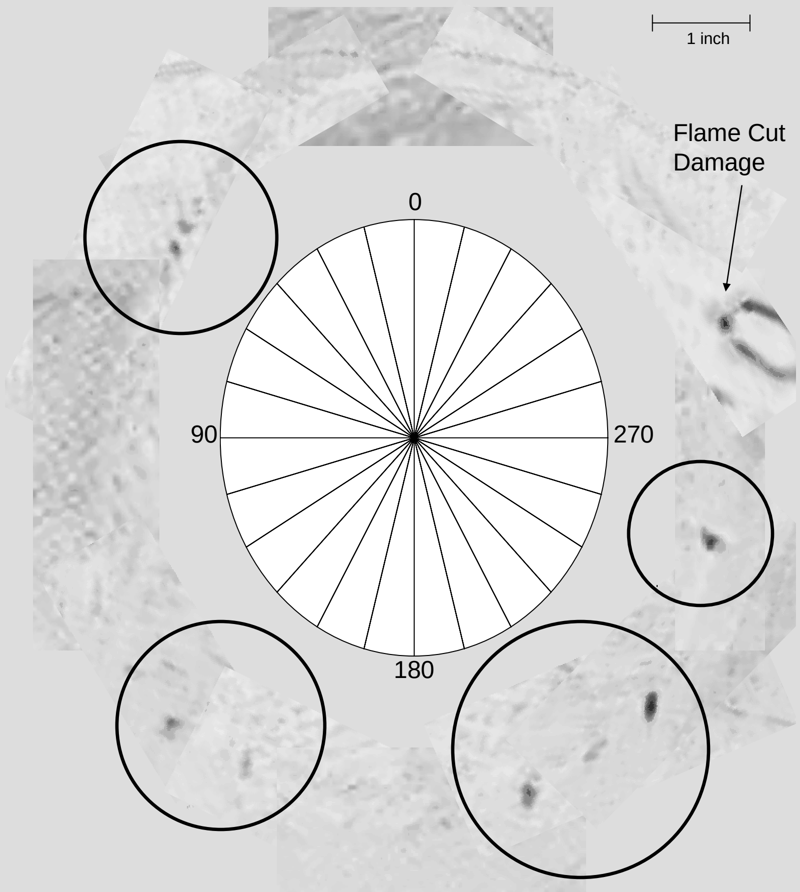
- No crack-like indications found.
- Indications consistent with shallow scratches discovered.
- J-groove weld clearly visible in data.

Eddy Current Results on Crown of J-Groove Weld and Buttering

Zero Degree Probe Rotation



45 Degree Probe Rotation



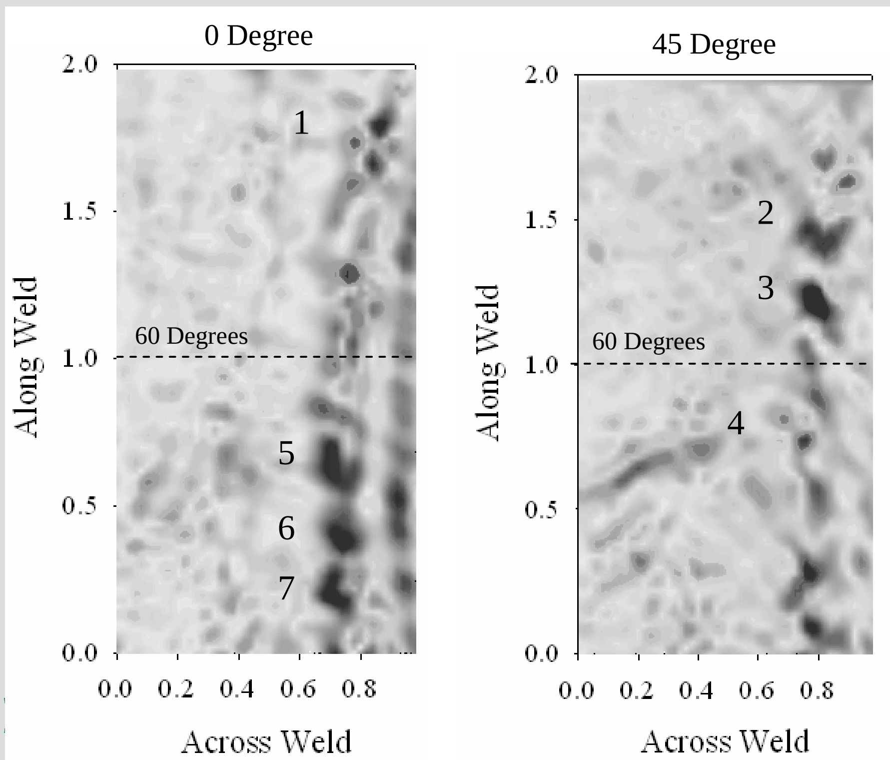
Summary of Eddy Current Indications

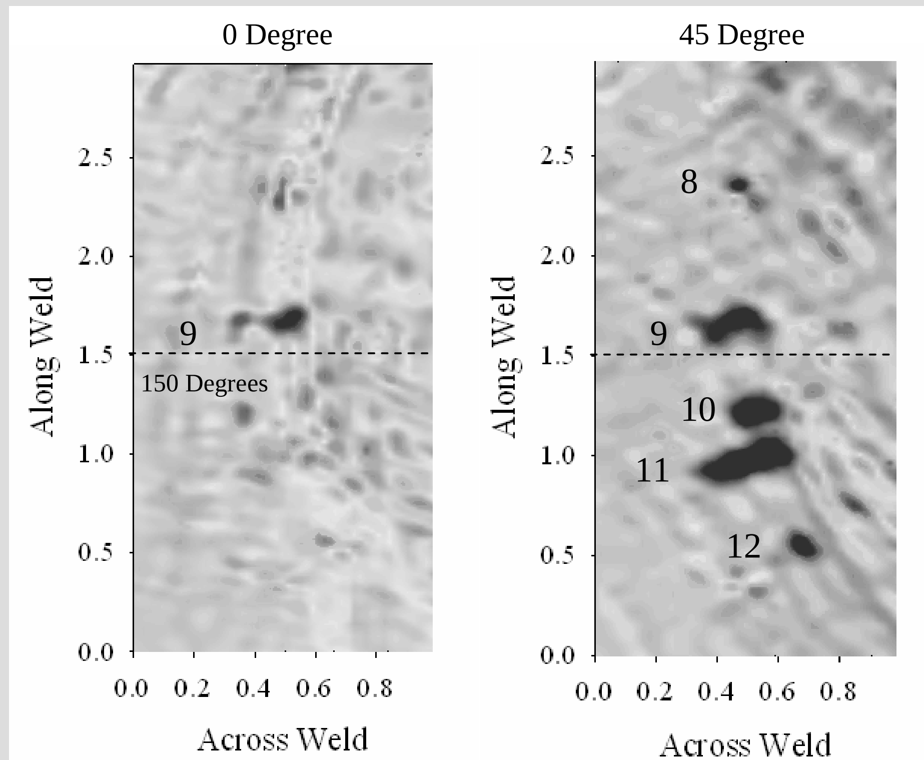
Centered on 60°

Indication	Length	Max Voltage
1	5 mm	2.1
2	3 mm	1.9
3	4 mm	3.3
4	2 mm	1.8
5	5 mm	2.2
6	3 mm	2.5
7	4 mm	2.3

Centered on 150°

Indication	Length	Max Voltage
8	3	2.3
9	8	3.2
10	6	3.3
11	10	4.1
12	4	2.6





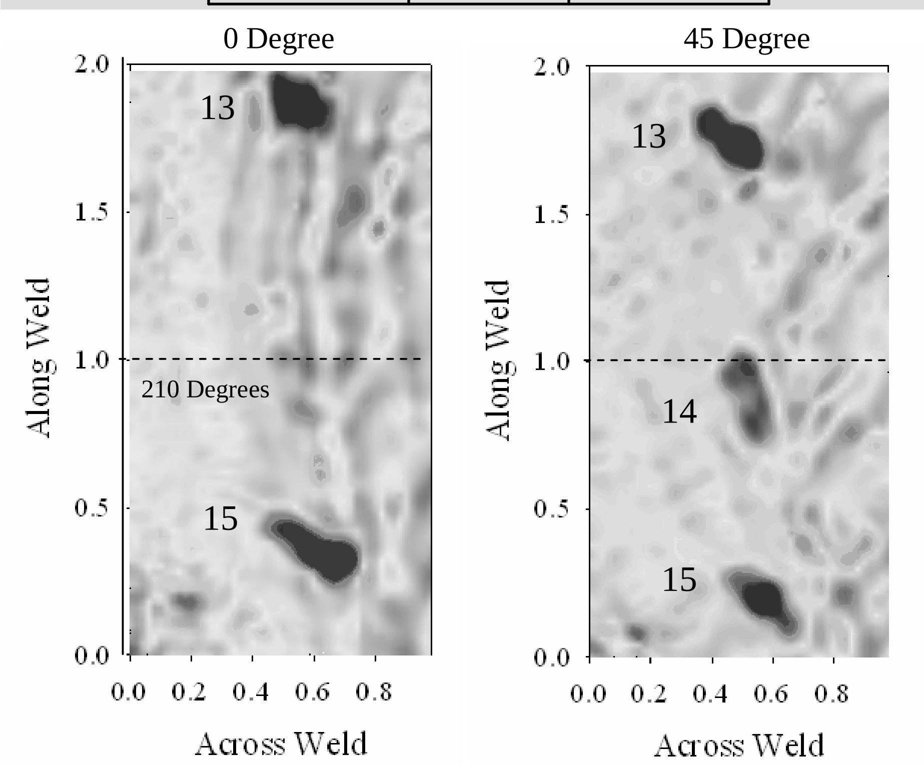
Summary of Eddy Current Indications

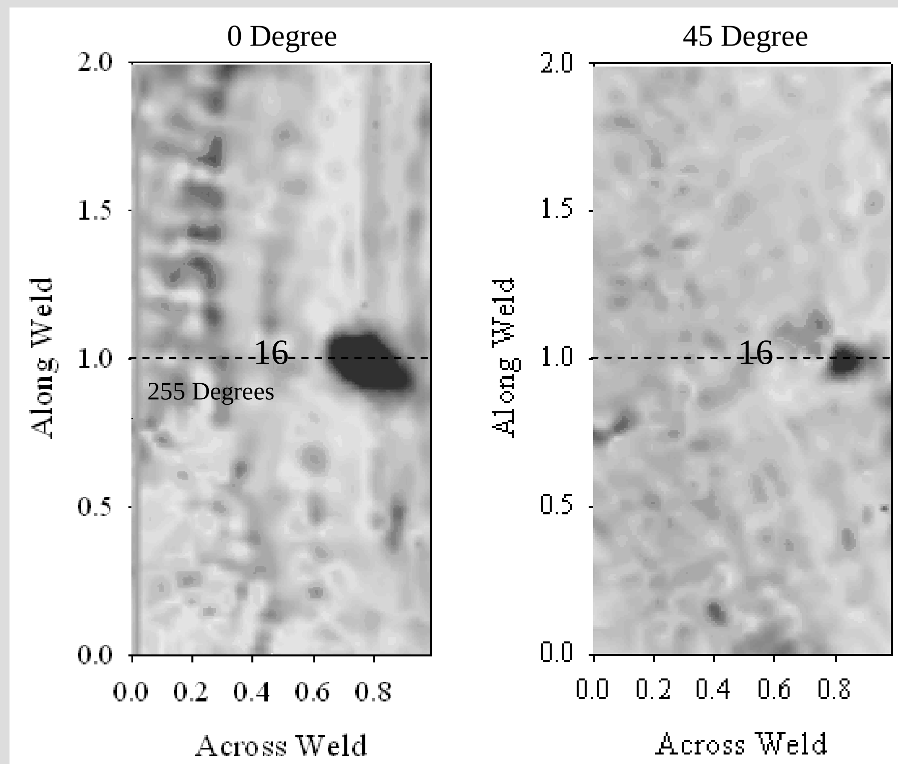
Centered on 210°

Indication	Length	Max Voltage
13	7	4.6
14	7	1.8
15	8	4.6

Centered on 255°

Indication	Length	Max Voltage
16	8	4.2





Nozzle #31 NDE Summary

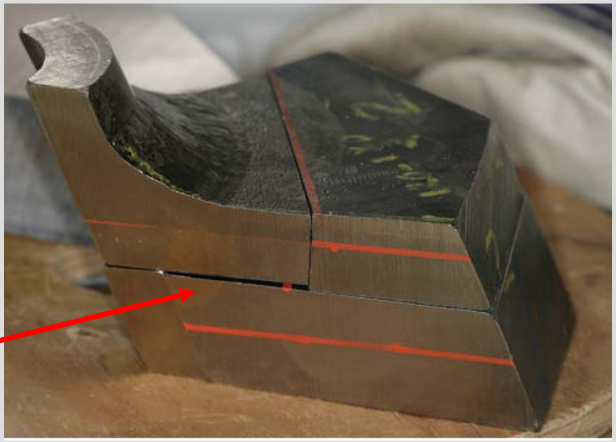
- The penetration tube appears to be pristine, there are no strong ET indications and no breaks in the lateral wave using TOFD.
- ET found sixteen crack-like indications and one area of interest around the J-groove weld. Two of the cracks (200° and 225°) were confirmed using PT and photography.
- Volumetric ultrasound and VT via replicant did not find cracks with high confidence.
- Volumetric UT was sensitive to many weld fabrication flaws.

Destructive Test Plan

- We had found many indications with several NDE techniques, but there was very little overlap, and no clear through weld crack was detected.
- Based on the ET, PT, and bare-metal photography primary interest was focused on the region from 180-270 degrees.
- Other areas of interest included the region near 150 degrees and near 45-60 degrees.
- We applied the "Alexandrian" solution to determine where the leakage had occurred.

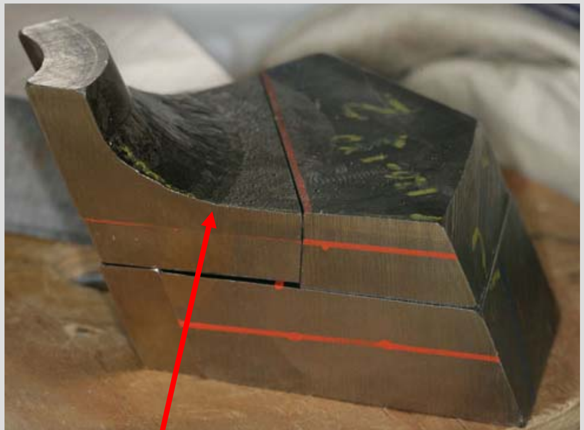
Crack Confirmed Through NDE

Located at 135 degrees

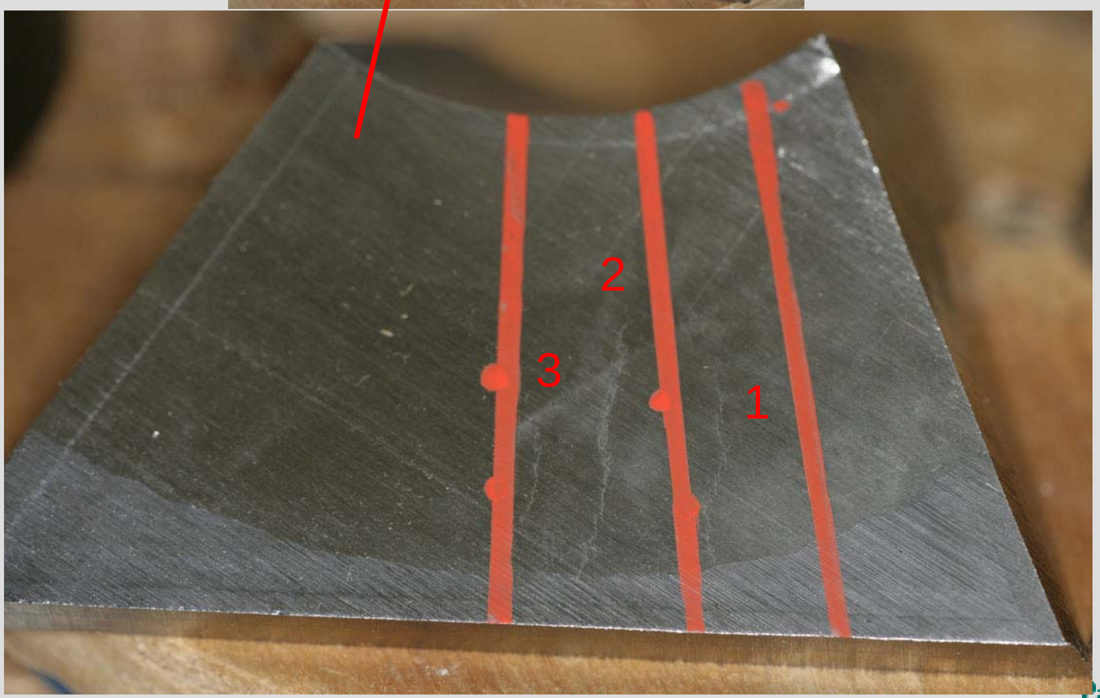


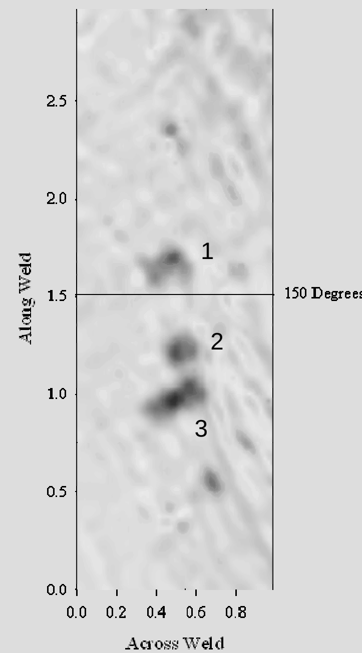
No confirmation of cracking (VT or ET) at any other location around the buttering

Cut 8 mm Below Wetted Surface



Indications near 150 degrees
No PT indications
#1: 146 degrees Max 3.1 V, 5 mm
#2: 153 degrees Max 3.3 V, 4 mm
#3: 157 degrees Max 4.1 V, 8 mm



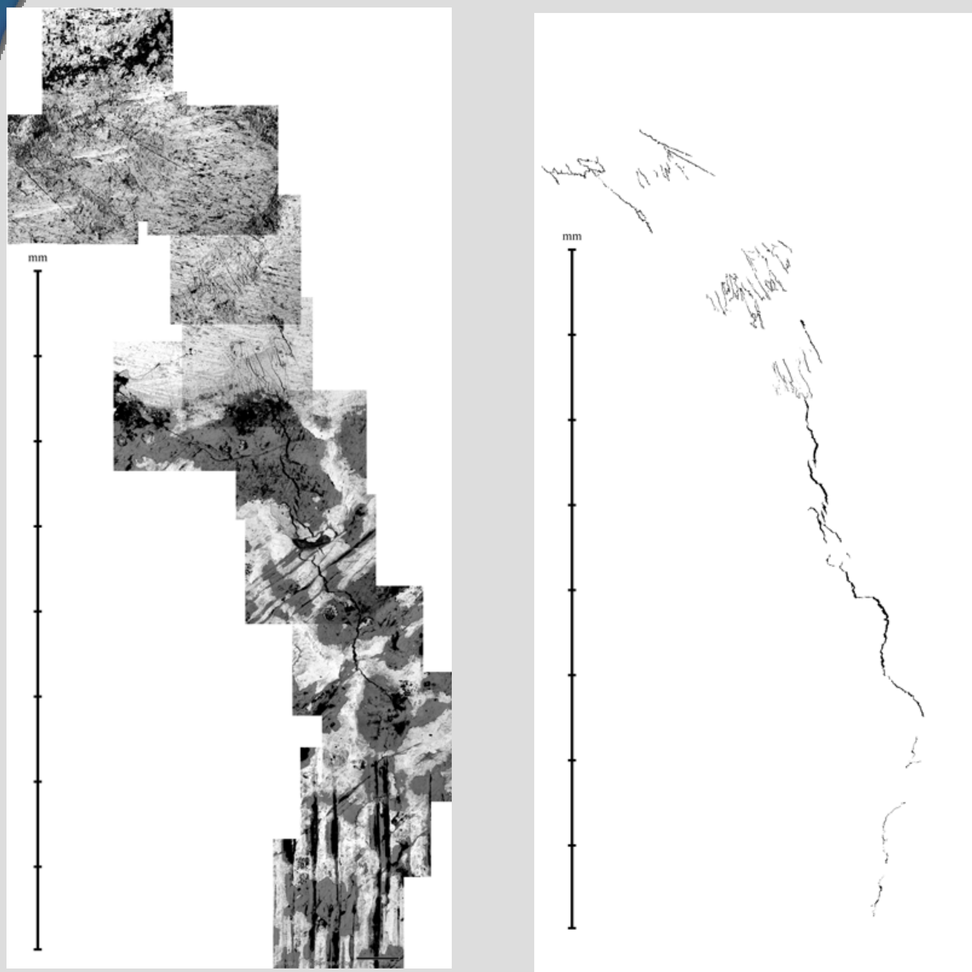


Metallography and Crack Reconstruction

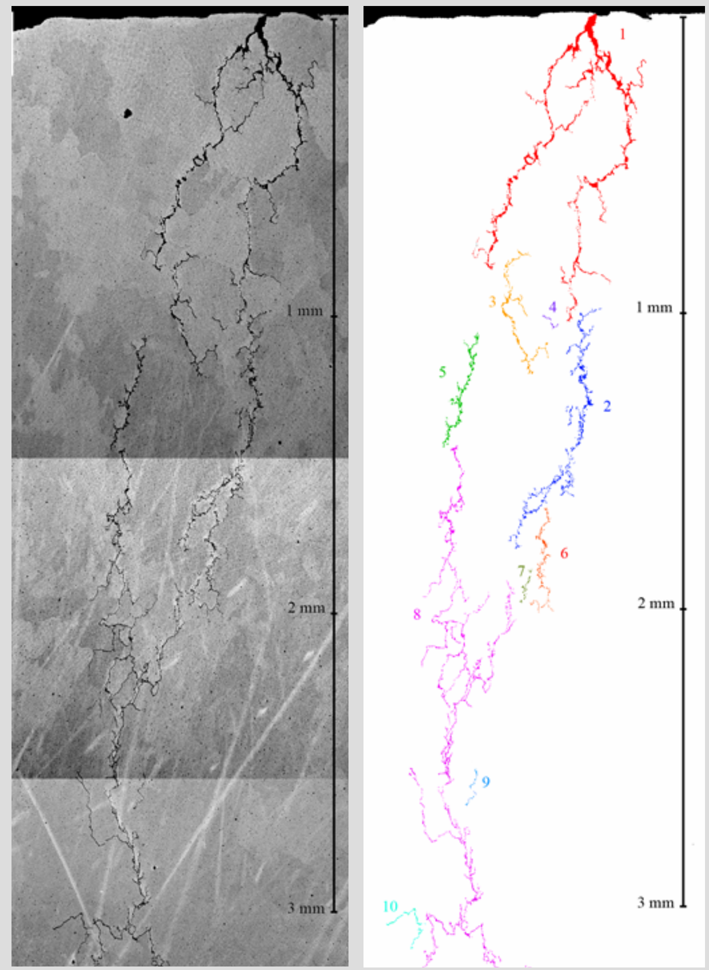
- Now that we have the leakage path reduced to a reasonable size, we can explore why the various NDE techniques were not able to identify it clearly.
- The wetted surface of piece A was examined under an optical and scanning electron microscope.
- Pieces A, C, and E were sliced into thin sections, polished, and examined under optical and scanning electron microscopes.

Microscopy of Crack #2

SEM of Surface



Side view of first three mm

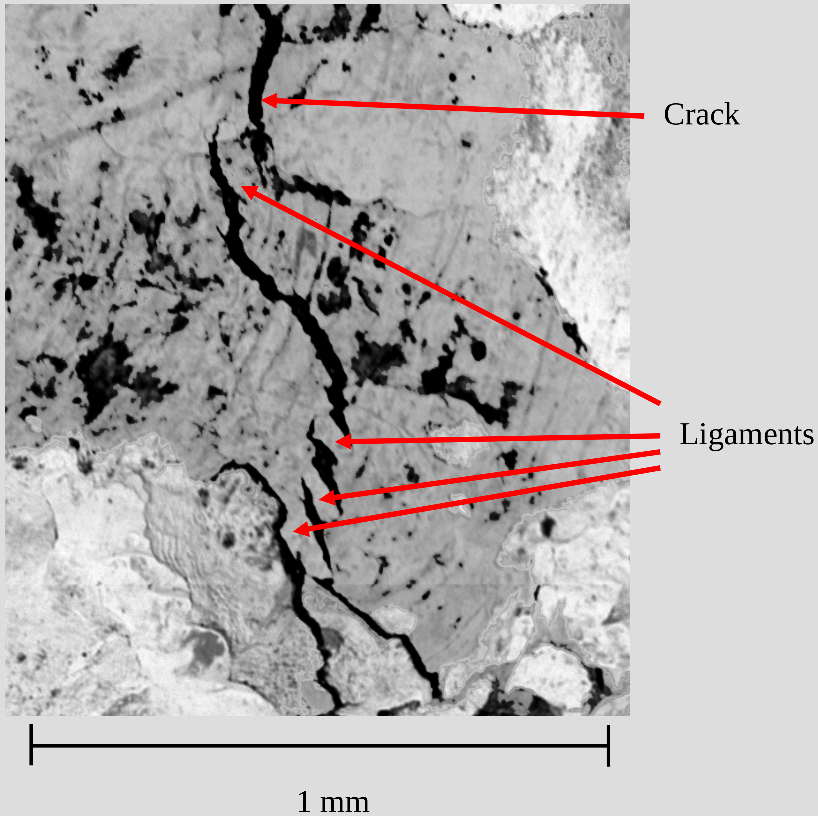


Expanded View of Through-Weld Crack

The through-weld crack has ligaments of metal crossing the crack in several places

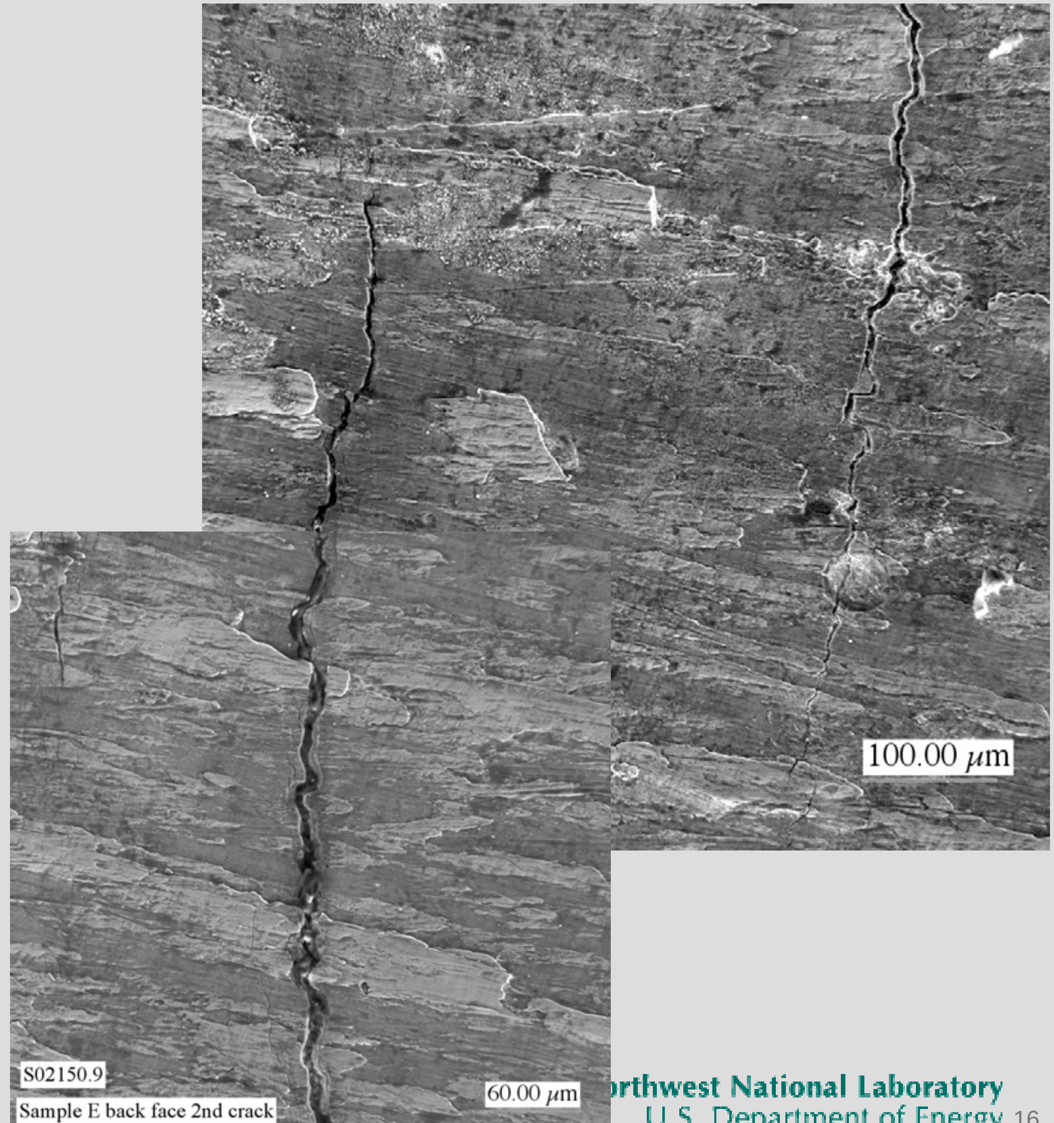
The meandering nature of the crack below the surface also allows for electrical contact between the crack faces.

This electrical contact between the crack faces is likely responsible for the reduced ET response.



Exit Point into Annulus

The crack was tracked from the wetted surface to the annulus.



Conclusions

- PNNL was able to find the likely primary leakage path through the J-groove weld.
- The through-wall leak was undetected by ultrasound. This is likely because the crack was predominantly radial and presented a “knife edge” to the ultrasound beam used in the inspection.
- The surface of the crack was too tight for effective visual testing using the bare metal inspection and visual testing using replicant.
- The crack was not located in a region that was inspectable using TOFD.
- The extreme tightness of the crack prevented sufficient penetrant dye to provide signal for detection using PT

Conclusions

- Eddy current testing was the most effective technique for detecting the through-wall crack.
- More needs to be done to discriminate between shallow and deep flaws.
- Many smaller cracks provided larger signals to the various NDE techniques.
- The presence of fabrication conditions and rough surfaces complicated the NDE.

Future Work

- Work is ongoing to characterize the non-through-weld cracks to better understand the correlation between the NDE and crack characteristics.
- Interim report on the NDE and the DE of the through-weld flaw will be available in the fall of 2007.
- A NUREG report on the NDE and DE of the through-weld and non through-weld flaws will be published at the end of 2007.