

NDE Assessment of PWSCC in Control Rod Drive Mechanism Housings

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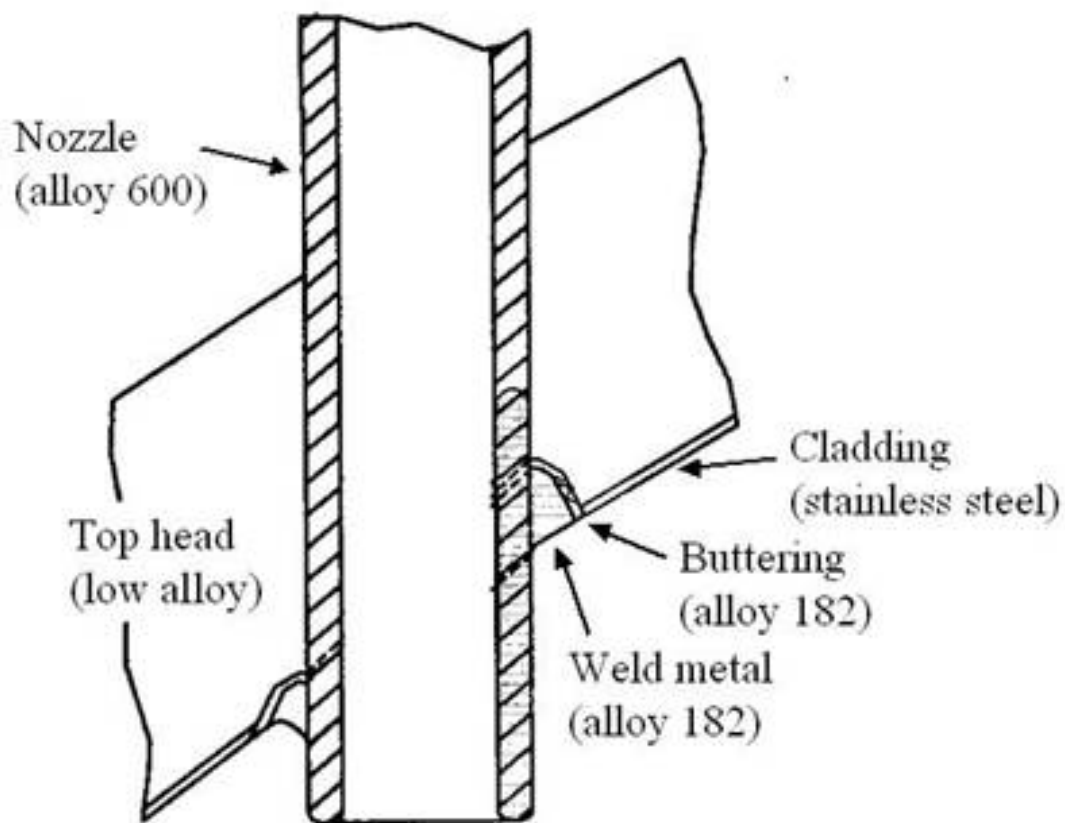
Outline

- ▶ NDE Goals
- ▶ NDE Techniques used
- ▶ NDE Results for Nozzle #59
- ▶ NDE Results for Nozzle #31
- ▶ Conclusions

NDE Goals

- ▶ Use removed from service CRDMs (cut from the head of North Anna 2) containing PWSCC to assess the extent of degradation and effectiveness of NDE techniques.
- ▶ Find all degradation and other flaws in the J-groove weld and buttering area and within the penetration tube wall under laboratory conditions.
- ▶ Verify and expand on previous NDE work during ISI and by ISI teams for inspections conducted at PNNL in 2004.
- ▶ Provide extremely precise and detailed information on the flaws to facilitate and guide developing a destructive test plan.

CRDM Diagram



Laboratory NDE Performed on CRDM Nozzles

- ▶ The interior of two penetration tubes was inspected using eddy current, TOFD, and the penetration tube of Nozzle #59 was also inspected using visual testing via Microset.
- ▶ The J-groove weld metal of both Nozzles was volumetrically inspected using zero-degree ultrasound.
- ▶ The J-groove weld area of both nozzles was examined using visual testing via Microset.



NDE Methods – Eddy Current Testing

- ▶ Eddy Current (ET) testing is sensitive to the presence of surface-breaking cracks on surface being inspected.
- ▶ ET is effective in detecting non-surface breaking cracks if crack is near to the surface.
- ▶ ET provides crack length information.
- ▶ ET does not require coupling media but must be in close contact with the surface for best test sensitivity and at a constant distance to provide consistent test results.
- ▶ Two frequencies, 150 and 350 kHz, and two gains, 15 dB and 30 dB, were used.

TOFD Technique

- ▶ Time of flight diffraction (TOFD) uses two ultrasonic transducers to detect acoustic anomalies between them.
- ▶ TOFD is extremely sensitive to cracking.
- ▶ TOFD is commonly used by industry for detection and depth sizing of cracks.

Inspection	Angle	Frequency	Notes
(#)	(degrees)	(MHz)	
1	60°	7.5 MHz	Very sensitive, detects many fabrication flaws
2	60°	5.0 MHz	Industry Standard

NDE Methods – Immersion Ultrasound

- ▶ Immersion ultrasound was used to examine the J-groove weld.
- ▶ UT performance degrades as the ultrasound propagates through the J-groove weld and buttering because of the coarse-grained anisotropic weld metal.
- ▶ Four frequencies were used, 5 MHz, 2.25 MHz, 1 MHz, and 500 kHz. The 5 MHz ultrasound is very sensitive to flaws in the fusion zone between the J-groove weld and the penetration tube, and the lower frequencies provide increasing sensitivity to flaws successively deeper into the weld metal

Visual Testing via Microset

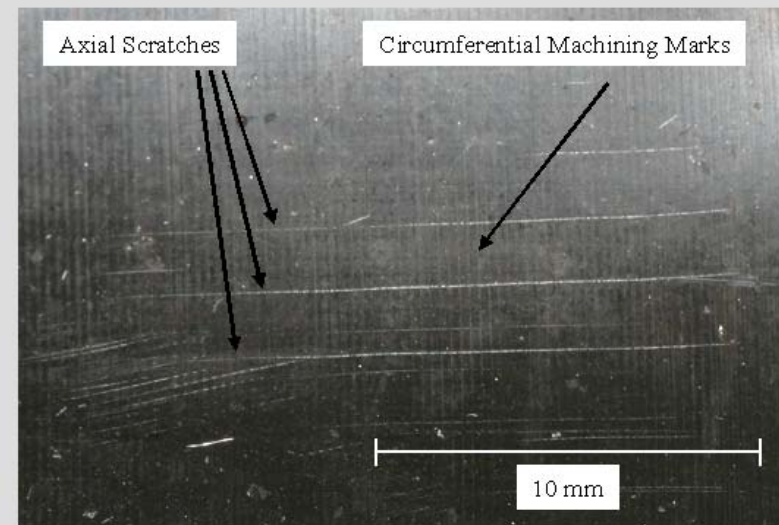
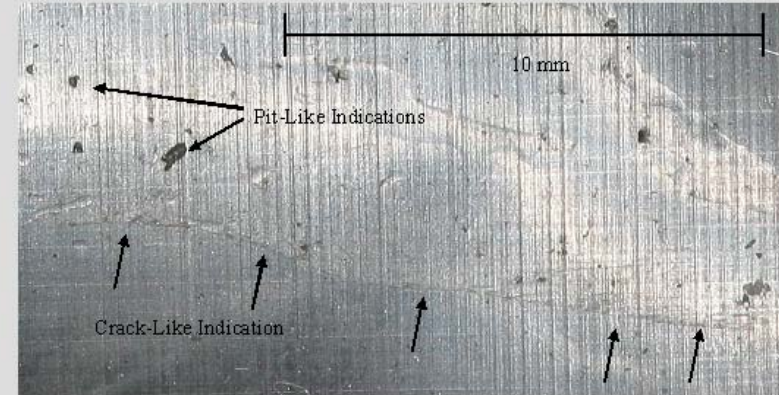
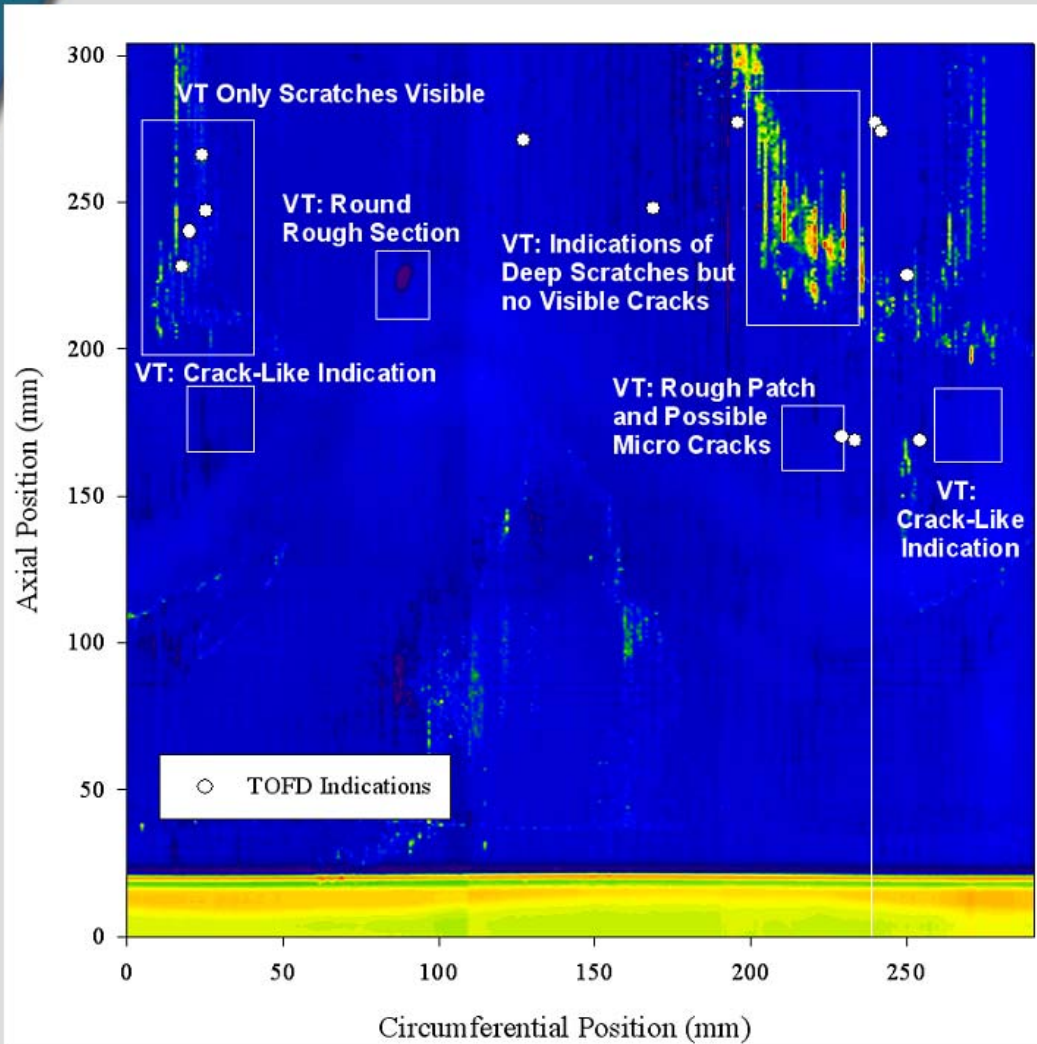
- ▶ Enhanced VT, when applied properly, can be a useful tool in detecting and characterizing component surface features.
- ▶ Microset is an epoxy-like polymer that is applied on a surface as a liquid and then it hardens, making an extremely high resolution replica of the surface that can capture details of as small as 0.1 microns in size.
- ▶ A Canon 1Ds Mk 2 camera with a 180 mm 1:1 macro lens was able to resolve 41 lines/mm using a 1951 Air Force resolution target.
- ▶ When photographing the Microset replicas, the camera was mounted on a graduated slide bar and a graduated tripod.

NDE Exam of Nozzles

- ▶ The penetration tube interior surface was first examined with ET as it requires no coupling fluid.
- ▶ The penetration tube interior surface was then examined using TOFD.
- ▶ After the TOFD was completed the bottom of the penetration tube was plugged and filled with water to conduct the immersion UT testing of the J-groove weld and buttering.
- ▶ Finally, the J-groove weld was covered in Microset and the Microset was removed and set aside for later visual testing.

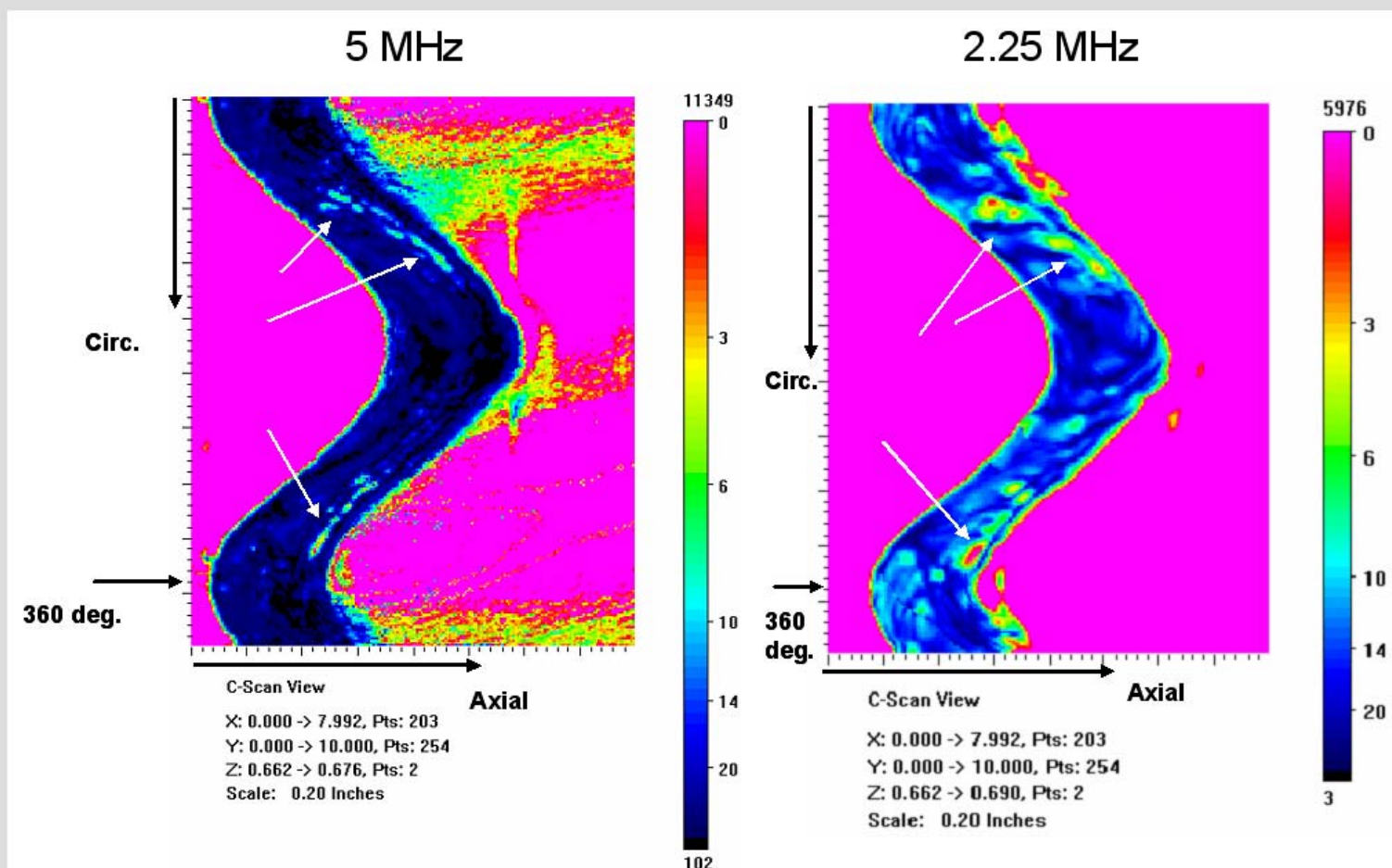
Nozzle #59- Penetration Tube ID

TOFD, ET, and UT Results



Nozzle #59- J-Groove Weld

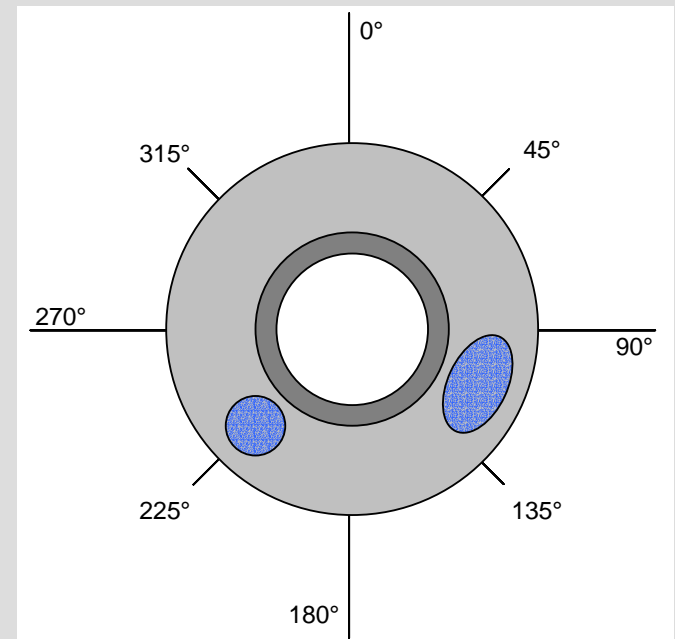
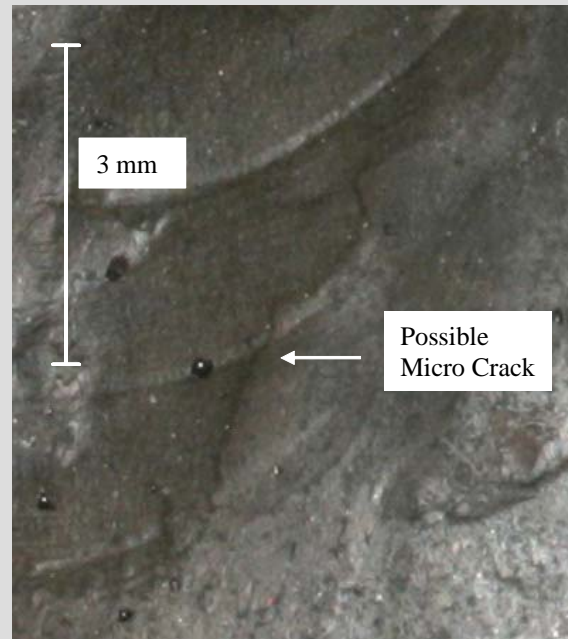
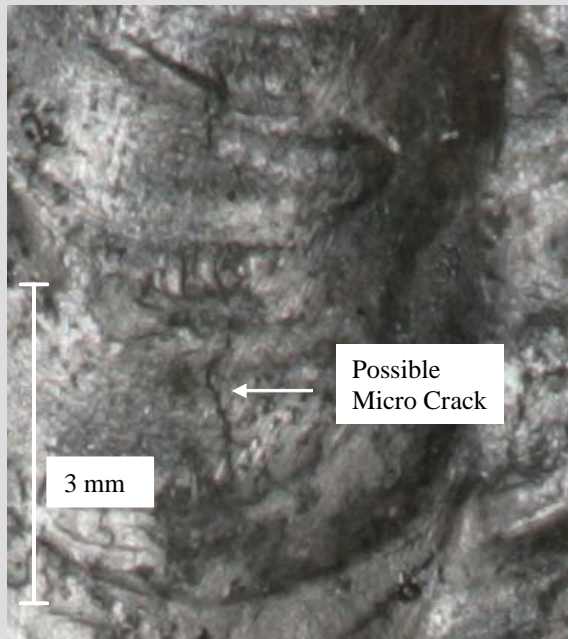
Immersion Ultrasound



Nozzle #59- J-Groove Weld

Visual testing via Microset results

Only indications for small cracks, no long crack-like indications discovered.

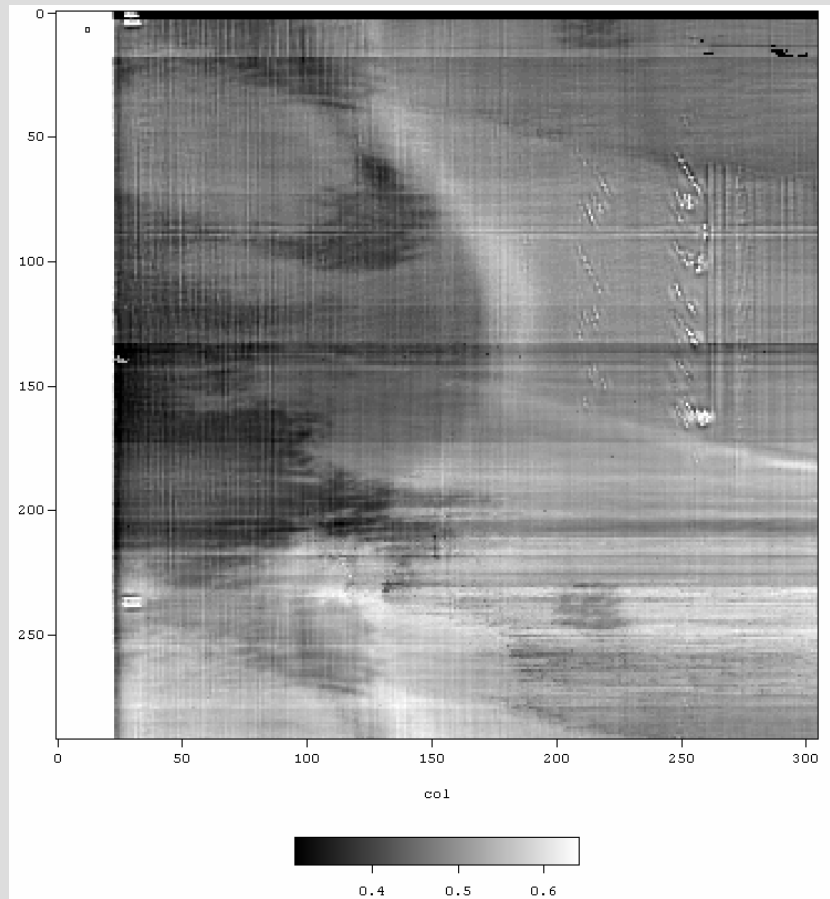


Nozzle #59 Summary

- ▶ Many indications were found in the penetration tube using TOFD and ET, but the TOFD and ET results are inconsistent as to where the flaws are located.
- ▶ VT found many axial scratches and pit-like indications that may have accounted for much of the ET results. One crack-like indication was discovered, although this was not solidly corroborated by the ET results.
- ▶ The examination of the J-groove weld using VT and UT showed defects in the weld.
- ▶ UT found strong reflection from the interference fit. One region of ultrasonic transmission was seen but is likely the result of the construction technique used to make the interference fit.

Nozzle #31- Penetration Tube

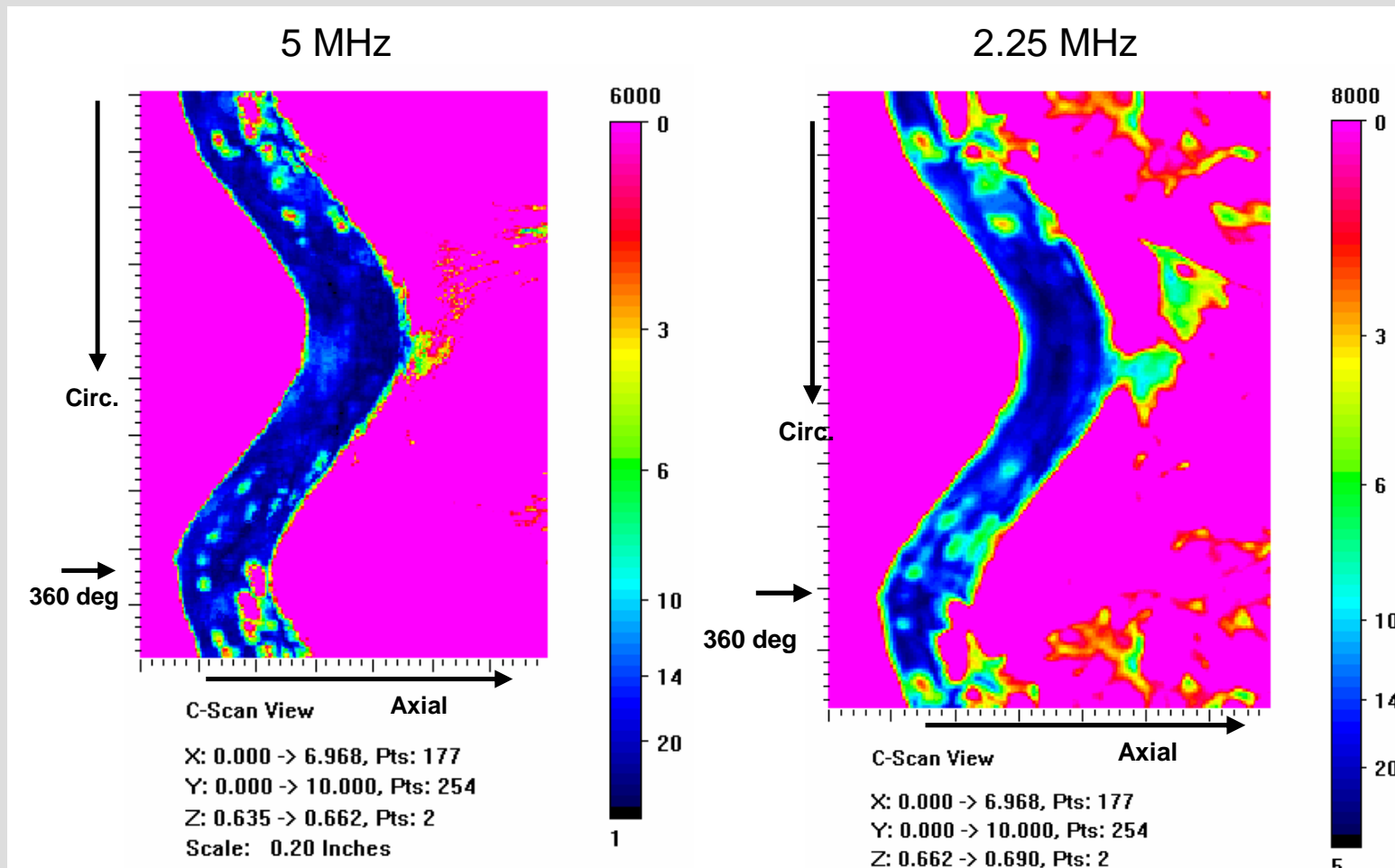
Eddy Current Testing



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

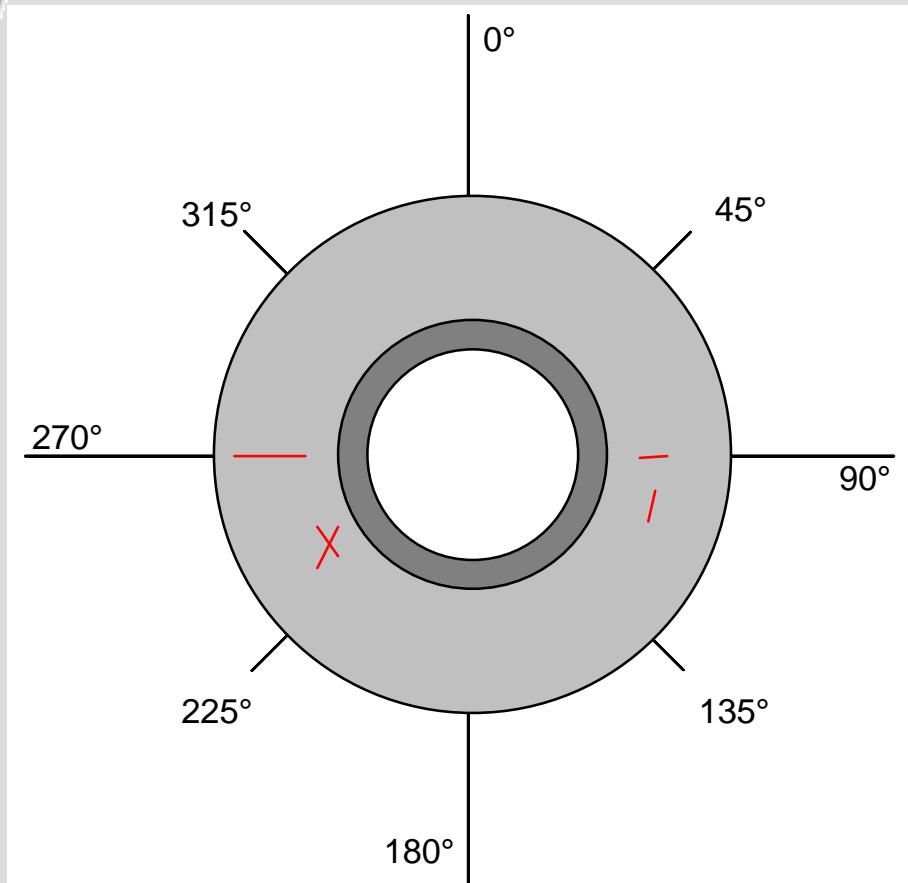
Nozzle #31- J-Groove Weld

Immersion Ultrasound

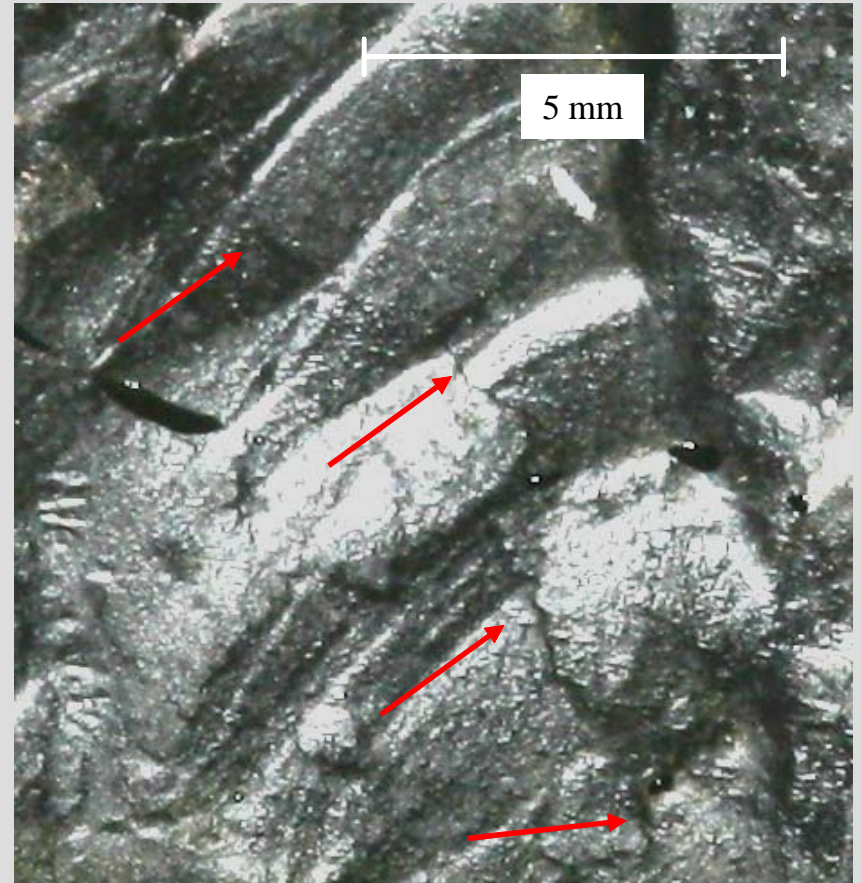


Nozzle #31- J-Groove Weld

Crack Locations



Crack at 100°



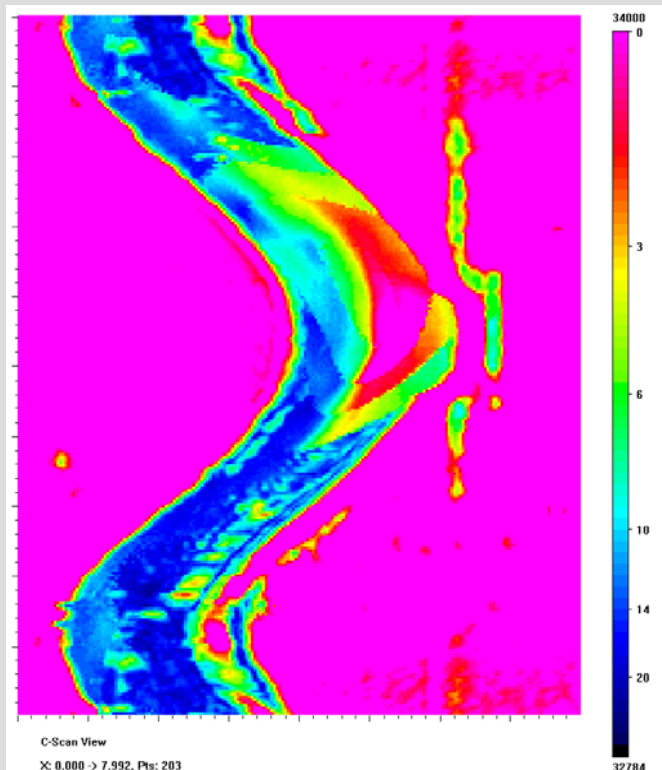
Nozzle #31 Summary

- ▶ The penetration tube shows no strong ET indications and no breaks in the lateral wave using TOFD.
- ▶ Immersion UT detected a very large indication in the J-groove weld metal that starts at 0° and continues to 50°.
- ▶ The J-groove weld metal crown surface shows cracking at 90-100 degrees via VT and an indication at 90° was detected by immersion UT.
- ▶ VT detected a crack-like indication at 270° that was not corroborated by the immersion UT.

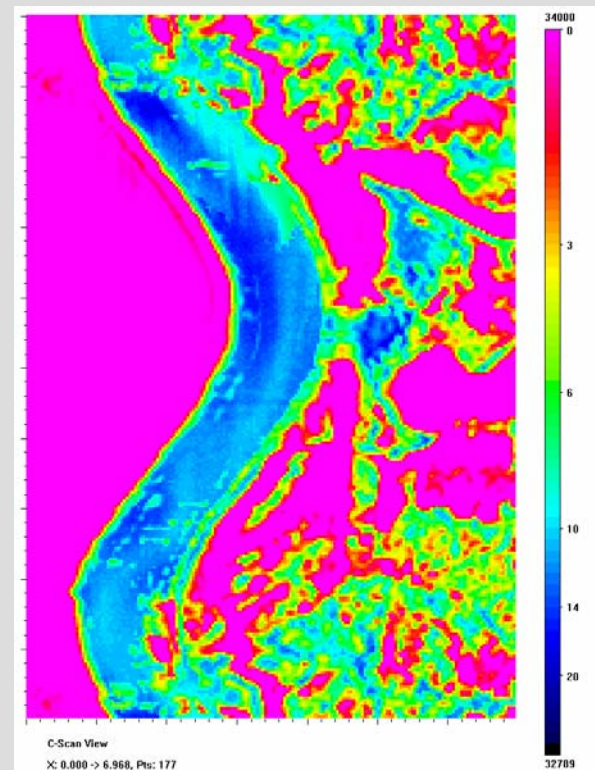
Nozzle #31 Summary

- ▶ In many places in the interference fit, the UT was well-coupled and produced a mottled pattern in the UT results. This is in strong contrast to the results seen in Nozzle #59 and the calibration Midland CRDM, where the interference fit allowed no coupling between the penetration tube and the carbon steel.

Nozzle #59 2.25 MHz



Nozzle #31 2.25 MHz



Conclusions

- ▶ The PNNL NDE inspections found crack-like indications in both Nozzles #59 and #31 that along with the ISI and round robin indications need to be validated by DE.
 - The penetration tube of Nozzle #59 showed crack-like indications
 - The J-groove weld and buttering of Nozzles #59 and #31 showed crack-like indications
- ▶ The J-groove weld of both Nozzles #59 and #31 showed evidence of embedded fabrication flaws such as lack-of fusion.
- ▶ The laboratory NDE results provide locations for many potential flaws. This information is being used to guide the destructive validation of flaws and PNNL is preparing to section the CRDMs for destructive validation beginning in June.

Acknowledgements

- ▶ Work funded by the Nuclear Regulatory Commission (NRC) Office of Nuclear Reactor Research.
- ▶ NRC Project Manager Wallace Norris on Y6867 and Carol Moyer for Y6534
- ▶ PNNL program supports the cooperative work between the NRC and the Electric Power Research Institute (EPRI)
- ▶ CRDMs from North Anna 2 supplied by EPRI