Comparison of Non-Destructive and Destructive Examination Findings for a Leak Path Assessment of a Pressurized Water Reactor Control Rod Drive Nozzle

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Outline

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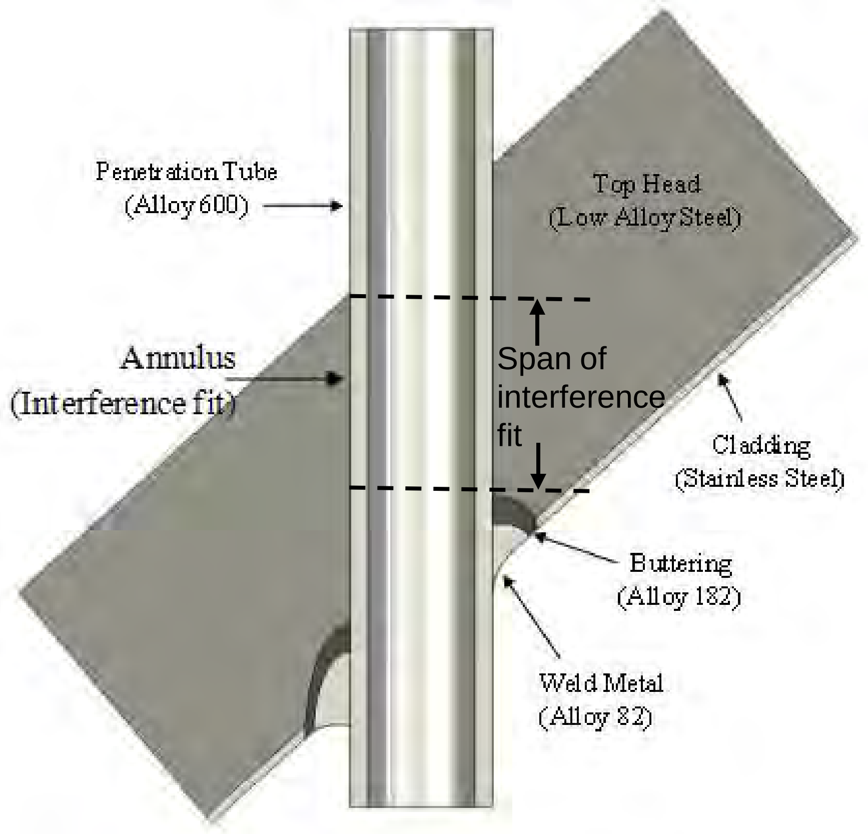
- Background and motivation
- Test setup and calibration
- Non-destructive examination findings
- Destructive examination findings
- Summary

Pressurized Water Reactor (PWR) Upper Head Penetrations



- Ni alloy penetration tube and J-groove weld
- Interference fit between penetration and reactor pressure vessel (RPV) head above J-groove weld

Leakage Through PWR Upper Head Penetrations

- Primary water stress corrosion cracking (PWSCC) of J-groove weld
- Leakage path through annulus of interference fit between nozzle and RPV head
- Title 10 Code of Federal Regulations, Part 50.55(a) requires demonstrated surface or volumetric leak path assessment for PWR upper head penetrations

Overview of NRC-Sponsored Research

- Conducted at Pacific Northwest National Laboratory
- Evaluated efficacy of ultrasonic testing (UT) methodology for leak path assessments of PWR upper head penetrations
- Compared UT findings to destructive examination
- Utilized Nozzle 63 from North Anna Unit 2:
  - Peripheral CRDM nozzle fabricated from Alloys 600/82/182
  - J-groove weld overlaid with Alloys 52/152 following indications of cracking and leakage in 2001 outage
  - RPV head replaced in 2002 following further indications of leakage

Testing Setup

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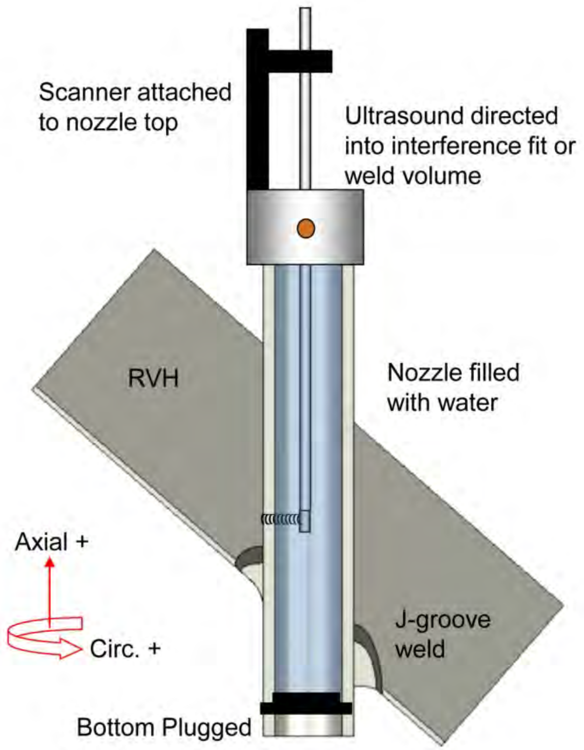
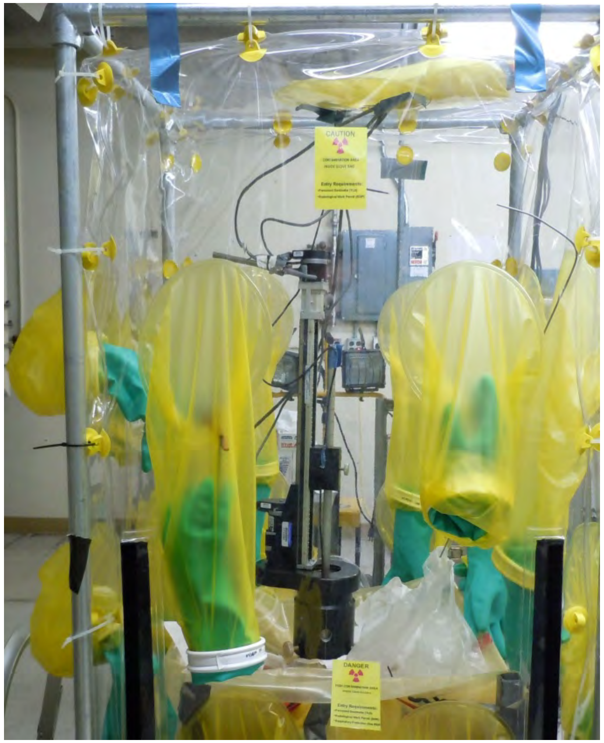
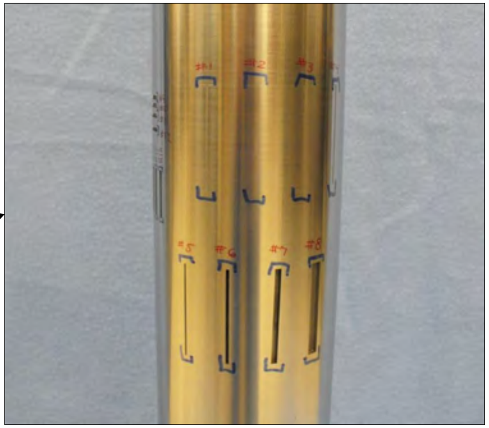


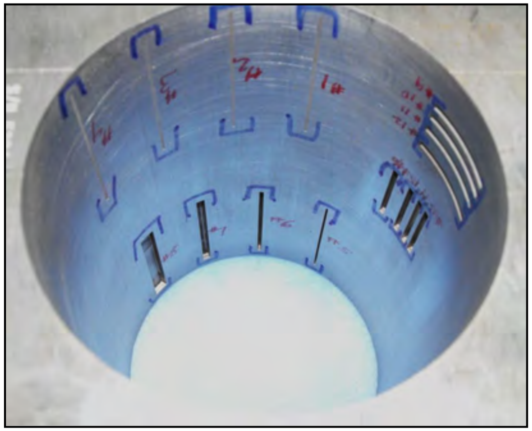


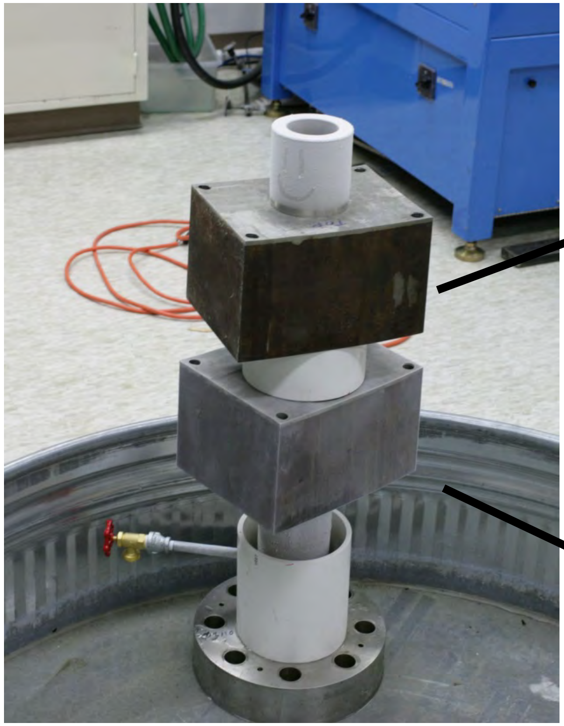
- Pulsed echo immersion 8-element phased array probe
- Scanning from nozzle inner diameter
- Axial and circumferential scanning

Calibration Mockup Design

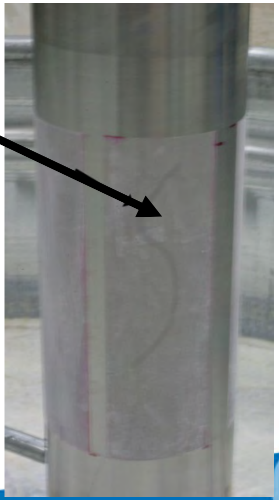
Machined notches simulate gap between nozzle and RPV head







Carbon steel blocks fit onto Alloy 600 tube



Simulated boric acid deposits in annulus

Calibration Mockup UT Response

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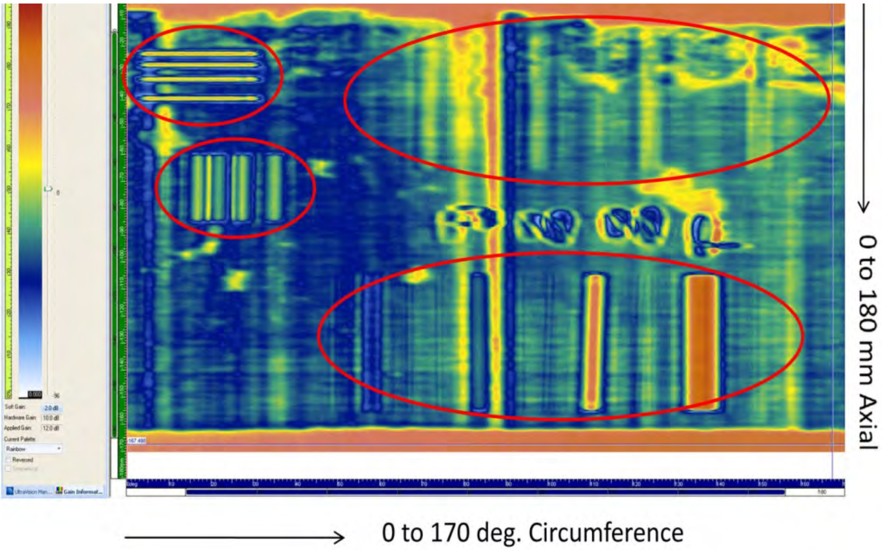
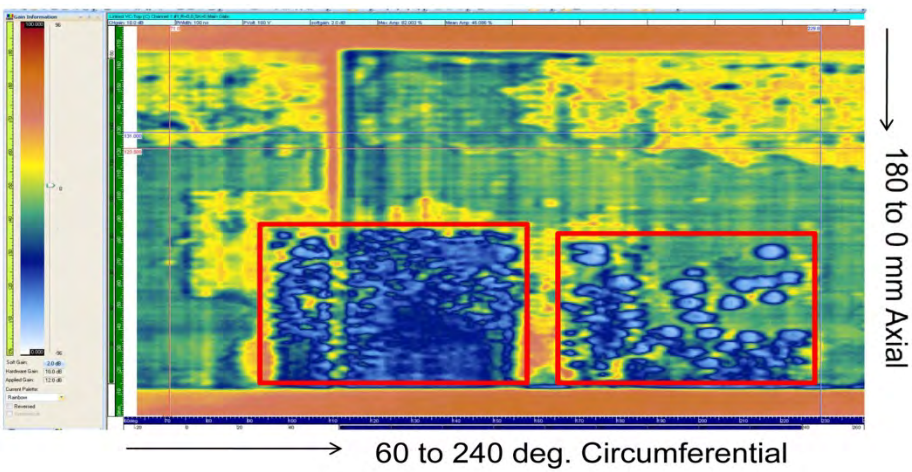
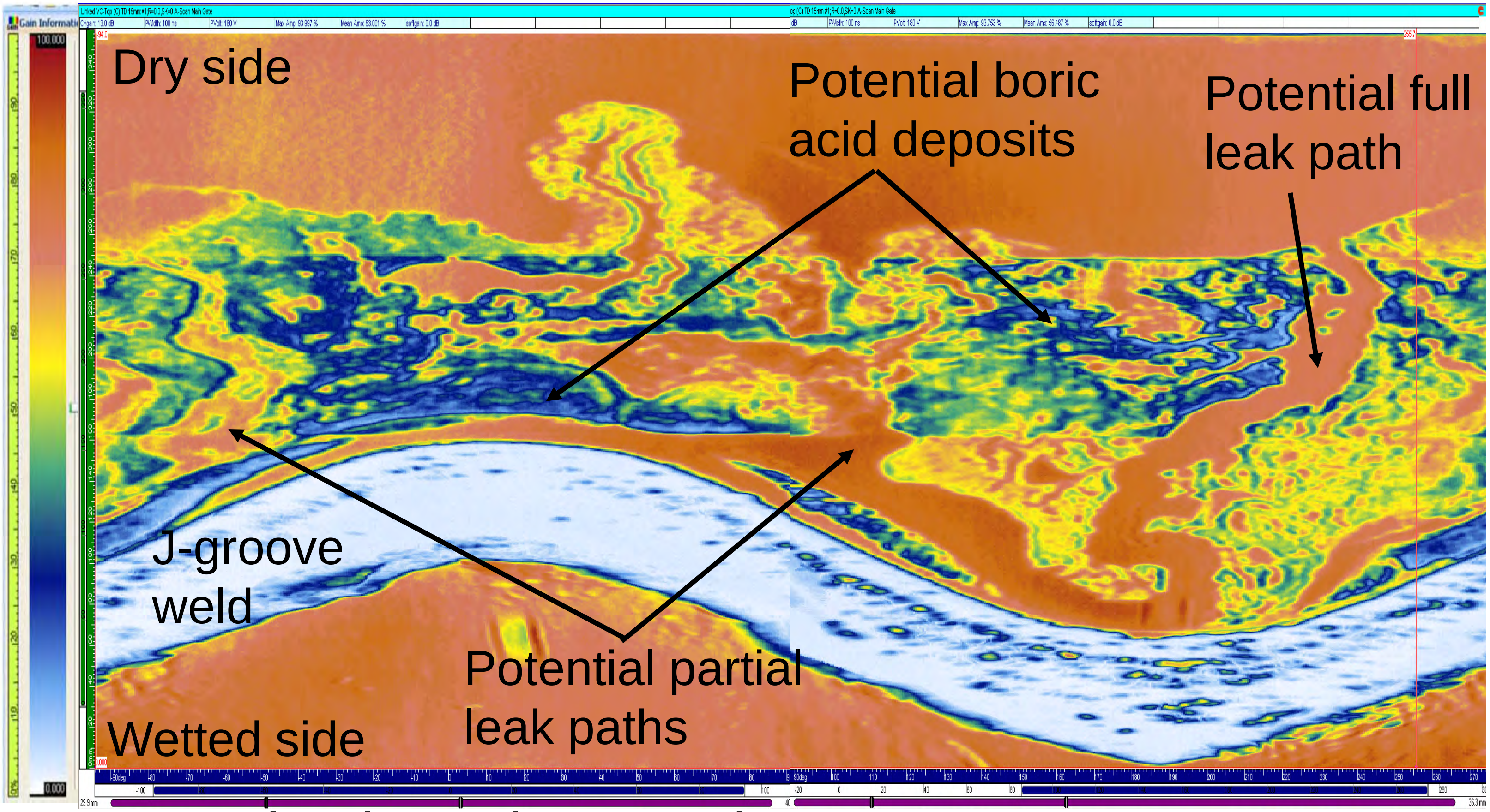


- Notch response:
  - Air gap between tube and block
  - Poor ultrasonic transmission
  - High amplitude signal response compared to background (orange and yellow)



- Boric acid deposit response:
  - Coupling between tube and block
  - Enhanced ultrasonic transmission
  - Low amplitude signal response compared to background (blue)

Nozzle 63 UT Response



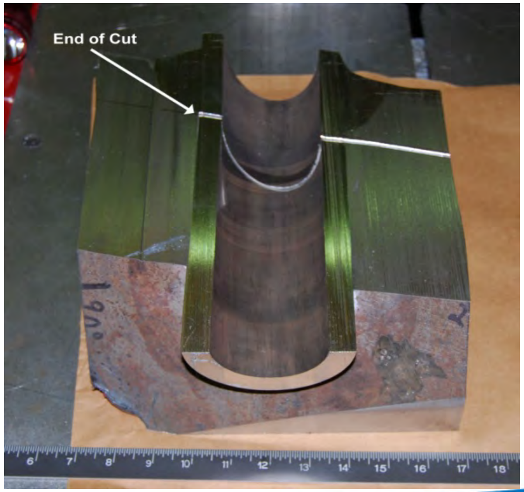
Interpretation based on mockup response:

- Orange = nozzle-to-air interface or gap between nozzle and RPV head
- Blue = boric acid deposit

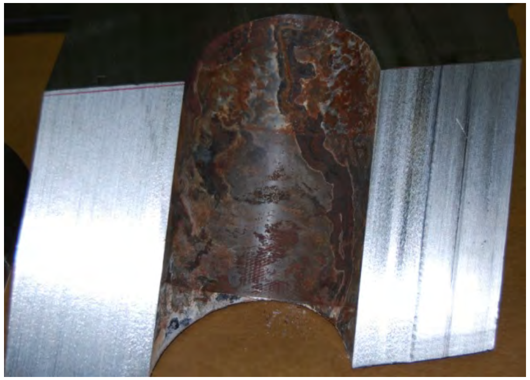
Destructive Examination of Nozzle 63

Bisection of nozzle

Removal of J-groove weld

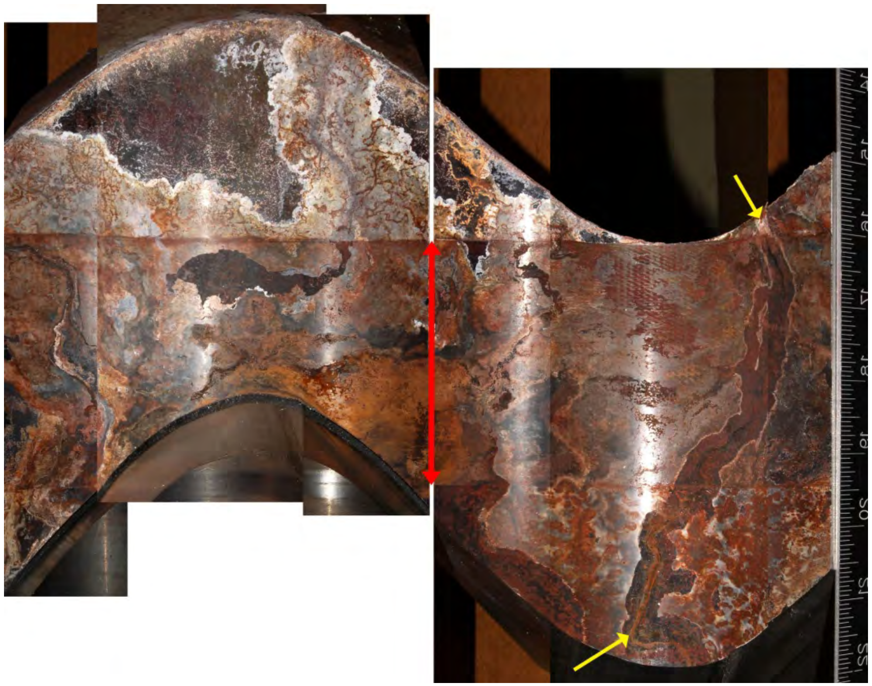


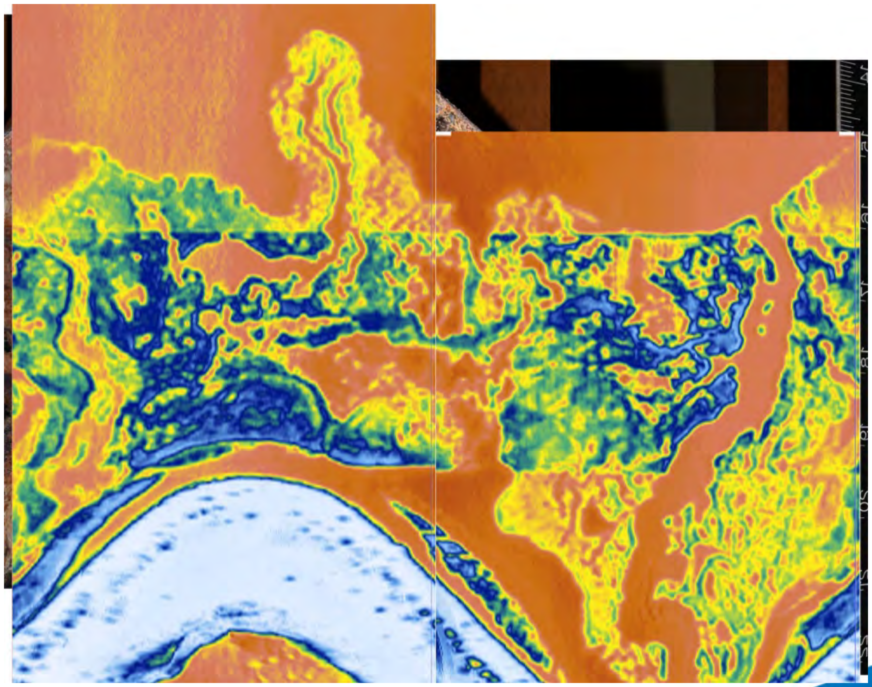
Separation of nozzle pieces from RPV head to reveal annulus of interference fit



Comparison of Annulus Surface to UT Response

RPV head annulus surface (red arrow indicates span of interference fit)





Good correlation between annulus condition and features identified in UT

Surface Deposit Thickness Measurements on RPV Head

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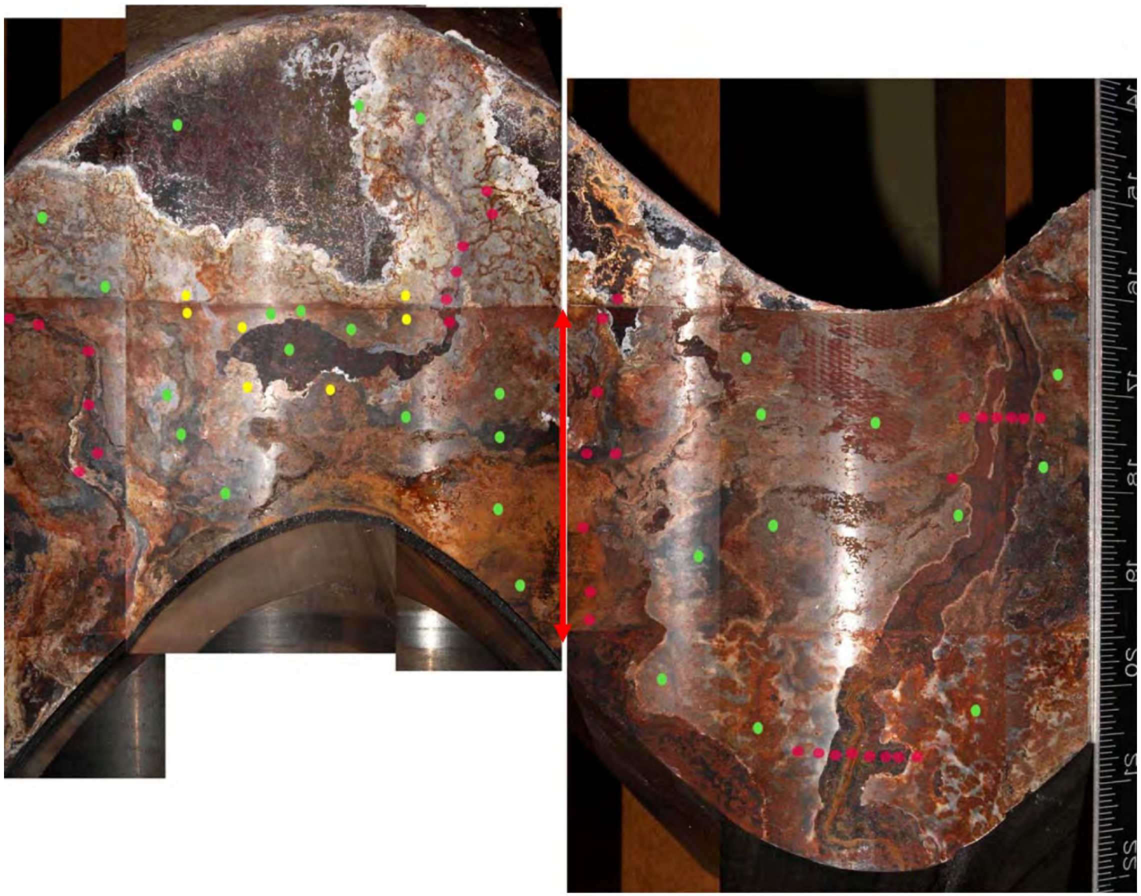
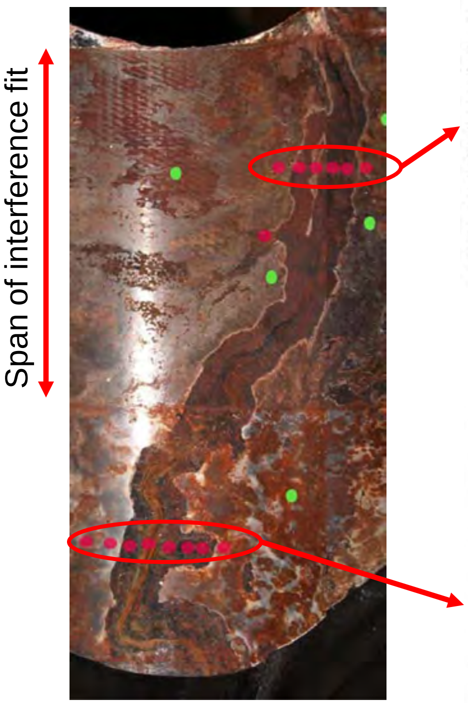


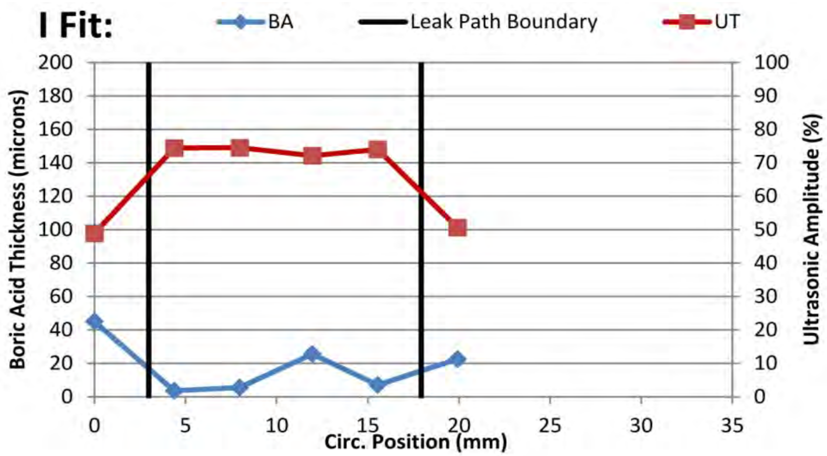
Eddy current probe measurements of surface deposit thickness, including:

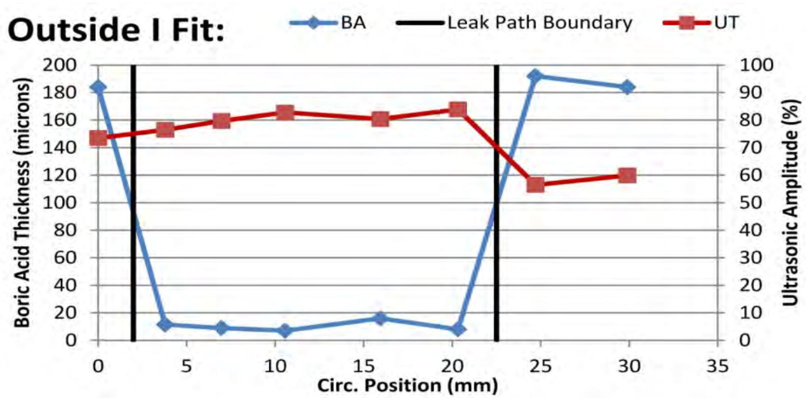
- Inside and above/below span of interference fit
- Profile across leakage path

Dots show locations of measurements

Deposit Thickness and UT Response Across Leak Path

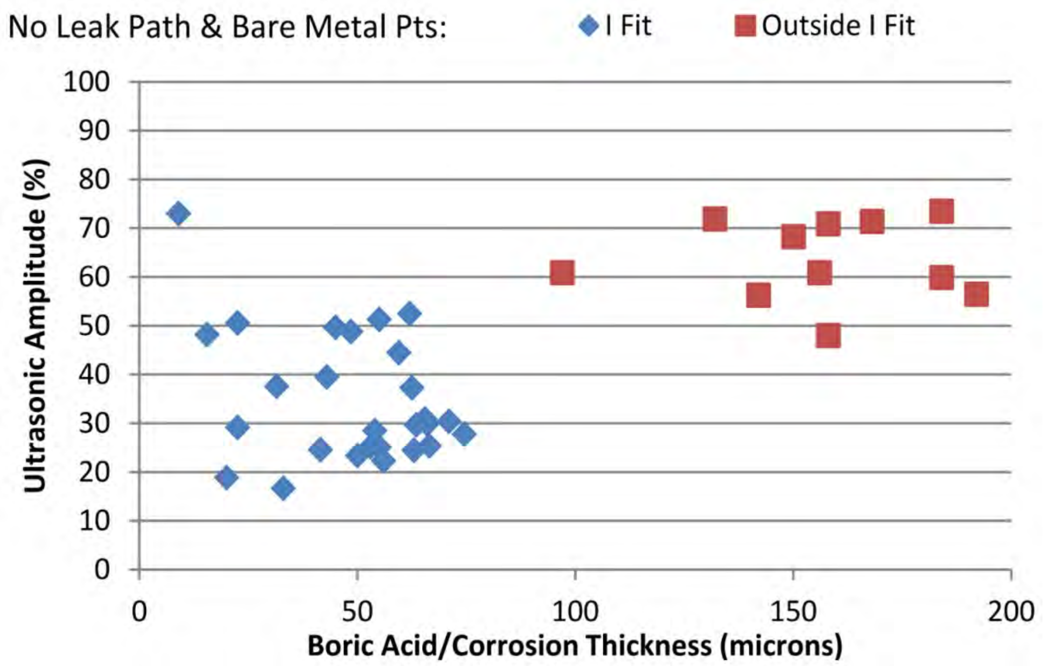






- Inside leak path
  - Low deposit thickness
  - High amplitude UT signal response
- Outside leak path
  - High deposit thickness
  - Low amplitude UT signal response

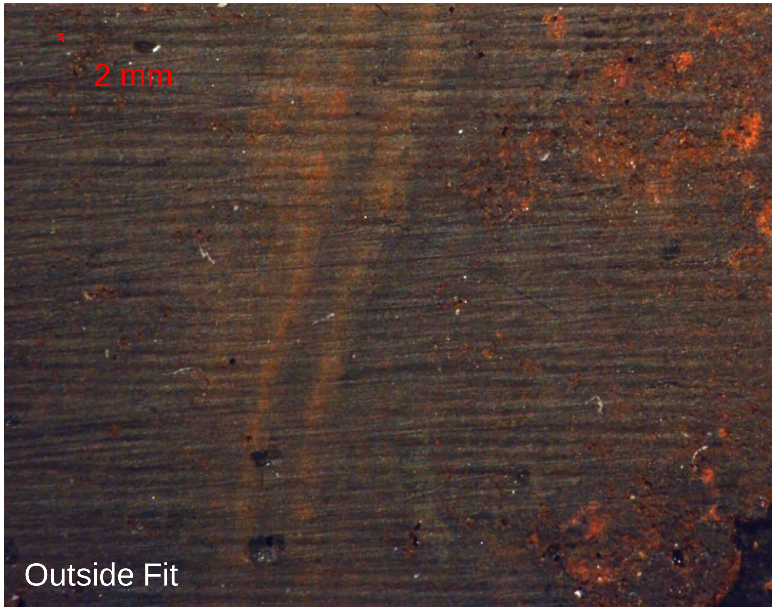
Deposit Thickness and UT Response Inside Vs. Outside Interference Fit

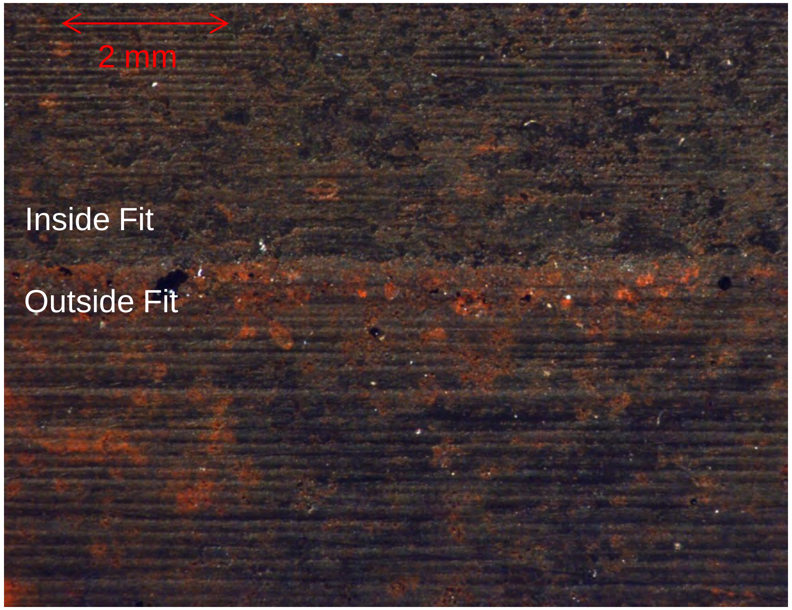


- Inside span of interference fit path
  - Lower deposit thickness
  - Lower amplitude UT signal response
- Outside span of interference fit
  - Higher deposit thickness
  - Higher amplitude UT signal response

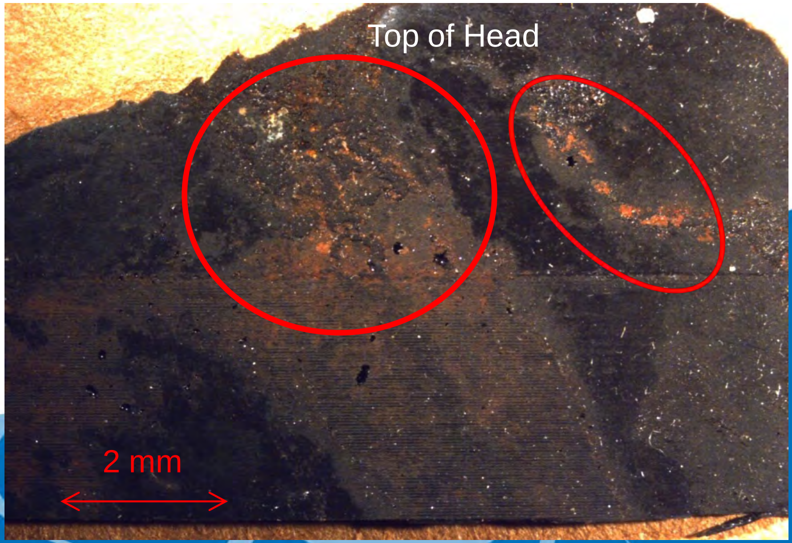
- Thinner but more compact deposits in span of interference fit that enhance UT transmission

Surface Replication of Leakage Path Area on RPV Head





- Microset replicant shows machining marks still visible in leak path
- Only minor corrosion or wastage visible near top side of RPV head
- Suggests minimal loss of material in leak path



Summary

- Good correlation between UT examination of Nozzle 63 and destructive analysis
- Leak path characterized by high amplitude UT response and low surface deposit thickness
- Deposits appear thinner and more compact and provide lower amplitude UT response inside span of interference fit compared to outside
- Minimal loss of material from corrosion in leak path

See Also…

- NUREG/CR expected in July/August, 2012
- A.D. Cinson, *et al.*, Proceedings of the 9th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, May 22-24, 2012, Seattle, WA, ADAMS ML121350004.
- A.D. Cinson, *et al.*, Proceedings of the 2012 SPIE Smart Structures/NDE Conference, March 11-15, 2012, San Diego, CA, ADAMS ML120800002.
- A.D. Cinson, *et al.*, Proceedings of the ASME Pressure Vessels and Piping Division PVP2011, July 17-21, 2011, Baltimore, MD, ADAMS ML111180425.