Status of Reactor Vessel Head Penetration Inspection Activities

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NRC-MRP Meeting

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EPRI NDE Center

Presentation Outline

- CRDM Issue Background
- Top-of-head Visual Exam Guidance
- MRP Approach to NDE Demonstration
- 2001 Demonstration Process & Results
- 2002 Demonstration Process & Results
- Future Demonstration Activities
- Other Future Inspection Committee Activities
  - Database??
- Summary

CRDM Head Penetration NDE Background

- **Original (97-01) demonstrations addressed cracks initiating on the inside surface of the penetration only**
- **Discovery of tube OD and weld cracking identified the need to modify the NDE demonstration program**
  - Inspection technology required rapid development, deployment and field adaptation of existing inspection equipment
- **Visual evidence of leakage vastly different from originally postulated**
- **First phase of MRP demonstrations was available to support fall 2001 inspections**
  - Detection of "safety-significant" flaws in the tube
- **Second phase performed to support fall 2002 inspections**
  - J-groove weld flaws
  - More base metal flaws to evaluate depth sizing

MRP Activities – Visual Examination Guidance

- **EPRI MRP Inspection Committee Task**

  - Develop visual inspection training package for fall 2001
    - Capture lessons learned related to conducting inspections and visual evidence

  - Updated TR was published for spring and Fall 2002 inspections

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MRP Approach to Demonstrations

- **<u>RPV Head Working Group</u> defines NDE objectives using analytical evaluations and service experience:**
  - Identify relevant flaw mechanisms
  - Define inspection locations & volumes (e.g., OD, ID)
  - Define ranges of flaws to address (depth, length, orientation)
- **<u>Inspection Working Group</u> develops demonstration program**
  - Approach
  - Mockup design & procurement
    - Specifications for flaws in mockups
    - Realism of mockups (geometry, distortion, clearance, access, scratches, magnetic deposits, etc.)
  - Demonstration protocol & schedules (blind/non-blind, scope, result reporting process)
- **<u>Tiger Team</u> formed to design mock-ups**
  - RPV Head Working Group
  - Inspection Working Group
    - Design criteria for mock-ups

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MRP Demonstration Process

- **All CRDM Head Penetration NDE demonstrations had the following characteristics:**
  - Blind
    - supported by non-blind preparation phases
  - Procedure demonstration
    - No acceptance criteria
    - Demonstration best available techniques
      - *ASME code will probably develop technique/personnel qualifications*
  - Measurements of flaw detection capability and limits
    - No acceptance (pass-fail) criteria

MRP Demonstration Process

- **Demonstration protocol**
  - Vendor collects data on mockups & reports findings
    - evaluates measured vs. true values
    - Detection (# detected/total flaws)
    - Location with respect to pressure boundary
    - Sizing results documented
    - False call performance
  - NDE Center documents procedure essential variables
    - Allows verification that the techniques used are the same techniques that were demonstrated
  - Analysis process used in the demonstration and must be captured in the procedure
  - Results are provided to utilities

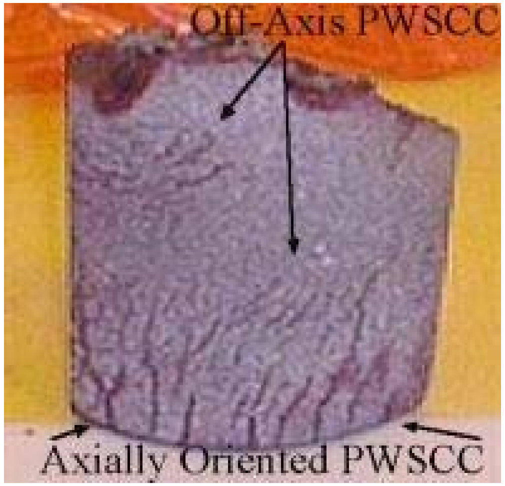
MRP Demonstration Process - Overview

- **Complicated examination volume**
- **Vendor UT inspection procedures include <u>many</u> technique options and probe combinations, examples:**
  - Open-tube probes
  - Blade probes
    - Probes are designed to accomplish specific objectives:
      - *Specific volumes*
      - *Flaw orientations, e.g., circumferential or axial flaws*
      - *Detection technique, e.g., corner trap or tip diffraction*
      - *Sizing technique*
- **MRP Demonstrations document performance of individual probes/scans**
  - More than one probe may be required to examine the specified inspection volume to detect/size specified flaw locations and orientations

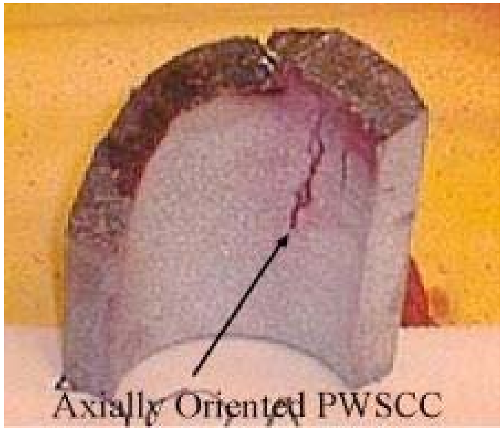
2001 Demo Description

- **Focus - Detection of "Safety-Significant" flaws in the tube base metal**
- **Mock-ups**
  - Oconee CRDM Penetration Tubes
    - Demonstrate flaw detection
    - Good range of flaw sizes and orientation
      - *OD Circumferential (up to 45 degrees off-axis), OD Axial, ID Axial*
  - Full-scale mock-up (Designed and deployed in 3 months)
    - Demonstrates effects of weld & capability to address geometry
      - *Deliver the tooling (i.e. maintain contact)*
      - *Query the appropriate inspection volume*
    - Important examination considerations
      - *Flaw location relative to weld*
      - *Flaw clusters*
      - *Triple-point indications*
    - Using EDM notches
    - Initial demo was blind; upon completion all data was shared with the inspection vendor to improve their techniques and train personnel.

2001 Demo Mock-ups - Oconee Specimens



- **Specimen #56**
  - OD-initiated PWSCC
    - Range of sizes & locations
  - Off-axis flaws (~45 degrees) are representative of circumferential flaw in outermost penetration



- **Specimen #50**
  - ID-initiated PWSCC

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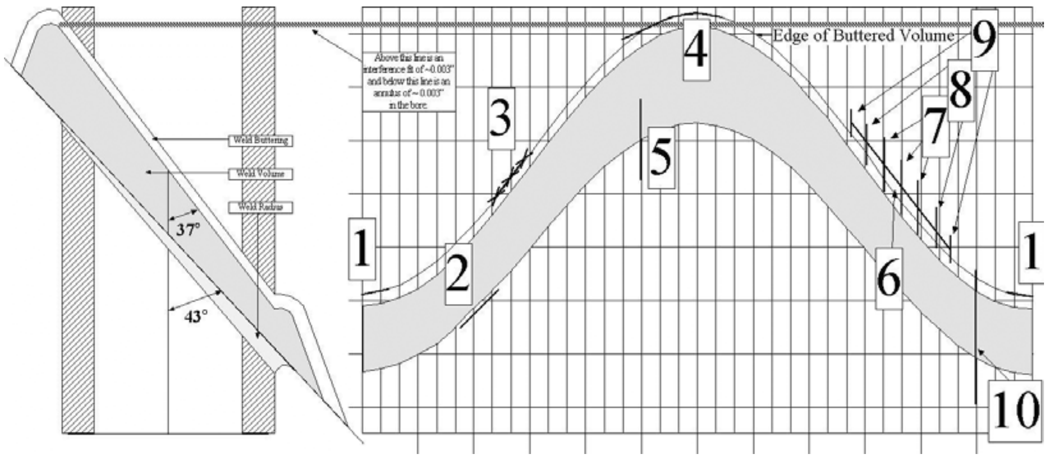
2001 Demo Mock-ups – Full Scale



- #1 & 4 – Circ. above weld. Corner trap one direction only. Min. skew angle. This circ position exhibits maximum distortion during fabrication, affecting UT contact.
- #2 – Circ. Below weld. No corner trap when UT oriented down. Near max skew angle.
- #3 – Circ. flaw at max skew. Cross-hatch simulates PWSCC affecting corner-trap
- #5 & 10– Axial flaw. Corner-trap lost over weld. Maximum distortion.
- #6,7, 8, 9 – Circ. & axial combination.

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2001 Demo - Participating Vendors

- **Three vendors participated**
  - WesDyne
    - Blade-probe and Open-tube UT and ET
  - Framatome
    - Blade-probe and Open-tube UT and ET
  - Tecnatom
    - Blade-probe and Open-tube UT and ET

2001 Demo Results

- **Distributed periodically by MRP**
- **Results summarize the capability of numerous probe types**
  - Vendors detected the crack tips in the Oconee tube ends after enhancing their procedures.
  - Vendors detected the flaws placed in the full scale mockup
- **In most cases, multiple demonstrations were supported**
  - As a result of
    - changing inspection requirements
    - equipment modifications and updates

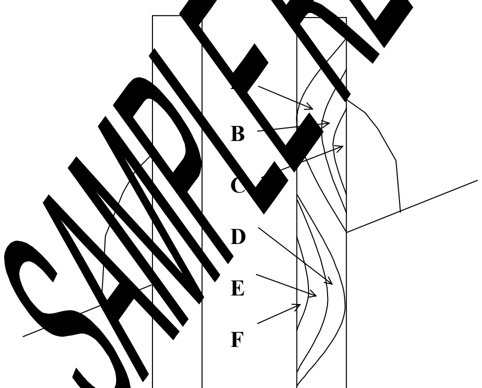
Vendor A 2001 UT Demo Results

Summary of Detection Techniques	A OD to ID	B OD to mid-wall	C Shallow OD-initiated	D ID to OD	E ID to mid-wall	F Shallow ID-initiated	Weld Mapping	Procedure # & Date	Demonstration Date
	WesDyne CRDM Demonstrations conducted for 97-01 (ID flaws).								
BP TOFD for Axial flaws (7 mhz)					D, S	D, S	M	EN 2.4.1 GEN 3 ***(1)***	02/1994
BP TOFD for Circ Flaws (7 mhz)					D, S	D, S	[illegible]	EN 2.4.1 GEN 3 ***(1)***	02/1994
BP ID ET					D, S	D, S	N/A		02/1994
RP TOFD for Axial Flaws (7 mhz)					D, S	D, S	M	EN 2.4.1 GEN 3 ***(1)***	02/1994
RP ID ET					D, S	D, S	N/A	***(1)***	02/1994
RP TOFD for Axial (7 mhz)					D, S	D, S	M	STD-AMD-061 ***(2)***	12/1996
RP ID ET					D, S	D, S	N/A	STD-AMD-061 ***(2)***	12/1996
BP TOFD for Axial flaws 10 mhz PCS 10 w/RD-Tech System					D, S	D, S	N/A	PB 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP TOFD for Axial flaws 6 mhz PCS 18 w/RD-Tech System					D, S	[illegible]	M	PB 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP TOFD for Circ flaws 10 mhz PCS 10 w/RD-Tech System					D, S	D, S	N/A	PB 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP TOFD for Circ flaws 6 mhz PCS 18 w/RD-Tech System					D, S	D, S	M	PB 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP ID ET					D, S	D, S	N/A	***(3)***	05/2000
	WesDyne CRDM Demonstrations conducted for MRP (OD flaws).								
BP TOFD for Axial flaws 6 mhz PCS 18 & PCS 24 w/RD-Tech System	***(4)***	***(4)***	***(4)***	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev. 0, 09/2001 ***(6)***	09/2001
BP TOFD for Circ flaws 6 mhz PCS 18 & PCS 24 w/RD-Tech System	***(4)***	***(4)***	***(4)***	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev. 0, 09/2001 ***(6)***	09/2001
BP PE for Circ flaws w/RD-Tech System	***(4, 7)***	***(4, 7)***	D	N/A	N/A	N/A	N/A	ISI-UT-002, Rev. 0, 09/2001 ***(6)***	09/2001
BP TOFD for Axial flaws 6 mhz PCS 18 w/Intraspect System	***(4, 5)***	***(4, 5)***	OR	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev. 0, 09/2001 ***(6)***	01/2002
BP TOFD for Axial Flaws 6 mhz PCS 24 w/Intraspect System	OR	D	D	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev. 0, 09/2001 ***(6)***	01/2002
BP TOFD for Circ flaws 6 mhz PCS 18 w/Intraspect System	***(4, 5)***	***(4, 5)***	OR	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev. 0, 09/2001 ***(6)***	01/2002
BP TOFD for Circ Flaws 6 mhz PCS 24 w/Intraspect System	OR	D	D	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev. 0, 09/2001 ***(6)***	01/2002
RP TOFD (only 5 mhz PCS 24 demonstrated) w/Intraspect System	OR	D	D	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	WDI-UT-008, Rev. 0 01/2002 ***(6)***	01/2002

Notes for Table:

BP: Blade Probe UT/ET.
TOFD: Time-of-Flight-Diffraction UT
PE: Pulse-Echo UT
D: Detected flaw successfully in Oconee specimens or EPRI 97-01 mock-ups. The 97-01 flaws were demonstrated to have similar ET and UT characteristics to PWSCC.
S: Sized flaw successfully in EPRI 97-01 mock-ups. The 97-01 flaws were demonstrated to have similar ET and UT characteristics to PWSCC. Sizing of OD initiated flaws not currently addressed by the MRP demonstration.
M: Weld mapping demonstrated with 97-01 mockups.
RP: Rotating Probe UT/ET.
OR: Outside depth range of probe design.

(1) Westinghouse Procedure (USA).
(2) ABB/CE Procedure (USA).
(3) Westinghouse TRC Procedure (Sweden).
(4) In the current MRP scope, but it was not demonstrated.
(5) Technically justified, based on the 97-01 demonstration results.
(6) WesDyne Procedure (Includes former Westinghouse-USA, ABB/CE-USA, and Westinghouse TRC-Sweden).
(7) Technically justified, based on detection of [illegible]-type (smaller) flaw.



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Demonstrations for 2002 & Future

Demonstration Scope

- Replaced EDM notches
  - More realistic using CIP processing
- Flaw characterization capabilities
  - Depth sizing
  - Length sizing
  - Location with respect to weld
- Increased population of flaws
- Attachment weld flaws
  - Identification of flaws reaching triple-point
- Effect of Cluster flaws
  - Masking flaws in remaining tube volume

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2002 Mockups – Tiger Team Goals

- Blind Mock-up
- Demonstrate sizing capabilities
- Full Scale Mock-up
- Establish Inspection Thresholds
- No POD
- Practice Blocks and Blind Blocks
- Include Effects of Crazed Cracking

2002 Mock-up Selection Considerations

- **Mock-up flaws must be representative and appropriate for the NDE Method(s) to be demonstrated**
  - Need to provide representative responses for:
    - UT
      - Specular reflection, Tip-diffracted response, Corner-trap response
    - ET
      - Realistic electromagnetic properties, crack width
- **Goal is realistic reproduction of Key detection or sizing variables**
  - Any differences are monitored and considered during the demonstration
- **Challenge: Numerous NDE methods are being applied & numerous flaw types/exam volumes to be considered**

2002 Mock-up Flaws Selected

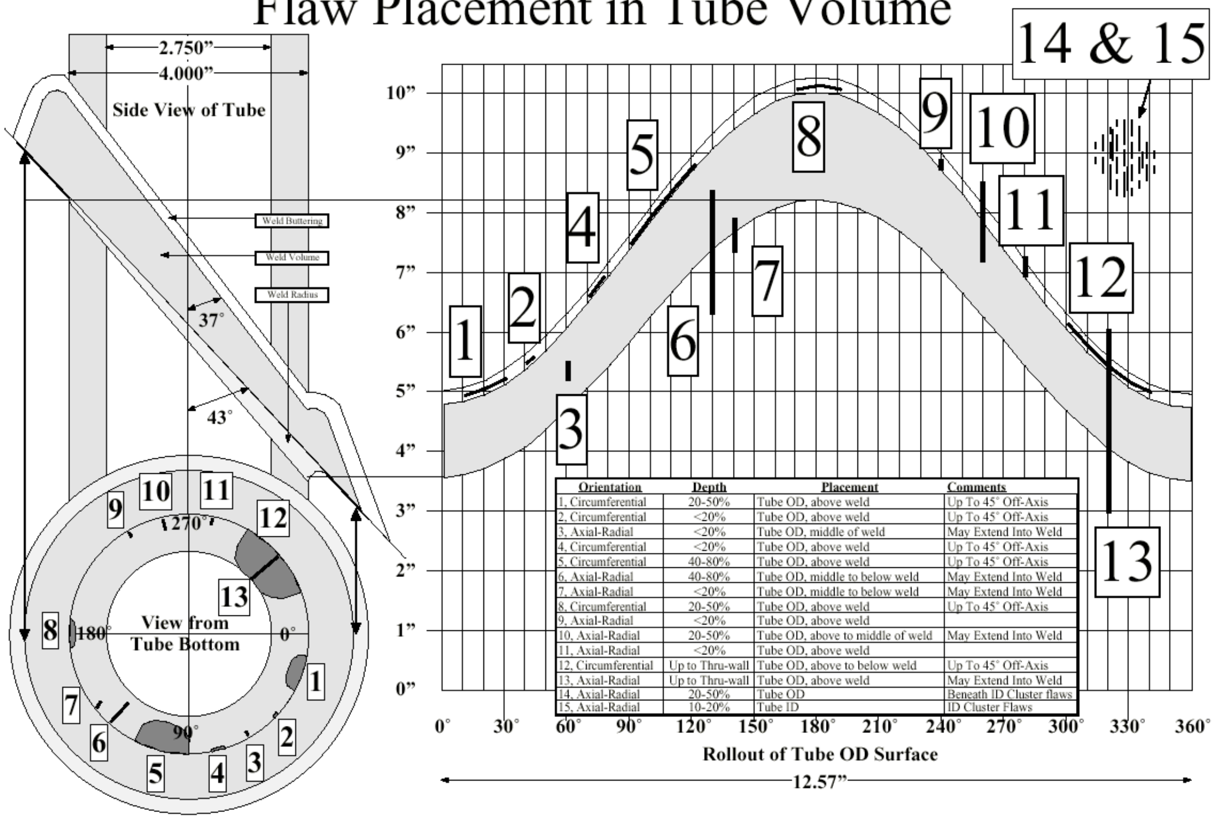
- **CIP**
  - Appropriate for ET
    - Tight, no unrealistic electromagnetic features
  - Appropriate for UT,
    - Comparable tip response
      - *Most important - primary method of detection*
    - Best control of flaw dimension
    - Realistic irregularity of flaw face in 600 tube
    - Branching simulated by using multiple flaws
- **Accelerated Corrosion Cracks**
  - Combined with CIP, will provide range of crack widths
  - No unrealistic electromagnetic features

2002 Mockups

- **Flaw types as determined by Tiger Team Committee**
  - Axial, circ, & off-axis tube flaws
    - ~20 flaws, up to 100% deep, 0.1 to 3.0" in length
  - Cluster flaws in tube
    - ~25 flaws up to 20% deep, 0.1 to .25" in length
  - Axial & circ. attachment weld flaws
    - ~15 flaws, up to 100% deep, 0.1 to 1.0" in length
    - Located at weld/head & weld/tube interface
      - *Most challenging geometry*
    - Flaws approaching & thru triple-point
      - *Allowing leak point to annulus*

2002 Mock-up – Tube Flaws

MRP CRDM Generic Mockup Layout for Flaw Placement in Tube Volume



Orientation	Depth	Placement	Comments
1, Circumferential	20-50%	Tube OD, above weld	Up To 45° Off-Axis
2, Circumferential	<20%	Tube OD, above weld	Up To 45° Off-Axis
3, Axial-Radial	<20%	Tube OD, middle of weld	May Extend Into Weld
4, Circumferential	<20%	Tube OD, above weld	Up To 45° Off-Axis
5, Circumferential	40-80%	Tube OD, above weld	Up To 45° Off-Axis
6, Axial-Radial	40-80%	Tube OD, middle to below weld	May Extend Into Weld
7, Axial-Radial	<20%	Tube OD, middle to below weld	May Extend Into Weld
8, Circumferential	20-50%	Tube OD, above weld	Up To 45° Off-Axis
9, Axial-Radial	<20%	Tube OD, above weld	
10, Axial-Radial	20-50%	Tube OD, above to middle of weld	May Extend Into Weld
11, Axial-Radial	<20%	Tube OD, above weld	
12, Circumferential	Up to Thru-wall	Tube OD, above to below weld	Up To 45° Off-Axis
13, Axial-Radial	Up to Thru-wall	Tube OD, above weld	May Extend Into Weld
14, Axial-Radial	20-50%	Tube OD	Beneath ID Cluster flaws
15, Axial-Radial	10-20%	Tube ID	ID Cluster Flaws

NOTE: Flaw locations and sizes are shown only to describe typical types of flaws to be included in blind mockups. Actual flaw sizes and locations are confidential. Drawing is not to scale.

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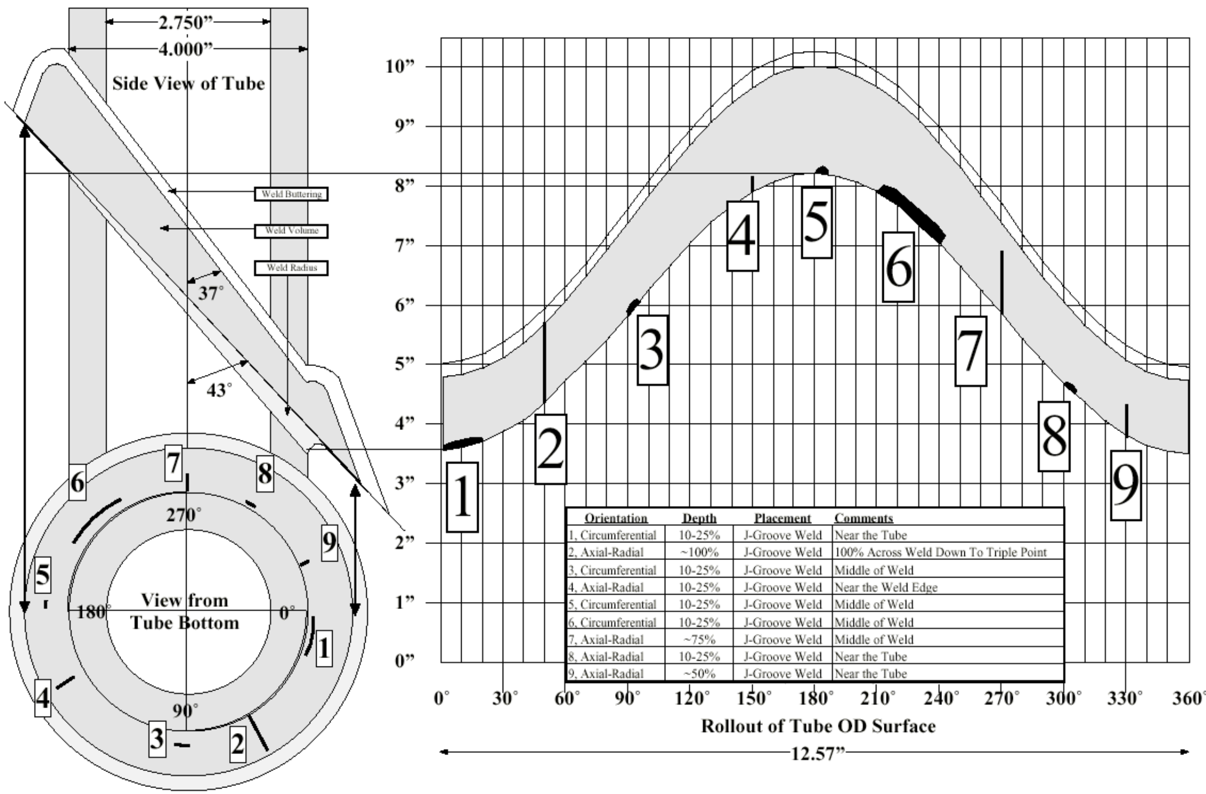
2002 Mock-up – Weld flaws

MRP CRDM Generic Mockup Layout for Flaw Placement in J-Groove Weld Volume

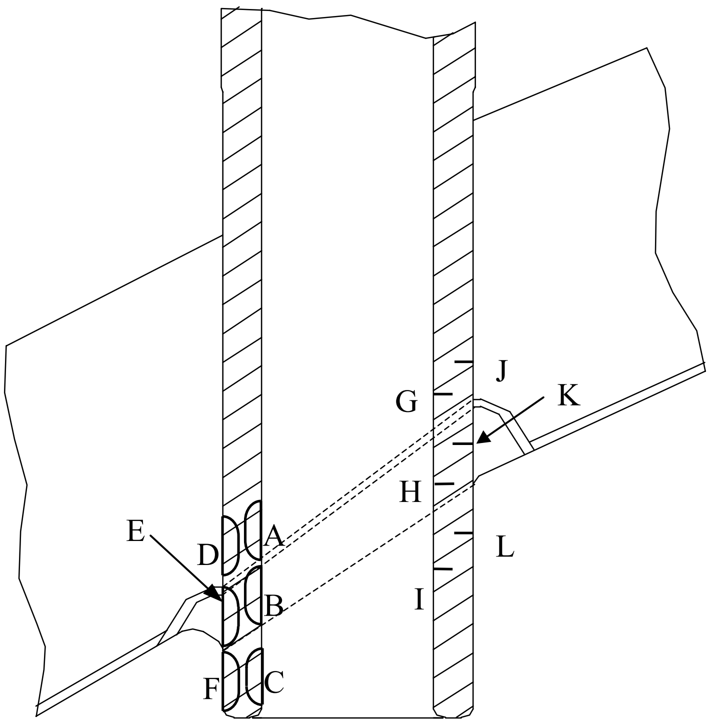


Orientation	Depth	Placement	Comments
1, Circumferential	10-25%	J-Groove Weld	Near the Tube
2, Axial-Radial	~100%	J-Groove Weld	100% Across Weld Down To Triple Point
3, Circumferential	10-25%	J-Groove Weld	Middle of Weld
4, Axial-Radial	10-25%	J-Groove Weld	Near the Weld Edge
5, Circumferential	10-25%	J-Groove Weld	Middle of Weld
6, Circumferential	10-25%	J-Groove Weld	Middle of Weld
7, Axial-Radial	~75%	J-Groove Weld	Middle of Weld
8, Axial-Radial	10-25%	J-Groove Weld	Near the Tube
9, Axial-Radial	~50%	J-Groove Weld	Near the Tube

NOTE: Flaw locations and sizes are shown only to describe typical types of flaws to be included in blind mockups. Actual flaw sizes and locations are confidential. Drawing is not to scale.

2002 Demo Tube Flaw mock-up "J"

- Full-scale mock-up with CIP flaws in tube



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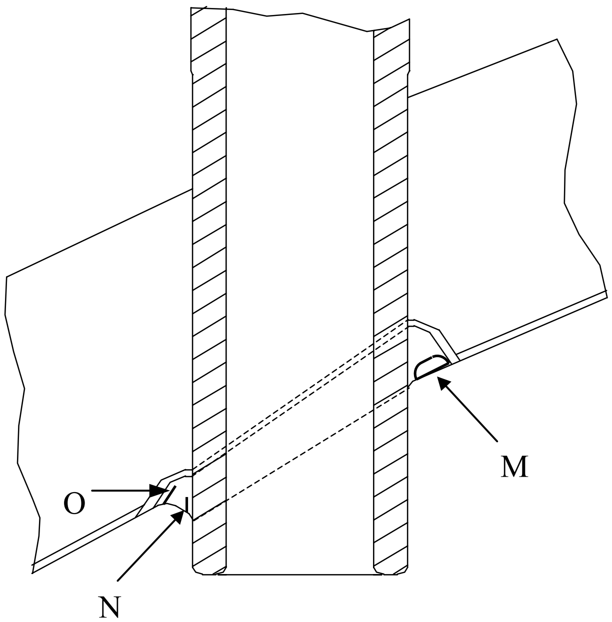
2002 Demo Weld Flaw Mock-up "K"

- **CIP flaws for**
  - UT from inside surface of tube
  - And ET from the wetted surface



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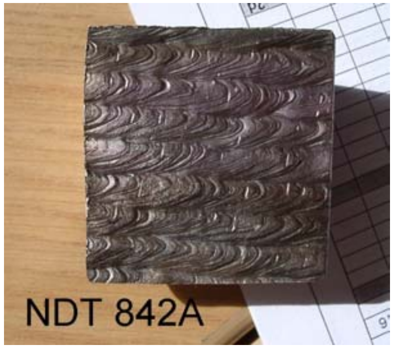
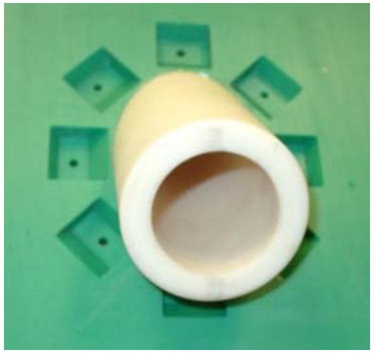
2002 Demo Weld Flaw Mock-up "L"

- **SCC flaw coupons for demo of ET on wetted surface**
- **Coupons contain cracks of varying**
  - width
  - length
  - Orientation





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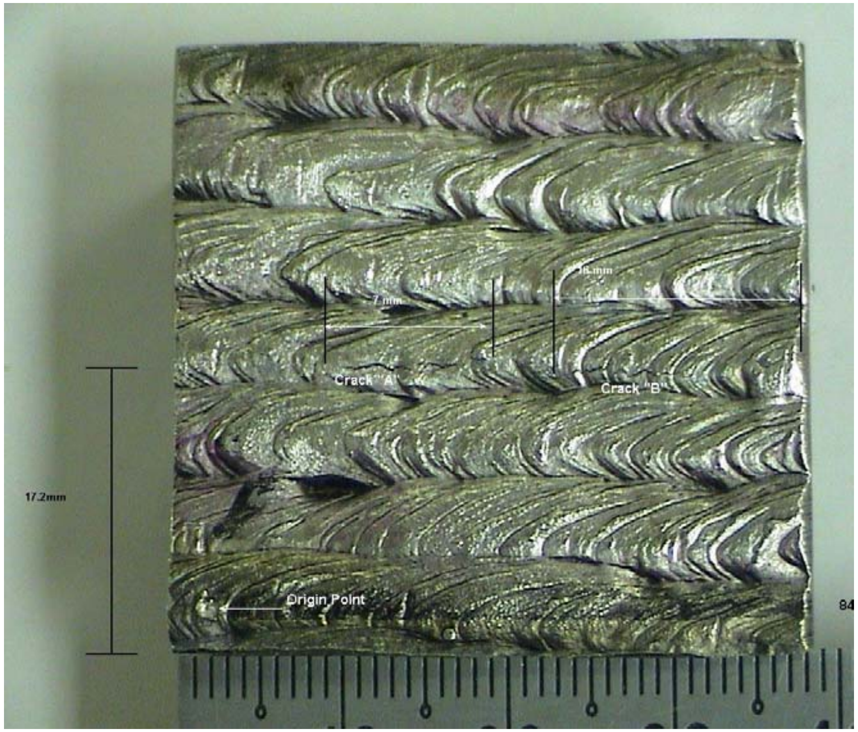
2002 Demo – Mock-up "L" Crack Specimens

- **Laboratory-grown SCC**
- **As-welded and ground surfaces**
- **Flaws vary in:**
  - Length, width, orientation with respect to weld direction



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2002 Demonstrations – Vendor A

- **Blade-Probe UT of penetration tube**
  - Flaws ranging ~ 15 to 100% TWE detected when flaws are oriented perpendicular to beam direction
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction
- **Open-tube "Rotating" probe of penetration tube**
  - Flaws ranging ~ 13 to 100% TWE detected when oriented perpendicular
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction

2002 Demonstrations – Vendor B

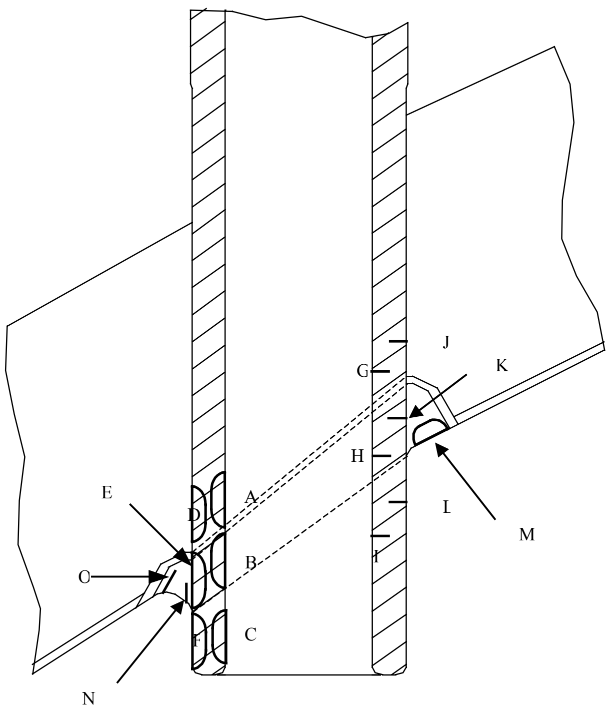
- **Blade-Probe UT of penetration tube**
  - Flaws ranging ~ 15 to 100% TWE detected when when flaws are oriented perpendicular to beam direction
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction
- **Open-tube "Rotating" probe of penetration tube**
  - Flaws ranging ~ 10 to 100% TWE detected when flaws are oriented perpendicular to beam direction
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction
- **Open-tube "Rotating" probe of tube/weld interface**
  - Tube/weld interface flaw detected when flaw length extended to triple-point
  - Weld metal flaws that did not extend to the triple point were not detected.

2002 Demonstrations - Vendor C

- **Blade-Probe UT of penetration tube**
  - Flaws ranging ~ 16 to 100% TWE detected when flaws are oriented perpendicular to beam direction
  - Flaws ranging ~18 to 100% TWE detected when flaws are oriented parallel to beam direction
- **Open-tube “Rotating” probe of penetration tube**
  - Flaws ranging ~ 13 to 100% TWE detected when oriented perpendicular
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction

Flaw Designations Nomenclature

Flaw Designation	Flaw Description	Contained in Mockups
A	ID Axial Above the Weld	Yes
B	ID Axial Over the Weld	Yes
C	ID Axial Below the Weld	Yes
D	OD Axial Above the Weld	Yes
E	OD Axial Over the Weld	Yes
F	OD Axial Below the Weld	Yes
G	ID Circumferential Above the Weld	N/A (Note 1)
H	ID Circumferential Over the Weld	N/A (Note 1)
I	ID Circumferential Below the Weld	Yes
J	OD Circumferential Above the Weld	Yes
K	OD Circumferential Over the Weld	Yes
L	OD Circumferential Below the Weld	Yes
M	Axial/Radial @ Wetted Surface of the J-Groove Weld	Yes
N	Circumferential/Axial (reference to tube) on Wetted Surface near interface of tube to J-Groove Weld	Yes
O	Circumferential/Axial (referenced to tube) on Wetted Surface near Head (clad) to J-Groove Weld	Yes
Notes:	(1) Presence of back-wall does not influence detection and analysis of ID surface initiated flaws to the degree that it affects OD surface initiated flaws	



Vendor A UT Detection Results

Field Used UT Techniques	Vendor A – UT Blade & Open Tube Probe Detection Results See Flaw Table 4 and drawing for description of flaw types "A" through "O"					
	A, B, & C ID Axial Flaws	**G, H, & I** ID Circumferential Flaws	**D, E, & F** OD Axial Flaws	**J, K, & L** OD Circumferential Flaws	**M, N, & O** Weld Flaws	**Cluster Flaws** OD Flaws under shallow (< 3 mm deep) ID Cluster Flaws
"Axial Blade" (TOFD UT COAF) (Note 1) **3 degree scan increment**	5%-86% TWE detected (Note 4) Orientation of flaws < 12 % TWE was inconsistent (Note 5)	11%-49% TWE detected Orientation of flaws < 12 % TWE was inconsistent	28%-100% TWE detected 4 flaws < 24% TWE missed: 1-D type flaw, 1-E type flaw, 2-EF type flaws	15%-100% TWE detected 1 K-type false call @ 7% TWE (Note 6)	(Note 7)	100% detection of ID & OD
"Circ Blade" (TOFD UT AOCF) (Note 2) **3 degree scan increment**	11%-86% TWE detected 1 B type flaw < 5% TWE missed Orientation of flaws < 12 % TWE was inconsistent (Note 5)	11%-49% TWE detected Orientation of flaws < 12 % TWE was inconsistent	15%-100% TWE detected 4 flaws < 13% TWE missed: 2-D type flaws, 1-E type flaw, 1-EF type flaw	15%-100% TWE detected 1 K-type false call @ 15% TWE (Note 6)	(Note 7)	100% detection of ID & OD
"Open-Tube" (Note 3) **5 degree scan increment**	5%-86% TWE detected (Note 5)	11%-49% TWE detected	13%-100% TWE detected 3 flaws < 12% TWE missed: 1-D type flaw, 1-E type flaw, 1-EF type flaw	15%-100% TWE detected 1 K-type false call @ 15% TWE (Note 6)	(Note 7)	100% detection of ID & OD
"Open-Tube" (Note 3) **3 degree scan increment**	5%-86% TWE detected (Note 5)	11%-49% TWE detected	13%-100% TWE detected 3 flaws < 12% TWE missed: 1-D type flaw, 1-E type flaw, 1-EF type flaw	15%-100% TWE detected 1 K-type false call @ 15% TWE (Note 6)	(Note 7)	100% detection of ID & OD
Notes:	(1) TOFD UT COAF (Circumferentially Oriented for Axial Flaws) used for detection and sizing of flaws. (2) TOFD UT AOCF (Axially Oriented for Circumferential Flaws) used for detection and sizing of flaws. (3) TOFD UT COAF/AOCF, Pulse/Echo, and 0 degree used for detection and sizing of flaws. (4) Through-wall-extent (TWE) of flaw depth in the tube thickness. (5) Inadequate resolution to separate closely associated (approx. 3 mm spacing) flaws. (6) Appears to be a welding defect at the tube-to-weld-interface. (7) Equipment and procedure were not optimized to resolve indications extending beyond the tube-to-weld interface in the weld volume.					

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2002 Demonstrations
ET of Attachment Weld

- **Detection is sensitive to weld surface conditions**
  - Ground Surface Condition
    - Detected 0.16″ long, 0.00031″ wide
  - Un-ground (as-welded) Surface Condition
    - Detected 0.55″ long, 0.00197″ wide
    - Missed; 1.42″ long, 0.00591″ wide
  - Continue to pursue additional/alternate techniques to improve the detection capabilities

Future Demos

- **Tecnatom**
  - ET of Attachment Weld
    - Delayed to July 2003
- **Framatome**
  - ET of Attachment weld
    - Conducted in April 2003
    - Improvements to be made and rescheduled for May 2003
    - Delayed to mid-June 2003
  - "Other" surface method for wetted surface of attachment weld
    - Scheduled for 1st quarter of 2003 – vendor delayed – waiting for new date

Future Demos (cont'd)

- **WesDyne**
  - UT of tube/weld interface
  - ET of attachment weld
  - Thermal imaging
- **B&W Canada**
  - UT of tube/weld interface
    - Scheduled for end of April 2003 - completed
  - ET of attachment weld
    - Scheduled for end of May 2003
    - Vendor delayed, waiting on new date

Future Activities

- **New mock-ups under construction**
  – Existing mock-ups will be made available to vendors for personnel training and technique refinement
- **Replacement head inspection**
  – Equivalence studies
  – Mock-up drawings
- **North Anna Head**
  – Coordinate & Support Data collection by other Vendors
  – Support sectioning and required NDE

Summary

- MRP has organized a comprehensive approach to address recent industry events
- Considerable progress has been made in a short amount of time
- Demonstrations continuing
- Emphasis on examination of attachment weld and increased inspection efficiency