Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

PNNL-SA-115353

Non-destructive Evaluation of Butt-fusion Joint Integrity in High Density Polyethylene Piping

INDUSTRY/NRC NDE TECHNICAL INFORMATION EXCHANGE PUBLIC MEETING

JANUARY 21, 2016

KM DENSLOW, SL CRAWFORD, TL MORAN, MS PROWANT, RE JACOB, TS HARTMAN, RA MATHEWS, KJ NEILL
AD CINSON* AND CA NOVE*

*U.S. NUCLEAR REGULATORY COMMISSION | OFFICE OF NUCLEAR REGULATORY RESEARCH

Outline

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Introduction
- Project Test Plan Summary
  - Probes
  - Pipe
  - Technical approach
- Progress
- Conclusions
- Observations
- Future Work

Introduction

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

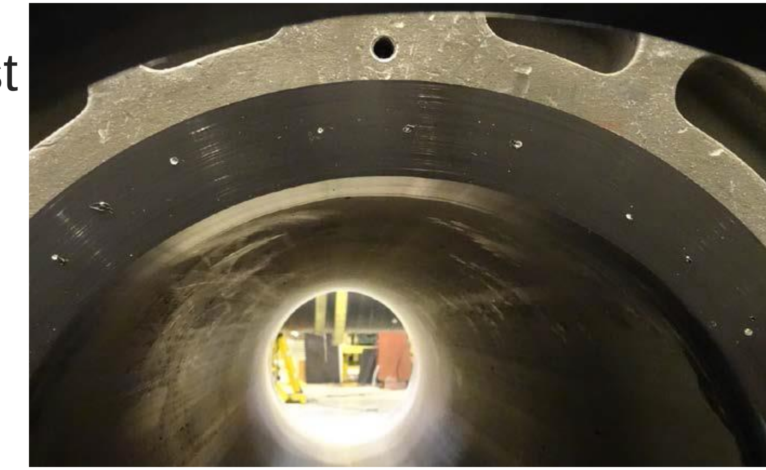
- Confirmatory research activities are funded by the U.S. Nuclear Regulatory Commission (NRC)
- PNNL is to conduct a review/assessment of NDE being proposed in ASME Code/Section III to ensure high-quality product enters service and structural integrity is maintained during service
- Focus of work:
  - Ultrasonic phased-array volumetric inspection of high-density polyethylene (HDPE) butt-fusion joints

This work is supported by the U.S. NRC – Office of Research
Tony Cinson, COR and Carol Nove, delegate COR

Introduction

Summary of progress made toward completing an evaluation of the phased-array ultrasonic test (PA-UT) method for its ability to detect:

- planar flaws (represented by S/S discs/pieces)
- particulate contamination (mimicked by tungsten powder)
- cold fusion fabrication flaws (attempted in-situ fabrication)



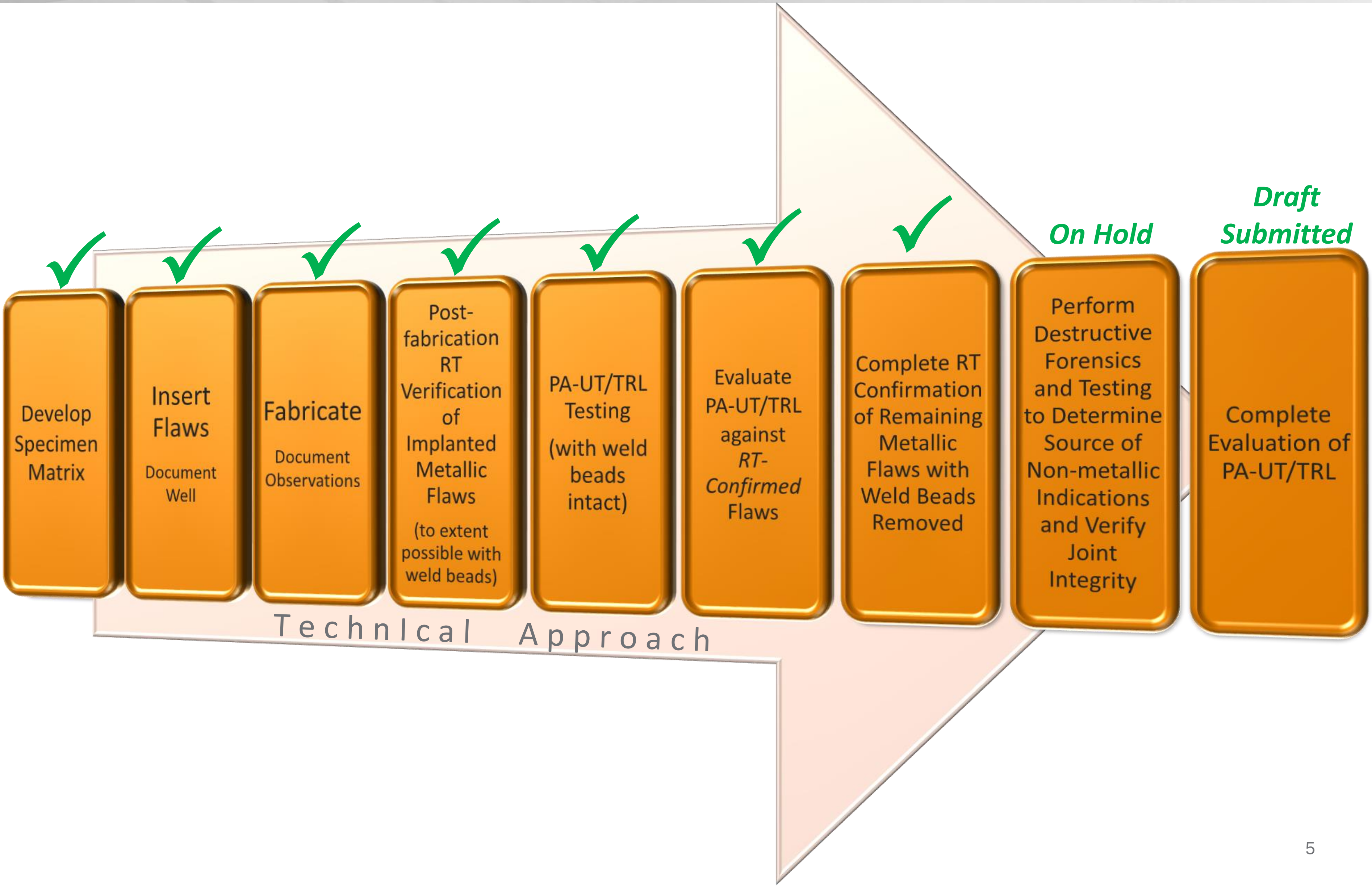
In:

- 12-inch dia., DR11 HDPE thermal butt-fusion joint specimens

Using:

- 2-MHz PA-UT probes
  - operating in transmit-receive longitudinal (TRL) mode
  - at three different aperture sizes (same element size)
- standard signal amplitude based signal analysis for flaw detection

Technical Approach and Progress

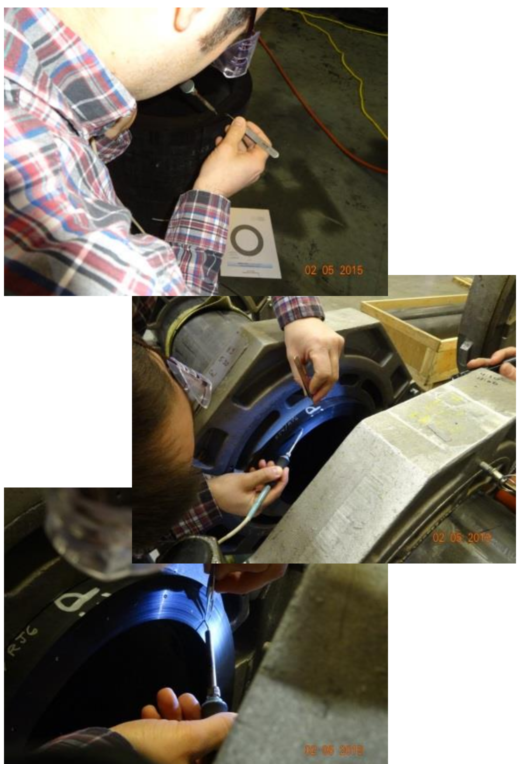


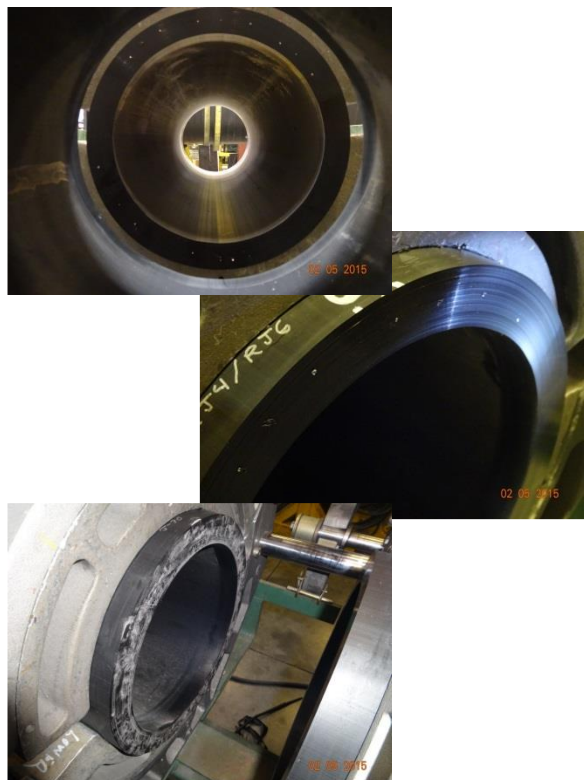
Specimen Matrix

ID No.	Pipe Number	Distance between Joints, in.	Joining Protocol	Flaw Type & Material	Flaw Size	Pre-fabrication Implanted Flaw Location
J-28	32	~ 12	ASME Code	None	None	None
RJ4/ RJ6	32	~ 12	ASME Code	Planar flaws, all discs fabricated from 0.02 mil thick S/S shim stock	2.17 mm (0.0854 in.), 1.38 mm (0.0543 in.), and ~0.8 mm (0.0315 in.)	Mid-wall and ±25% of mid-wall
RJ4/ RJ6-2	32	~ 12	ASME Code	Planar flaws, all discs fabricated from 0.02-mil thick S/S shim stock	2.17 mm (0.0854 in.), 1.38 mm (0.0543 in.), and ~0.8 mm (0.0315 in.)	Mid-wall only
RJ-8	32	~ 12	Violated ASME Code – limited to 2-minute heat soak	Planar flaws, all discs fabricated from 0.02-mil thick S/S shim stock; attempted cold fusion	2.17 mm (0.0854 in.), 1.38 mm (0.0543 in.), and ~0.8 mm (0.0315 in.)	Mid-wall only
J-29	33	~ 12	ASME Code	Coarse particulate contamination (tungsten particles)	118 micron (4.65E-3 in.) dia. (d_{50})	ID to OD, all quadrants
J-30	33	~ 12	ASME Code	Fine particulate contamination (tungsten particles)	26 micron (1.0E-3 in.) dia. (d_{50})	ID to OD, all quadrants
J-31	32	~ 12	Violated ASME Code – excess interfacial pressure applied during heat soak	Attempted cold fusion	N/A	N/A

Fabrication

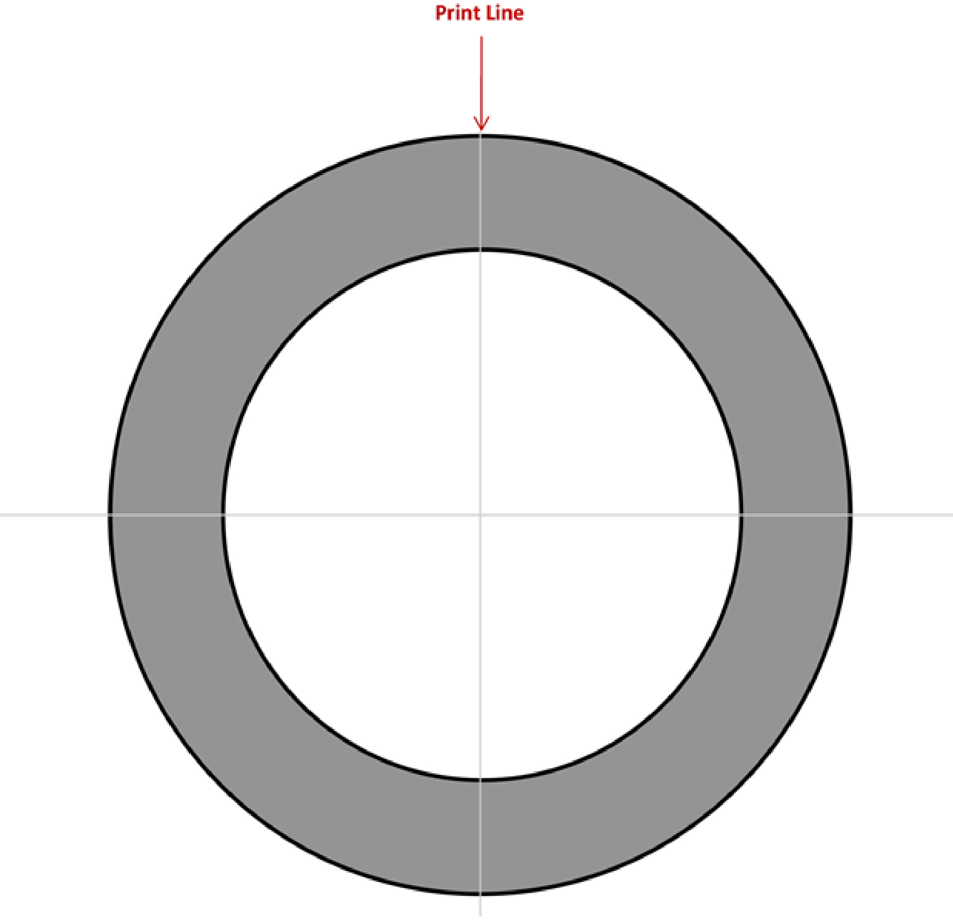
- Implanted flaw types
  - None (baseline)
  - Planar flaws (S/S discs/pieces)
  - Particulate contamination (tungsten powder)
  - Attempted cold fusion (compromised heat soak)



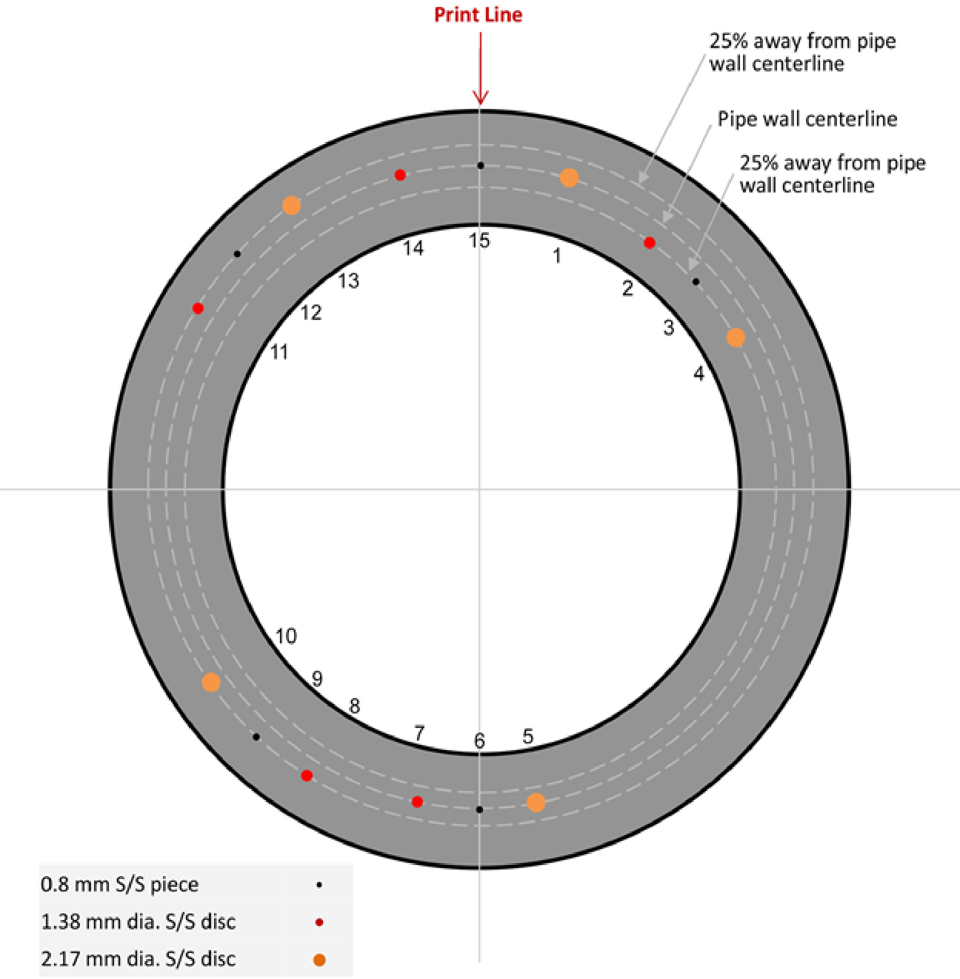


Test Specimens: Pre-fabrication State

Specimen J-28 (baseline; no implanted flaws)
Fabrication: TR-33

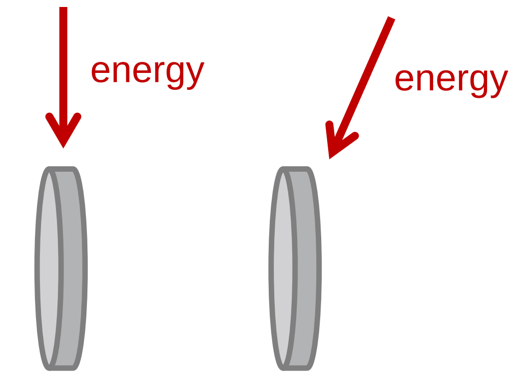


Specimen RJ4/RJ6 (planar flaws)
Fabrication: TR-33

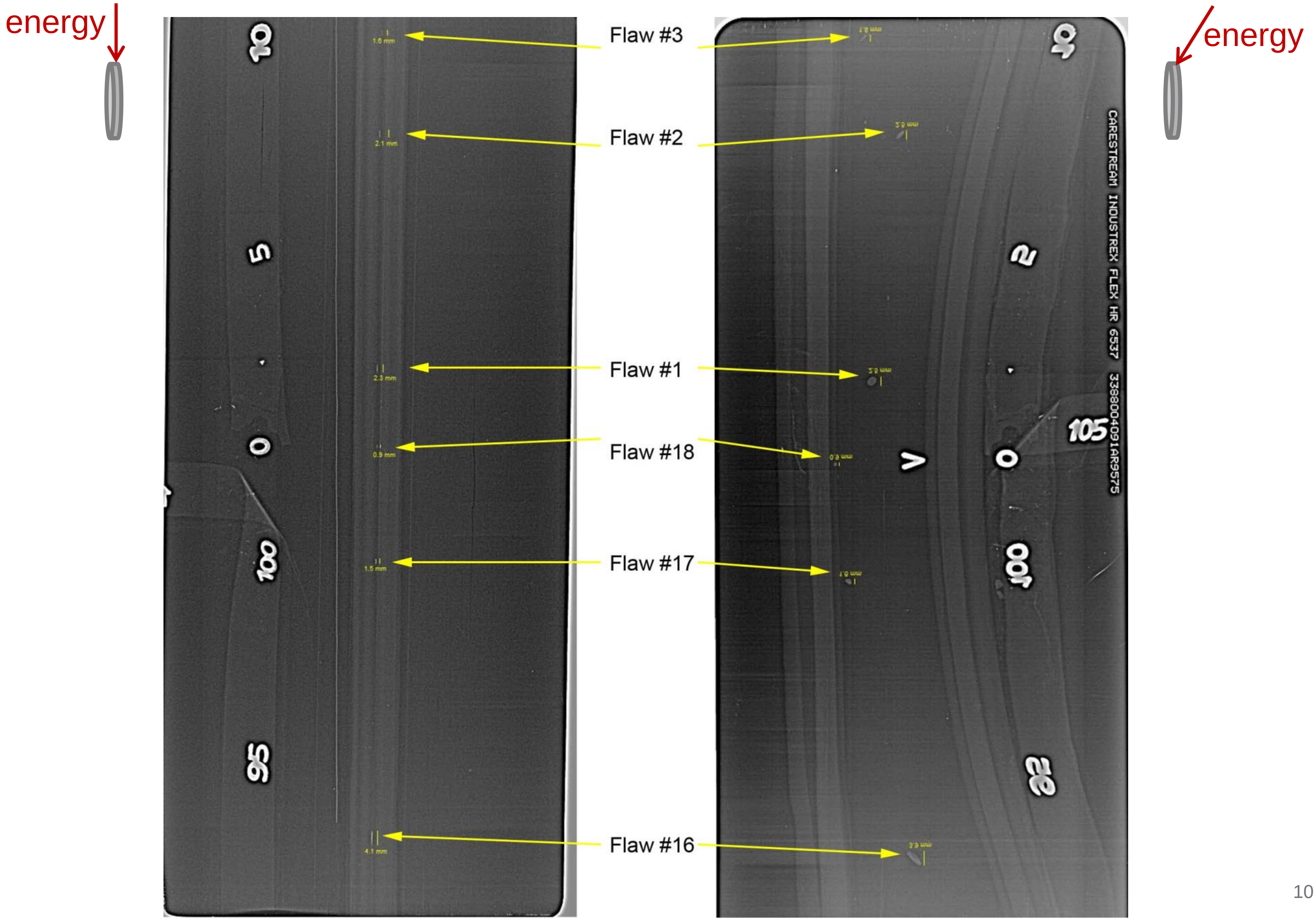


Post-fabrication RT Verification of Implanted Metallic Flaws

- High densities of metal lends it to detection in HDPE using X-ray radiography
- Radiography performed to:
  - Verify quantity and circ. positions of S/S discs/pieces in fusion joints
  - Verify presence of tungsten powder in fusion joints
- Normal incidence and angled incidence

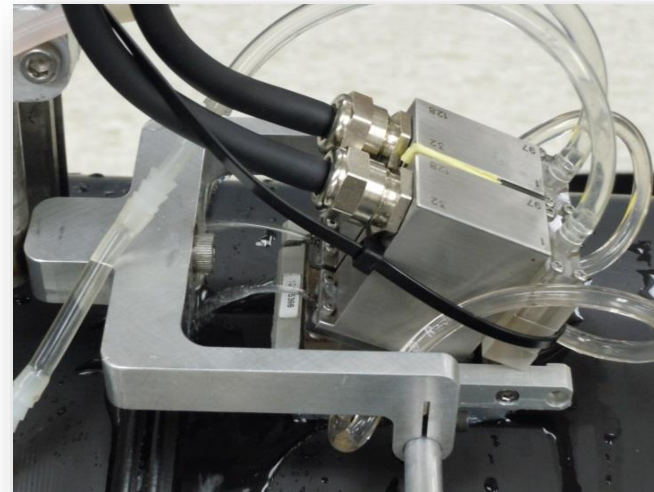


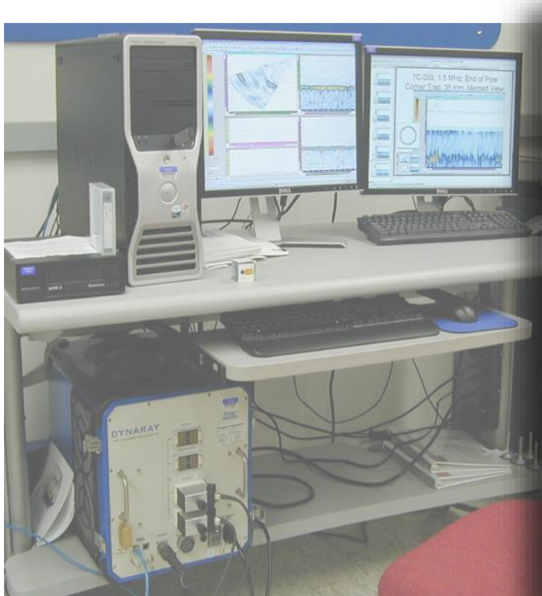
Example: S/S Discs/Pieces in RJ-8

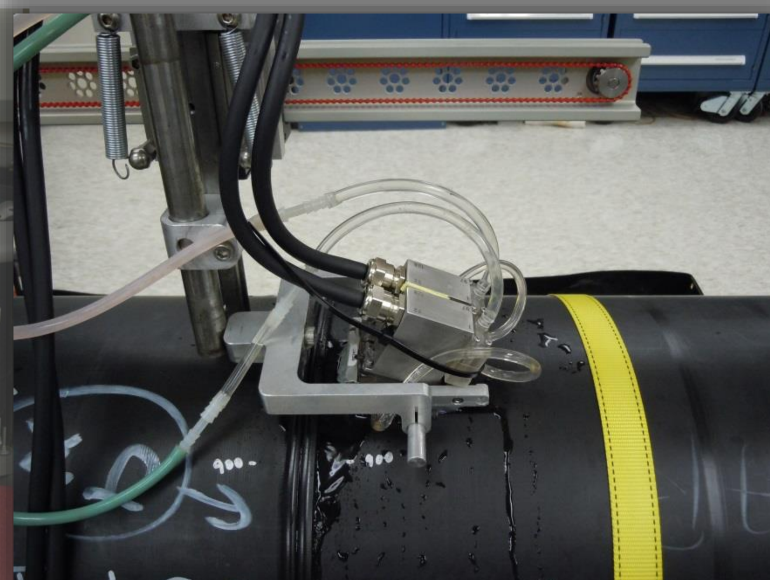


PA-UT/TRL

- Phased-array ultrasonic testing
- Transmit-receive longitudinal mode
  - 128 full aperture
  - 64- and 32-element reduced aperture
- Weld beads intact
- Both sides of the fusion joint
- Flaw/indication reporting: 3 dB above noise, within 3 mm of fusion joint

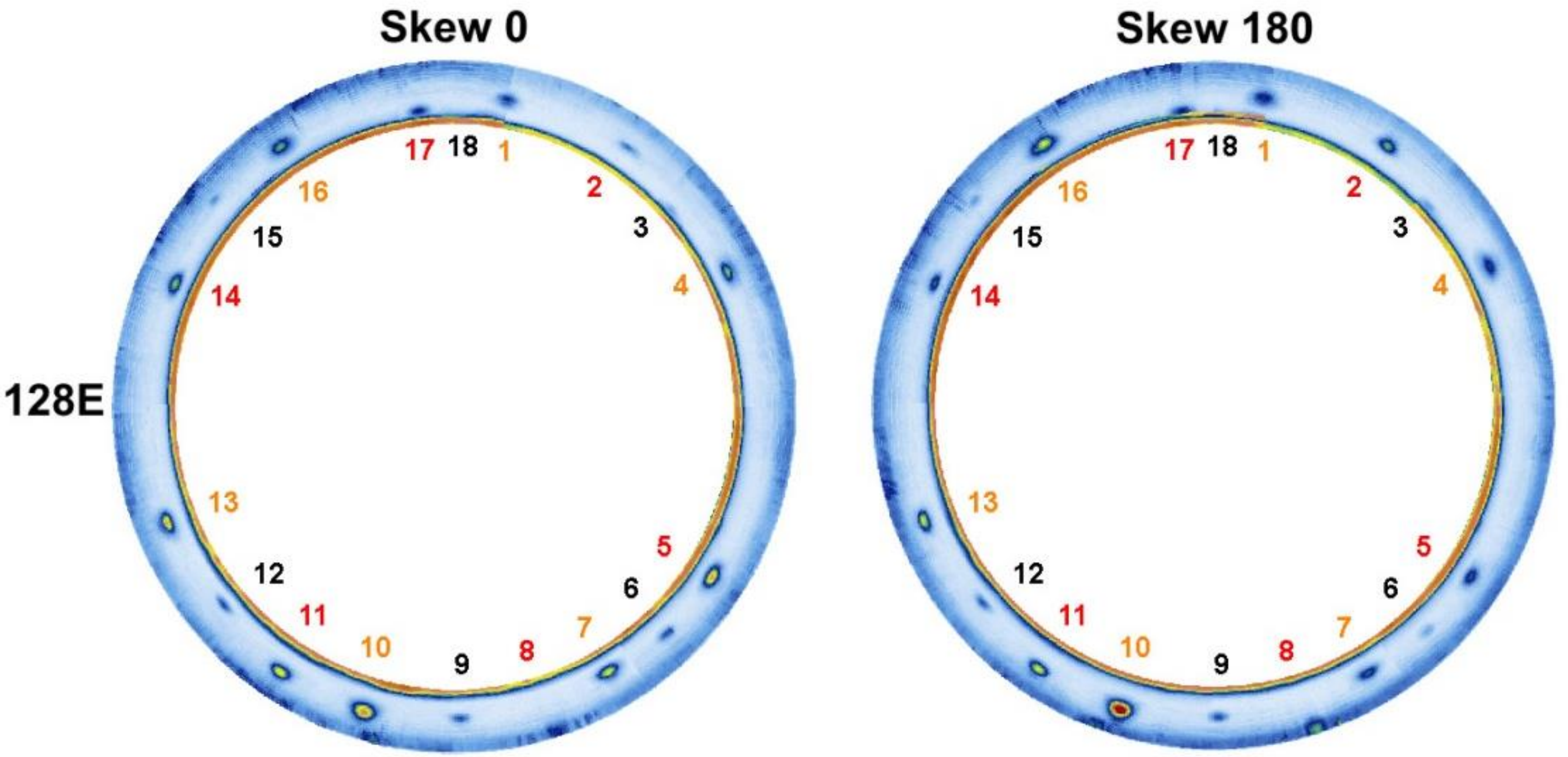






RJ-8

- Implanted planar flaws
  - 2.17 mm S/S discs (gold)
  - 1.38 mm S/S discs (red)
  - ~0.8 mm S/S pieces (black)
- Pre-fab: Positioned mid-wall
- RT detected all implanted flaws
  - Radial position verified for most

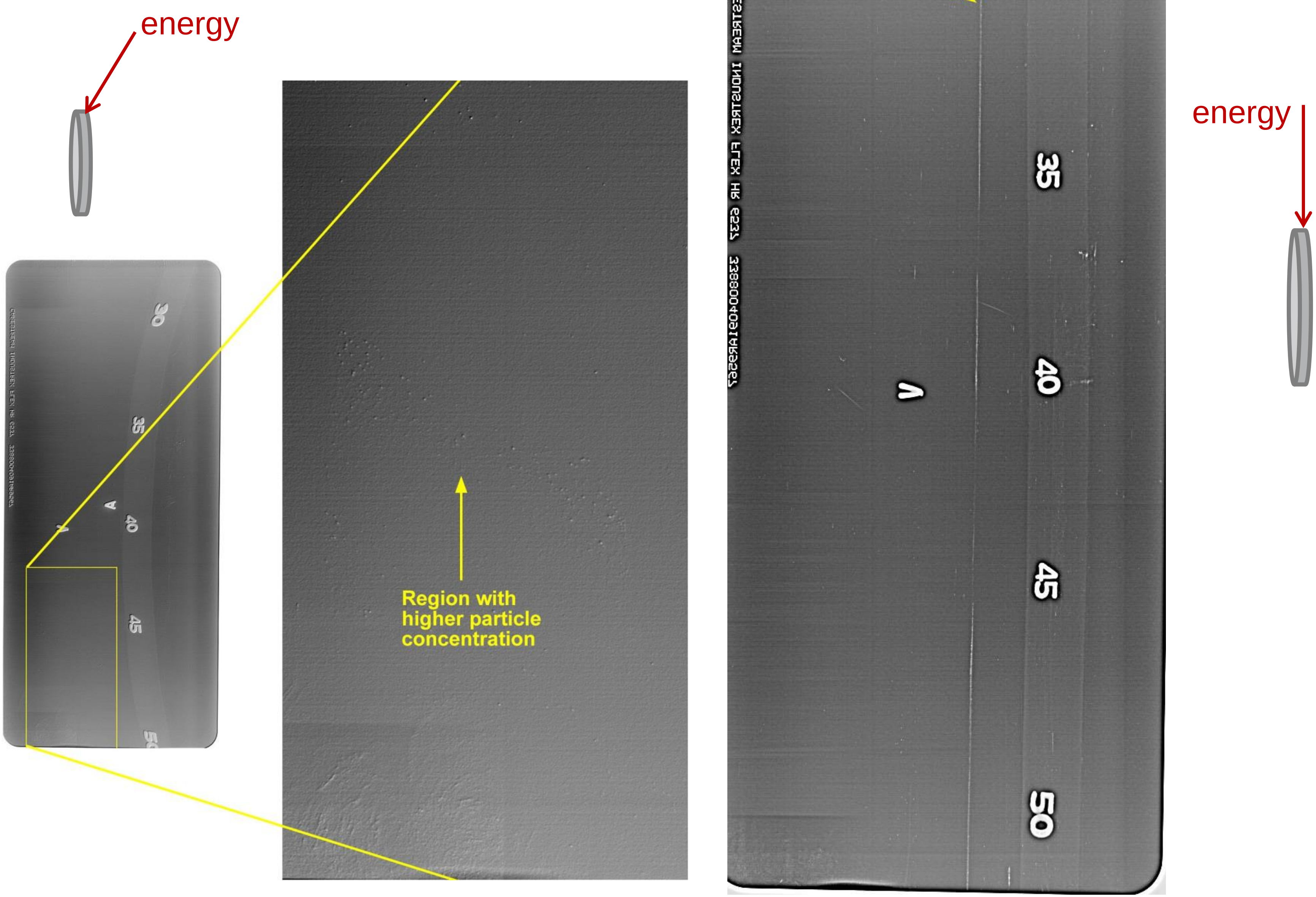


- 128-element aperture results
  - Detected RT-verified flaws from both sides of the fusion joint

	~0.8 mm S/S piece	1.38 mm S/S disc	2.17 mm S/S disc
ID	**Flaw 3 ✓** **Flaw 18 ✓**	**Flaw 17 ✓**	
Mid-wall	**Flaw 6a ✓** **Flaw 6b ✓** **Flaw 9 ✓** **Flaw 12 ✓** **Flaw 15 ✓**	**Flaw 2 ✓** **Flaw 5 ✓** **Flaw 11 ✓** **Flaw 14 ✓**	**Flaw 1 ✓** **Flaw 4 ✓** **Flaw 7 ✓** **Flaw 10 ✓** **Flaw 13 ✓** **Flaw 16 ✓**
OD		Flaw 8	

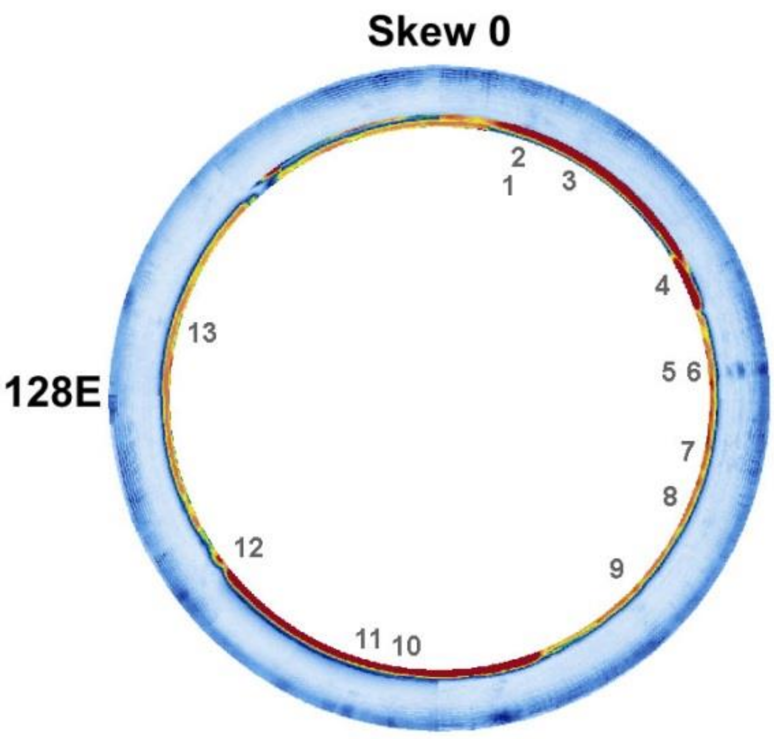
Confirmed by RT	**Bold Text ✓**
Not yet confirmed by RT	Standard text
Detected by PA-UT/TRL from both sides of the fusion joint (skew 0 and skew 180)	[Cell highlighted in dark green]
Detected from PA-UT/TRL from one side of the fusion joint (skew 0 or skew 180)	[Cell highlighted in light green]

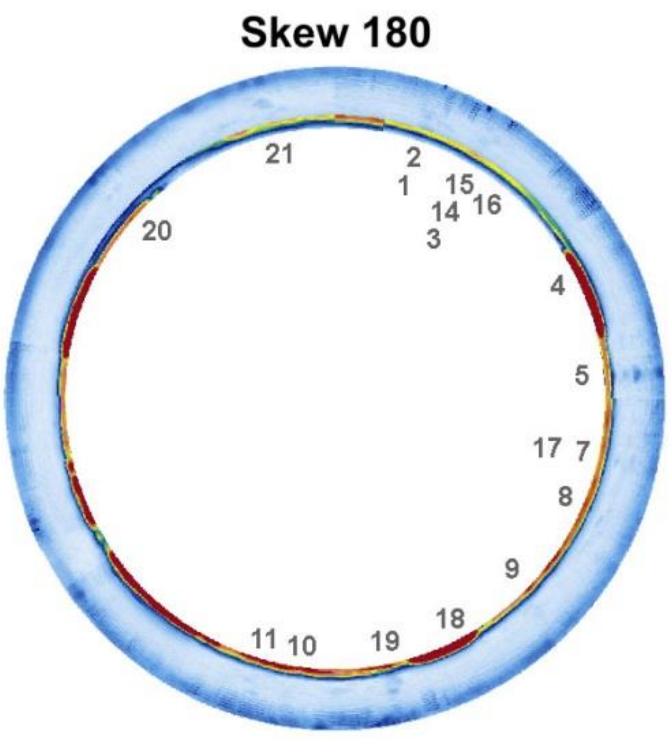
RT: Tungsten Powder



J-29

- Implanted “coarse” particulate contamination
  - 118-micron PSD d50
- Pre-fab: Applied OD to ID across circumference
- Fabricated per ASME Code
- RT confirms particulate is in the fusion joint
- Appears PA-UT/TRL can detect at a certain concentration level
  - Require better understanding of actual concentration across wall and circumference





J-29

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

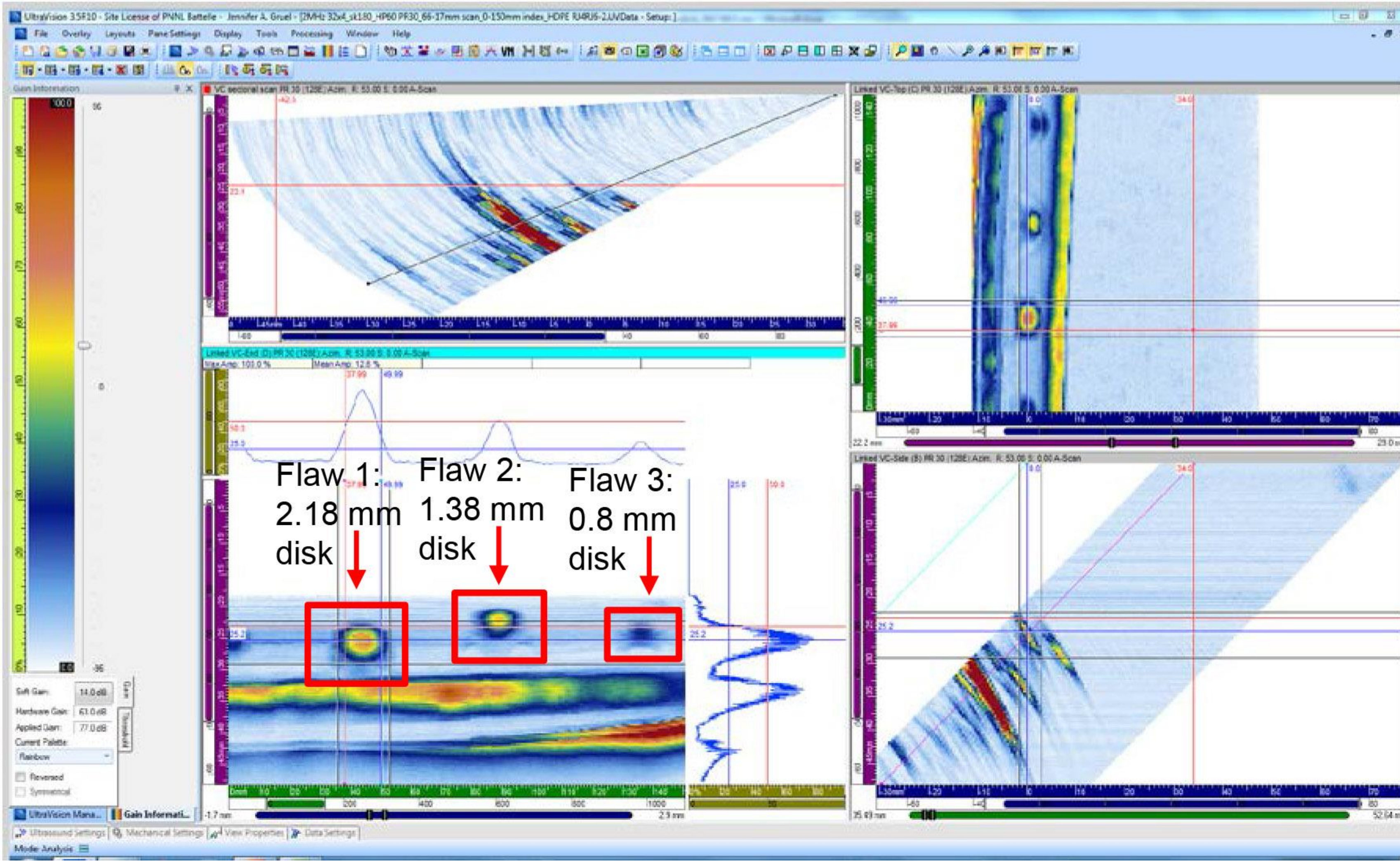
RT Circumferential Position	Corresponding 128E Nominal Circumferential Locations	Corresponding 64E Nominal Circumferential Locations	Corresponding 32E Nominal Circumferential Locations
~ 50 mm (1.97 in.)	~50 mm (1.97 in.), mid-wall and near ID	~49 mm (1.93 in.), near ID	
		~56 mm (2.2 in.), near ID	
~ 240 mm (9.45 in.)	~235 mm (9.25 in.), mid-wall	~236 mm (9.29 in.), mid-wall	~ 236 mm (9.29 in.), mid-wall
	~235 mm (9.25 in.), OD	~235 mm (9.25 in.), OD	
~ 470 mm (18.5 in.)	~467 mm (18.39 in.), mid-wall	~469 mm (18.47 in.), mid-wall	
~ 650 mm (25.59 in.)	~647 mm (25.47 in.), ID		
~ 800 mm (31.5 in.)	~790 mm (31.1 in.), mid-wall		
~ 950 mm (37.4 in.)	~954 mm (37.56 in.), mid-wall		

Detected by PA-UT/TRL from both sides of the fusion joint (skew 0 <u>and</u> skew 180) [Cell highlighted in dark green]

Detected from PA-UT/TRL from one side of the fusion joint (skew 0 <u>or</u> skew 180) [Cell highlighted in light green]

PA-UT/TRL Data Example: 128E Aperture

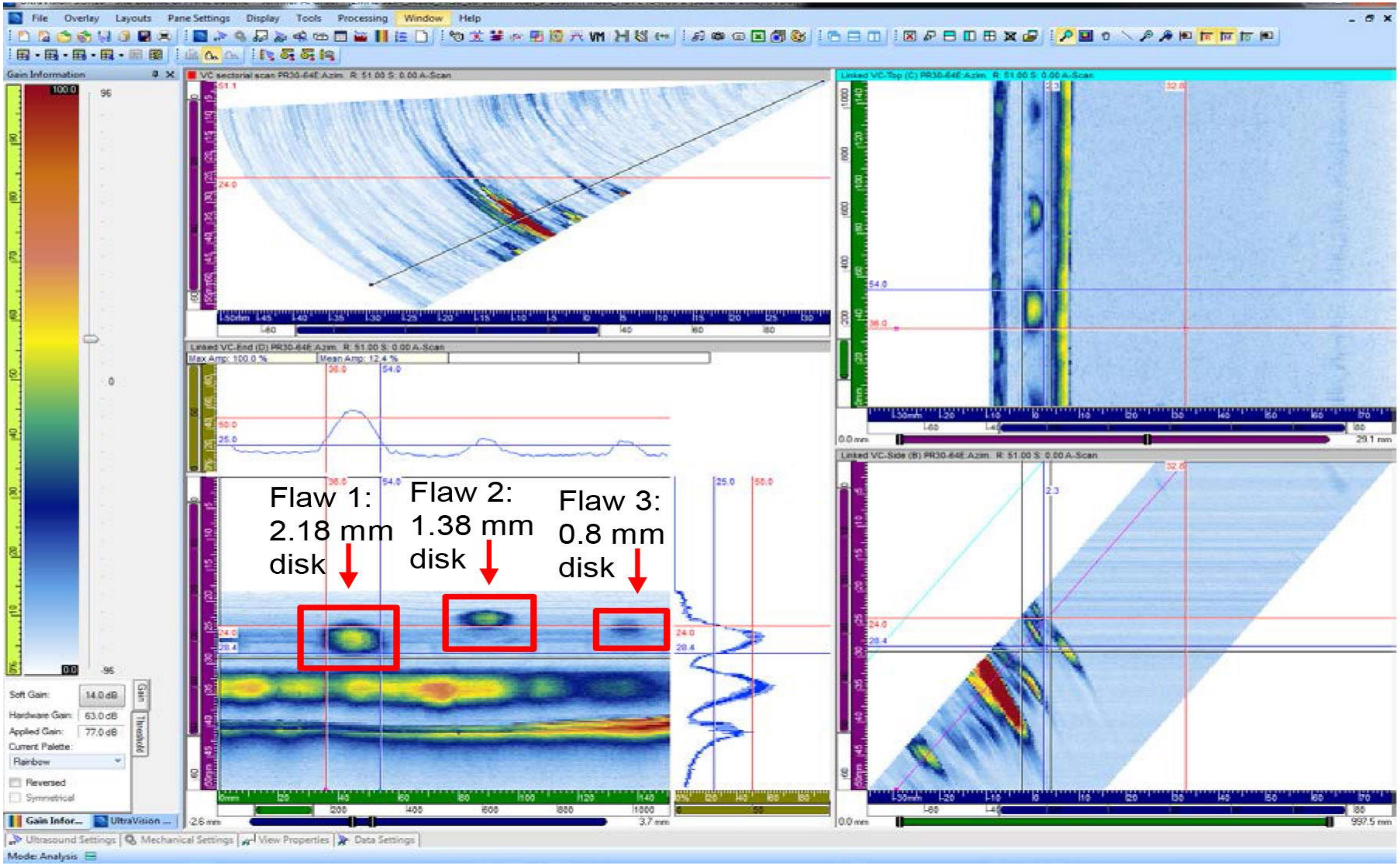
- Flaws 1, 2, and 3 in RJ4/RJ6-2 with 128E Aperture from Skew 180



PA-UT/TRL Data Example: 64E Aperture

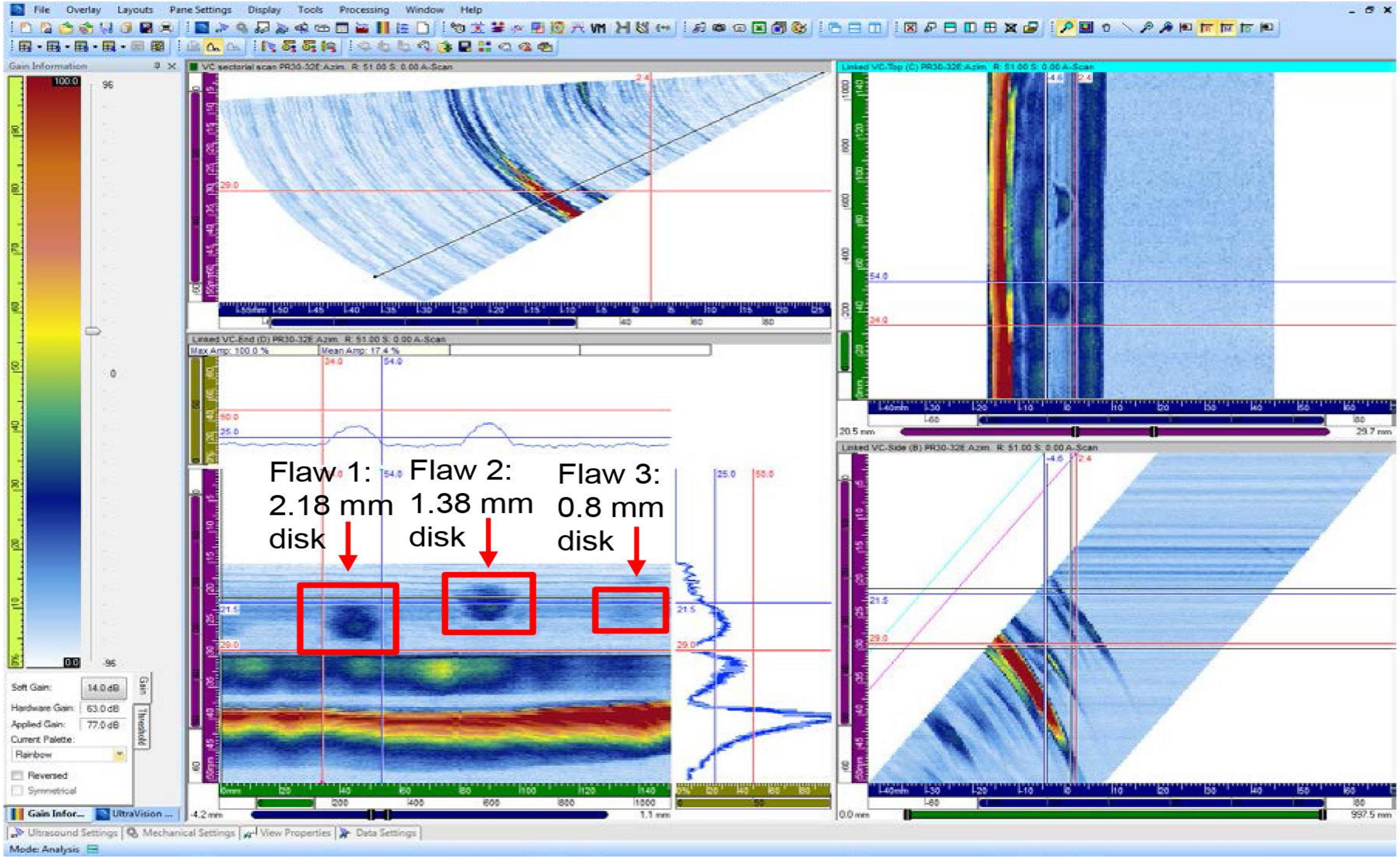
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Flaws 1, 2, and 3 in RJ4/RJ6-2 with 64E Aperture from Skew 180



PA-UT/TRL Data Example: 32E Aperture

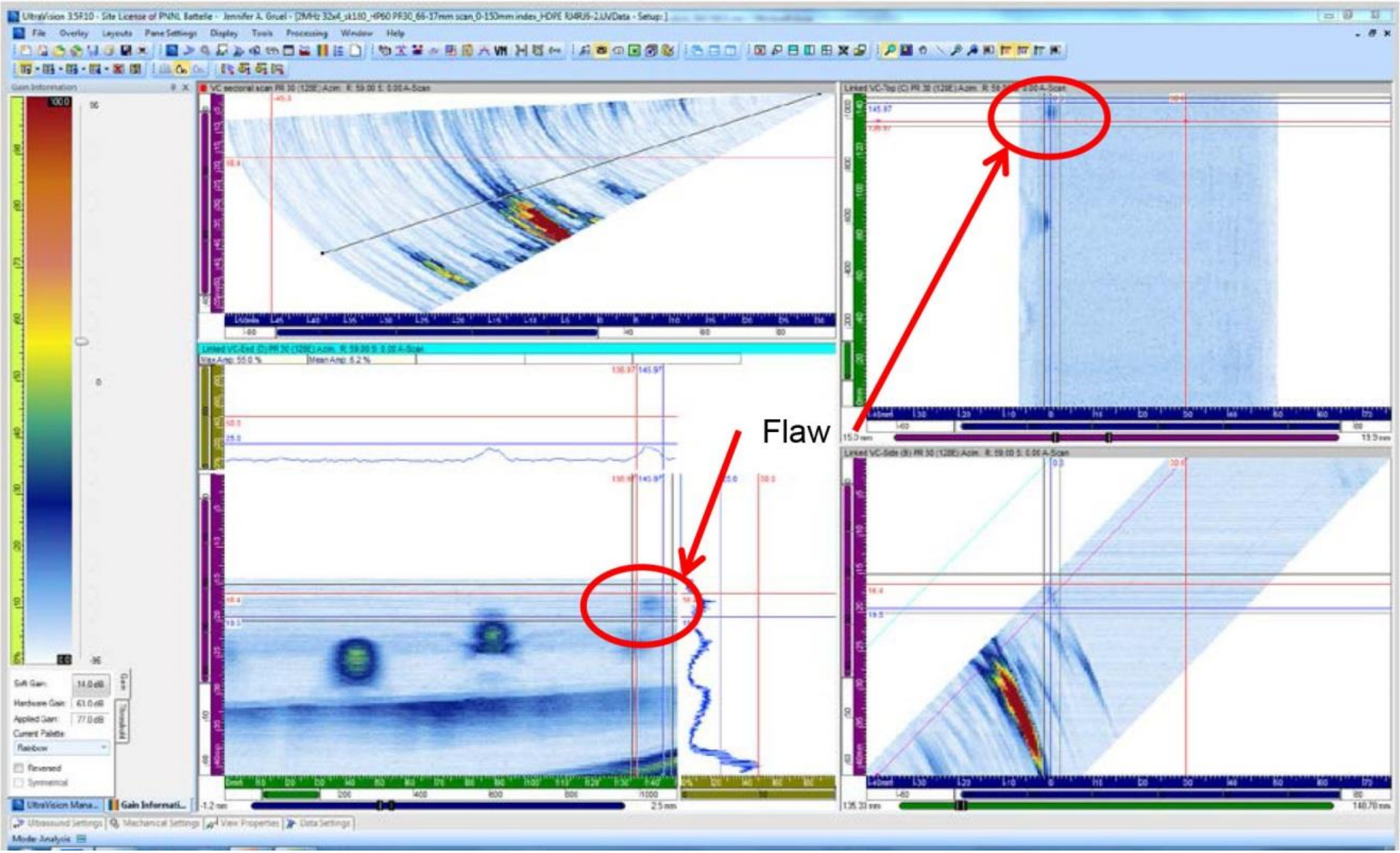
- Flaws 1, 2, and 3 in RJ4/RJ6-2 with 32E Aperture from Skew 180



Other Fusion Joint Indications

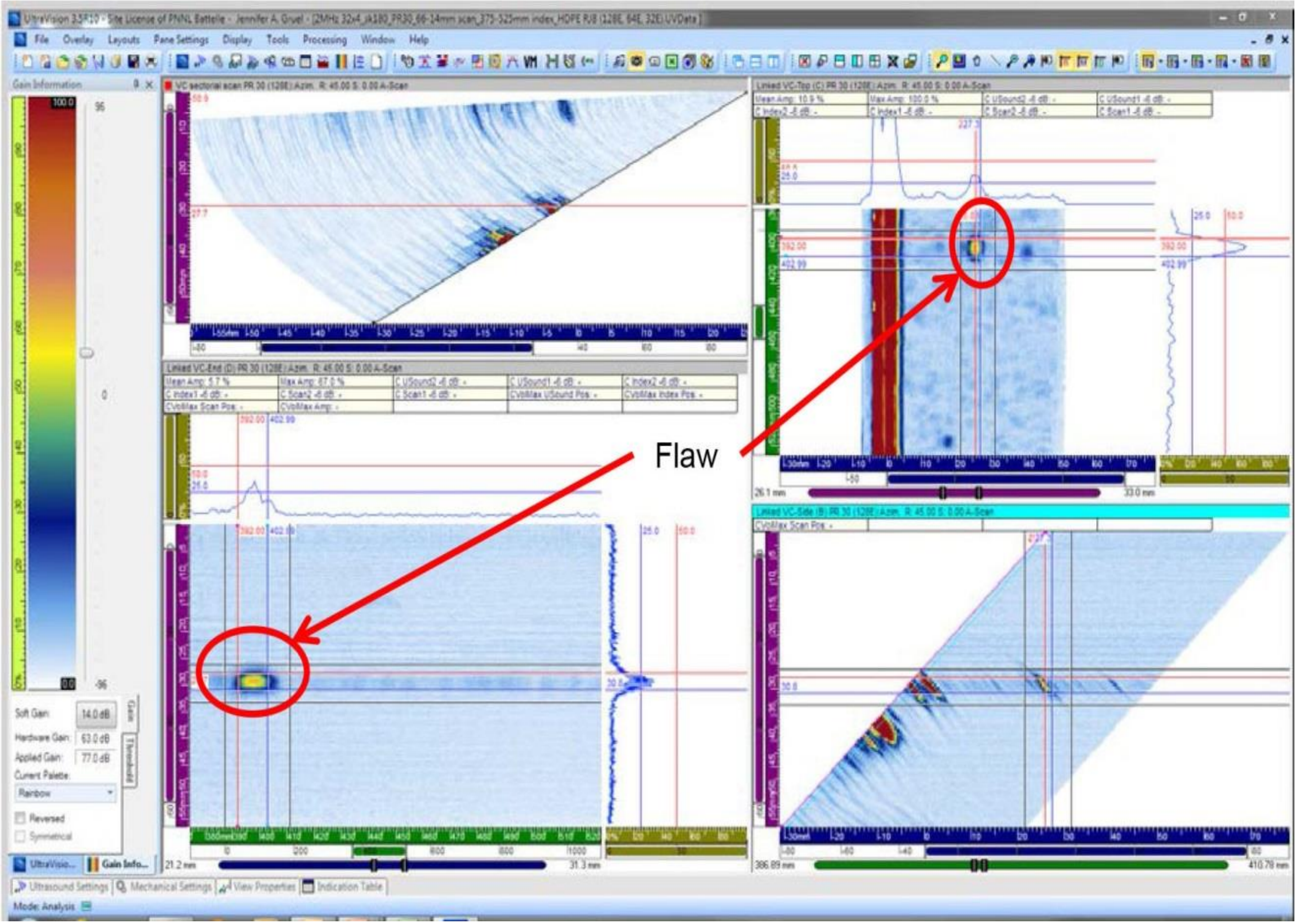
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Not implanted, meets flaw/indication reporting criteria
- RJ4/RJ6-2, “Flaw 6” 137–146 mm, 128E Aperture, Skew 180



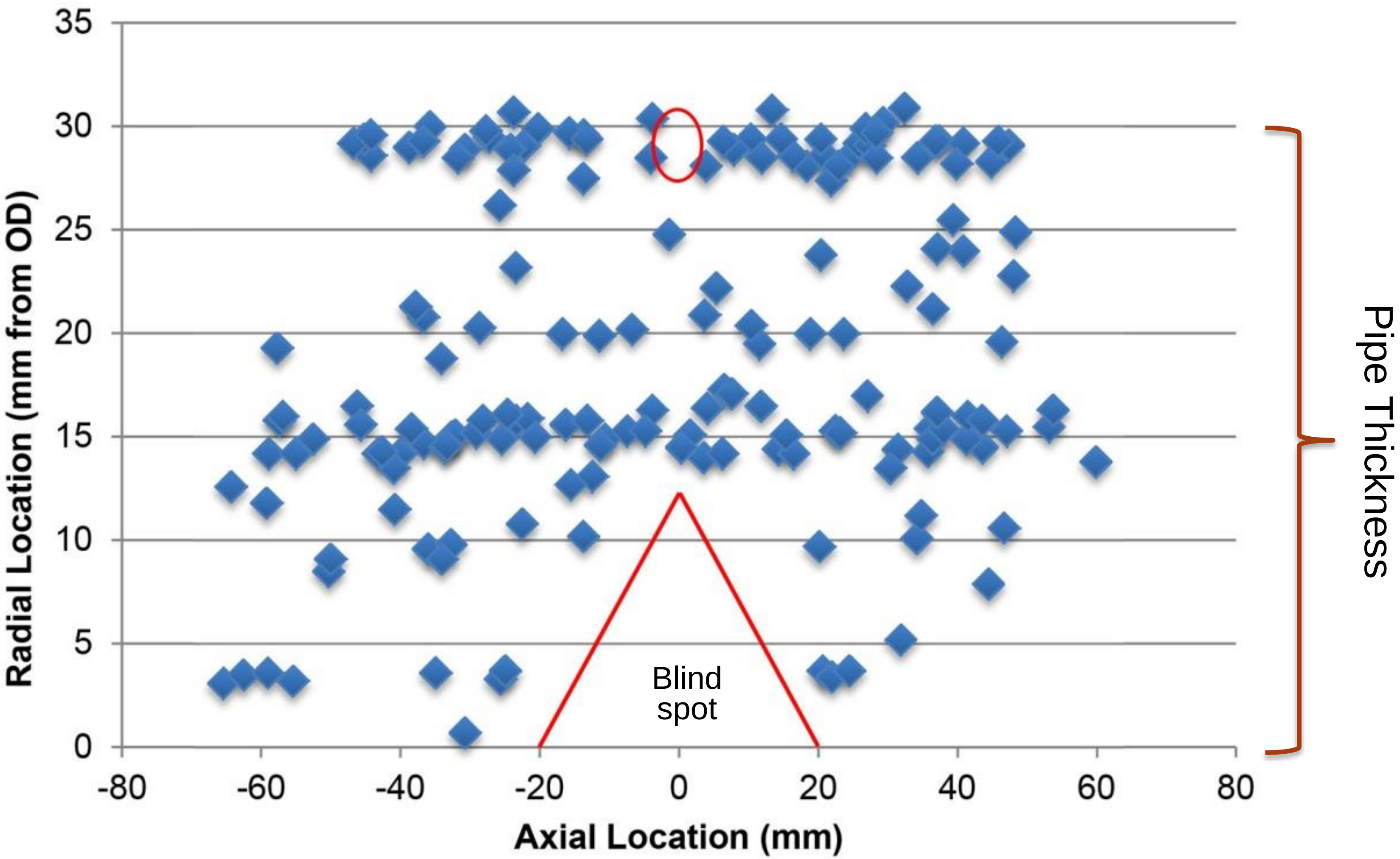
Parent Material Indications

- Adjacent to fusion joint
- Example: RJ-8, 128E, skew 180 (“Flaw” PM12, 392–403 mm)



Parent Material Indications

- Distribution from OD to ID (128E aperture)



Observations

- PA-UT/TRL detected more fusion joint “flaws” than were implanted
  - Forensic testing necessary to characterize these indications
- Parent material indications were persistent in PA-UT/TRL data sets
  - These potentially represent another flaw source beyond those associated with fabrication
  - Examples of larger indications were provided here
  - High spatial density
  - High probability of parent material “flaws” entering the fusion joint
  - Non-metallic indications in the fusion joints may be the result of parent material “flaws” that entered the fusion joint during fabrication

Conclusions

- Butt-fusion fabrication per the TR-33 standard fusing procedure resulted in no detectable flaws using PA-UT/TRL with signal-amplitude-based analysis
  - Destructive testing necessary to confirm integrity of the fusion joint

- PA-UT/TRL (signal-amplitude-based analysis) is effective at detecting planar flaws
  - Assessment of radial position sensitivity needs to be completed after RT verification of beadless specimens
  - The probability of detecting a planar flaw improves when examinations are performed on both sides of the fusion joint
  - The ability to detect planar flaws can depend on the probe aperture used, with detection ability increasing with increasing aperture size

Conclusions

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

PA-UT/TRL (signal-amplitude-based analysis)…

- Can detect coarse particulate contamination
  - Concentration level required to enable detection is not clear
- Cannot detect fine particulate contamination
  - Through-wall distribution and concentration of the particles need to be understood to confirm this
- Does not appear to be sensitive to cold fusion
  - Destructive testing necessary to confirm cold fusion was fabricated

Future Work:

- Complete Planar Flaw Assessment
  - Remove OD weld beads and rescan challenging areas
  - Explore orthogonal NDE methods (microwave examination)
  - Determine smallest possible detectable planar flaw, model in CIVA
- Destructive Forensics and Testing
  - Mine out and identify cause of non-disc fusion joint “flaws”
  - Characterize the nature of the indication (debris, unmelted resin, void?)
  - Verify joint integrity through destructive testing
- Quantifying PA-UT/TRL Blinds Spots
- Investigate Parent Material Inclusions