UT in Lieu of RT for Nuclear Power Plant Applications

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Outline

- NRC staff concerns with UT in lieu of RT
- NRC program to evaluate UT in lieu of RT
  - Equipment
  - Specimens
  - Data Acquisition
  - Data Analysis
- What the NRC staff has learned…
- NRC staff's unresolved concerns…
- Acknowledgements

NRC Staff Concerns with UT in lieu of RT

- NRC staff acknowledges that UT has great potential to be used in lieu of RT for repair/replace activities (RRA)
- The benefits of reduced inspection time and occupational exposure are significant
- History shows that the combined use of RT for fabrication exams followed by the use of UT for pre-service and inservice exams ensures that workmanship is maintained while potentially critical, planar fabrication flaws are not put into service

NRC Staff Concerns with UT in lieu of RT

Until studies are complete that demonstrate the ability of UT to replace RT for RRA, the NRC staff will not generically allow the substitution of UT in lieu of RT for fabrication exams. However, the NRC staff will continue to review plant specific relief requests for the use of UT in lieu of RT.

NRC Staff Concerns with UT in lieu of RT

Performance Demonstration Requirements

- What are the requirements for performance demonstration for UT equipment, procedures, and personnel used for examinations for repair/replacement activities?
  - Mockups
    - How many flaws and what types are required?
    - Spatial distribution of flaws
    - Geometric and material conditions that require discrimination from flaws
  - Acceptance criteria for length and depth sizing of fabrication flaws
  - Is flaw discrimination/classification required?

NRC Staff Concerns with UT in lieu of RT

Acceptance criteria for fabrication type flaws

- Cannot use RT acceptance criteria due to differing physics of methods
- Applying Section XI acceptance criteria may result in accepting welds with poor workmanship
- Applying Section III may reject acceptable flaws causing unnecessary repairs

Demonstration of UT characterization capability

- – Section III acceptance criteria relies on distinguishing the types of flaw
- – Does UT have capability to reliably discriminate between planar and volumetric flaws?

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NRC Staff Concerns with UT in lieu of RT

Detection reliability – Can UT reliably detect and characterize fabrication flaws?

- UT at NPPs is typically used for pre-service and in-service exams. Method suited to detecting and sizing service-induced type flaws (surface-connected).
- Fabrication exams aimed at finding surface- and sub-surface flaws that result from welding.
- The use of UT to discriminate between planar and volumetric flaws has been limited.

NRC Staff Concerns with UT in lieu of RT

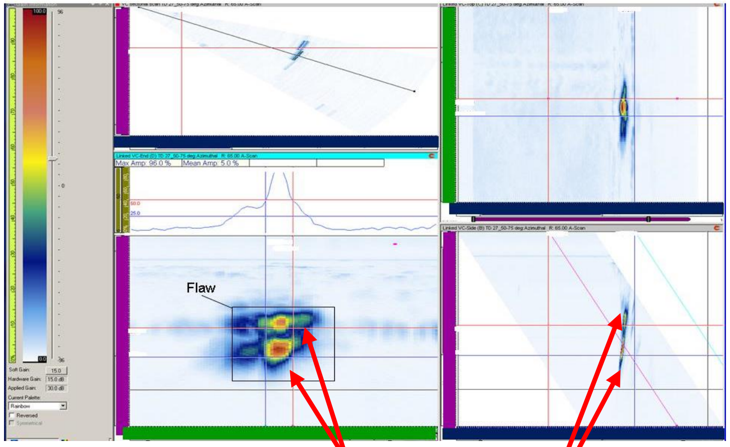
Sizing Reliability

Length Sizing

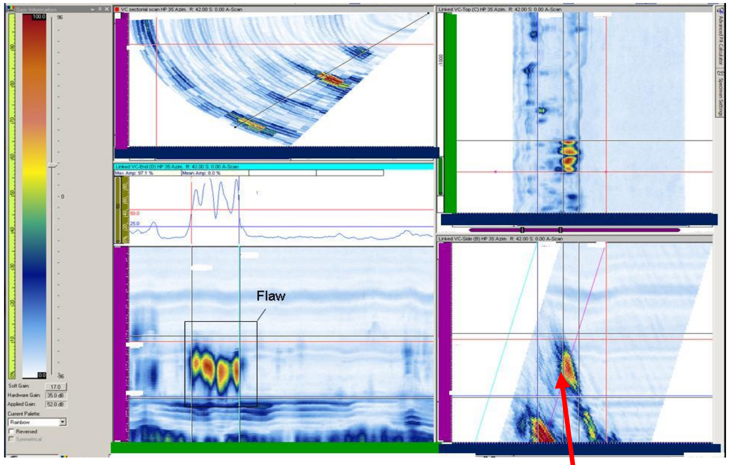
– How do UT and RT compare in ability to length size flaws?
– Does UT undersize/oversize fabrication flaws for length?

Depth Sizing

- UT has an advantage over RT to depth size planar flaws as well to discriminate flaws stacked throughout thickness
- Is UT limited in its ability to detect flaw height for volumetric flaws (without tips)?



Planar Flaw - base and tip responses



Volumetric Flaw - No tip responses

NRC Staff Concerns with UT in lieu of RT

Define equipment requirements for fabrication type flaws

Beyond the use of UT methods that encode position and amplitude, what are the other minimum equipment requirements that must be identified/defined, including, but not limited to the following:

- Pulse-echo; pitch catch; phased array; transmit-receive
- Angle of inspection
- Scan direction
- First leg only, or first, second and third legs allowable
- Focused beams, either through zone focusing or focal laws (phased arrays)

Documentation requirements/record keeping

- RT provides a permanent record of the inspection
- What is required for UT? (format, content, etc.)

NRC Staff Concerns with UT in lieu of RT

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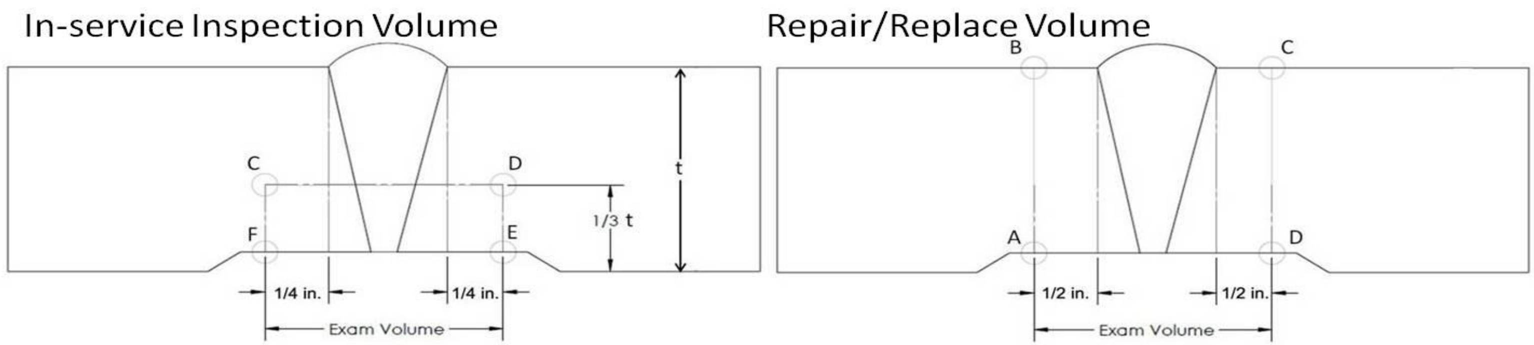
Examination volume

Exam volume very different – cannot just use ISI UT techniques for RRA



Must address issues that will enable full-volume weld exam:

- Weld Geometry and Access Limitation
  - Single sided access and welds with crowns not ground flush require the use of 1 & 1 ½ V path scans.
- Wave modality
  - Longitudinal or shear waves acceptable when using ½ V path
  - Only shear is acceptable using 1 or 1 ½ V path due to mode conversions
- UT Zone focusing
  - PAUT based inspection techniques are refined to provide optimum detection on ID surfaces. How must techniques be modified to include the full weld volume?

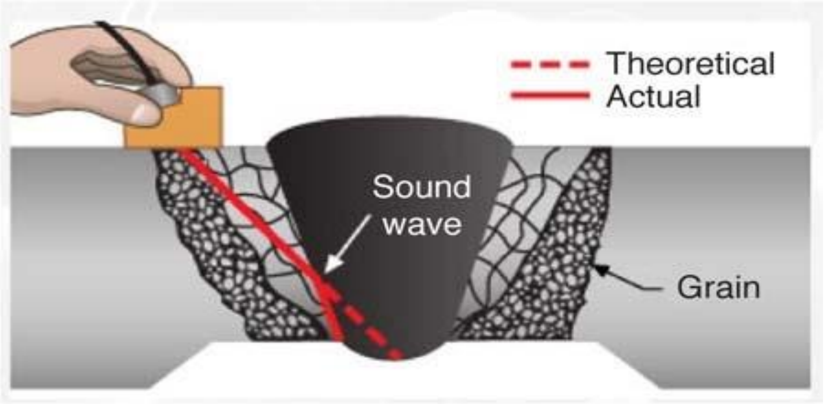
NRC Staff Concerns with UT in lieu of RT

Component Applicability

- Complex geometries and component limitations
  - Current NRC project focus on piping
  - Nozzles, Vessels, Weld Crowns, Different Diameter and Thickness…

Materials applicability

- Current evaluation indicates UT is fine for CS
  - shear waves respond as predicted
  - can use 2nd and even 3rd leg data
- However, is UT fine for austenitic materials?
  - beam redirection
  - attenuation (can't use shear)
  - use of RL (can't use 2nd leg)
  - flaw discrimination
  - inspection frequency
  - accurate flaw sizing



Ultrasonic beam redirection (figure from EPRI 1022922)

NRC Program to evaluate UT in lieu of RT (UT & RT for NDE)

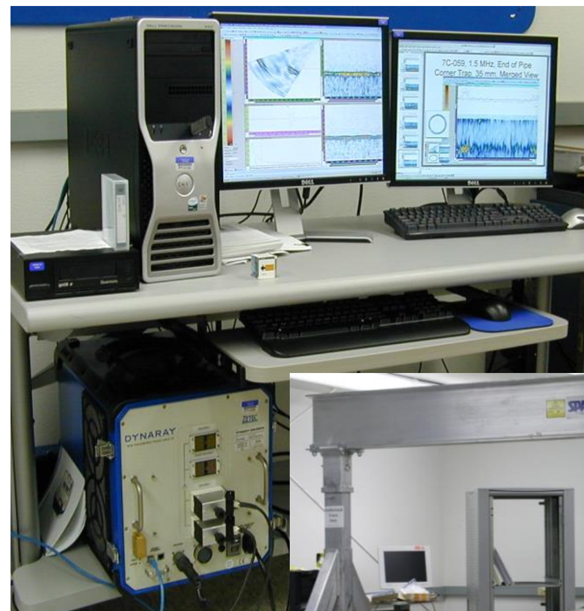
Effectiveness and Reliability of UT & RT for NDE Activities (JCN-V6097)

Objective of the project is to evaluate the capabilities and effectiveness of ultrasonic testing (UT) to replace radiographic testing (RT) for Section XI, repair/replace activities.

Equipment

- PNNL RT Equipment
  - 450 kV X-ray system
  - Computed radiography w/ digital flat panel detectors

- PNNL UT Equipment
  - ZETEC Dynaray PA System
  - 0.2 – 20 MHz, 256 channels



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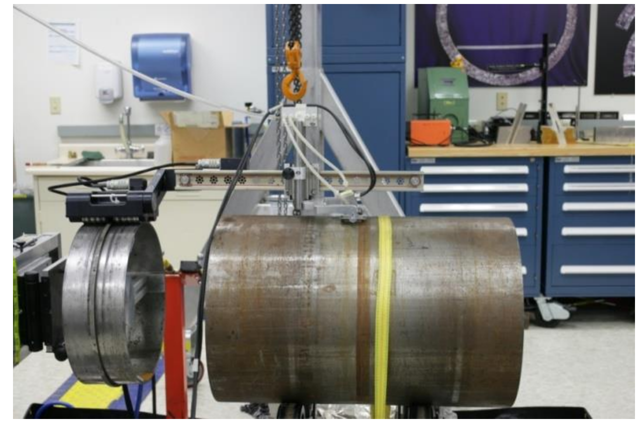
Specimens

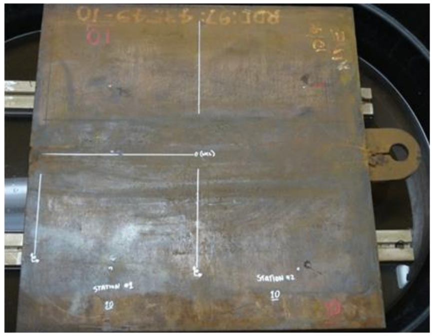
- 4 borrowed Carbon steel pipe-to-pipe welds
  - Diameters – 14” and 16”
  - Thickness – 0.75” through 1.091”
  - Implanted Welding flaws
    - Lack of fusion (LOF), Lack of penetration (LOP), Crack (CRK), Slag (SLG), and Porosity (POR)

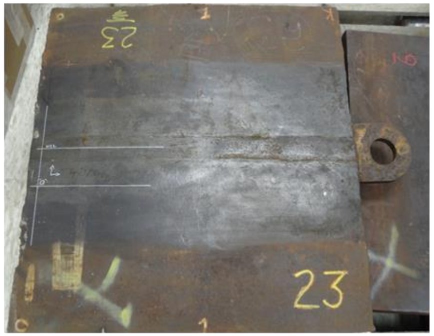


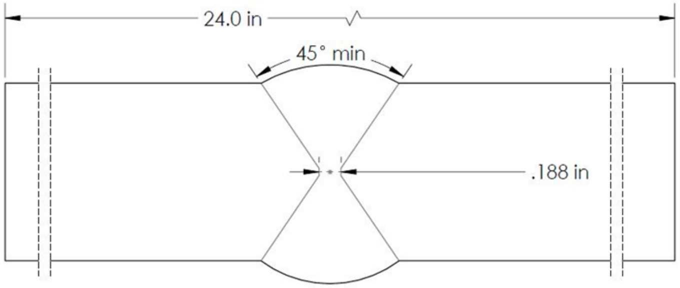
Flaw Type		Length, mm (in.) Min	Max	Mean
Planar	LOF	5.7 (0.23)	51.4 (2.02)	11.1 (0.44)
	LOP	3.4 (0.14)	13.8 (0.54)	6.5 (0.26)
	Crack	10.3 (0.41)	39.2 (1.55)	23.9 (0.94)
Volumetric	Slag	6.4 (0.25)	51.1 (2.01)	14.6 (0.57)
	Porosity	3.2 (0.13)	7.8 (0.31)	4.8 (0.19)

Specimens

- 3 borrowed Navy "UT/RT" carbon steel test plates
  - Thickness – 1.5" and 2.2"
  - Implanted Welding flaws
    - Lack of fusion (LOF)
    - Crack (CRK)
    - Slag (SLG)
    - Porosity (POR)





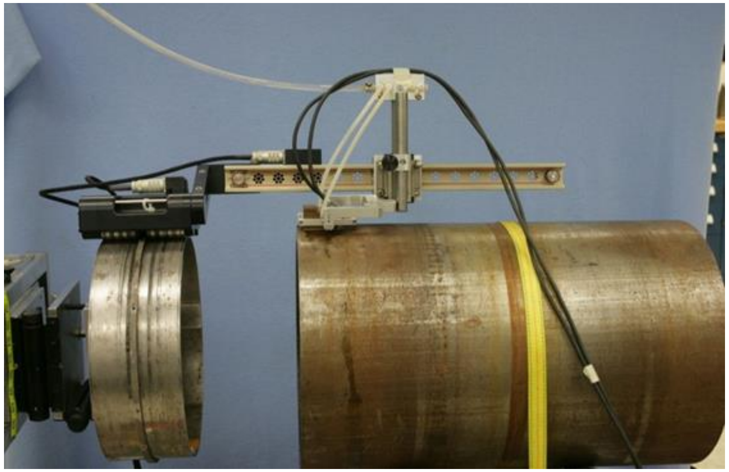


Flaw Type		Length, mm (in.) Min	Max	Mean
Planar	LOF	12.7 (0.5)	33.02 (1.3)	19.95 (0.78)
	Crack	15.24 (0.6)	15.24 (0.6)	15.24 (0.6)
Volumetric	Slag	10.16 (0.4)	22.86 (0.9)	18.3 (0.72)
	Porosity	2.54 (0.1)	15.24 (0.6)	11.0 (0.43)

Data Acquisition

- Pipe Specimens
  - RT: Single-wall, film and CR for true State (length sizing and flaw type)
  - UT: 4.0 MHz TRS, linear PA (32 X 1 elements per probe); insonification angles 45 – 75 degrees; axial and raster scanning from both sides of weld
- Navy Plates
  - UT: 5.0 MHz TRS, linear PA (32 x 4 elements per probe); Insonification angles 45 – 75 degree; initial line scans performed from both sides of welds for detection; raster scans performed for characterization

* all UT done with ½ V, full V, and 1-1/2 V sound path



Data Analysis

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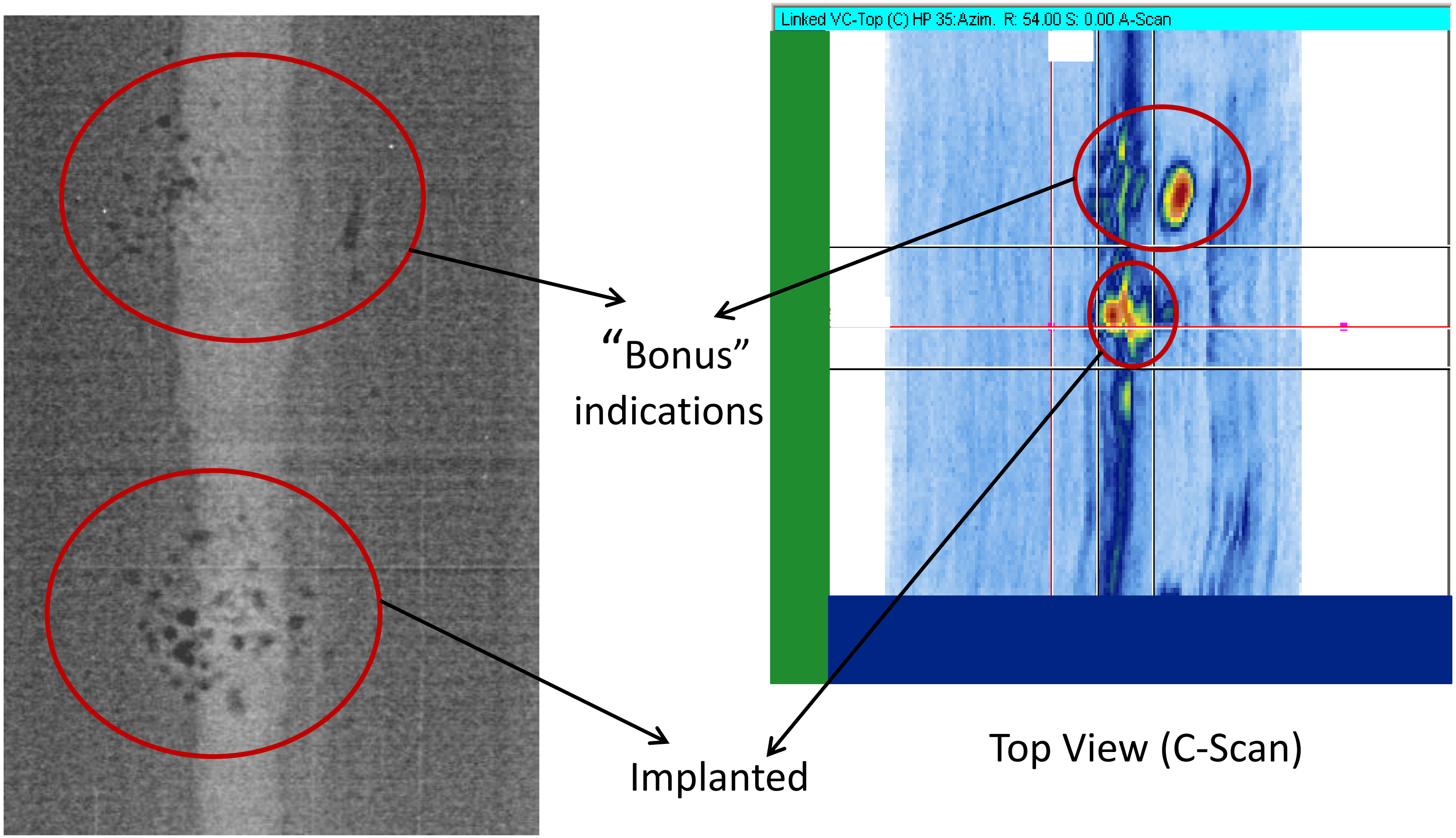
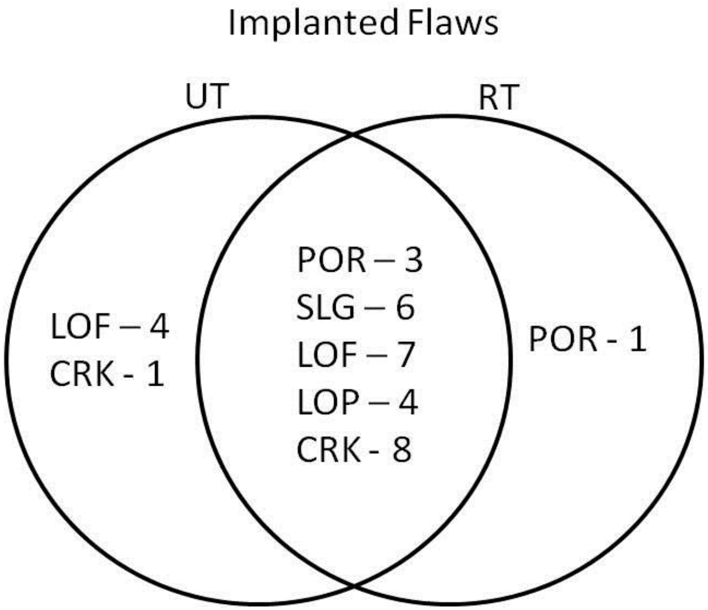
Detection Reliability – UT and RT found both implanted (planned) flaws as well as bonus (unplanned) flaws on all four carbons steel pipe specimens.



Data Analysis

Detection Reliability – Implanted flaws in carbon steel piping

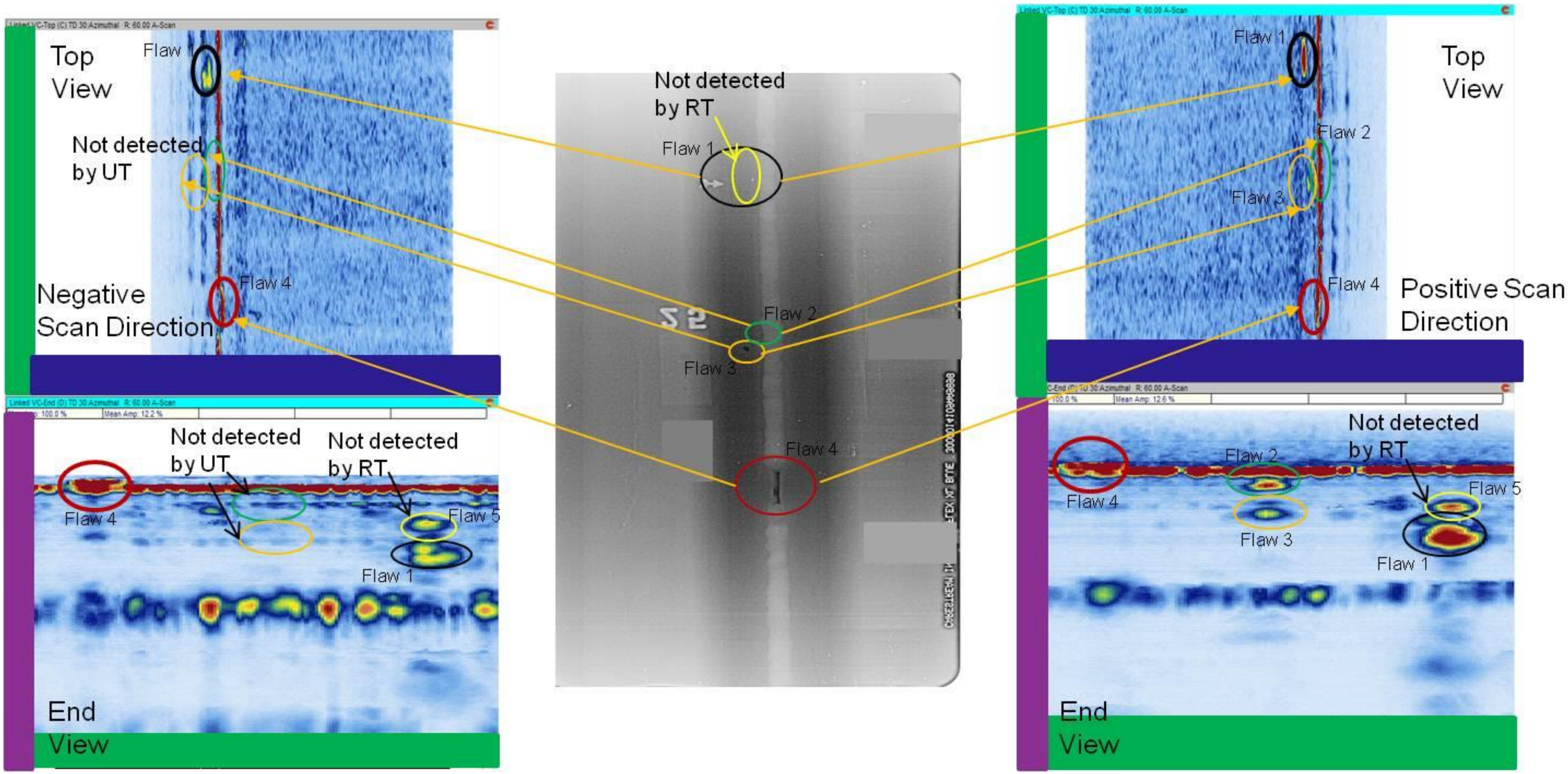
- UT and RT appear to have similar detection capability for volumetric flaws
  - UT missed 1 small porosity (5.3 mm (0.2 in.) in length
- UT has a better detection capability for planar flaws
  - RT missed 5 planar flaws
  - Planar flaws are more likely to grow throughout the service lifetime of the plant and could be more detrimental



Data Analysis

Detection Reliability –

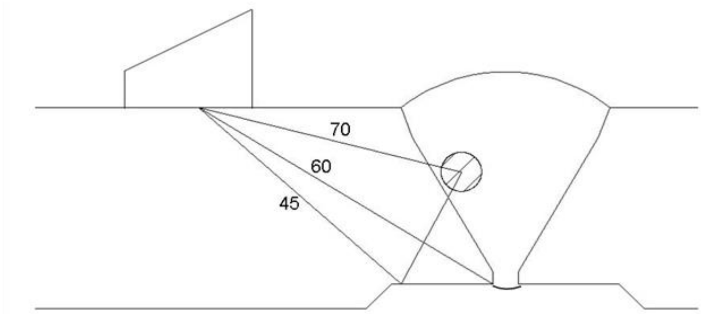
- Single sided vs. double sided exams - Some fabrication flaws were not detected with single side UT exams

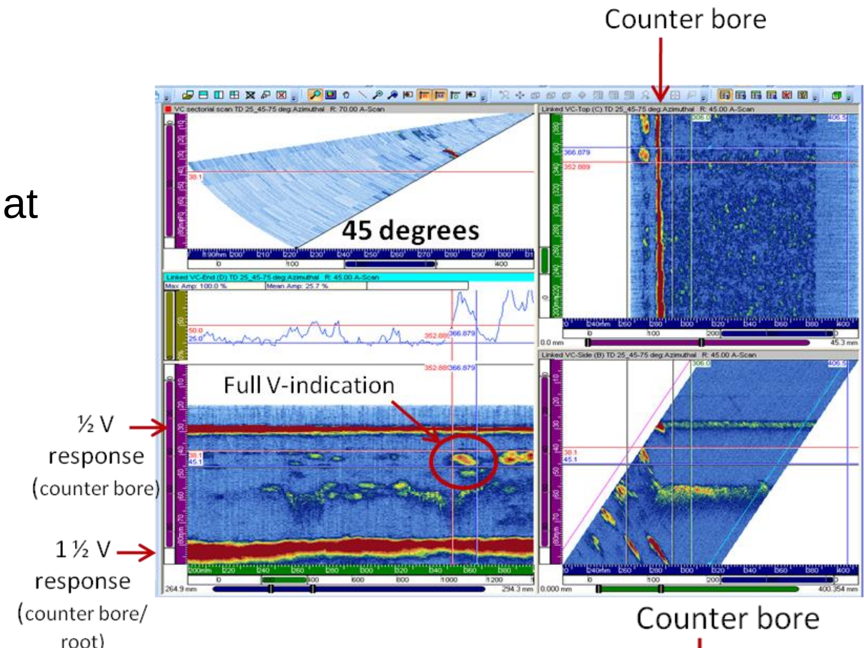


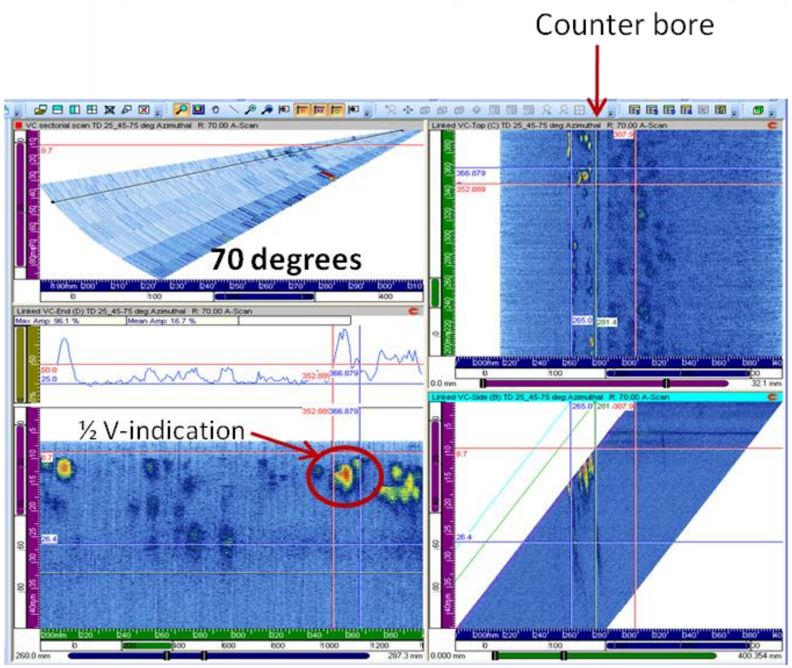
Data Analysis

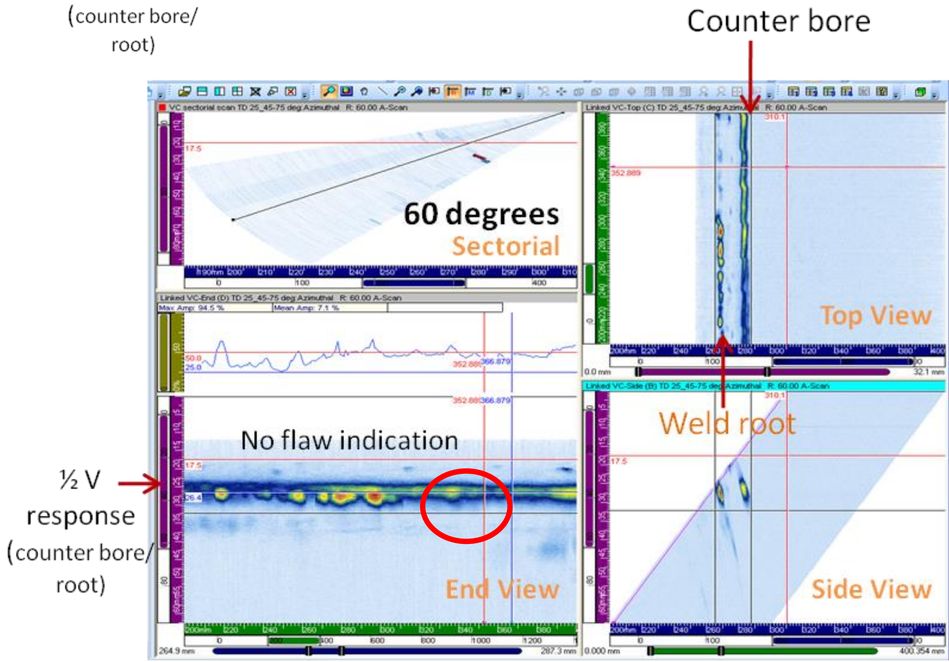
Detection Reliability - Phased array (multi angles) vs. single angle

- Depending on location may not see flaw at certain angles









Data Analysis

Sizing Reliability - limited data set on carbon steel piping

- Length Sizing
  - Many factors influence sizing results such as size of flaw, surface connectedness, flaw type, inspection angle, use of 2nd and 3rd leg of sound…
  - POR, SLG, and LOF were sized better with -6 dB sizing method
  - LOP and CRK were sized better with -12 dB sizing method
- RMSE within Section XI, Appendix VIII acceptance criteria of 19.05 mm
  - Criteria developed for service induced, surface breaking type flaws (cracks) and may not necessarily be applicable to fabrication flaws
- Over- and under- sizing - Potential to make a call to accept a rejectable flaw or reject an acceptable flaw

	UT Length (4.0 MHz)			
Flaw Type	Near Side		Far Side	
	6 dB RMSE	12 dB RMSE	6 dB RMSE	12 dB RMSE
Porosity	3.18 (-)	7.08 (+)	3.45 (+)	6.89 (+)
Slag	5.41 (-)	8.96 (+)	8.70 (-)	8.99 (+)
LOP	8.46 (-)	5.44 (-)	6.40 (-)	2.30 (-)
LOF	8.24 (+)	10.45 (+)	6.03 (+)	8.26 (+)
Crack	11.08 (-)	7.31 (+)	9.46 (-)	7.45 (+)

Data Analysis

Characterization – flaw characterization using flaw-type decision matrix (shown below) performed on flaws in Navy plates and on one pipe specimen

		Echo Dynamic Travel "Walk"	Evidence of Tip Signals	Amplitude Signal from Same Side[a,b]	Evidence of Mode Converted Signals	Detection Angle Effect on Signal Response	Absent Root Response	Rise and Fall Response	Amplitude from Opposite Side of Weld[a,b]	Relative Amplitude from other Flaw Types	Location of Signal
General Flaw Type	Specific Flaw Type	Short/Long	Yes/No	Similar/ Lower or No Detection	Yes/No	No effect/ Lower angles better signal response	Yes/No	Multiple Peaks/ Quick	Lower/ Higher/ Similar	Higher/ Lower	Sidewall/ID connection/ short of weld root/anywhere in volume
Planar	CRK[c]	Long	Yes	similar	Yes	[d]	No[e]	---	[f]	Higher	ID connection
	LOF	Long	Yes	Lower or No Detect	---	No effect[g]	No	Multiple Peaks	Higher	Higher	sidewall
	ICP	---	Split Signal Response - similar to tip	Similar	---	Lower angles better signal response	Yes	---	Similar	Higher	short of weld root
Volumetric	SLG	Short	No	Similar	---	No effect	No	Quick	Similar	Lower	anywhere in volume
	POR	Short	No	Similar	---	No effect	No	Quick	Similar	Lower	anywhere in volume

(a) Applies to single V welds and upper half of a double V weld.
(b) For lower half of double V weld - switch LOF responses from same and opposite side of weld in the table.
(c) These are typical responses from ID-connected cracks.
(d) Higher angles mean that amplitude can be similar or higher if the same reference sensitivity criteria are applied to each angle.
(e) Yes, if flaw is in base material on same side access.
(f) Can be higher in carbon steel based on flaw orientation.
(g) Based on bevel angle/flaw orientation.

Data Analysis

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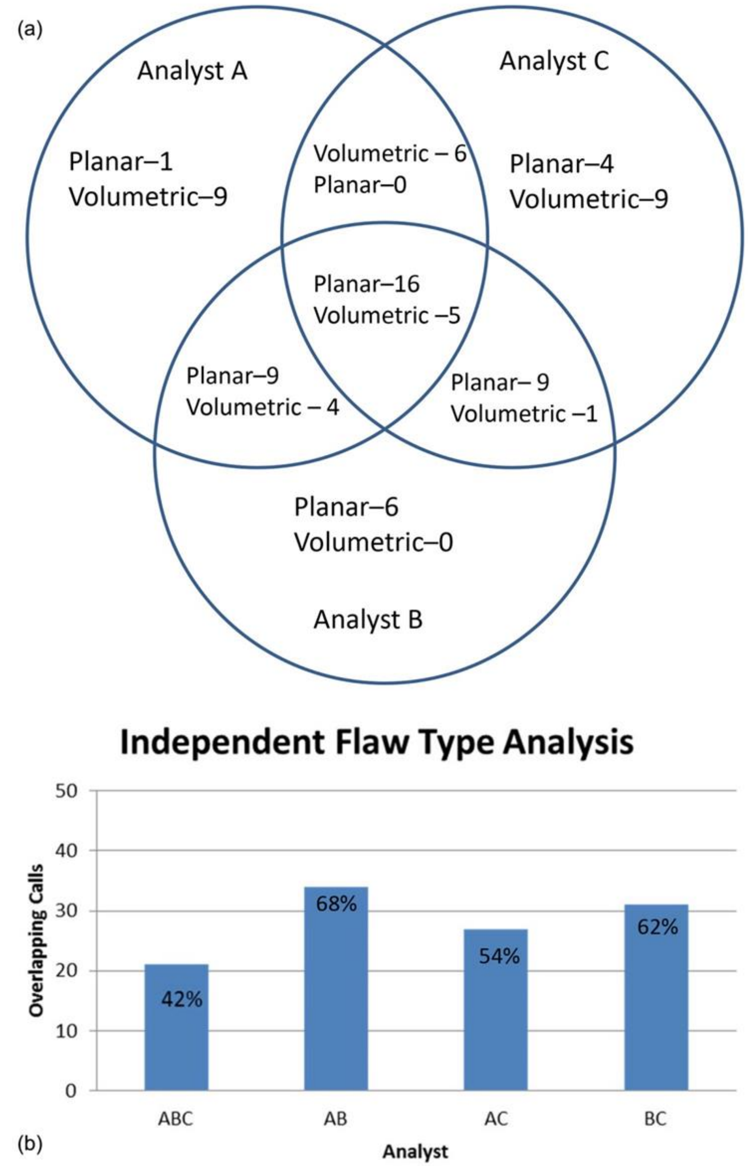
Characterization –

- Three analysts independently applied the flaw-type decision matrix criteria
- Flaws were characterized as planar or volumetric only
- Flaws did not display all of the “ideal” characteristics for each of the flaw attributes being assessed
- Results were highly subjective and depended on analyst experience
- Results call into question the ability to consistently and accurately characterize flaw type



What the NRC Staff has learned…

- Detection:
  - PAUT has the ability to successfully detect flaws in carbon steel welds to performance levels comparable to, or even greater than, that achievable with RT.
  - PAUT detection capability is degraded when only single-side access is available, and even more so when weld crowns remain in place.
- Sizing:
  - PAUT both under-sizes and over-sizes, depending on flaw type. Sizing the fabrication flaws in carbon steel piping welds fell within the sizing acceptance criteria of ASME Code, Section XI, Appendix VIII; however, the applicability of this criteria to fabrication flaws is questionable.

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What the NRC Staff has learned…

- Flaw Characterization:
  - The results of this study indicate that the ability to characterize flaws as either planar or volumetric is very analyst subjective.
  - Thus, whether its appropriate to apply current welding fabrication flaw acceptance criteria, which are highly dependent on UT characterization, is questionable.

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NRC Staff's unresolved concerns…

- Consideration of whether ASME Code, Section XI, Appendix VIII UT performance demonstration requirements are applicable to repair/replacement activities
  - Flaw types and inspection volumes very different from pre-service and in-service inspections
- Acceptance criteria for fabrication type flaws
  - Cannot directly use RT acceptance criteria due to differing physics of methods
  - Applying Section XI acceptance criteria may result in accepting welds with poor workmanship
  - Applying Section III may reject acceptable flaws causing unnecessary repairs

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NRC Staff's unresolved concerns…

- Only PAUT assessed in this study. Whether conventional UT methods could be successfully applied for these applications remains unknown at this time.
- Study limited to fine-grained, carbon steel butt welds. No conclusions should be drawn regarding the applicability of UT in lieu of RT for other NPP weld materials or configurations.

NRC's Current Activities on UT in lieu of RT

Completion of the task to look at UT in lieu of RT for carbon steel welds:

- Using statistical methods to assess the performance demonstration requirements proposed in CC N-831
- Performing a comparative analysis of conventional UT to phased array UT to assess whether conventional UT is fundamentally capable of meeting the performance demonstration requirements for application to CS piping welds

Beginning to look at UT in lieu of RT for austenitic welds

- Assess variables that must be considered for coarse-grained welds including identifying appropriate UT frequencies and modalities
- Specimens needed – will be designed and built, if necessary

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