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UT in Lieu of RT for Nuclear Power Plant Applications

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Outline

- Project Objective
- Equipment
- Specimens
- Data Acquisition
- Data Analysis
- Summary to date
- Recent Modeling Work
- Upcoming PNNL Work
- Not yet considered…
- Summary of Navy “UT/RT” Program

Project Objective

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 (RRA).
  - Assess whether would also be applicable to Section III, new construction
  - Related to ASME Code Cases N-659 and N-713.

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

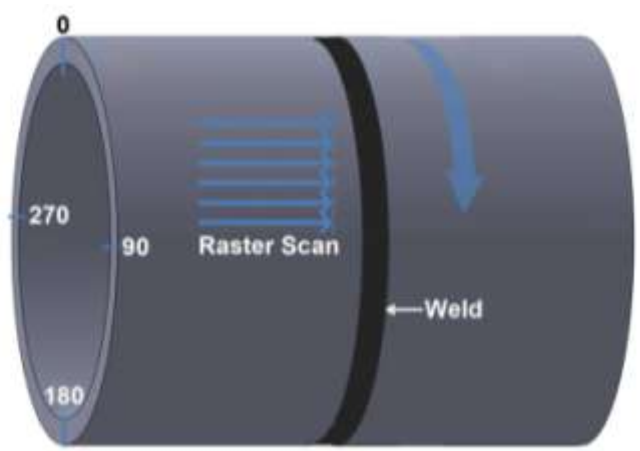
Specimens

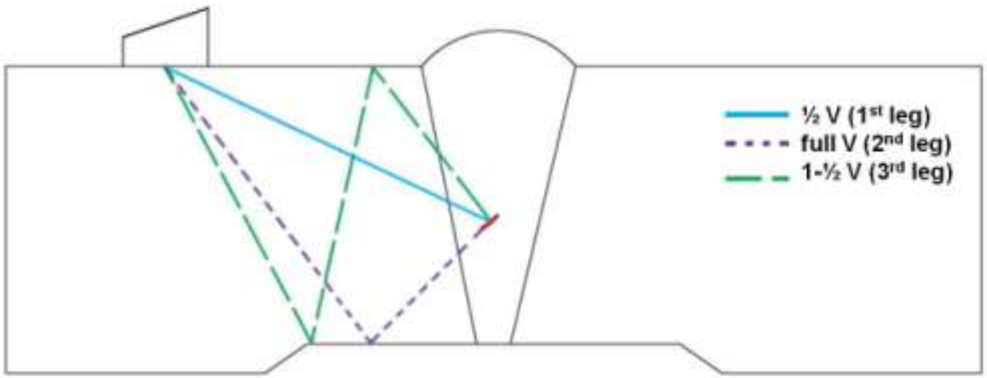
- 4 borrowed Carbon steel pipe-to-pipe welds
  - Diameters – 14” and 16”
  - Thickness – 0.75” through 1.091”
  - Implanted Welding flaws
    - Lack of fusion (LOF), Lack of penetration (LOP), Crack (CRK), Slag (SLG), and Porosity (POR)

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)

Data Acquisition

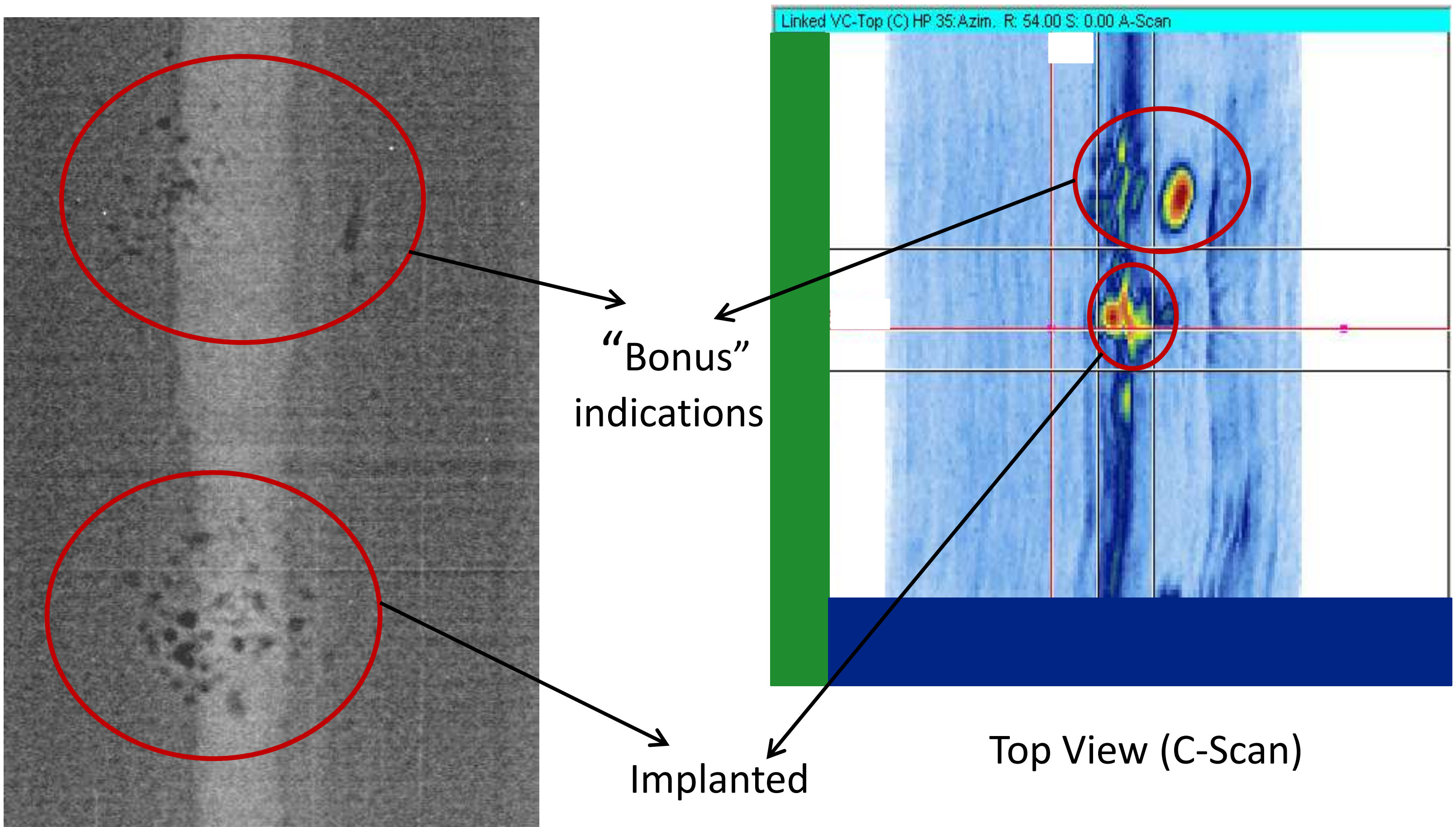
- RT
  - Single-wall, film and CR
  - True State – length sizing and flaw type
- UT
  - 4.0 MHz TRS, linear PA (32 X 1 elements per probe)
  - Insonification angles 45 – 75 degree
  - Axial Raster Scanning, both sides of weld
  - ½ V, full V, and 1-1/2 V sound path





Data Analysis

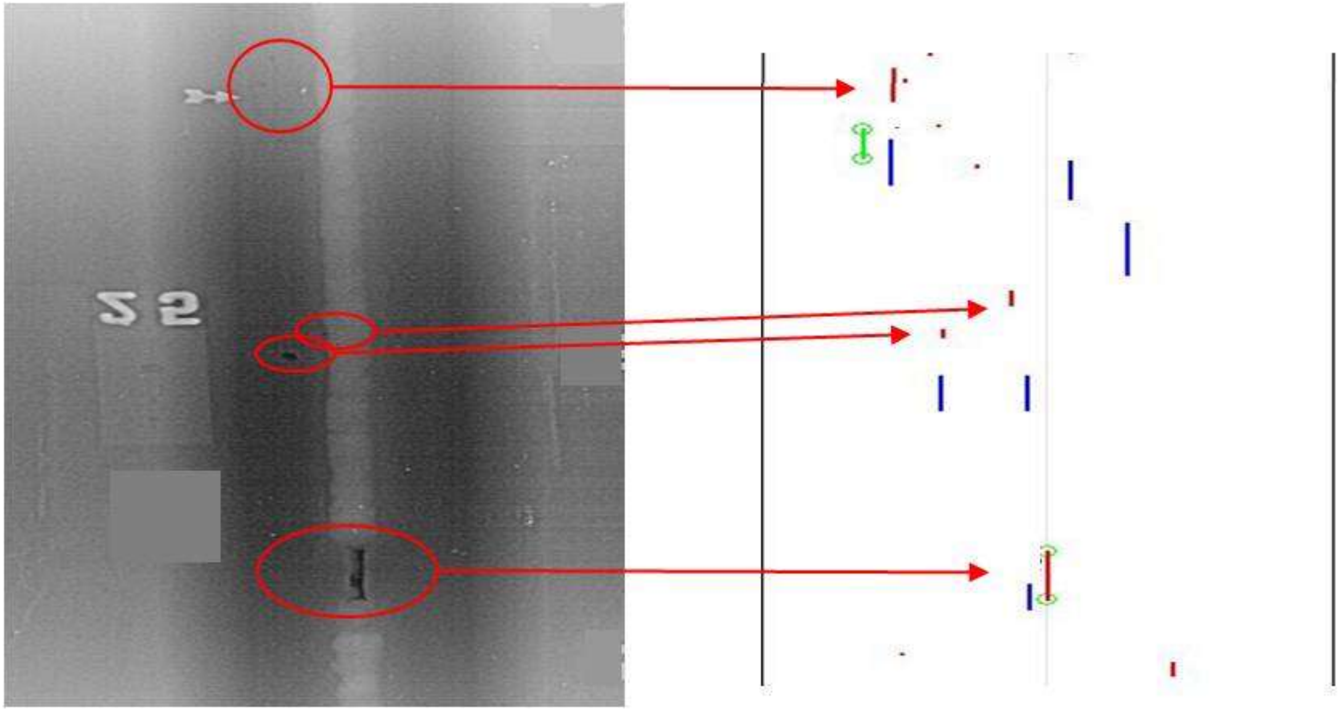
Detection Reliability – UT and RT found both implanted (planned) flaws as well as bonus (unplanned) flaws on all four carbons steel specimens



Data Analysis

Detection Reliability - Flaw Maps were created for each pipe depicting length and location for both RT and UT (from each side)

- Green = Flaw manufacture provided implanted flaw location
- Red = RT indication



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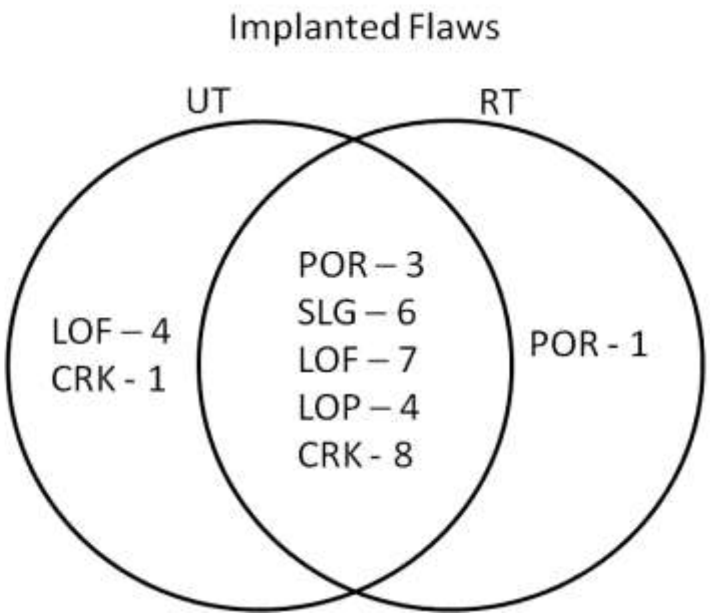
Data Analysis

Detection Reliability – Implanted flaws in carbon steel piping

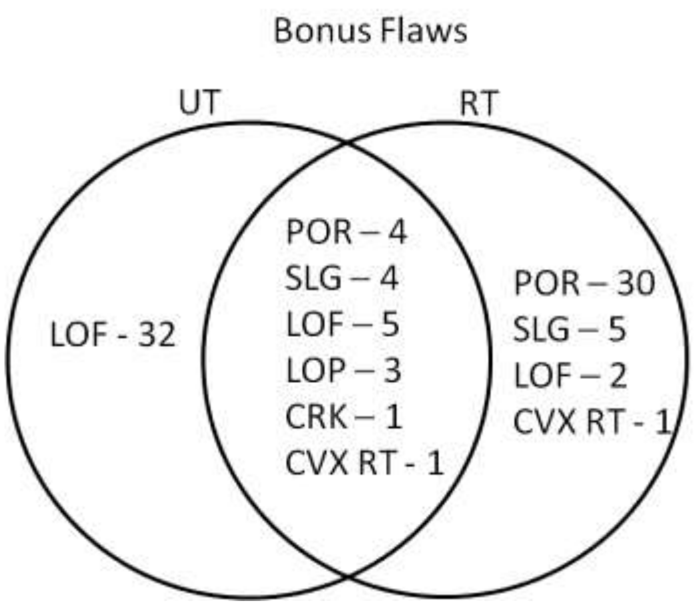
- UT and RT appear to have similar detection capability for volumetric flaws
  - UT missed 1 small porosity (5.3 mm (0.2 in.) in length)
- UT has a better detection capability for planar flaws
  - RT missed 5 planar flaws
  - Planar flaws are more likely to grow throughout the service lifetime of the plant and could be more detrimental
- Average UT Signal-to-Noise Ratio
  - for planar flaws = 29.1dB
  - for volumetric flaws = 22.6 dB

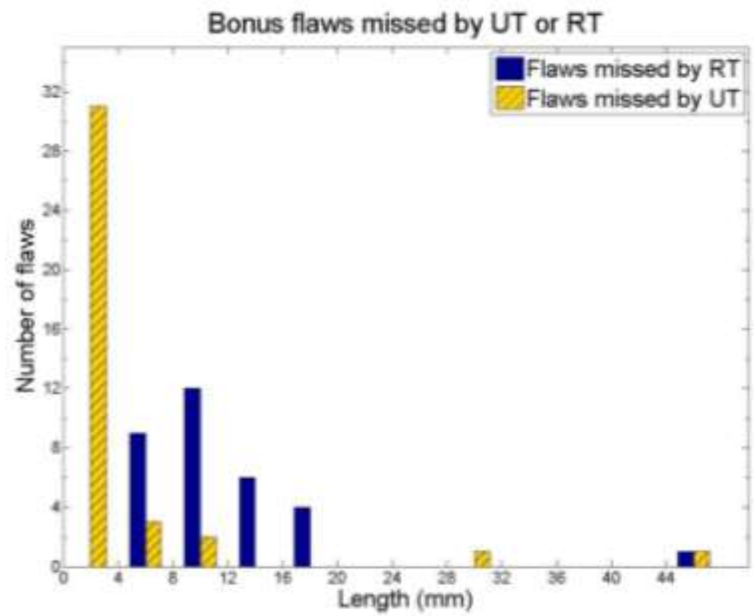


Data Analysis

Detection Reliability – Bonus flaws in carbon steel piping

- UT missed 38 Flaws
  - 35 volumetric flaws that were nominally less than 4 mm in length (smaller than focal spot size of PA probe)
  - 1 porosity was large enough to be unacceptable
- RT missed 32 Flaws
  - All assumed to be planar flaws (LOF)
    - Missed due to relative orientation of x-ray beam and/or being masked by flaws in the same axial and circumferential positions

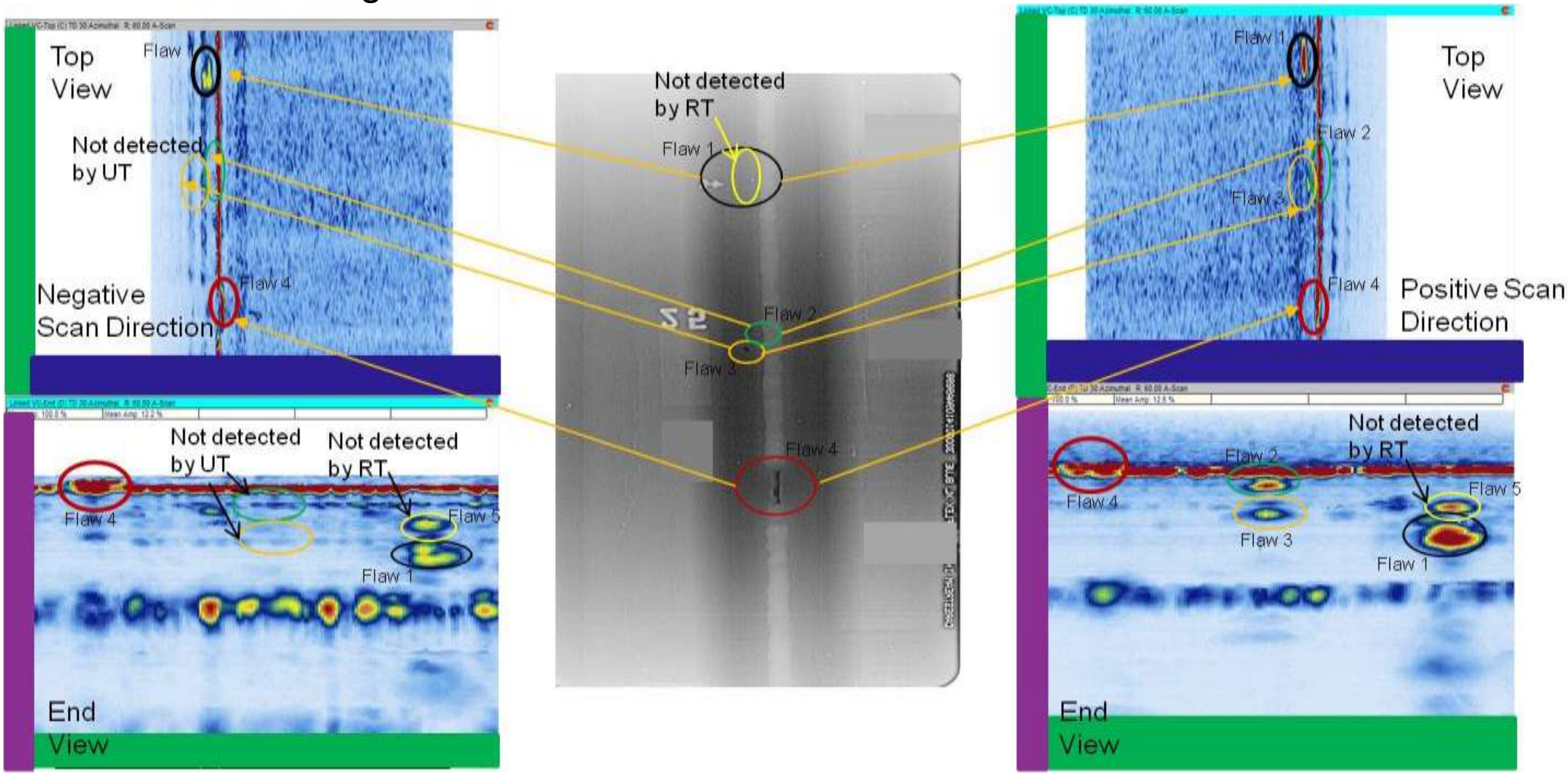




Data Analysis

Detection Reliability –

- Single sided vs. double sided exams - Some fabrication flaws may not be detectable from a single side UT exam
- Depth Positioning – Important advantage of UT is its ability to detect flaws stacked throughout thickness in same circumferential location



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 2^{nd} and 3^{rd} leg of sound…
  - POR, SLG, and LOF sized better with -6 dB sizing method
  - LOP and CRK sized better with -12 dB sizing method
- RMSE within Section XI, Appendix VIII acceptance criteria of 19.05 mm
  - Typically applied to cracks and may not necessarily translate to fabrication flaws
- Over- and undersizing
  - 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 (+)

Summary of detection reliability result to date

Detection Reliability – carbon steel piping

- UT has a better detection capability for planar flaws
- UT's most significant detection limitation is detecting small volumetric flaws that have less of an impact on the structural integrity of the specimen
- One of the main advantages that UT has over RT in detection is its ability to assess through-wall depth information as well as its ability to discriminate flaws stacked throughout the thickness in the same circumferential location
- UT was able to detect flaws using the 2nd and 3rd leg of sound when the 1st leg of sound could not be used due to a weld crown
- UT did not always detect flaws from both sides which would impact single-sided examinations

Summary of length sizing results to date

Sizing Reliability (limited data set on carbon steel piping)

- RMSE within Section XI, Appendix VIII acceptance criteria of 19.05 mm for all fabrication flaws evaluated
  - Typically applied to cracks and may not necessarily translate to fabrication flaws
- UT is more likely to oversize SLG, POR, and LOF, which may cause the flaws to be rejected when they should have been accepted
- UT tended to undersize CRK and LOP, which may cause an unacceptable flaw to be accepted

Recent modeling work

PAUT Probe Design

- 4 MHz TRS, linear PA 2x(32x1) elements per probe used to date
  - Probe sufficient for 1” thick CS
  - Modeling performed to determine extent of probe’s capabilities
- “Idealized” probe designed for use in thicker CS samples (approx. 2”)
  - Resulted in 5 MHz probe with 2x(32x4) elements

Modeling

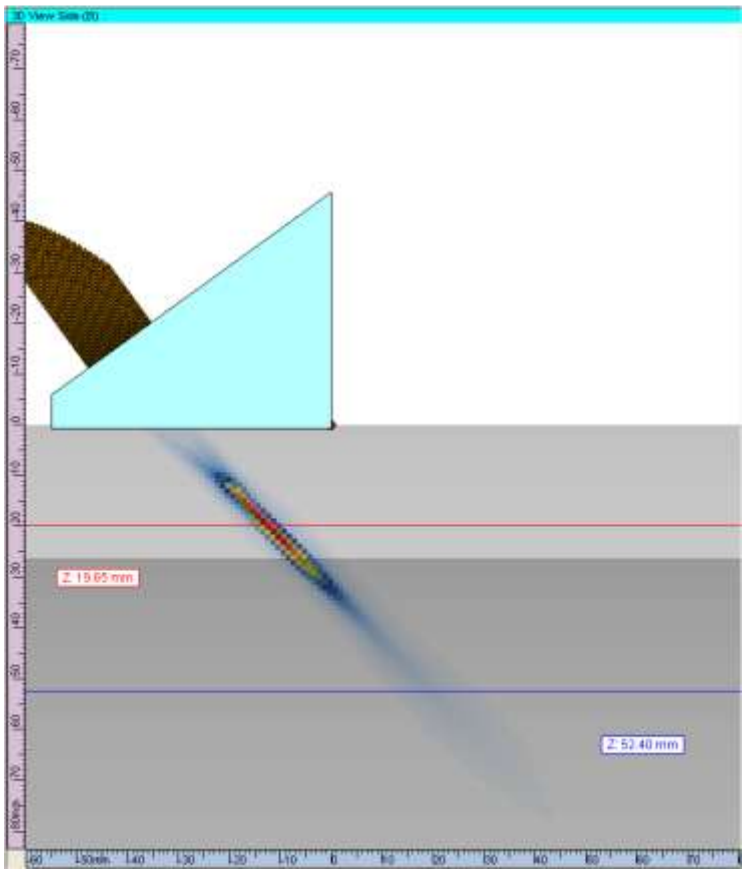
- Beam directivity
  - acoustic pressure calculation using Huygen’s principle
  - existing 4.0-MHz probe produces an unwanted grating lobe when sweeping (directing) from the part center angle
- Beam simulations
  - Ultravision’s modeling tools
  - 5.0-MHz probe produces a better focal zone throughout the thickness of the material and has better focusing capabilities, thereby improving signal-to-noise values for flaw detection and characterization for thicker carbon steel materials (i.e., Navy plates)

Recent modeling work

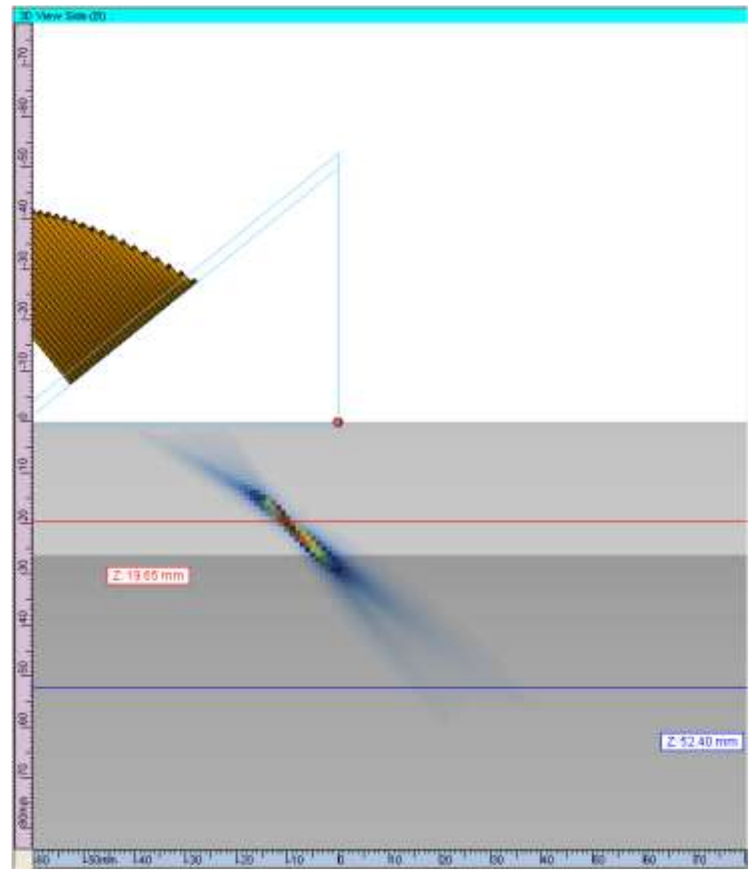
Simulations in 1” pipe specimen

- TD Focus 3/4T, 45 Deg. (Bounce Metal Path)

5.0 MHz



4.0 MHz



Upcoming PNNL Work

Examination of several Navy “UT/RT” test plates

- Collect and evaluate data on several of the remaining Navy UT/RT test plates
- New PAUT probe designed for thicker material will be used
- “Flaw maps” are available to provide true state (location, size, and classification) of discontinuities in the plates.
  - Sectioning and metallography cost prohibitive to perform.
  - Cannot section mockups scanned to date as they belong to industry.
- Determine if Navy study conclusions that UT is a good alternative to RT (for submarine hull weld inspections) may translate to NPP CS materials/piping systems as well as the PAUT method

Not yet considered…

- 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-/in-service inspection
- Acceptance criteria for fabrication type flaws
  - Applicability of RT acceptance criteria? 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

Summary of U.S. Navy program "Ultrasonics as an Alternative to Radiography (UT/RT) for Submarine Hull Weld Inspection"

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Summary of Navy "UT/RT" Program

- U.S. Navy program "Ultrasonics as an Alternative to Radiography (UT/RT) for Submarine Hull Weld Inspection"
  - Mid 1980's – early 1990's
  - The Navy believed that UT for weld inspection would result in reduced cost of inspection, increased productivity, immediate inspection results including knowledge of depth of discontinuity, and potentially more accurate sizing of the discontinuity.
  - Objectives of program:
    - to determine if structural welds could be ultrasonically inspected with repeatability and reliability comparable to that obtained with radiographic inspection
    - to assure that future UT inspections of welds provides objective, hard copy records

Summary of Navy "UT/RT" Program

Publications summarizing this program:

- Lebowitz, Carol A. and DeNale, Robert, "Evaluation of a Computer-Assisted Ultrasonic Inspection System (P-Scan) for Structural Weld Inspection," Proceedings for the 4th Canadian Forces/CRAD Meeting on Research in Fabrication and Inspection of Submarine Pressure Hull, 4-6 June, 1991, Halifax, Nova Scotia, Canada.
- DeNale, Robert and Lebowitz, Carol, "A Comparison of Ultrasonics and Radiography for Weld Inspection," Review of Progress in Quantitative Nondestructive Evaluation, Vol. 8, Eds. D.O. Thompson and D.E. Chimenti, Plenum Press, New York (1989).
- DeNale, Robert and Lebowitz, Carol, "Detection and Disposition Reliability of Ultrasonics and Radiography for Weld Inspection," Review of Progress in Quantitative Nondestructive Evaluation, Vol. 9, Eds. D.O. Thompson and D.E. Chimenti, Plenum Press, New York (1990).
- Lebowitz, Carol A., "Evaluation of an Automated Ultrasonic Scanner," Review of Progress in Quantitative Nondestructive Evaluation, Vol. 10, Eds. D.O. Thompson and D.E. Chimenti, Plenum Press, New York (1991).
- DTRC-SME-90/30 February 1990, Ultrasonics as an Alternative to Radiography for Submarine Hull Weld Inspection, by Robert DeNale and Carol A. Lebowitz (not open literature; however, copies may be requested from NAVSEA 05P24)

Summary of Navy "UT/RT" Program

Techniques evaluated in UT/RT program

- Standard practice manual ultrasonics (MUT)
  - Krautkramer-Branson USL-48 flaw detector with ¾" x 1", 2.25 MHz, 60-degree shear wave transducer
  - Eight shipyard inspectors (equivalent to ASNT Level II)
- Standard practice radiography (RT)
  - X-ray, cobalt-60 and iridium-192 sources with Kodak types AA and M film (Ir/AA most commonly used in shipyards)
  - Eight shipyard film interpreters (equivalent to ASNT Level II)
- Computer-assisted ultrasonic (CAUT)
  - Danish Welding Institute P-scan System (Model PSP-3) with ¾" x 1", 2.25 MHz, 60-degree shear wave transducer
  - Five to eight shipyard inspectors using a manual weld scanner (CAUT) – each completed 40 hours of formal training in operating the P-scan and evaluating data prior to use
  - One "experienced operator" using a manual weld scanner (CAUT*)
  - One "experienced operator" using an automated scanner (CAUT**)

Summary of Navy "UT/RT" Program

Evaluation of standard practice UT and RT:

Test plates:

- 18 x 2-ft.welds fabricated for study with purposely induced discontinuities
  - SMAW and GMAW (automated and semi-automated) welding processes
  - 24" x 24" x 1-1/2" thick HY-80 steel
  - Slag, lack of fusion, incomplete penetration, cracks, slugs, clustered porosity, and scattered porosity
- 18 x 1-ft. welds cut from decommissioned submarine
- "Consensus" discontinuities identified by reviewing all inspection results from the exams of the 36 test plates, characterizing as to discontinuity type, and for several welds, verification by sectioning and metallography.

Evaluation of Computer Assisted UT

- Up to 8 inspectors used the CAUT equipment to inspect 15 fabricated test plates and 17 of the welds cut from the decommissioned submarine
- Discontinuities in several test welds were verified by sectioning and metallography

Summary of Navy "UT/RT" Program

Initial Results

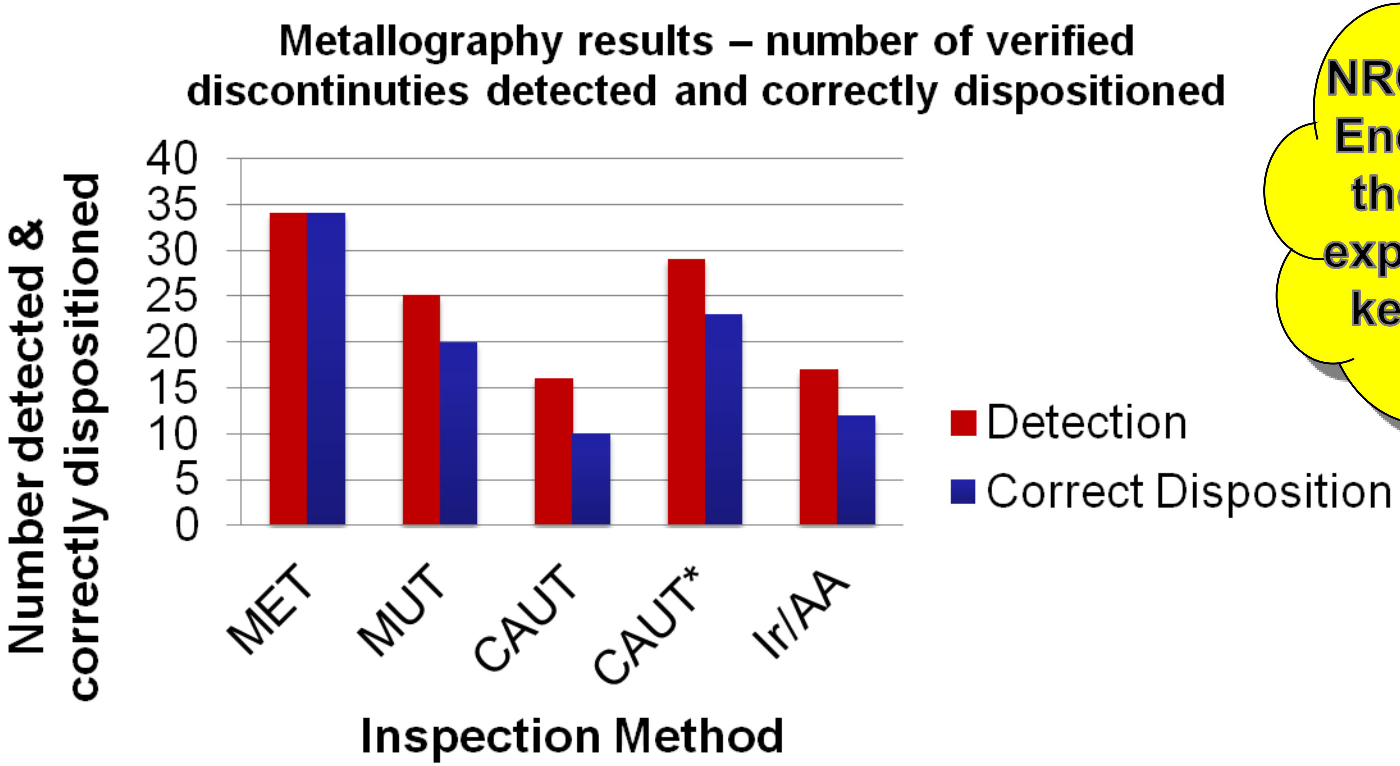
- From 3024 inspection reports on 36 test plates, 212 consensus discontinuities identified.
- UT had highest detection rate, followed by RT with X-ray, Ir-192 and Co-60
  - For RT, as energy of source increases, number of calls decreases. Also, the higher energy sources preferentially missed planar discontinuities.
- MUT detected more discontinuities than RT, and in particular, MUT detected more planar discontinuities. However, MUT detected approximately the same percentage of volumetric discontinuities as RT.
- Of rejectable discontinuities (those that are detected and rejected by consensus), UT rejected more than RT. Specifically, UT rejected more planar discontinuities than RT.

Summary of Navy "UT/RT" Program

Metallography

- Five plates containing 34 consensus discontinuities were sectioned for verification purposes.
- The classification assigned to 78% of the discontinuities verified by metallography agreed with the metallographic interpretation. This result indicated that the discontinuity identification procedure was a reliable method for classifying discontinuities.
- UT detected more metallographically rejectable discontinuities than Ir/AA radiography, regardless of discontinuity type.
  - Data indicated that UT performed by experienced operators correctly dispositions 2x as many metallographically rejectable discontinuities as did Ir/AA RT.
  - UT had fewer incorrectly dispositioned discontinuities than did Ir/AA RT.

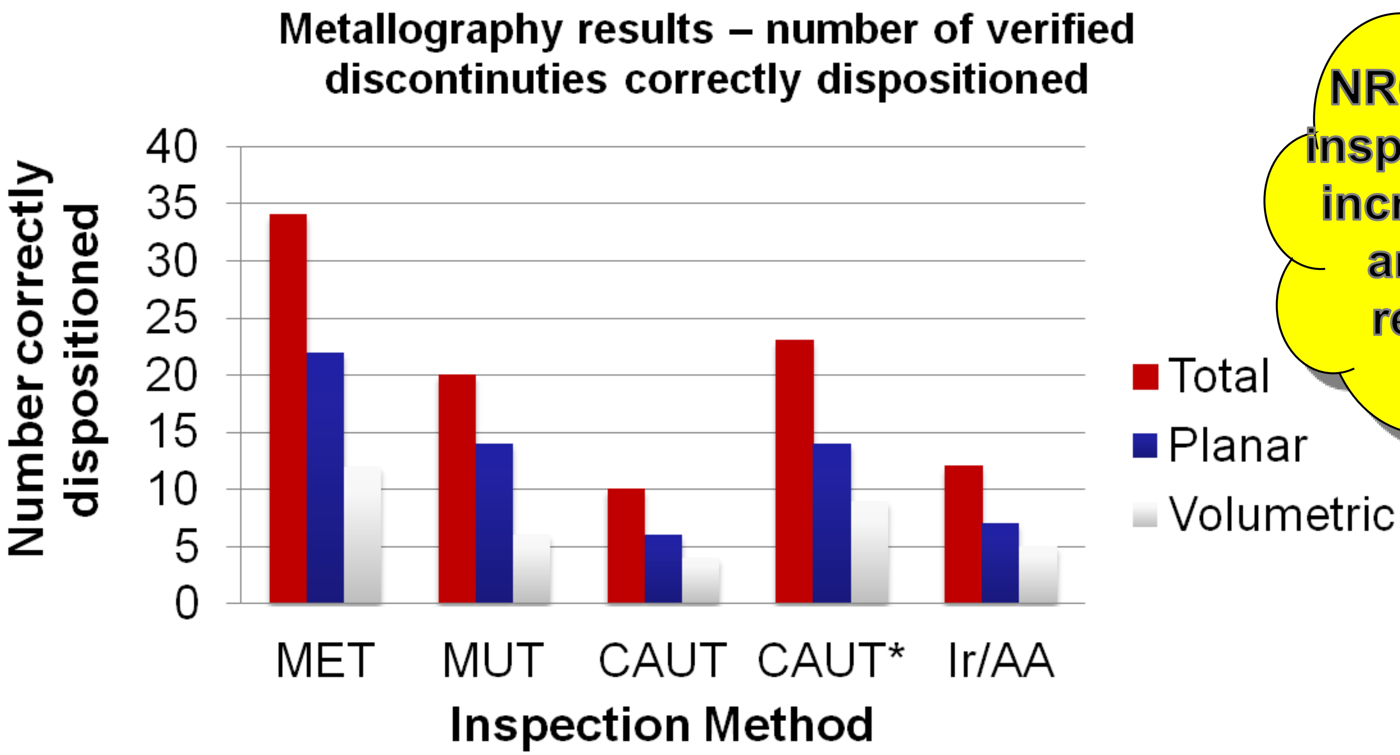
Summary of Navy "UT/RT" Program



NRC "take away" - Encoded UT best, though operator experience plays a key role in exam reliability

	MET	MUT	CAUT	CAUT*	Ir/AA
Detection	34	25	16	29	17
Correct disposition	34	20	10	23	12

Summary of Navy "UT/RT" Program



NRC "take away" – inspector experience increases detection and disposition reliability of UT

	MET	MUT	CAUT	CAUT*	Ir/AA
Total	34	20	10	23	12
Planar	22	14	6	14	7
Volumetric	12	6	4	9	4

Summary of Navy "UT/RT" Program

Assessment of inspection repeatability

- MUT and CAUT are more consistent than RT when discontinuity is planar
- RT is more consistent when discontinuity is volumetric
- Overall, UT and RT repeatability comparable when examining purposely introduced flaws

- UT will be most consistent method for rejecting flaws in automated welding processes where flaw types are expected to be planar
- RT will be most consistent method for rejecting flaws in manual welding processes where flaws are expected to be volumetric

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Summary of Navy "UT/RT" Program

Error Analysis

- Error analysis was performed on 34 discontinuities that were found during metallographic evaluation of 5 test plates
- Null hypothesis is that a discontinuity is acceptable
- Type 1 errors occur when an acceptable discontinuity is rejected – this results in increasing production costs
- Type 2 errors occur when a rejectable discontinuity is accepted – this results in not meeting the design criteria
- Results indicated that a similar number of errors occurred with each method evaluated; however, when looking at the data in terms of errors made per total number of discontinuities detected, UT performed better than RT as it detected a greater number of discontinuities resulting in a smaller percentage of errors.

	CAUT*	MUT	Ir/AA	CAUT
Total Detected	29	25	17	16
Type II Error	5	4	5	6
Type I Error	1	1	0	0

Summary of Navy "UT/RT" Program

Navy's Conclusion (from DTRC-SME-90/30):

- "Based on the results of the work presented herein, ultrasonic weld inspection, if implemented under carefully controlled conditions, will provide an acceptable alternative to radiography as an inspection method for submarine hull welds."