Agenda Wednesday afternoon

1:10	Virtual mockups - progress update	EPRI
1:30	Adaptive coupling: UT on wavy surfaces	EPRI
1:50	Update on volumetric exams for BMNs	EPRI
2:00	PWR RPV internals bolting protocol	EPRI
2:15	BWRVIP NDE update	EPRI
2:35	Human factors, training, and practice	NRC
3:05	Break	
3:25	Human factors in NDE	EPRI
3:55	Analysis of empirical probability of detection data for dissimilar metal welds	NRC
4:25	Public comment period	NRC
4:30	Adjourn	

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Virtual mockups – progress update

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NRC / Industry
NDE Technical Information Exchange Meeting
Washington, DC
January 2019

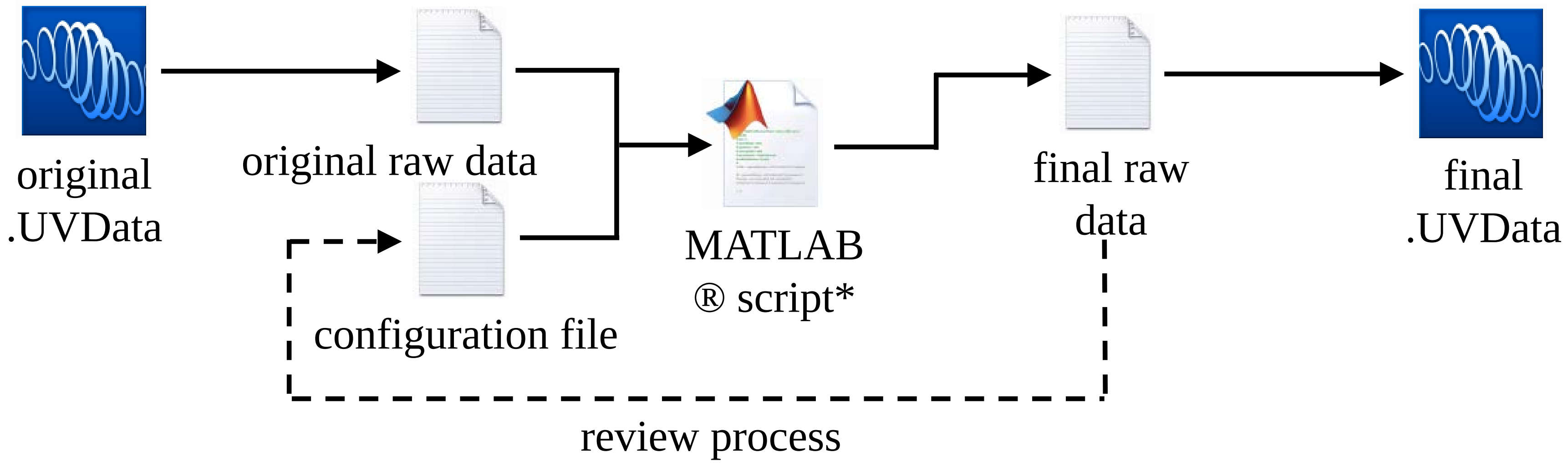
Past Research

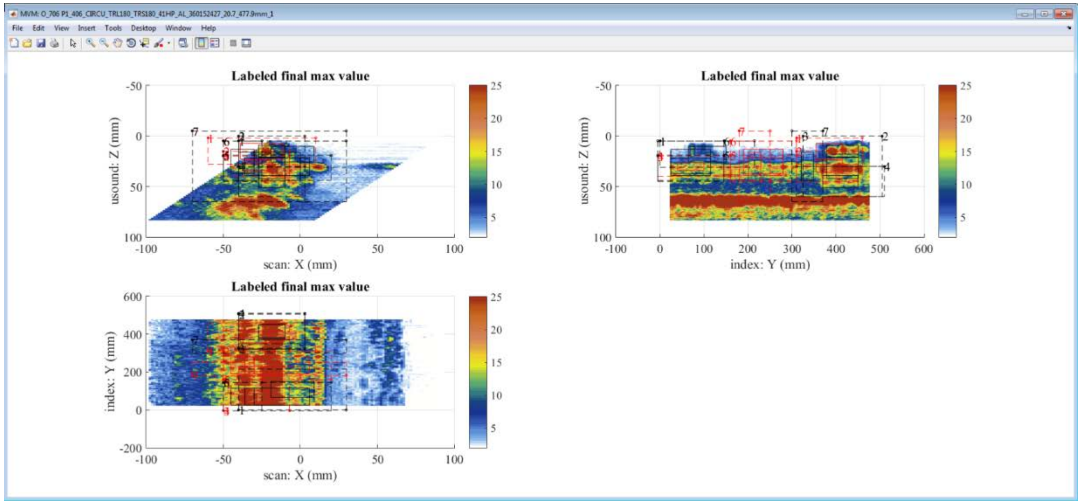
- Project work performed in the past
  - *Nondestructive Evaluation: Virtual Mockups – A Feasibility Study into Electronic Implantation of Flaw Responses into Previously Recorded Data.* EPRI, Palo Alto, CA: 2018. 3002013152.
    - Report detailing results of 2016 - 2018 phase of project
  - *NDE Training Data Utilizing Virtual Flaw Technologies.* EPRI, Palo Alto, CA: 2014. 3002004414
    - Data set of all data generated during the past phase
      - Phased array DM data
      - Conventional piping data
      - TOFD CRDM data
  - *Nondestructive Evaluation: Virtual Mockups – A Feasibility Study into Electronic Implantation of Flaw Responses into Previously Recorded Ultrasonic Data: NDE Training Utilizing Virtual Flaw Technologies.* EPRI, Palo Alto, CA: 2014. 3002003022

The Basics

- What is a Virtual Mockup?
  - It's a mockup that only exists in a data file on a computer – it does not physically exist. It is made up of components and flaws sourced from real mockups or created in a modeling environment (e.g. CIVA).
- What is a Virtual Flaw?
  - It is a flaw that is sourced from real data (i.e., a flaw that exists in a real physical mockup) and placed into a data file to create a Virtual Mockup.
- What is a Synthetic Flaw?
  - It is a flaw that is sourced from a modeling source (e.g. CIVA) – this is a flaw that has never physically existed in a real mockup that gets used to create a Virtual Mockup.

Process for sourcing virtual flaws from existing data -





Current Capability for Creating Virtual Mockups

- Limitless new mockups can be created using the data from one or more mockups with many flaws
- Virtual mockups should match physical mockups in weld properties / geometry / materials in order to maintain cost effectiveness
- Best situation – manufacture one blank mockup (no flaws) and one or two flaw-heavy mockups (10+ flaws per mockup) – ensure that all of the flaws required for the target application are represented in flawed mockups
  - Utilizing these 2 or 3 mockups as many mockups as required could potentially be built (virtually)
  - Downside – must create new set of virtual mockups for each procedure / technique that requires qualification

Industry Activities with Virtual Mockups

- 2017 – Industry focus group was formed to further inform the project. Focus group had participation from several US utilities.
  - Dominion, Southern Nuclear, TVA
- Focus group provided direction to build two virtual samples that could be provided to vendors for review and comment.
  - Data from mockups provided by Dominion
    - One mockup was a simple pipe to pipe configuration
    - One mockup was a pipe to elbow configuration
  - Requested output was two pipe to pipe mockups with a subset of flaws from the defect inventory currently implanted in the mockups

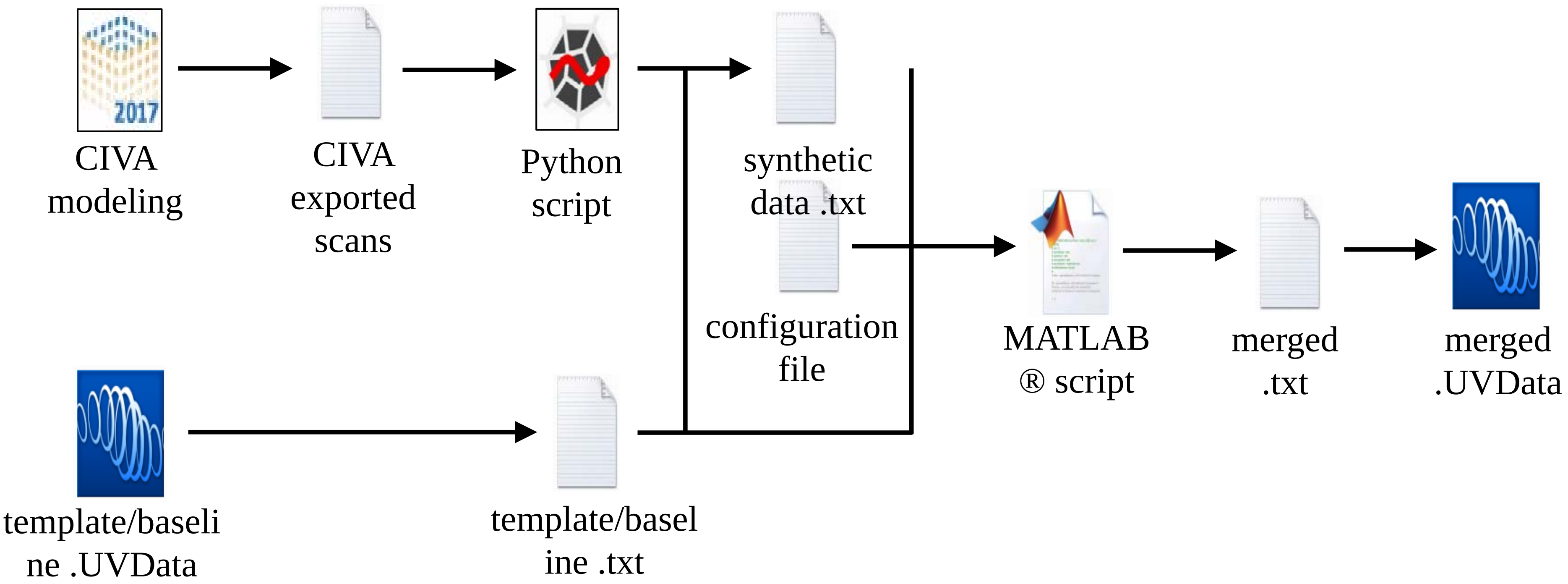
Industry Activities with Virtual Mockups

- Pipe to pipe mockup
  - 1st mockup created with the improved tools (creation was straightforward)
  - Sample exposed to 10+ data analysts with no ability to discern the difference between the physical mockups and the virtual mockups
- Pipe to elbow mockup
  - Flaws on the elbow side of the configuration proved to be challenging when importing them into a pipe to pipe configuration
    - Geometry; flaw location within the mockup
  - Sample exposed to multiple data analysts who were unable to distinguish from other physical mockups
- Take away – creating virtual samples using flaws from similar mockups is straightforward; changes in geometry between the source mockup and the final mockup can cause challenges but is possible (may not be cost effective)

Future Research Areas

- Digital mockup creation based on needs without ever creating a physical mockup to base it off of
  - Relies heavily on ability of modeling software to accurately model data that mimics physical data collected with an entire ultrasonic system including the probe characteristics and material noise
  - Does not seem plausible nor cost effective at this time
- Develop robust modeling processes using physically manufactured blank mockups (no flaws)
  - Consistent weld properties / geometry / materials
  - Validation of modeling inputs and results
- Create flaws in modeling software and import into data from blank mockup
  - Proof of concept points to plausibility and cost effectiveness
  - Further testing planned

Process for creating synthetic flaws and injecting into previously collected data



Current Workscope

- Involves completing initial research into the area of synthetic flaws and reporting out on uses / limitations at year end
  - Will involve trials utilizing seasoned qualified individuals to understand the potential use of these types of flaws in a "blind" scenario
  - Work will involve performing an internal "QA" evaluation into the flaw and mockup creation process to understand which processes will need to be controlled and documented going forward for use in a "blind" scenario
  - Work will also involve more detailed discussions around potential use of this new process for training, demonstration, and / or qualification activities as applicable

Supporting a Virtual Mockup Library

- While research into synthetic flaws is ongoing – a set of “open” unflawed mockups are planned be built to match the PD inventory of piping / DM samples
  - Utilizing these new “open” samples along with the current inventory of PD samples an unlimited number of virtual mockups could be created to be utilized with the EPRI simulator
  - Flaws found in the field can be installed into proper configurations – the value of these types of flaws for training and testing is priceless (think IGSCC program)
    - These ‘open blanks’ won’t cover every case, but any member with a unique configuration can augment it; the manufacturing cost of a ‘blank’ is low
    - Set up a generic location to house any collected field flaw data and have it available for all members

Summary

- Process for utilizing existing mockups to harvest flaws and create new virtual mockups is viable and can be utilized by the industry for
  - Creating new mockups for use with the ultrasonic simulator
  - Creating new practice data for encoded examinations
  - Collecting a library of flaws and interesting observations that have been observed in encoded field data to support training and hands on practice opportunities
- Further research being performed
  - Synthetic flaws
  - Quality process steps / requirements for use in “blind” testing
  - Future storage of field removed flaws / observations
  - Data collection guidelines for use of field data in virtual mockups / simulator files

discussion

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Adaptive Coupling: UT on wavy surfaces

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January 2019

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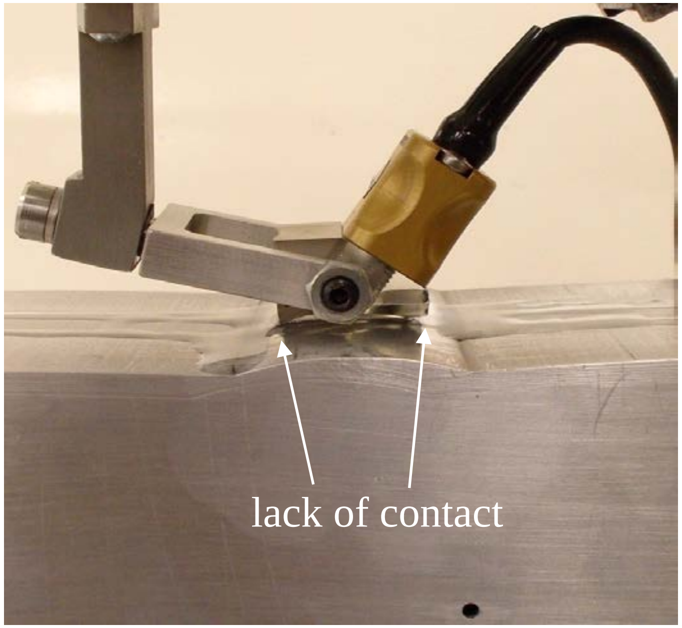
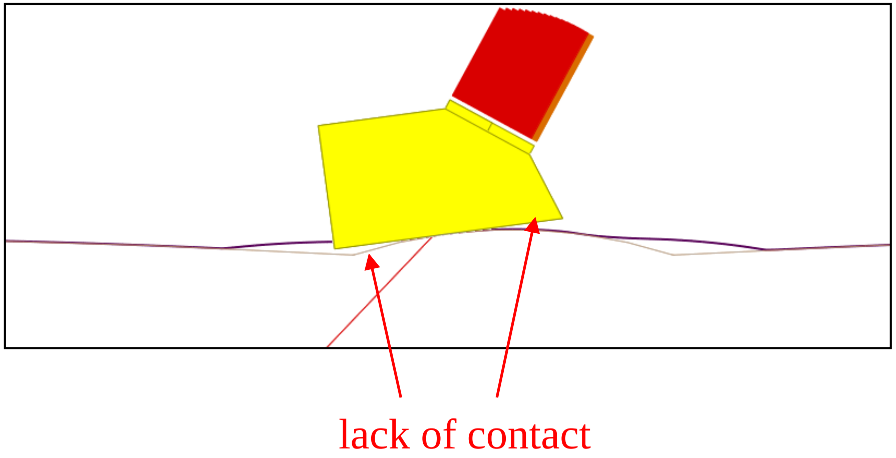
Project Objective

- Investigate practical methods to improve probe/component contact while providing quality ultrasonic examination data.
  - Are there materials, an apparatus, data collection techniques, and/or algorithms to help with this need?
  - Identify the strengths and weaknesses of each method.
  - Uneven probe path, rotational movement, and large gaps (> 1/32”)



- Rotational movement affects the direction of ultrasonic propagation



Typical Ultrasonic Examination Procedure Surface Condition Requirements

- RMS finish approximately 250 RMS and free of irregularities, loose material, or coatings, which may interfere with the ultrasonic wave transmission.
- The weld crown condition shall be flush with the base material to allow for adequate scanning on top of the weld and butter material. Flush is defined as no more than a 1/32" gap between the search unit and the examination surface for the entire length of the scan. Examples of conditions that can cause this effect include weld shrinkage, tapers or transitions, or weld toes.
- Areas that do not meet the surface requirements above or where ultrasonic contact is inadequate shall be documented as limitations.

Technical Challenges

The two most high level technical challenges for successfully scanning a wavy component are:

1. ***Coupling*** - achieving sufficient coupling between the probe and part for gaps greater than 1/32 inch (0.8 mm).
   - Sound must be capable of being transmitted into and received from the component.
   - Air gaps must be minimized.
2. ***Imaging*** - accommodating for the changing materials and surface geometry to achieve sufficient beam steering, focusing, and/or imaging reconstruction.
   - Gaps filled with water, polymers, or any alternative coupling material will cause additional beam refraction.
     - Most software and instruments do not account for this.
   - Wavy surfaces will affect beam focusing, steering, and image reconstruction.
     - Fixed transmission/reception laws are degraded by drastic changes in beam refraction or surface profiles.

Coupling Solution - Conformable Wedges

- Silicone wedge or water filled wedge connected directly to transducer.
  - These wedges are very soft and can conform to changes in the wedge-to-component interface.

0° | Angle Beam

Silicone

Water

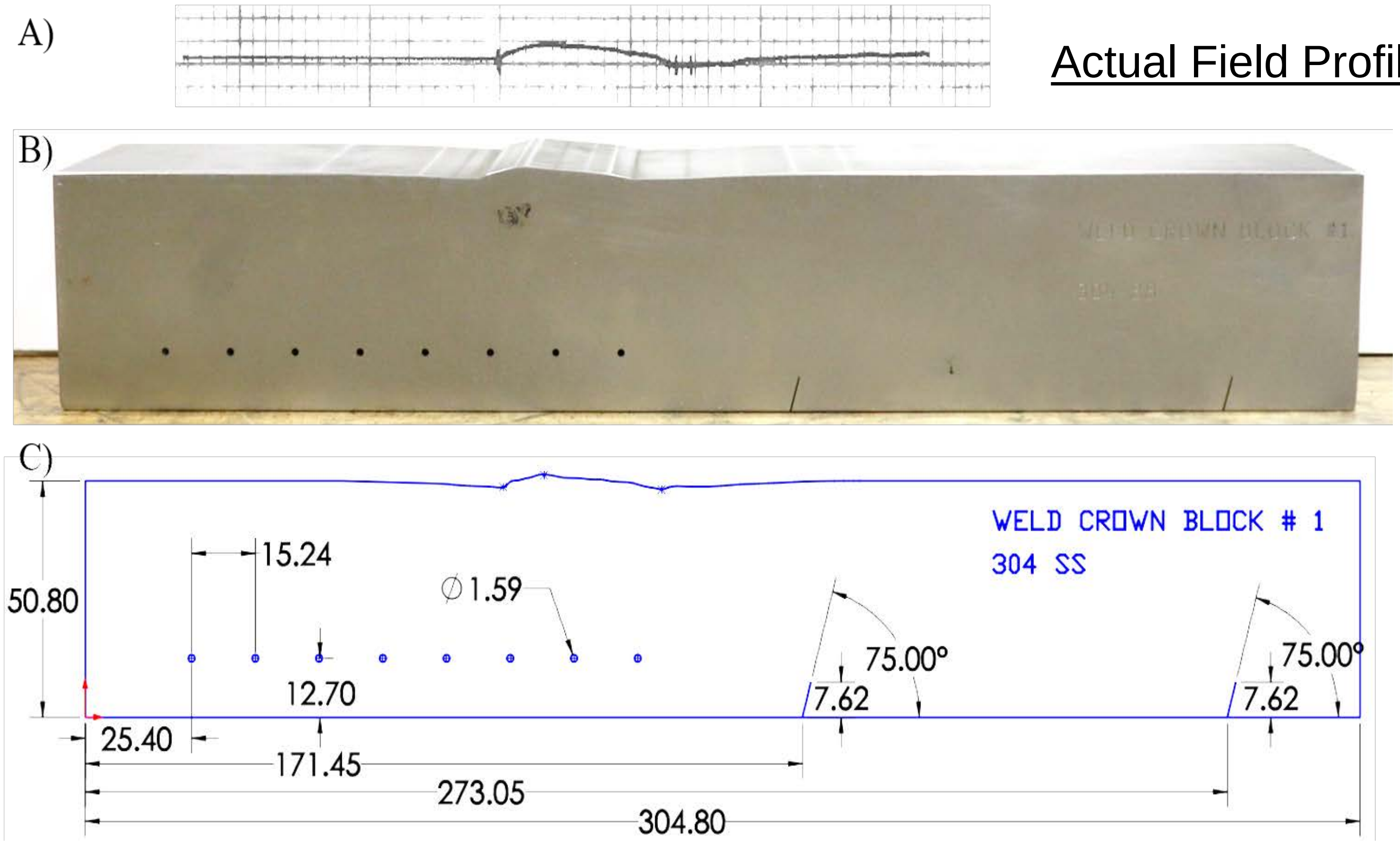
Imaging Solution

Two significantly different ultrasound techniques exist:

1. ***Fixed focal laws*** – focal and delay laws are fixed in magnitude
   - This is performed for traditional UT and phased array UT (PAUT)
   - Nearly all industrial UT instruments/software operate under this assumption
     - *Does not* account for coupling beam refraction or wavy component surface
2. ***Adaptive focal laws*** – receive laws are adjusted
   - EPRI chose to use full matrix capture (FMC) data or a subset of that data (e.g., plane wave)
     - Requires phased array transducers and emerging instruments/software
     - Receive laws are accounted for by adaptive total focusing method (ATFM) algorithm
     - *Does* account for coupling beam refraction or wavy component surface

Weld Crown Block

- Stainless steel block with eight side-drilled holes (SDH) and two tilted notches.
  - Data was collected and analyzed using M2M's GEKKO Adaptive TFM module.
  - Tested with silicon wedges and water filled wedges.



Weld Crown Block - 0° Wedge

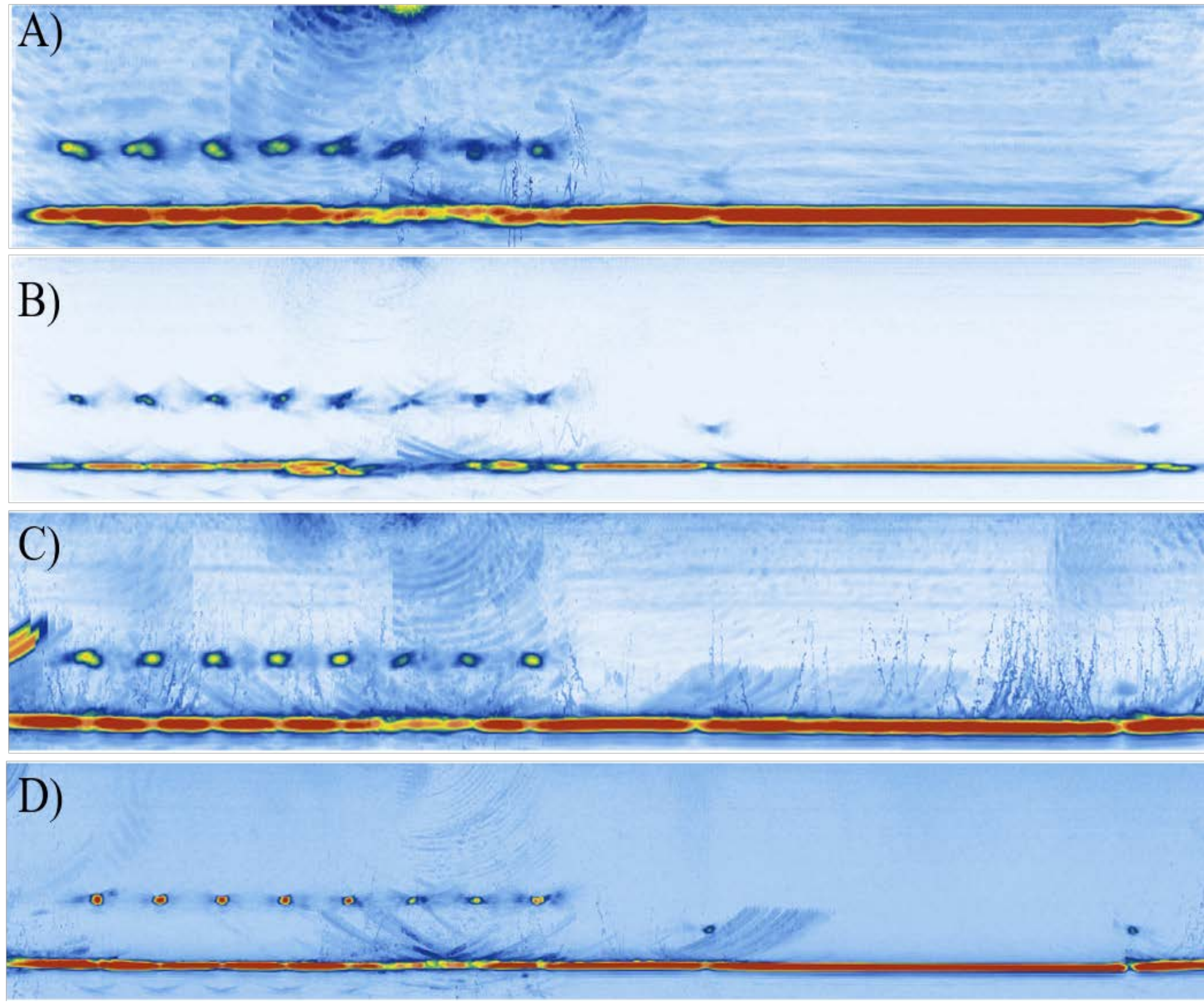
- All defects were detectable.

A) 2MHz probe with a silicon wedge

B) 5MHz probe with a silicon wedge

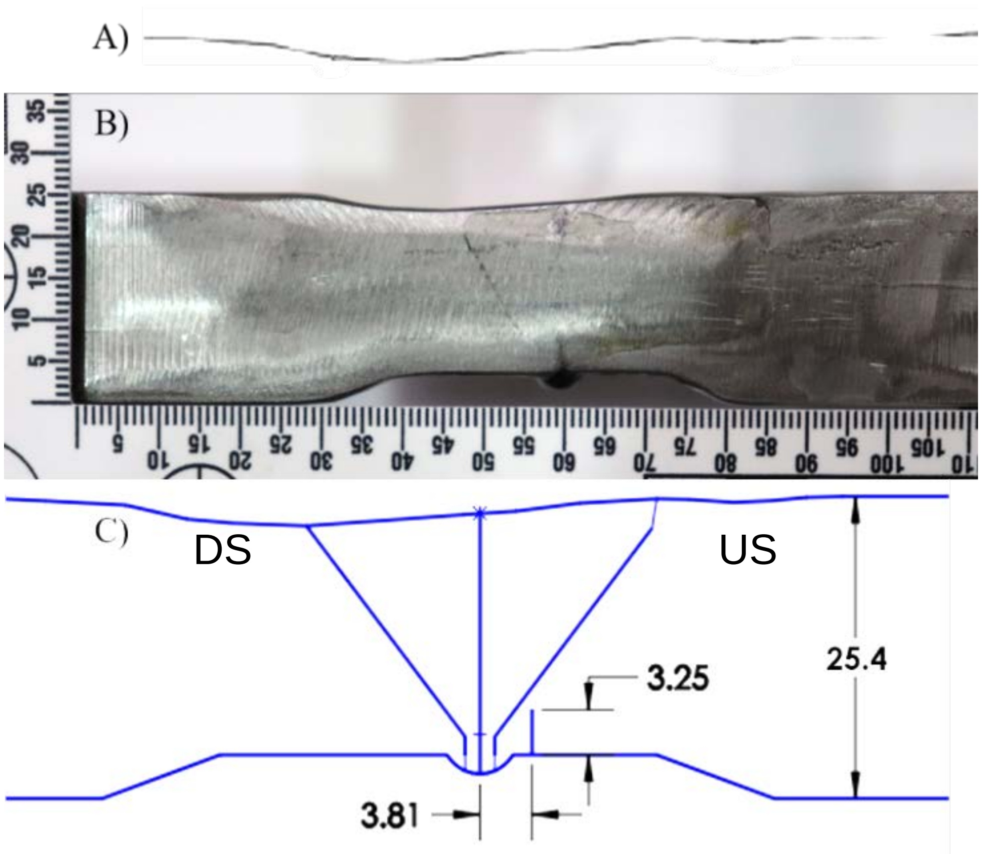
C) 2MHz probe with a water wedge

D) 5MHz probe with a water wedge



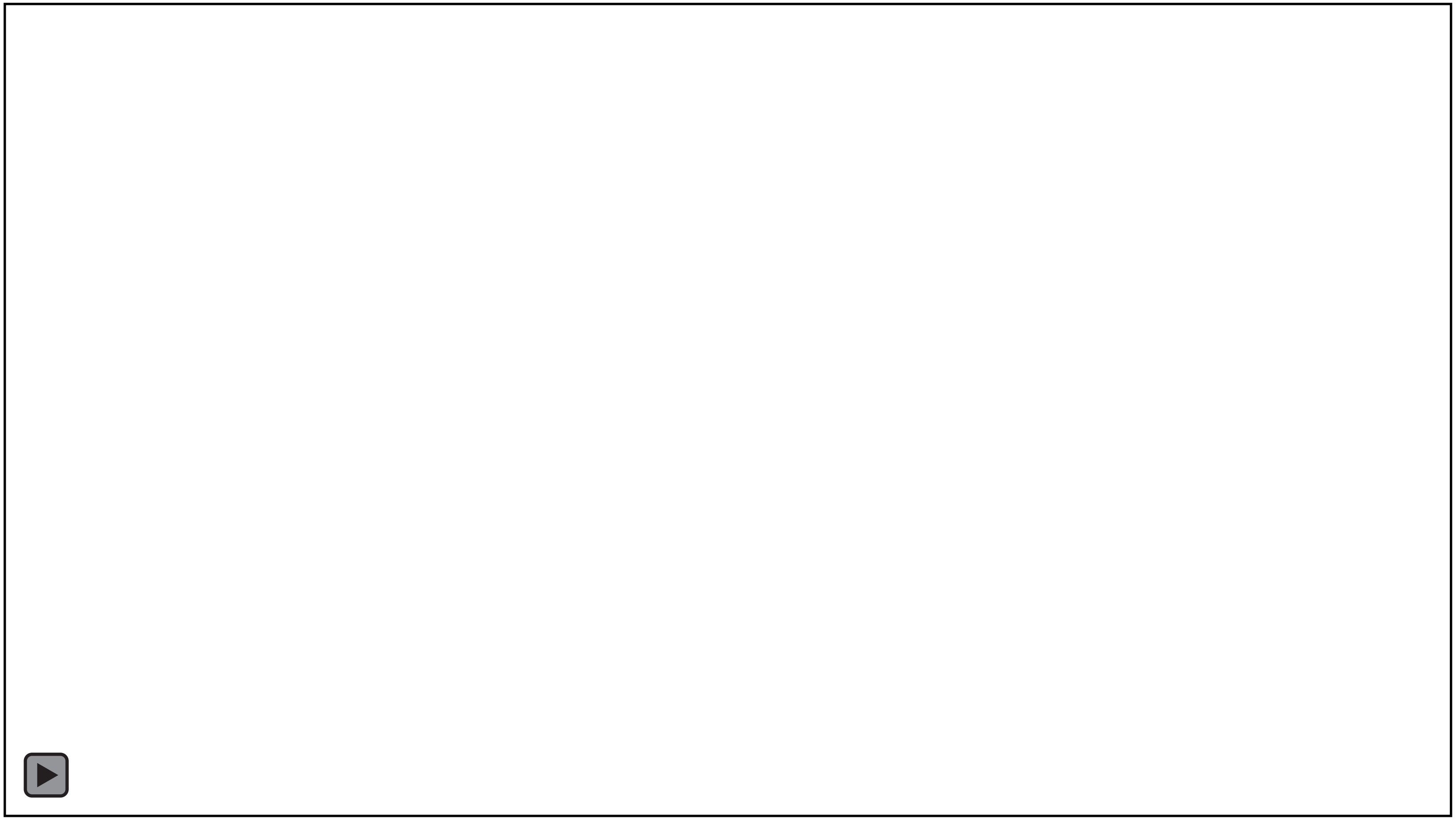
Austenitic Weld

- 316 stainless steel weld with a field surface profile was examined using conformable wedges with Imasonic 2MHz and 5MHz transducers.
  - 0° water and silicone wedges: data was collected and analyzed using the GEKKO.
  - Water filled (23° wedge angle) and silicone (13.2° wedge angle) wedges: data was collected and analyzed using OEM-PA 256:256 with ARIA V3.2.9 software



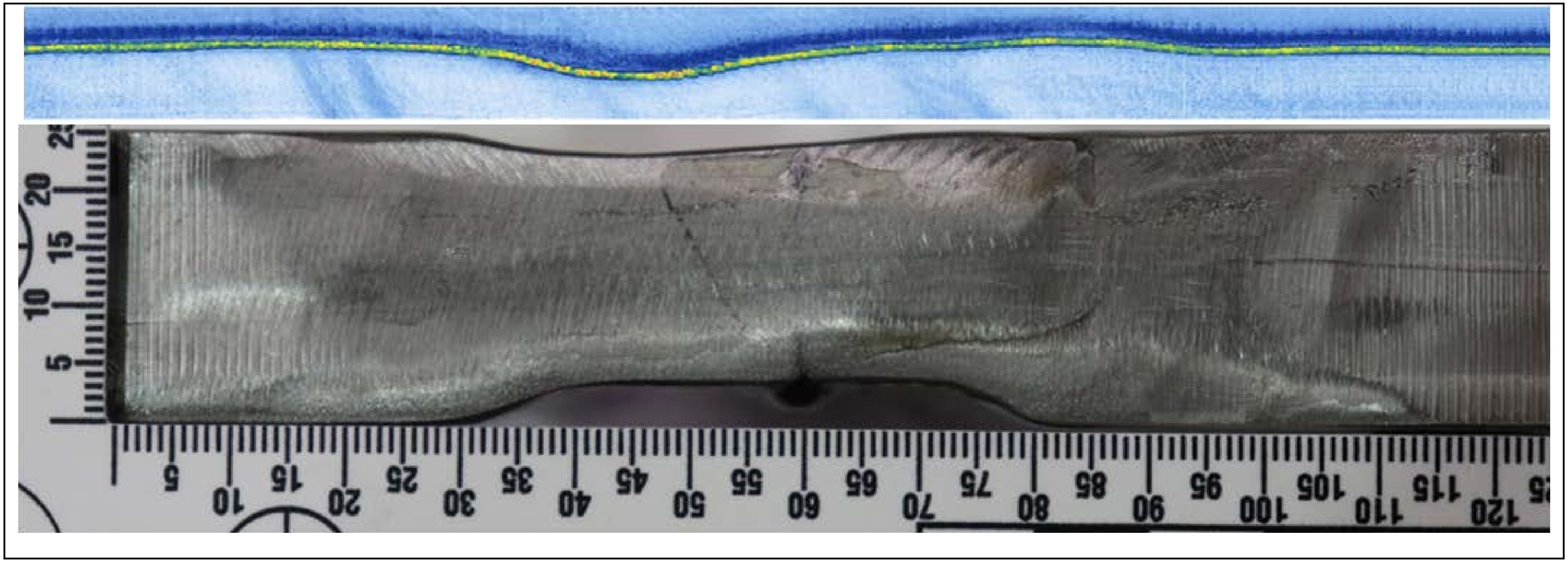
Austenitic Weld – 0˚ Wedge Inspection

- A real-time inspection when using a silicone wedge.



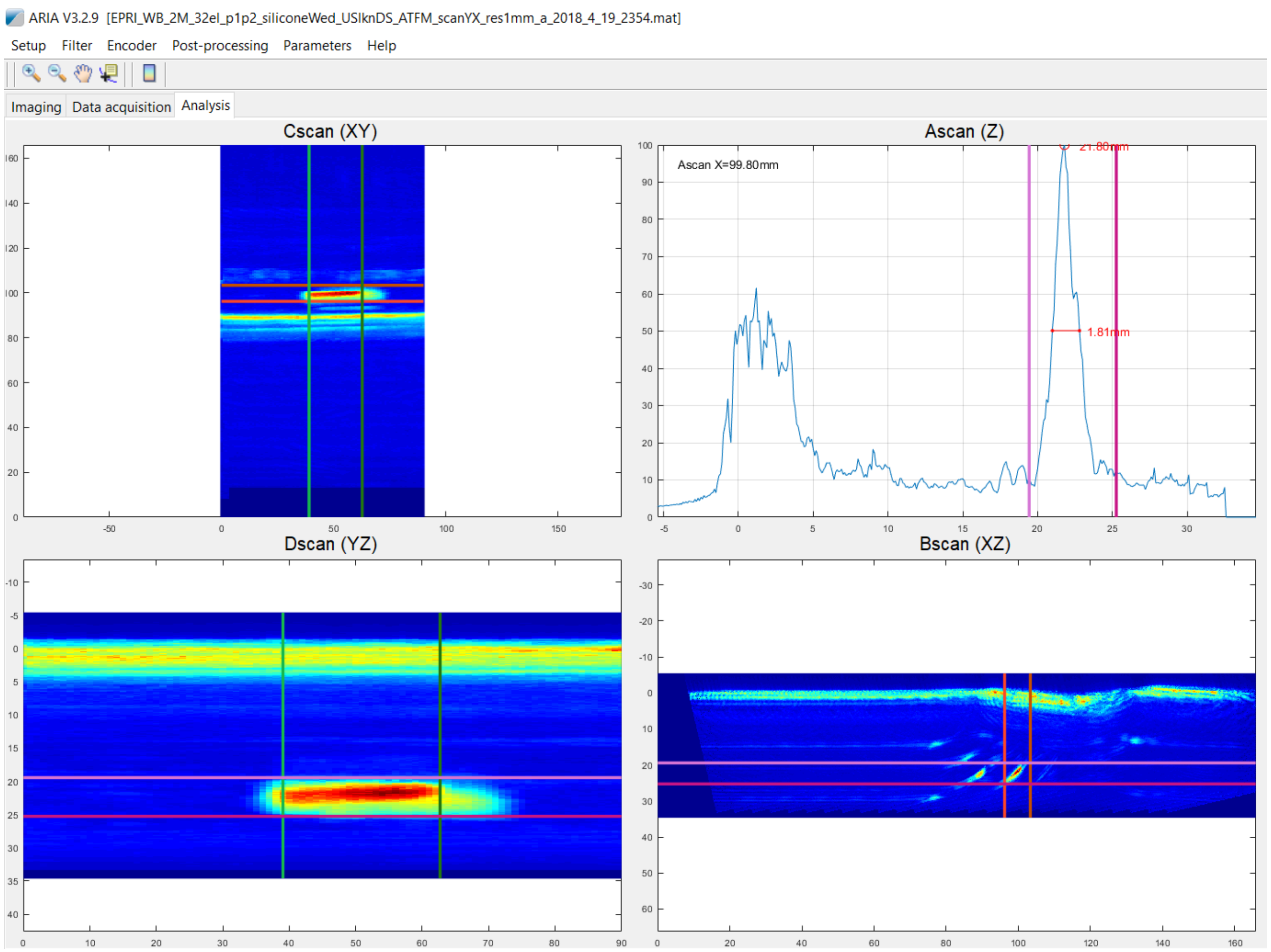
Austenitic Weld – Surface Reconstruction

- An example of the surface profile reconstruction following a scan.



Austenitic Weld – Angle Beam Wedge (Near Side)

- 2MHz silicone wedge; flaw is on the same side as the probe.
  - Flaw is detected



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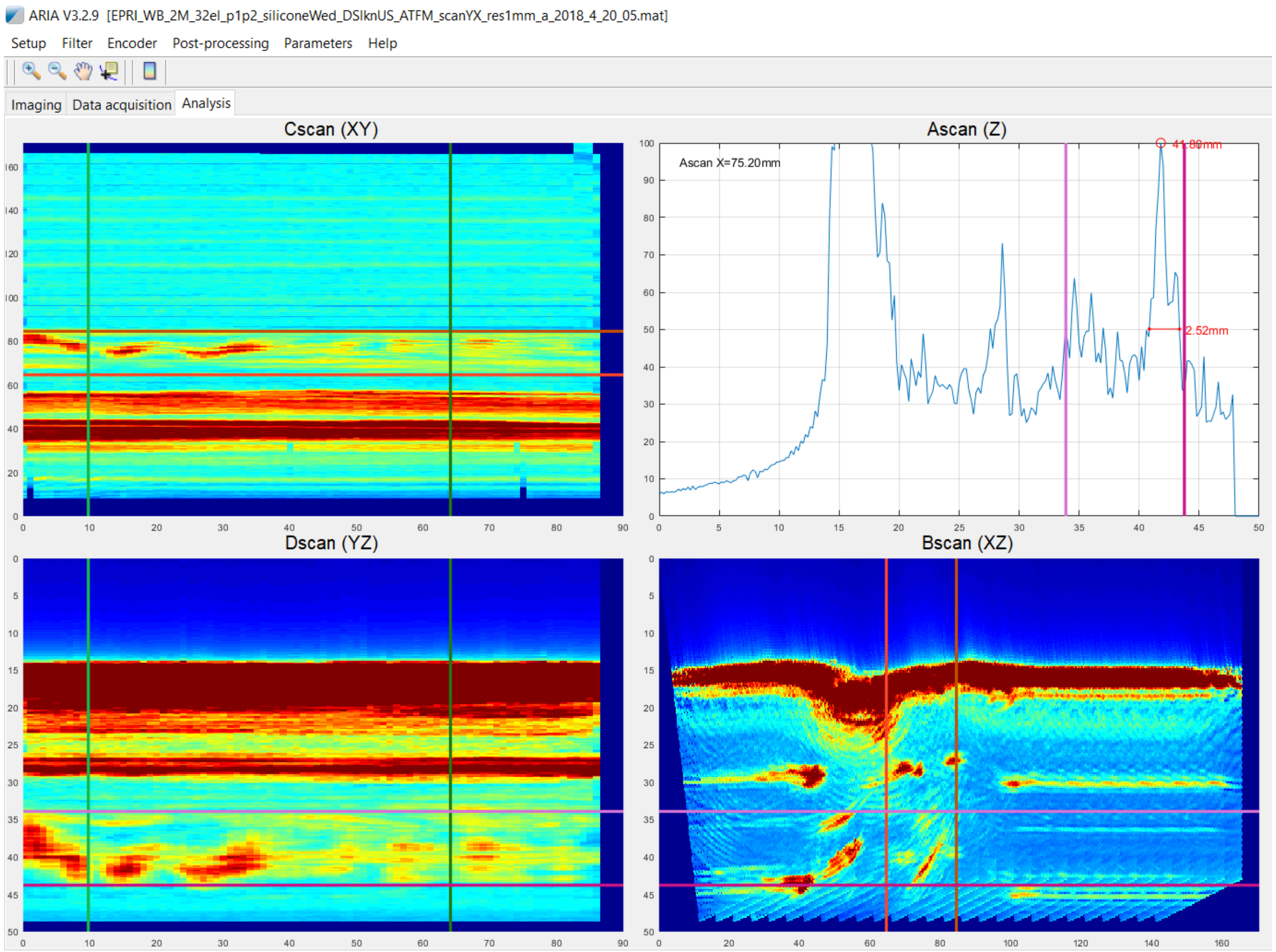
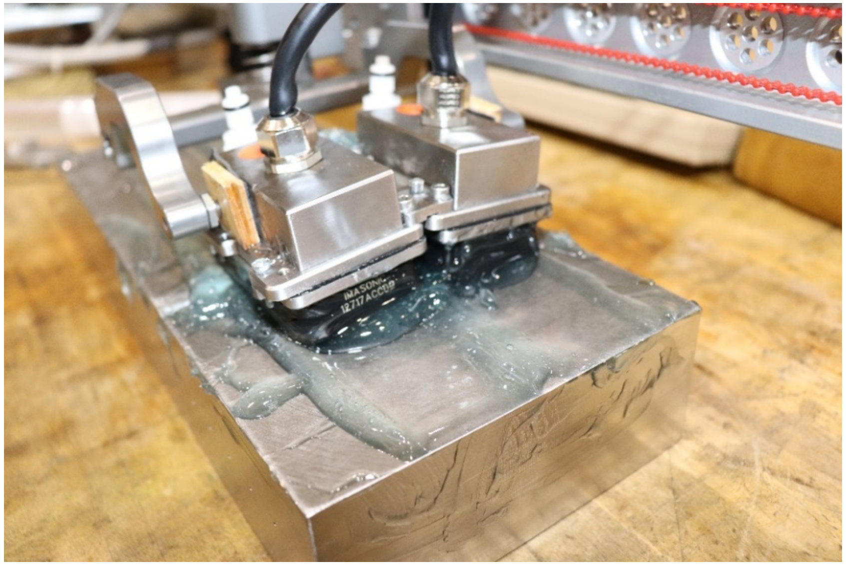
Austenitic Weld – Angle Beam Wedge (Far Side)

- 2MHz silicone wedge; looking through the weld.
  - Flaw was not detected



Next Steps

- Continue testing using adaptive laws.
  - Portable instruments are easy to program.
  - Minimal tests will be performed using fixed laws.
- Scan more welded specimens:
  - Austenitic and dissimilar metal welds (DMW).
  - Need greater variety and surface profiles.
- Probe and wedge types:
  - Angle beam water and silicone wedges.
  - Possibly pitch-catch configurations.



<u>Refer to EPRI Report</u>: *An Investigation of Ultrasonic Coupling Techniques for Unsmooth Surfaces.* EPRI, Palo Alto, CA: 2018. **3002013141**.

discussion

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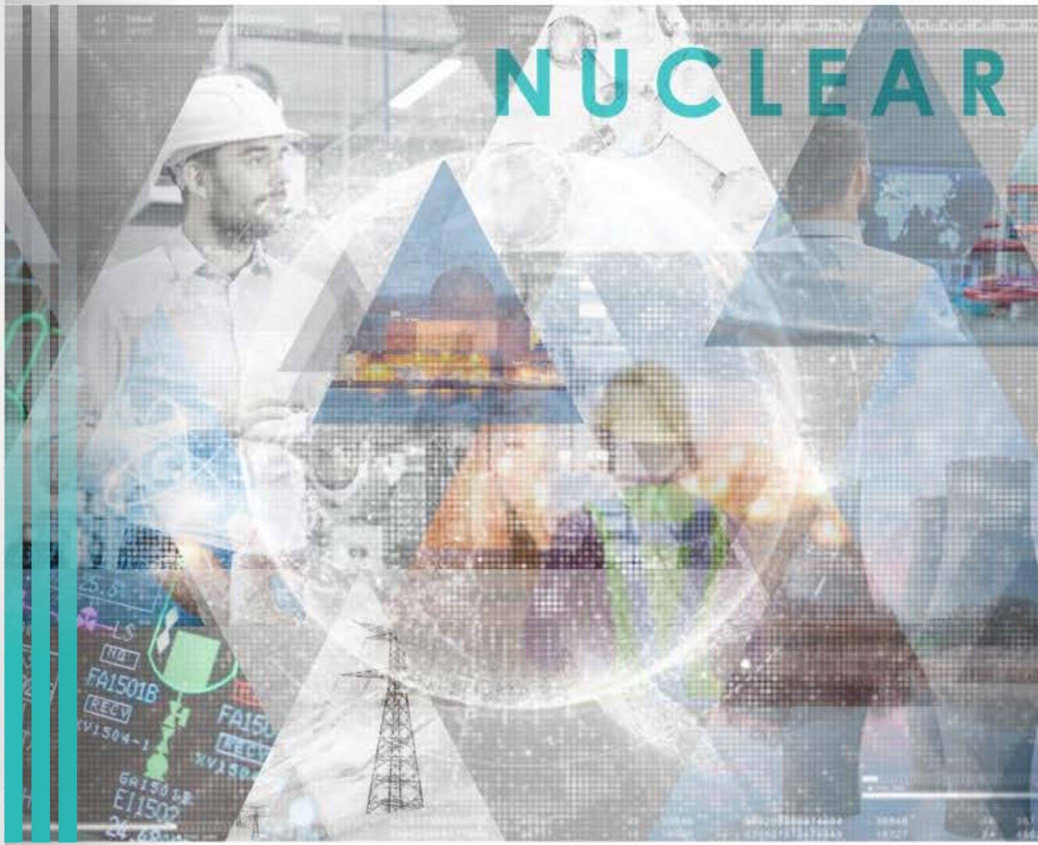
Update on Volumetric Examinations for BMNs



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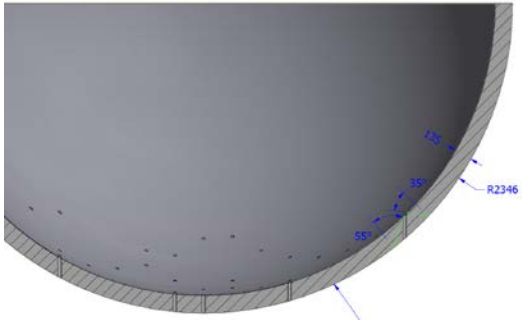
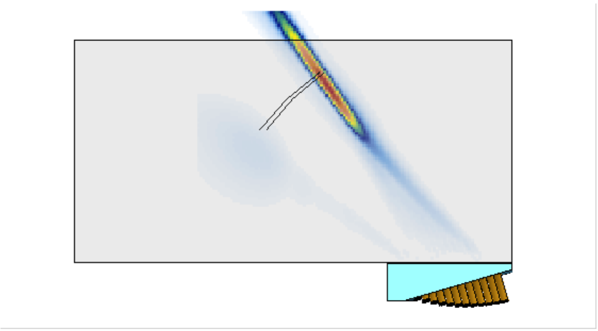
Phased Array UT of BMNs Feasibility Study

- Materials Issue Being Addressed:
  - Leaking BMNs need non-visual NDE to characterize the flaws
  - Some PWRs have performed a non-visual NDE of BMNs
  - Current techniques require removal of fuel to access the BMNs
- Objectives of the Project
  - Evaluate PAUT technique to examine BMNs from the outside surface of the lower head of the reactor vessel
  - If successful, plants could examine BMNs to characterize flaws without removing upper head or fuel
  - Develop probes and transfer techniques to NDE vendors

PAUT Study

- Summary of Key Results To Date
  - Probe design completed for first phase
    - Created simple 3D CAD models of a few PWR bottom head BMN designs
      - Determined refracted angles, examination/coverage limitations, etc.
    - Reduced footprint to account for PWR bottom-head geometry
    - Dual 5x12 matrix arrays to allow for electronic beam skewing
      - A single encoded exam to interrogate for circumferential and radial flaws
    - Dual 64-element arrays also compatible with newer 64:128 portable phased array instruments
      - Allows for manual (i.e. non-encoded) examinations





Status

- Examined two BWRs with similar partial penetration nozzle
- Ongoing Activities include:
  - Scan cancelled bottom head sections, if available, using existing EPRI probes
    - Field trials planned with new probes - Hold-point decision
    - U.S. NRC stated we can scan field-removed bottom head at PNNL
    - This is a project hold-point to determine if numerous fabrication indications within the weld make characterization unreliable using smaller probes
  - After hold-point:
    - Finalize optimized probe design and purchase arrays
  - Transfer technology to vendors

discussion

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PWR RPV Internals Bolting Protocol

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January 2019

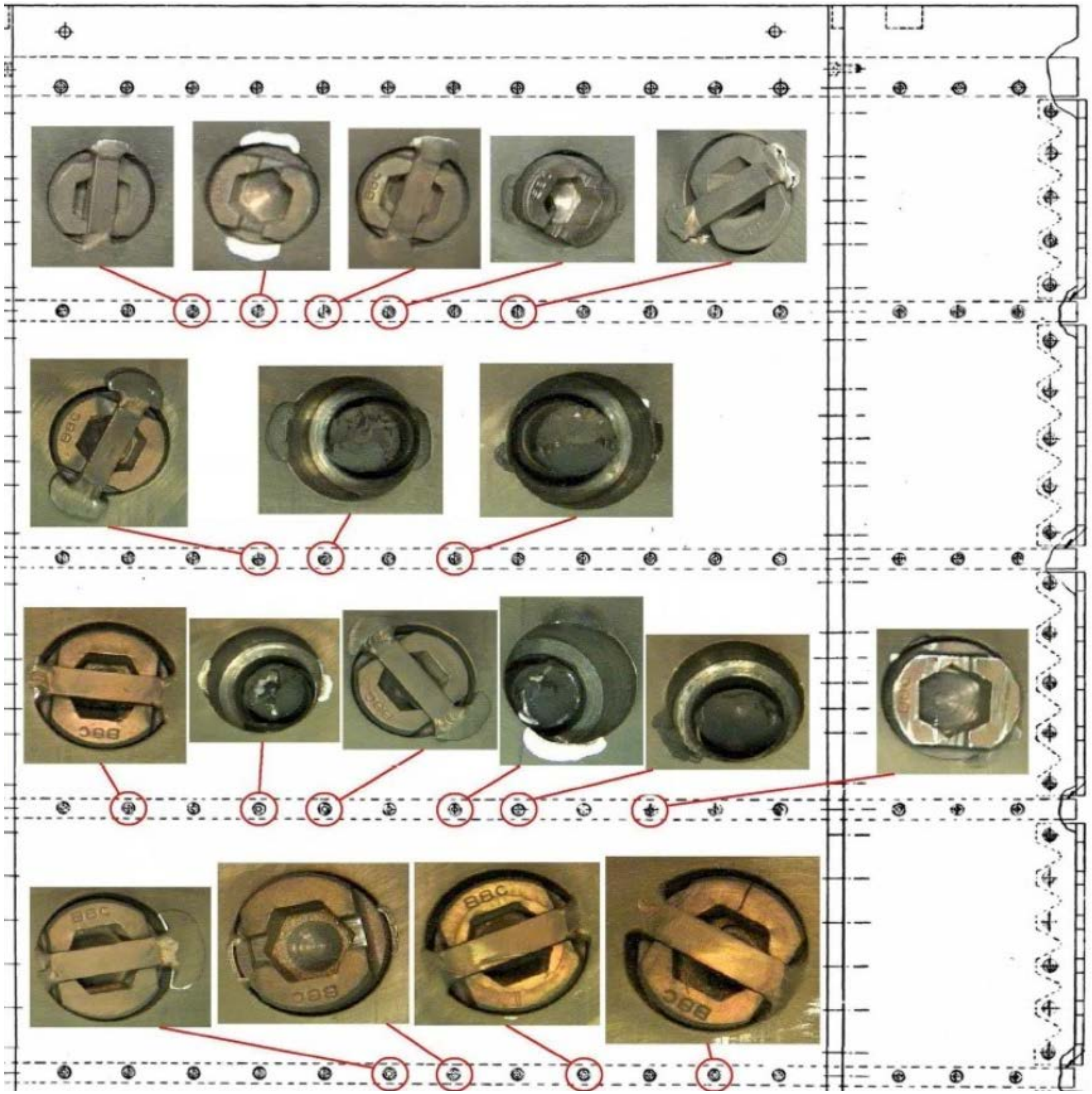
Outline

- Background
- Baffle-Former Bolt Examination/Removal Experiences
- Protocol Objectives
- Protocol Review
- Implementation
- Questions

Background

- NDE (UT and visual) examinations are finding defective bolts
- Bolt removal validate many of the NDE findings through broken bolts and “loose” bolts
- Bolting replacement has identified some bolts as potentially defective that were not detected with UT
- Mechanical testing results indicated that some bolts with a UT indication were structurally functional
  - Metallurgical results could rarely find source of UT signals for intact bolts
- Improved UT procedures and techniques are required to increase NDE reliability
- A probability of detection (POD) is needed to support engineering analysis

Bolting Images



Baffle-Former Bolt Examination/Removal Experiences

Outage	Tier-Plant	# Visibly Defective	# UT Indications	# BFBs Replaced	# Removed in 2-pieces	# Loose BFBs	# Found with IASCC
10/2010	1A-Cook2	18	No UT	52	42		3
3/2016	1A-IP2	31	182	278	107	120	TBD
4/2016	1A-SAL1	18	139	189	141	17	TBD
11/2016	1A-Cook2	4	170	201	55	76	TBD
12/2016	1B-SEQ1	0	6	0			
3/2017	1A-IP3	0	256	270	TBD	TBD	TBD
4/2017	1A-SAL2	0	9	129	0		TBD
5/2017	1A-DCPP1	0	1	61	0		
5/2017	1B-Seq2	0	No UT				

- Bolt removal findings validate significant quantities of broken bolts and “loose” bolts (based on torque wrench reading)

Protocol Objectives

- Provide qualification requirements for ultrasonic (UT) procedures and personnel for vessel internals bolting
- Increase reliability for UT examinations of internals bolting
- Establish a POD that can be used for engineering analysis

Bolting Protocol Review

- UT systems are required to be qualified by technical justification and performance demonstration
- Applicable to all reactor internals bolting
- Demonstration mockups shall be representative of normal field configurations that may limit the UT
  - such as locking bars, locking devices, weld tabs, internal hex head, non-flat-bottomed internal hex head, dimensions, material type, etc.
- Cross-sectional area of the flaws should be within 20% to 90% of the bolt cross-section area (CSA)
- Procedure must contain definitive steps for identifying flaw signals and distinguishing relevant from non-relevant indications

Bolting Protocol Review (continued)

- Procedure demonstrations meet the "high rigor" requirements of Article 14 and provide the POD
  - Blind demonstrations
  - At least 30 flawed bolting mockups
  - Unflawed mockups must be at least 1 ½ times the number of flawed
  - 100% detection of all flaws
  - At least 50% of flaws shall be in the head to shank region with a tilt between 0° and 30° (at least 40% with a tilt of 15°)
  - At least 15% of flaws shall be in the shank region
  - At least 15% of flaws shall be in the threaded region
  - At least 50% of the flaws shall be oriented perpendicular to the locking device
  - At least 75% of the flaws shall have a 25% to 40% CSA
  - Must include the search unit end effector that will be applied during field examinations
- Qualified procedures will provide at least a minimum POD of 90% at a lower bound confidence level of 90%

Bolting Protocol Review (continued)

- Data analysis personnel demonstrations meet the “intermediate rigor” criteria
  - Blind demonstrations
  - At least 10 flawed bolting mockups
  - Unflawed mockups must be at least 1 ½ times the number of flawed
  - Must detect at least 80% of the flaws
  - Maximum false call rate of 10%
  - Flaw shape, size, and distribution shall comply with the procedure demonstration requirements

Implementation

- MRP-228, Revision 3, “Inspection Standard for PWR Internals” was published December 05, 2018
  - Includes an NEI 03-08 Needed requirement to implement the “MRP Demonstration Protocol for PWR Internals Bolting Ultrasonic Examination Procedures and Personnel” (MRP Letter 2017-018)
- Shall be implemented for all examinations occurring six months after publication

discussion

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BWRVIP Nondestructive Evaluation

Update of 2018 activities

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Content

- Inspection vendor NDE demonstrations completed in 2018
- Update on NDE development activities completed in 2018

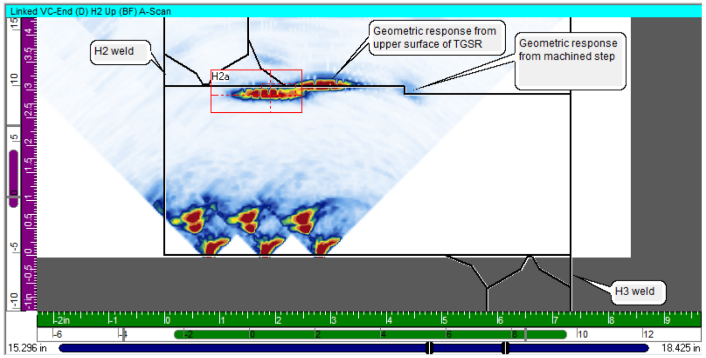
Update on New Inspection Vendor Demonstrations

Demonstrations completed in 2018

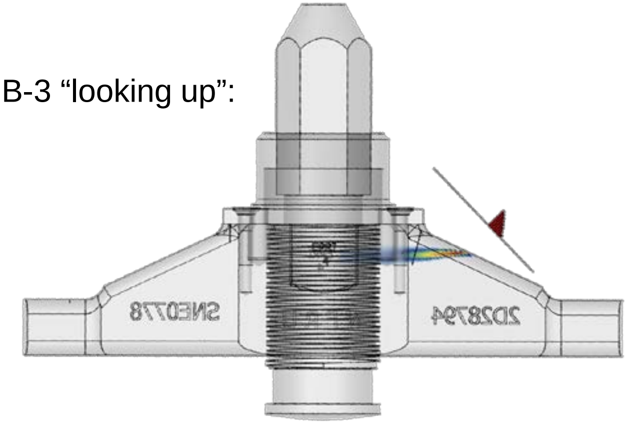
Inspection Vendor Demonstrations Completed in 2018

- Two core shroud demonstrations
  - H2 and H3 core shroud welds
    - Top-guide support ring side HAZ of BWR/2 through BWR/5
    - Phased array UT from under side of top-guide support ring
- Two “Group 2” jet-pump beam demonstrations
  - Two different inspection vendors
  - Both demonstrations included a mix of immersion and contact techniques
  - One included phased array examination of all three inspection regions (i.e. BB-1, BB-2, BB-3)
    - First time phased array examination of BB-1 inspection region of Group 2 configurations
    - Technology transfer of industry supported *BWRVIP NDE Development* effort

H2 “looking up”:



BB-3 “looking up”:



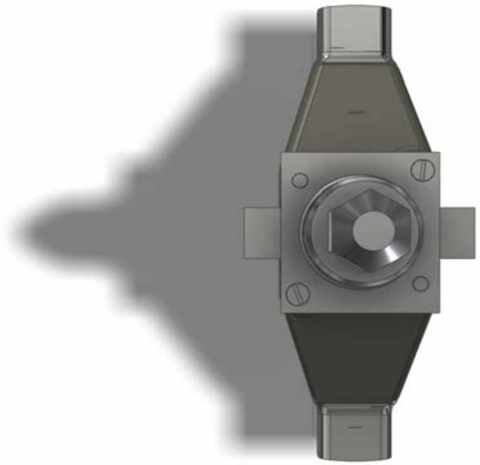
Not a busy 2018, but seven inspection vendor technique demonstrations are already in progress as 2019 starts

Update on NDE Development Activities

Group 2 jet-pump beam mock-up revision and phased array ultrasonic examination technique development

"Group 2" Jet-Pump Beam Mock-up Revision

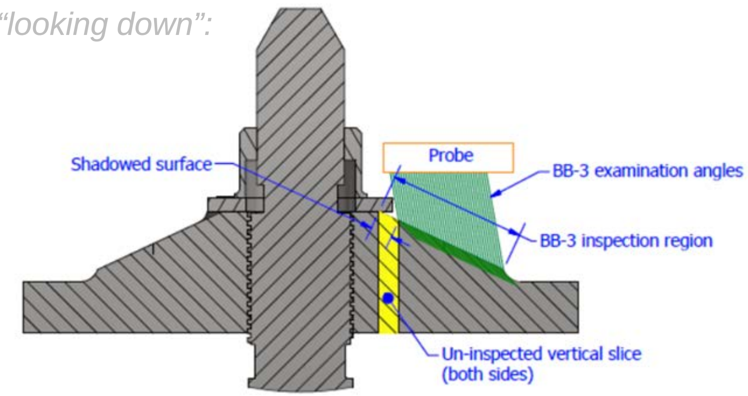
- New flaws added to a "hidden" region under the locking plate overhang of Group 2 beams
- The size of the previously existing "hidden" flaw was overly conservative given the required re-inspection interval
  - The "hidden" region contains the lowest stresses also containing the largest cross-sectional area of jet-pump beam
  - The revised mock-up flaws are based on LEFM evaluation results of BWRVIP-138-R1-A
    - "Crack plane H" results used to establish revise flaws
      - Crack planes E, F, G, & H are all located wit the BB-3 inspection region, "crack plane H" corresponds to the location under the over of the locking plate
- Some inspection vendors no longer included interrogation of the "hidden" region because of difficulties detecting the small flaw



Inspection Challenge of BB-3 “Hidden Region”

- Overhang of locking plate shadows “looking down” examination techniques
  - Right image
- Overhang geometry produces a significant geometric response in the “looking up” examination data
- Geometric response can mask very small surface indications
  - Lower animation
- Flaws of more appropriate size do not require that ultrasonic energy be transmitted directly under the overhang geometry

BB-3 “looking down”:

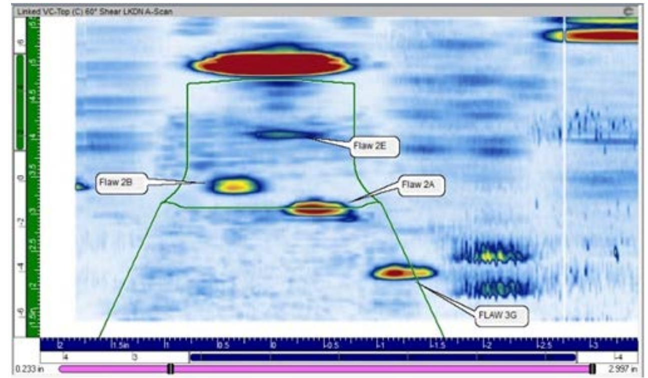


SECTION A-A

Phased Array Examination of Group 2 Jet-Pump Beams

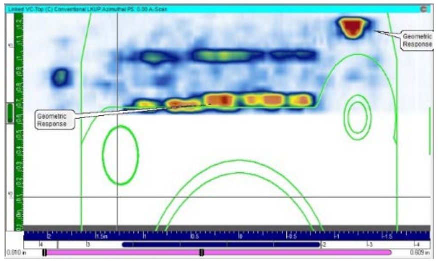
- Phased array examination technique was optimized for the Group 2 configurations
  - Details of the "Group 3" phased array technique presented during 2018 NRC Technical Exchange
- Allows for effective interrogation of hidden region
  - All of the appropriate flaws located under the locking plate were detected without having to direct ultrasonic energy directly under the locking plate

Unhidden BB-2 and BB-3 regions

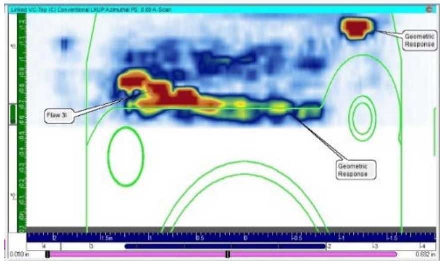


Hidden Region

Unflawed BB-3 region



Flawed BB-3 region



Two inspection vendors have now demonstrated new ultrasonic examination techniques using the revised mock-ups

Update on NDE Development Activities

Oversight guidance document for implementation of “off-axis” core shroud weld UT examinations

Oversight Guidance for "Off-axis" Core Shroud UT

- Oversight guidance published to assist Licensees perform off-axis UT examinations
- "The main objective of the guidance is to create awareness of potential error traps that might be present during the first-of-a-kind examinations."
  - Contains information about:
    - Mechanical Scan / Index Orientations when using electronic skews
      - Provides examples of good and bad data
    - OE from initial deployments
    - Remnant attachment welds / weld dilution areas
      - Influence on NDE
      - Discussion about shroud fabrication
    - OE from comparing UT and remote-VT data

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2018-024 BWR Vessel & Internals Project (BWRVIP)

March 9, 2018

TO: BWRVIP Assessment Committee Members
BWRVIP Inspection Committee Members

FROM: Chris McKean / Jeff Landrum

SUBJECT: Oversight Guidance for "Off-axis" Core Shroud Ultrasonic Examinations

Interim guidance was previously issued by BWRVIP (Letter no. 2016-030) requiring Owners of BWRs to perform a one-time inspection of core shroud welds for "off-axis" or "atypical" flaws. The guidance provided the Owners with the option of performing either visual or ultrasonic examinations. As a result, inspection vendors have begun to develop advanced ultrasonic examination techniques. To meet the requirements of the interim guidance, certain aspects of the core shroud techniques differ from previous core shroud examinations. To assist plant NDE personnel, the Inspection Committee members recommended that guidance (Attachment 1) for performing effective oversight of examinations be developed and provided to members. The main objective of the guidance is to create awareness of potential error traps that might be present during the first-of-a-kind examinations.

Please note that this guidance is primarily intended to assist Licensee NDE staff performing oversight during off-axis core shroud examinations.

If you have any questions, please contact Jeff Landrum (704 595 2553, jlandrum@epri.com) or Bret Flesner (704 595 2601, bflesner@epri.com) at EPRI Charlotte.

c: BWRVIP EPRI Task Managers
BWRVIP Technical Chairmen

Update on NDE Development Activities

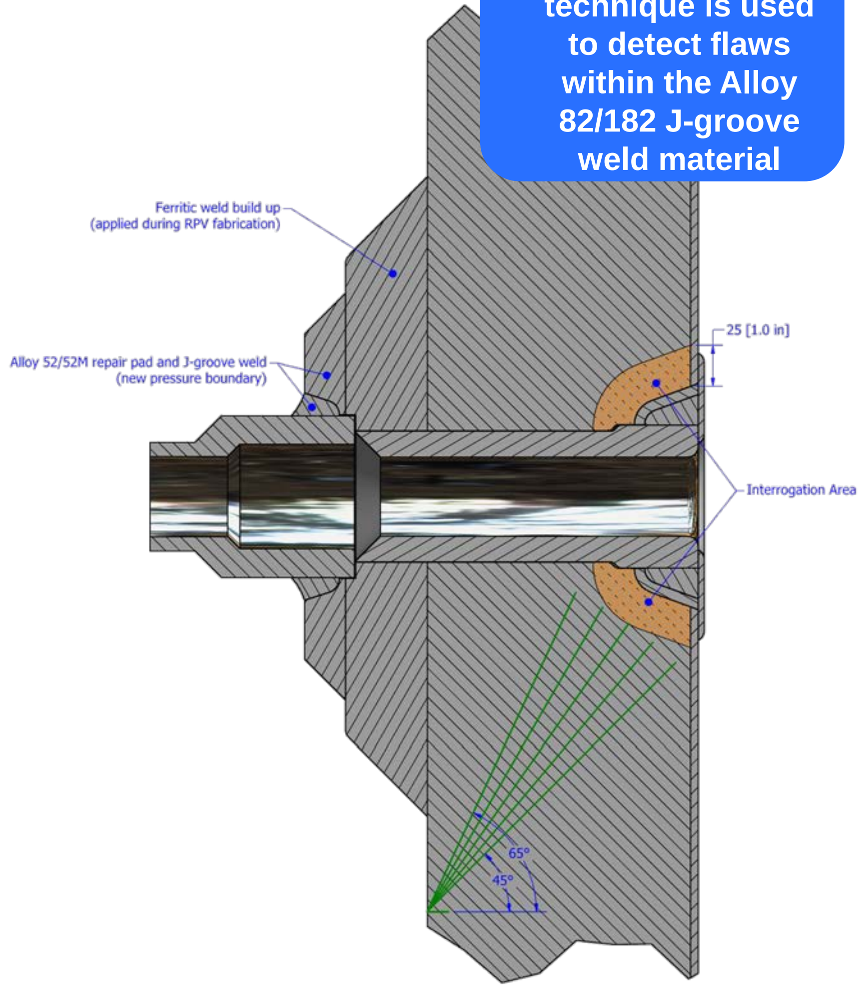
BWR water level instrument penetrations

Phased array examination of low-alloy RPV material surrounding repaired J-groove welds

Water level instrument penetration UT

- Development of examination techniques for repaired water level instrument penetrations
- Manual phased array interrogation of the low-alloy RPV material surrounding J-groove welds
  - Detection of radial and circumferential flaws <u>that have propagated into low-alloy RPV material</u>
- Applicable when Alloy 52/52M weld pads (repairs) are applied to ferritic weld pads that were installed during RPV fabrication
- 4MHz shear wave 32-element linear array
  - Probe contains mechanical focusing along secondary axis (FS ~240mm)
- Inspection vendor currently demonstrating the BWRVIP developed technique for use during the spring 2019 outage season

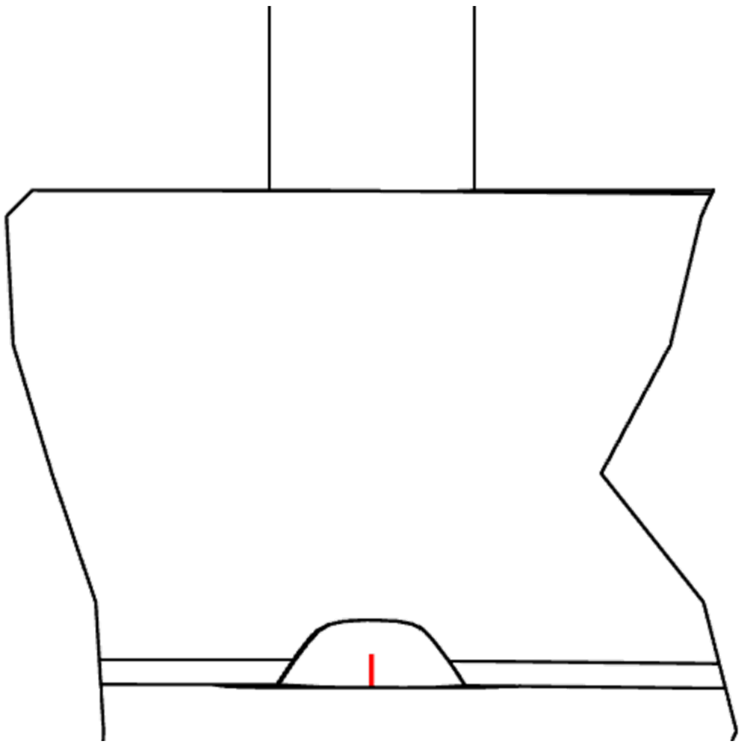
A separate technique is used to detect flaws within the Alloy 82/182 J-groove weld material



Water level instrument penetration UT

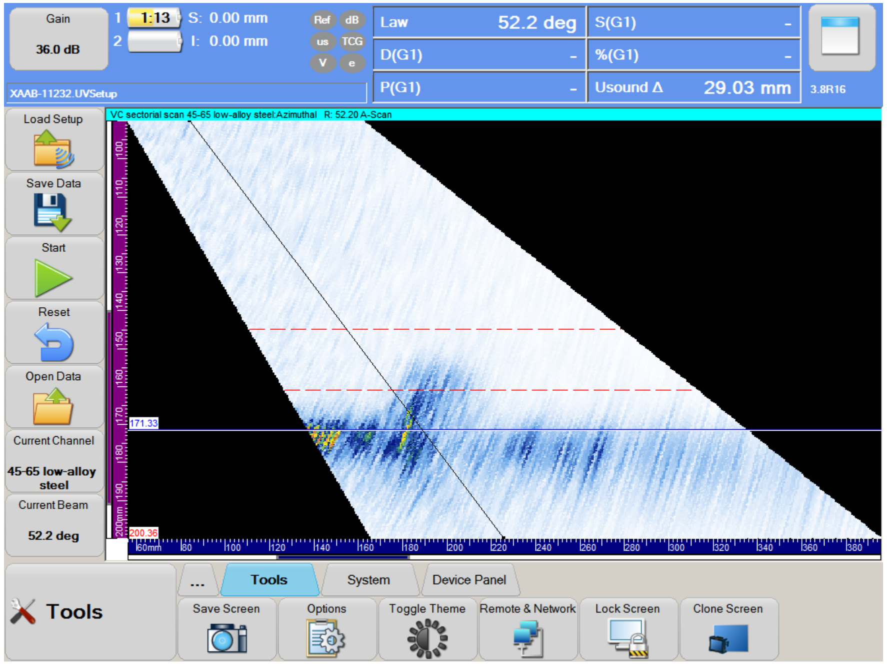
BWRVIP-IP-1 mock-up radial flaw 1A

Contained within weld material



Weak response contained within "weld noise"

(i.e. *the flaw is contained within the J-groove weld*)



Weak UT response contained within "weld noise" is indicative of flaws contained entirely within the Alloy 82/182 J-groove weld material

(i.e. this flaw does not propagate into the low-alloy RPV material)

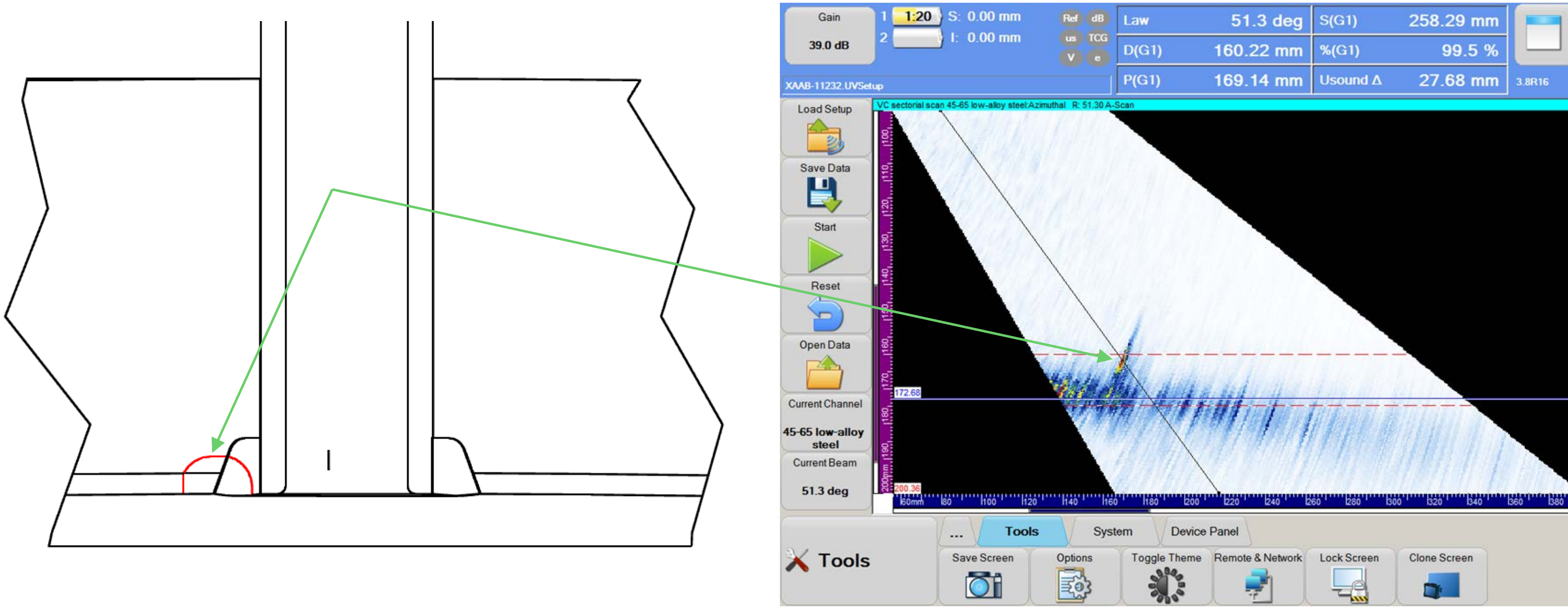
Water level instrument penetration UT

BWRVIP-IP-1 mock-up radial flaw 1B

propagates into low-alloy RPV material

Easy to identify response absent of "weld noise"

(i.e. *the flaw <u>has</u> propagated into the low-alloy RPV material*)



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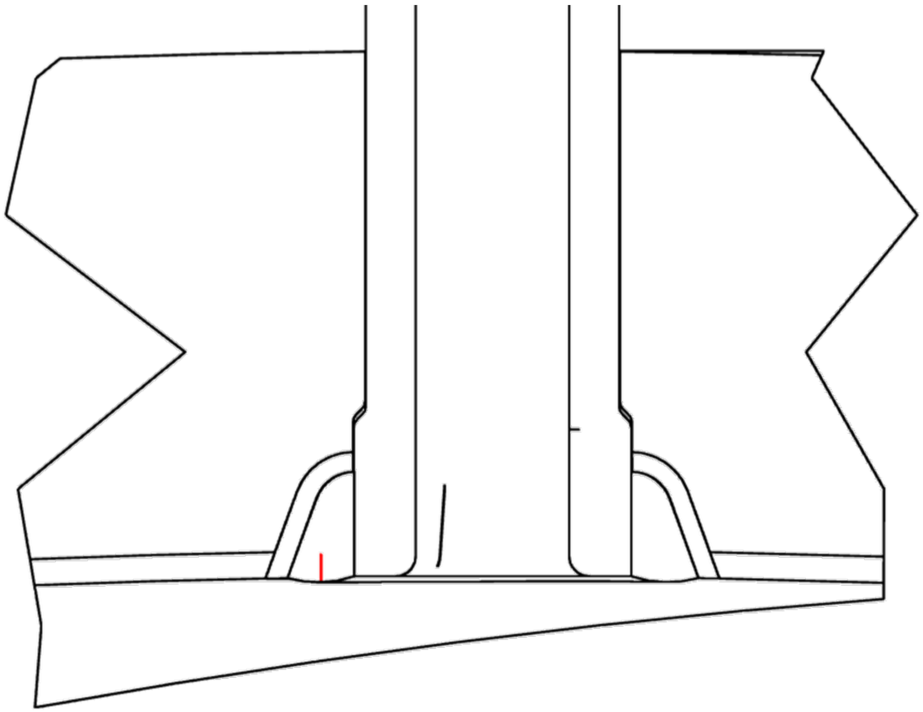
Water level instrument penetration UT

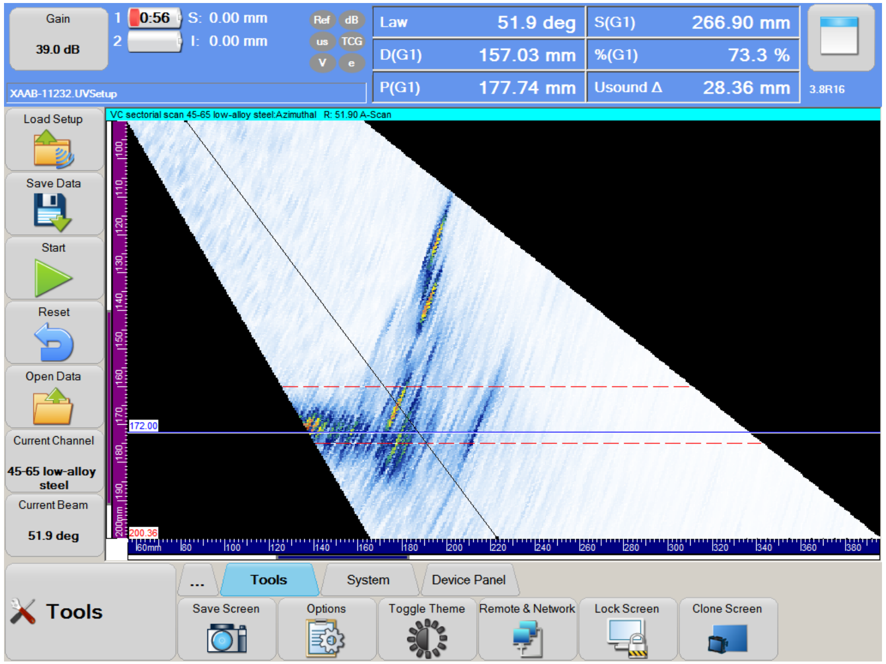
BWRVIP-IP-1 mock-up circumferential flaw 2A

Contained within Alloy 82/182 weld material

Weak response contained within "weld noise"

(i.e. *the flaw is contained within the J-groove weld*)





Weak UT response contained within "weld noise" is indicative of flaws contained entirely within the Alloy 82/182 J-groove weld material

(i.e. this flaw does <u>not</u> propagate into the low-alloy RPV material)

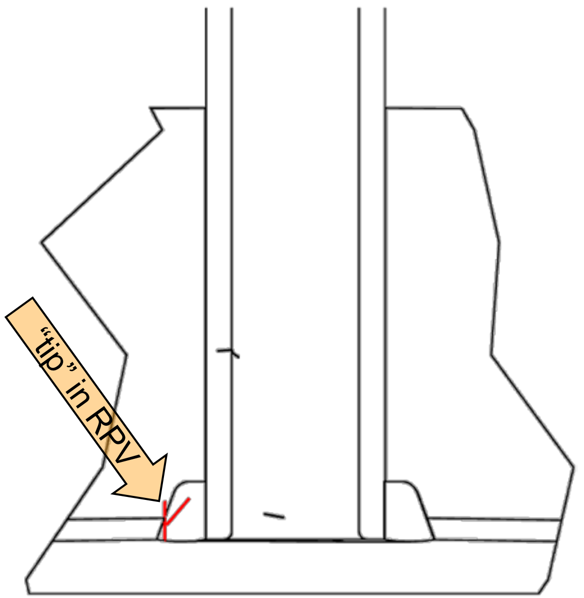
Water level instrument penetration UT

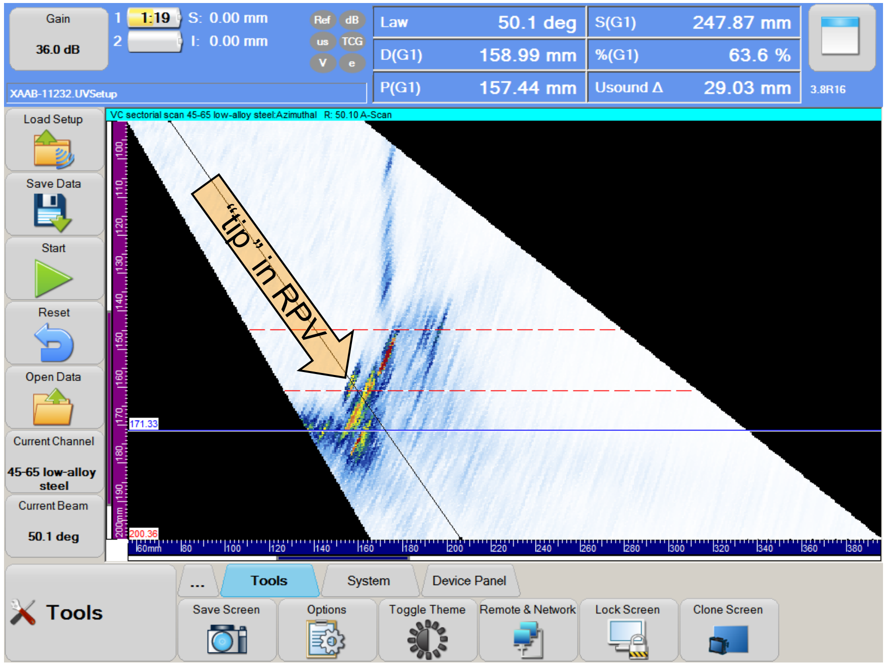
BWRVIP-IP-1 mock-up circumferential flaw 1C

Multi-branched flaw that partially propagates into low-alloy RPV material

Flaw "tip" located outside of "weld noise"

(i.e. *flaw branch <u>has</u> propagated into low-alloy RPV material*)





Water level instrument penetration UT results

- All J-groove weld propagating into the low-alloy RPV material provided easy to identify responses using the focused 4MHz shear wave phased array probe
  - All flaws propagating into the low-alloy RPV material were detected
- The J-groove weld material generated an easy to identify landmark (i.e. “weld noise”) that can be used to determine if J-groove flaws remain within J-groove weld material or have propagated outside of the J-groove weld material
  - A small number of flaws contained within the J-groove weld were detected, but clearly imaged within the “weld noise”
  - A separate phased array examination technique was previously developed for detection of flaws contained within the alloy 82/182 J-groove weld material so these flaws are outside the scope of this effort

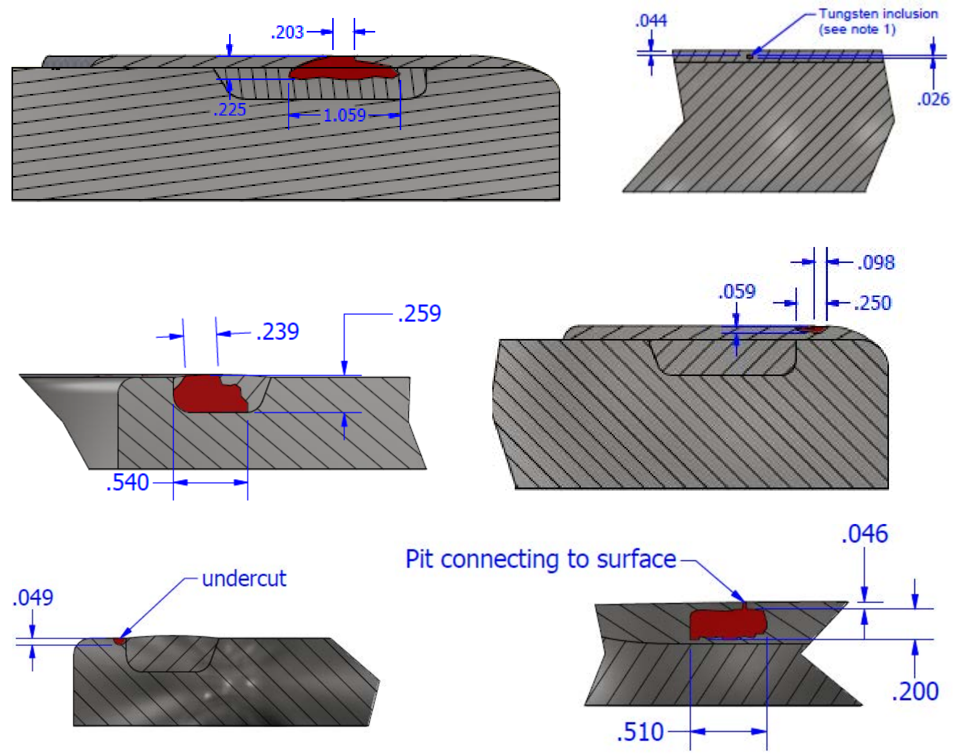
Update on NDE Development Activities

Water level instrument penetrations

Eddy current array examination of penetration tube material and J-groove weld / CRC material

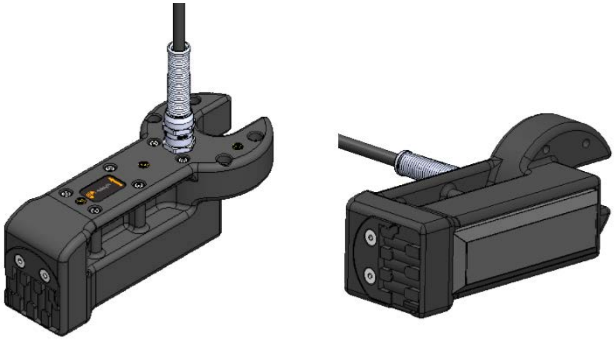
New water level instrument penetration J-Groove mock-ups

- One mock-up with CRC and one without
- Contain 25 flaws
  - Pits, cracks, inclusions, subsurface LOF and weld toe undercut
- Contains crack profiles based on MRP destructive examinations of actual J-groove weld flaws
  - Pitting and small cracks openings that become longer cracks below the surface
- Focus was on reliable characterization of fabrication flaws as much as on detection of service induced SCC

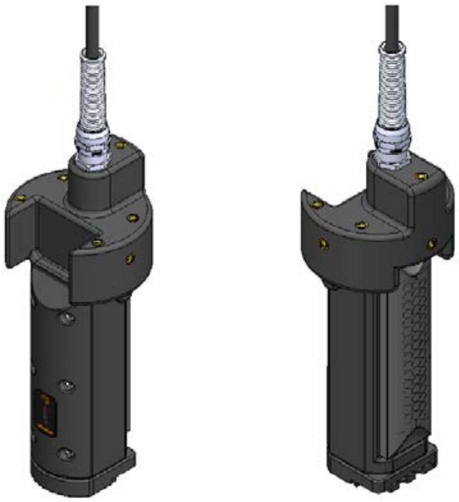


ECA Probe Construction

- Two separate arrays (separate wiring and connectors) and housings that can be bolted together to form one probe unit
  - Each array contains 3 rows of 16 coils, each coil is Ø5mm



J-Groove Probe

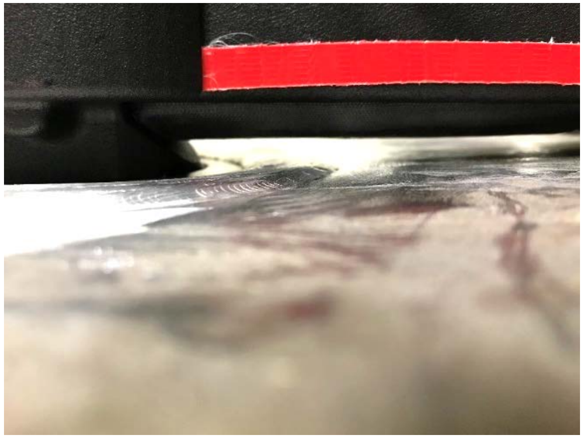


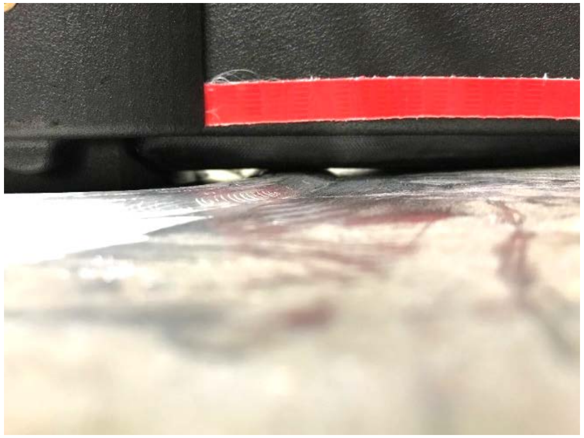
Tube Probe

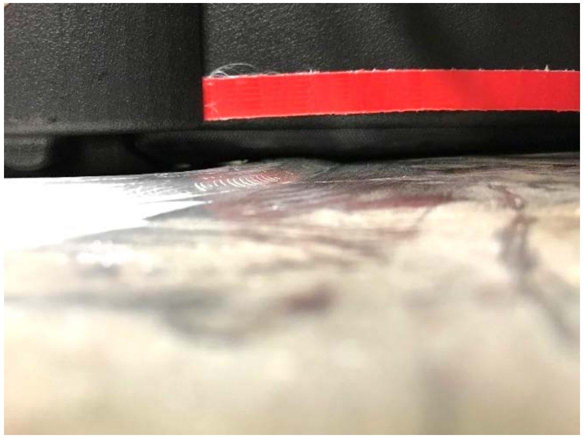
Assembled Probe

Padded Array Functionality

Padded array conforms to RPV cladding and J-groove weld crown



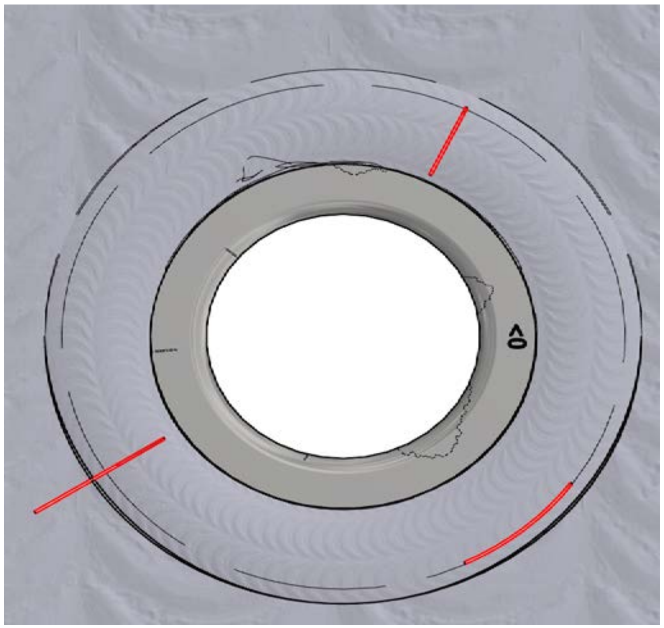


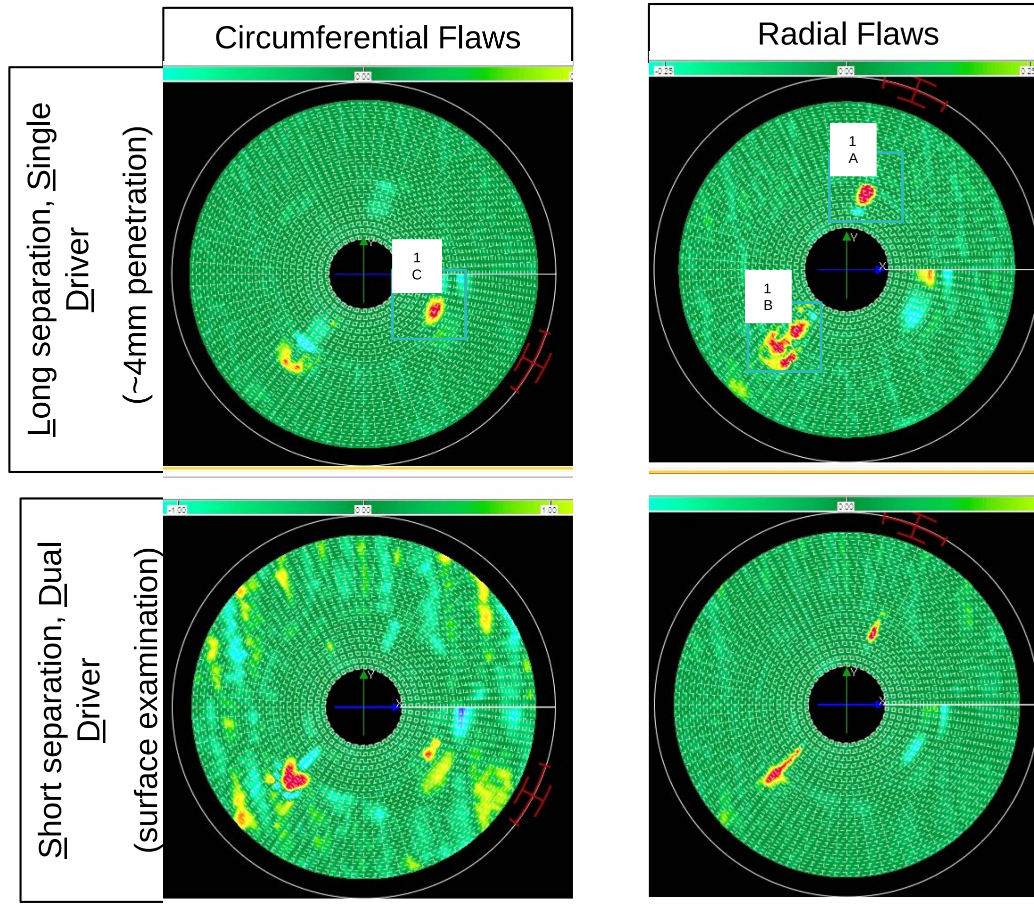


Data Collection BWRVIP-IP-1 J-Groove (video)

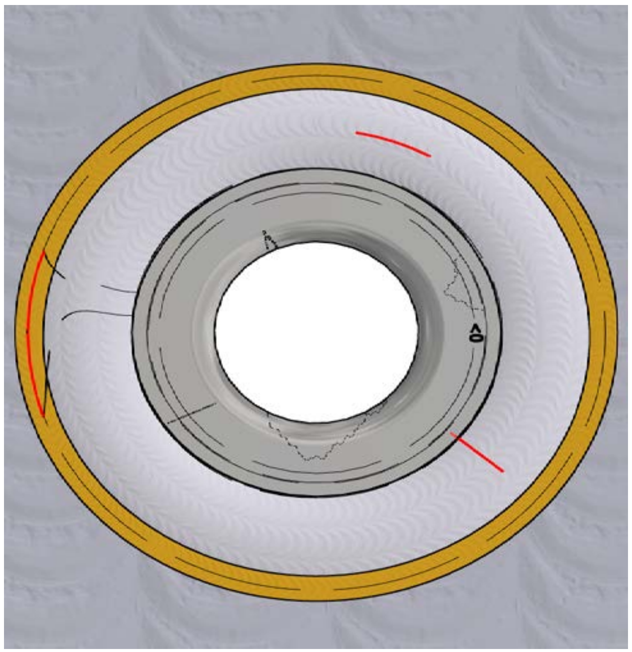
Array interrogates J-groove weld and penetration tube material to a maximum depth of penetration of ~4mm

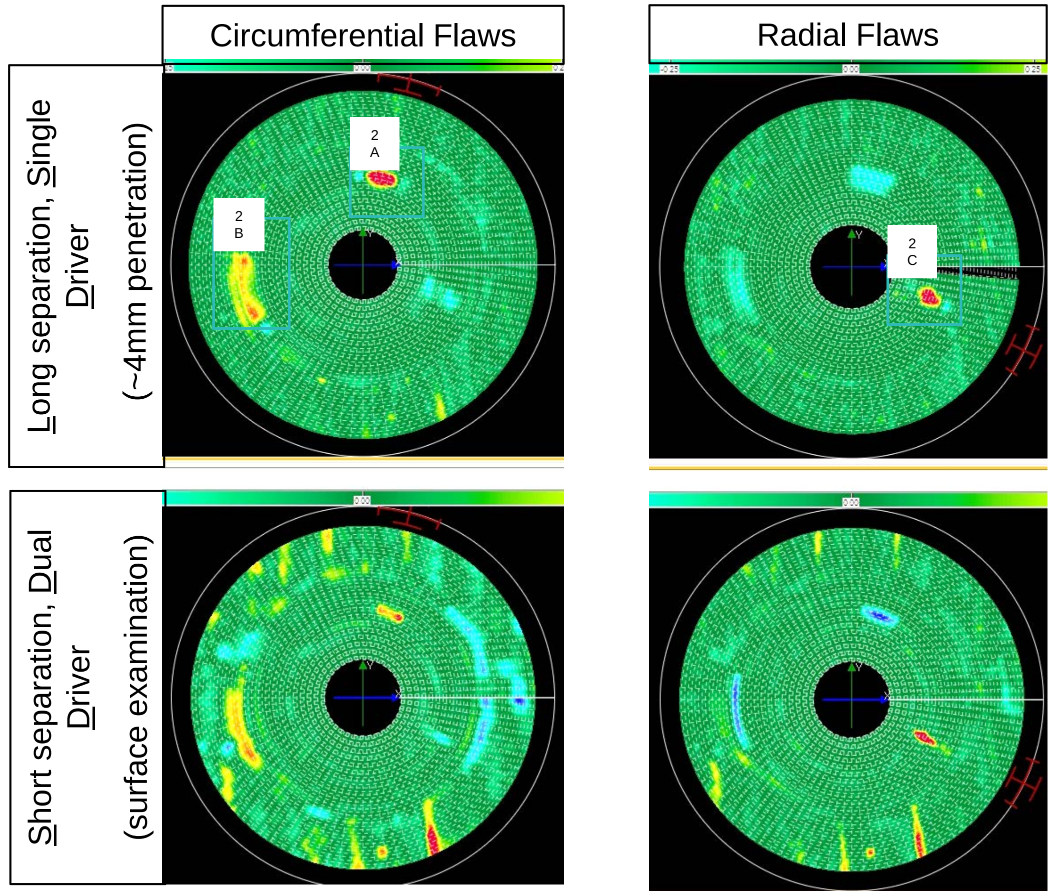
BWRVIP-IP-1 Penetration 1 Weld



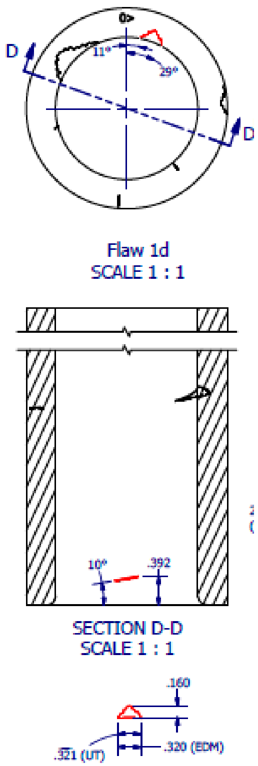


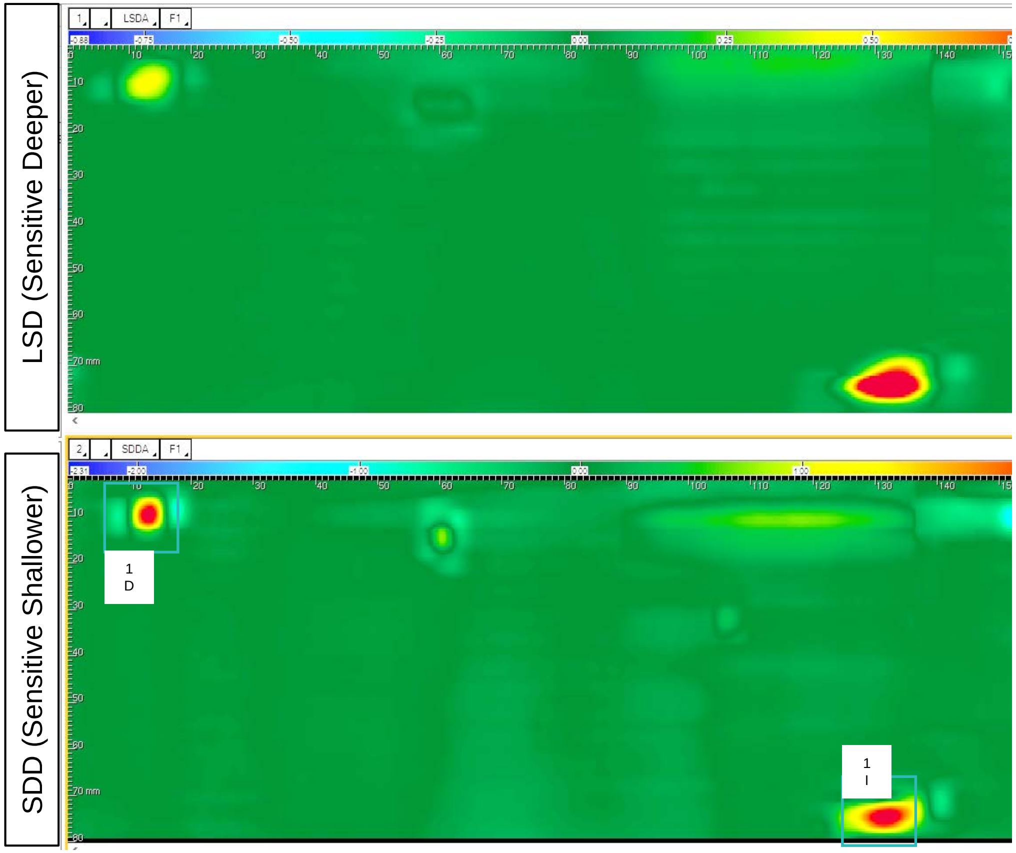
BWRVIP-IP-1 Penetration 2 Weld

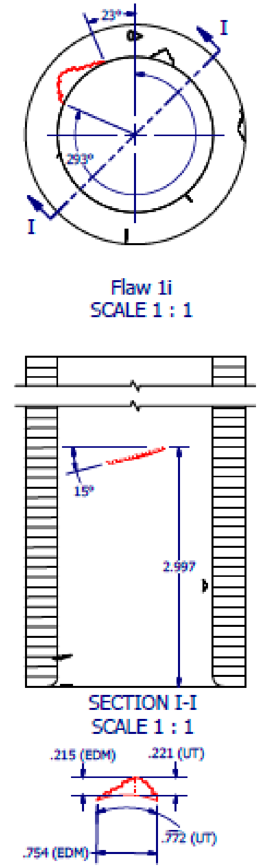




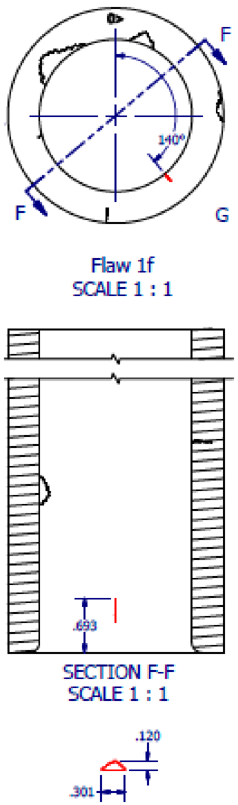
BWRVIP-IP-1 Penetration 1 Tube – Circumferential Flaws

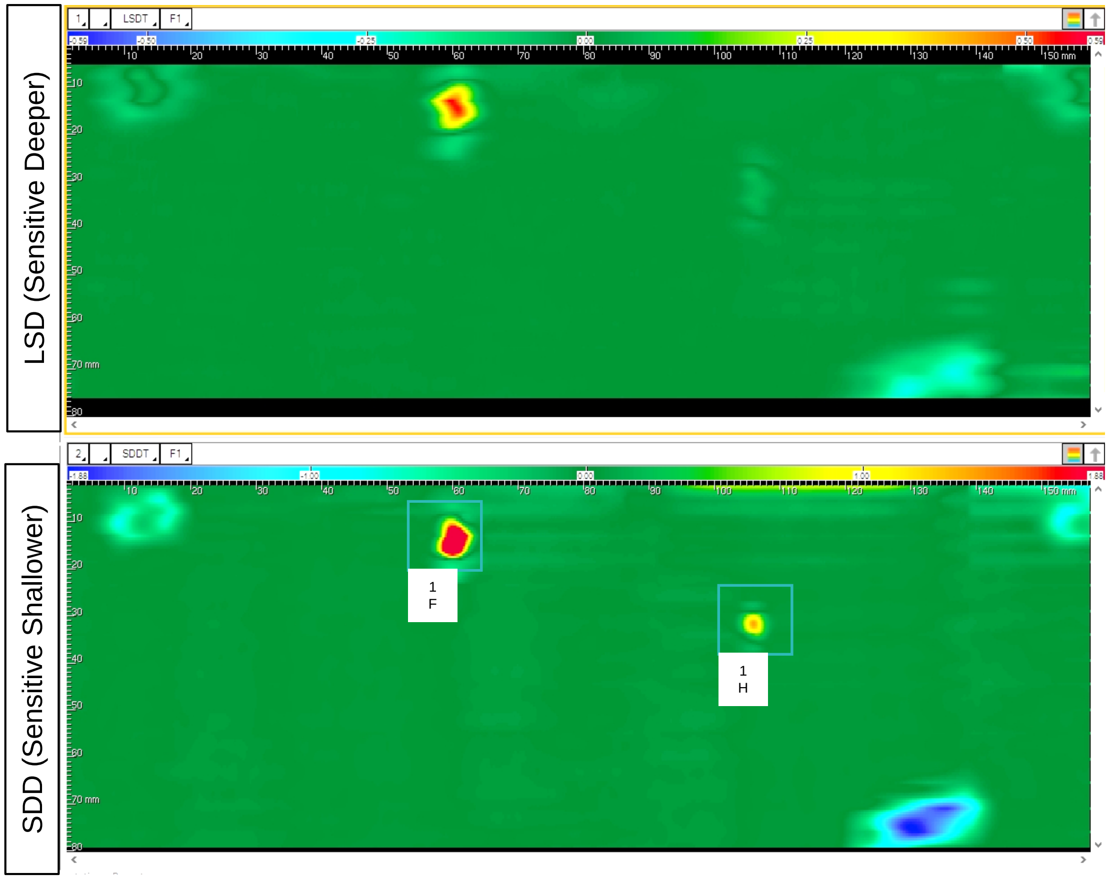


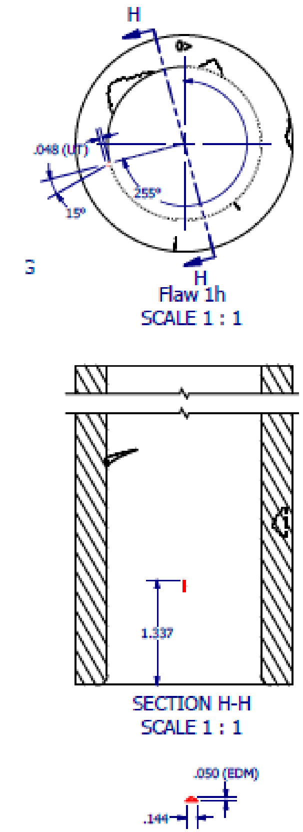




BWRVIP-IP-1 Penetration 1 Tube – Axial Flaws







Water level instrument penetration ECT results

- All inside surface initiating planar cracks located in the penetration tube and J-groove weld were detected
  - None of the OD penetration tube flaws could be detected
  - Implanted surface fabrication flaws and some of the implanted subsurface fabrication flaws were also detected, but it was possible to characterize as such
- ~4mm depth of penetration enhances ability to detect planar cracks initiating from small surface pits (cracks initiate slightly subsurface)
- ~4mm depth of penetration enhances ability to characterize indications as originating from either superficial surface conditions versus planar cracks
- Dual topology operation enhances ability to characterize indications as originating from planar cracks or slightly subsurface weld fabrication flaws

Summary of BWRVIP NDE Development Activities

Summary of BWRVIP NDE Development Activities

- Inspection vendor demonstrations started late in 2018
  - So now 2019 is kicking off with a flurry of demonstration activity
    - UT and ECT of water level instrument penetration tubes and J-groove welds (from the ID surface)
    - Manual phased array UT of water level instrument penetrations (from the OD surface)
    - Core spray sparger bracket UT
    - Jet-pump diffuser UT
    - Core shroud radial ring segment weld UT
- NDE Development activity will continue in 2019 on several projects of interest to the BWRVIP Inspection Committee
  - Jet-pump slip-joint wear NDE
  - Guidelines for comparing data from successive UT examinations
  - Adapt instrument penetration phased array UT technique to other internal attachment weld locations

Together…Shaping the Future of Electricity

Human Factors in NDE: Progress Update

January 2019

NRC: Amy D'Agostino, Stephanie Morrow, Niav Hughes, Carol Nove

PNNL: Tom Sanquist

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Background

- Project started in 2015 at NRR request
- Coordinated efforts with EPRI through MOU
- Research goals:
  1. Systematically evaluate the human factors that can affect UT examiners
  2. Identify future actions to address human factors challenges in NDE
- Multi-method approach

Research Approach

TOPIC CHARACTERIZATION

- Obtain high-level understanding of NDE human factors
- Methods: SME discussions, code reviews, plant visits, EPRI visits
- NRC Technical Letter Report: "Review of Human Factors Research in Nondestructive Examination" https://www.nrc.gov/docs/ML1705/ML17059D745.pdf

TASK ANALYSIS

- Detailed description of examiner task
- Methods: 61 SME interviews, procedure reviews, plant visits, EPRI visits
- NRC/PNNL Technical Letter Report (PNNL-27441): "Human Factors in Nondestructive Examination: Manual Ultrasonic Testing Task Analysis and Field Research." https://www.nrc.gov/docs/ML1817/ML18176A055.pdf

STRATEGIC PLANNING

- Identify areas for future action
- 2 interactive presentations to stakeholders – what is working, what is not?
- Joint NRC/EPRI Presentation publicly available (ML18214A191)
- Additional findings will be incorporated into forthcoming NRC NUREG

Factors Identified by Examiners as Important

Planning

- Timely communications between utility and vendor
- Completeness and accuracy of work package
- Adequate preparation of component
- Availability of work opportunities and personnel

Preparing

- Variations in standards and expectations across organizations
- Adequate time for preparation
- Equipment selection, setup, and usability
- Proper calibration
- Calculation of exam coverage
- Procedure usability
- Last minute changes or delays during preparation
- Quality of pre-job brief

Conducting

- Disruptions or delays in conducting exam
- Identification of correct component
- Awareness when conditions do not match expectations
- Accessibility of component
- Distractions from external sources during exam
- Distractions due to physical environment
- Time pressure during scanning
- Field conditions affect signal interpretation (relevant vs. non-relevant)
- Working in pairs

Reporting

- Adequate time for documentation
- Lack of standardized process for documentation

Training and Practice

- Access to samples to practice detecting flaws
- Opportunities for feedback
- Opportunities for gaining practical on-the-job experience

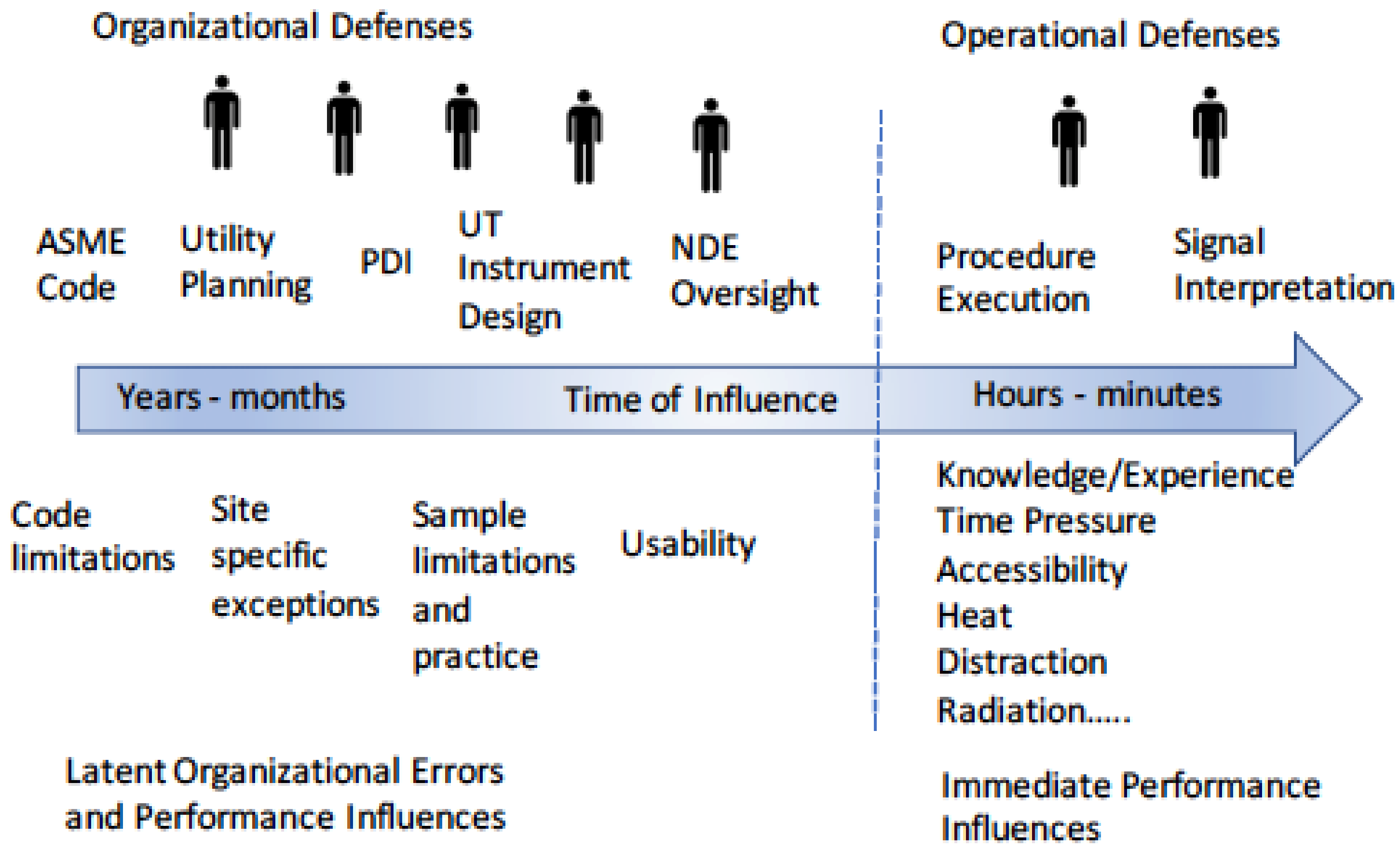
Summary of Stakeholder Feedback (1 of 2)

- Training and Practice
  - Access to samples improving (e.g., EPRI Specimen Management Tool (SMT))
  - Post-job briefs would be opportunity for feedback, but not as consistently practiced as pre-job briefs
  - Desire for more practical experience, barriers exist when Level 1 field experience not prioritized
- Planning Exam
  - EPRI Best Practice document addresses utility/vendor communication, potential gap in disseminating best practice information
  - Good practice of having walk down prior to exam
- Preparing for Exam
  - Some equipment allows calibrations to be performed automatically – reduces opportunity for calibration errors
  - Last minute changes are a significant issue, but difficult to change
  - Pre-job brief quality has improved significantly in last 10 years

Summary of Stakeholder Feedback (2 of 2)

- Conducting Exam
  - Using Level III as buffer can help with distractions during exam
  - Perceived time pressure recognized as problem, may be lessened through communication (i.e., during pre-job brief)
  - Positive comments regarding working in pairs, but can be dependent on composition of pair—better to have two knowledgeable examiners
  - Recent positive results with team scanning seem to be reducing skepticism toward the practice
- Reporting Results
  - Adequate time for documentation is a recognized challenge, can be dependent on workload and pressure from utility
  - Lack of standardized documentation a frustration, errors can be mitigated by sharing sample documentation prior to inspection
  - Possible opportunity to better standardize documentation across industry with same code requirements and more uniform procedures

Research Findings Useful for Developing Error Modeling Frameworks to Identify Error Mitigation Opportunities



Systematic Identification of Error Types, Precipitating Factors and Potential Consequences (1 of 2)

Error Type	Selective Precipitating Factors	Potential Consequences
	Planning Examination	
Incorrect inspection requirements	Plant drawings wrong	Flaw undetected, false positive on wrong component, need to re-do exam on proper component, additional examiner dose
Component to be inspected not properly prepared	Poor communication with craft specialties	Increased examiner workload, stress, fatigue; time pressure
Inspection vendor with wrong training and certifications	Wrong requirements, poor communication with vendor	Increased examiner workload, stress, fatigue; time pressure
Schedule conflicts with other maintenance procedures	Over scheduling to reduce outage length	Exam delayed, not performed, or time pressure upon examiner
	Preparing for Examination	
Incomplete or erroneous pre-job briefing	Time pressure, incomplete or inaccurate information used in planning	Conditions or procedure execution not as expected
Need to repeat calibration	Incorrect file recalled on instrument, new shift, temperature change	Increased examiner workload, stress, fatigue; time pressure
Material left behind (e.g., probes, etc.)	Memory lapse, incomplete pre-job briefing	Need to exit exam area to retrieve necessary items, exam delayed, time pressure
Excessive wait time to enter controlled area	Over-scheduling other work in same area; many other crew in HP area	Inefficient use of examiner time, fatigue, delay of other procedures

Systematic Identification of Error Types, Precipitating Factors and Potential Consequences (2 of 2)

	Conducting Examination	
Wrong component examined	Work package error, wrong drawings, prepped wrong component	Flaw undetected, false positive on wrong component, need to re-do exam on proper component, additional examiner dose
More time required at pipe than planned	Surface conditions poor, undocumented accessibility problems	Stop exam, re-surface, do exam with limitations, additional dose, time pressure
Incomplete exam coverage	Obstructions, surface prep	Flaw undetected
Erroneous data recording	Noise, heat, visibility	Missed indications, erroneous documentation
Procedure steps left out	Informational use procedure	Failure to execute procedure as written, need to re-do exam
	Reporting Examination	
Documentation inaccurate or incomplete	Large number of welds examined before documentation, inadequate note taking, poor team coordination at weld	Critical information about conditions left out of report
Documentation not to plant standards	Varying formats across utilities, varying coverage calculator methods, examiners unfamiliar with plant expectations	Information left out of report, re-work of reports, need to re-do exam
Plant personnel escalate unimportant finding	Premature communication with non-NDE personnel prior to full evaluation	Unnecessary oversight from Outage Control Center
Failure to escalate finding of potential flaw in timely manner	Lack of post-job briefing, inadequate communication between vendor and utility	Time pressure, failure to properly characterize indication

Human Factors in NDE: Next Steps

- NRC team preparing NUREG in FY19 – formal publication of research results
- Human factors insights will be incorporated into other ongoing projects (e.g., Training and Practice)
- NRC may pursue additional human factors research topics following completion of NUREG

Training and Practice for NDE

Training and Practice Research Questions

- How much time does it take for a person to learn to a criterion of mastery?
- What are the factors that determine retention of information (e.g., time, repeated use, practice)?
- How many hours are required to become proficient?
- What kinds of hours are required (e.g., field, classroom, lab)?
- What kinds of retraining or practice are necessary, over what period?
- How much retraining or practice is necessary to maintain or enhance competency?

Step 1: Literature Review

- Basic Science of Learning
  - Study of how people learn
- Science of Training & Instruction
  - Study of how to help people learn
- Science of Expert Performance
  - Study domain experts

Product: Detailed review of the relevant areas and finding, with a written report ~ Summer 2019.

NEXT STEPS:

- Understanding current training/practice
  - Subject matter experts for in-person or telephone interviews are desired – Please contact us

Thank You

If you have questions or interest in participating in future research, please email:

Amy.Dagostino@nrc.gov or Stephanie.Morrow@nrc.gov

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Human Factors in NDE

Myles Dunlap
EPRI

NRC / Industry
NDE Technical Information Exchange Meeting
Washington, DC
January 2019

Outline

- Introduction to Human Factors
- Human Factors in NDE Project
- Results and Applications
- Conclusions

Introduction to Human Factors

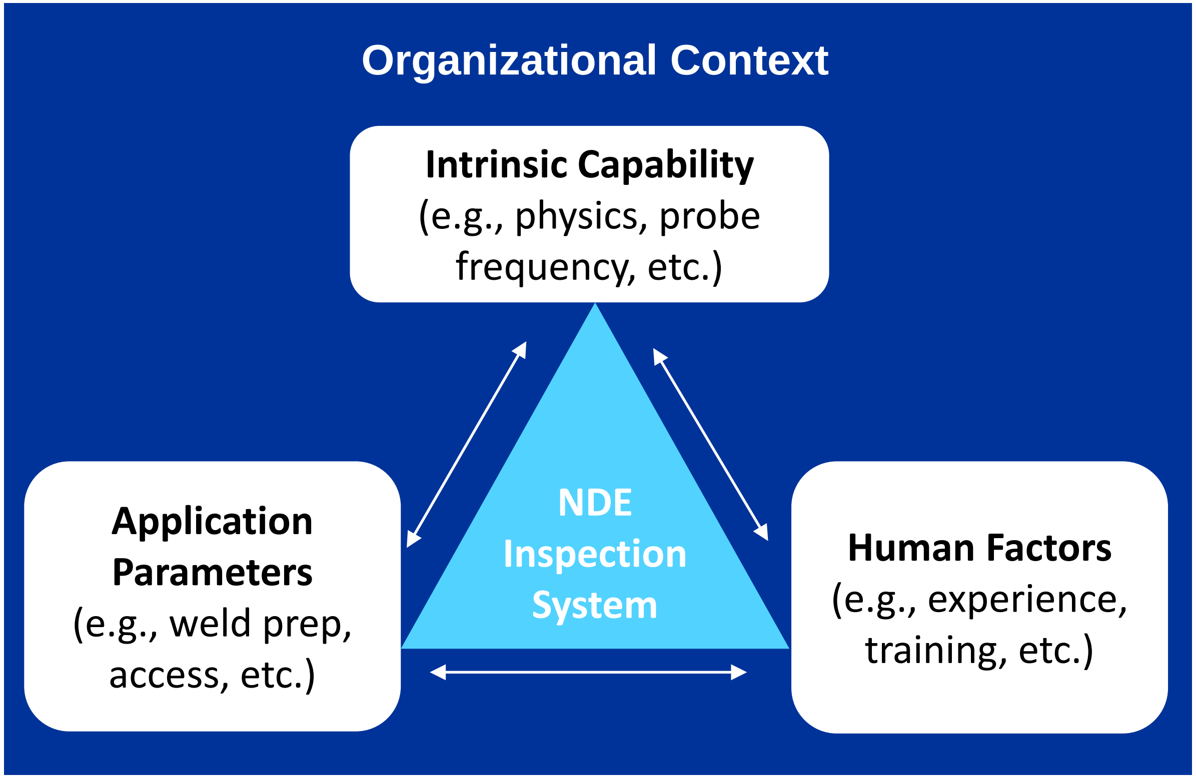
Human Factors (HF)

- Discipline of applying what is known about human capabilities and limitations to the design of
  - Products
  - Processes
  - Systems
  - Work environments
- Application to system design improves:
  - Ease of use
  - System performance and reliability
  - User satisfaction
- While reducing:
  - Operational errors
  - Technician stress
  - Training requirements
  - User fatigue
  - Product liability

NDE Reliability – The Big Picture

- The *Modular Reliability Model*[1,2] defines four primary influencing factors of NDE reliability: intrinsic capability, application parameters, human factors, and organizational context.

- Human factors and organizational context have received the least amount of research.
  - Provides new opportunities for NDE reliability



Content sourced from 1, 2.

1: Paradigm Shift in the Holistic Evaluation of the Reliability of NDE Systems. C. Müller et al., 2013, *Materials Testing*, 55(4), p. 264.

2: Conclusions of the 6th European American Workshop on Reliability of NDE. C. Mueller et al., 2015.

Human Factors in NDE Project

Project Focus and Objective

- Characterize differences in human factors for manual ultrasonic testing (UT) between a controlled laboratory and field environments.
- What, if anything, should be investigated to better prepare examiners for the field?
- The NRC performed a similar research study.
  - EPRI and NRC are worked together through a Memorandum of Understanding (MOU).

Laboratory

Field

MOU Tasks

- Human factors MOU activities are being finalized and will be completed in 2019.
  - EPRI and NRC have collaborated on and researched these tasks.

- Task 1 - Systematically evaluate the human performance issues facing examiners.

- Task 2 - Identify the key differences between human performance in qualification versus in the field.

- Task 3 - Prioritize the human performance issues for examinations in the field.

- Task 4 - Outline the potential applicability of the research results to other NDE methods.

Timeline of EPRI's Project

- The project timeline is 2016 – 2019:

2016
Literature review
On-site observations

2017
Domestic Interviews
Technical Update [1]

2018
Industry Workshops
Simulator Development

2019
International Interviews
Final Report

[1] EPRI Report available at www.epri.com

Product ID 3002010462: *Human Factors in Nondestructive Evaluation (NDE): A Literature Review and Field Observations.*

Results and Applications

2017 – Domestic Examiner Interviews

- EPRI and NRC interviewed 61 examiners.
  - Mix of interview techniques (in-person, phone, focus groups), utility and vendor, UT levels, and geographic regions

	Level II	Level III	Total
Vendor Employee	19	14	*33*
Utility Employee	9	19	*28*
Total	*28*	*33*	*61*

- Interview questions were focused on:
  - Task Analysis
    - What high level tasks need to be accomplished? Which are most important?
  - Challenges and opportunities as a UT examiner
    - How could training be improved? What in training is unnecessary and why? What could make your job more satisfying?

Results from EPRI's Examiner Interviews 1 of 2

- The top 3 most frequently mentioned Important Tasks were:
  - Understanding and applying procedures
  - Calibration
  - Selecting equipment and other materials

- These same 3 tasks were described as potentially more error prone. In addition, locating and identifying the correct component in the field was described as challenging by many examiners.

- The desire for more hands-on practice and feedback on results was by far the most requested improvement for training.

- To make the job better, having conditions in the field ready for examiners to start work took top honors.

Results from EPRI's Examiner Interviews 2 of 2

- Schedule pressures reduce job satisfaction, but a significant number of examiners were currently satisfied in their job.
- Given one thing they would want to change, the need for newer/better equipment stood out.
- In Performance Demonstration at EPRI, the stress of taking a test is ever-present. Many examiners asked for feedback about their test performance.
- In the field, the intrinsically hazardous environment was at the fore. Unnecessary distractions occur when observers ask questions during the time critical exam in radiological environments.

2018 - Industry Feedback via Workshops

- Feedback on the results of examiner interviews was gathered during two major periodic meetings of industry leaders:
  - EPRI NDE Technology Week in June 2018
  - ASME Code Week in July 2018

- After presenting results, audience feedback was gathered related to:
  1. Training and practice
  2. Planning for NDE
  3. Preparing for NDE
  4. Conducting NDE
  5. Reporting results

Results from 2018 Workshops 1 of 2

1. Training and Practice:
   – Practice samples and availability/access to them
   – Providing feedback after exams and in the field
   – Appendix VII requirement for experience, and what that should entail
   – On the job training and experience for newcomers

2. Planning for NDE:
   – Distributing Industry NDE best practice materials
   – Preparations and communications before the examiners start their work
   – NDE proficient walkdown team to assess component preparedness

3. Preparing for NDE:
   – Preparing examiners for unavoidable last minute schedule changes
   – Procedure usability has been a focus for the industry

Results from 2018 Workshops 2 of 2

4. Conducting NDE:
   - Identifying correct component
   - Preparing for access to components in challenging locations
   - Minimizing unnecessary distractions from outsiders during the exam
   - Minimizing perceived time pressures
   - Using two people for field exams
   - Communicating the importance of following the procedure versus being rushed

5. Reporting Results:
   - Making documentation consistent and efficient
   - Allowing time for documentation
   - Conducting post-job briefs for exams without indications

Meeting Examiner Requests with Human Factors

- In 2017 EPRI asked 31 present day examiners the following:

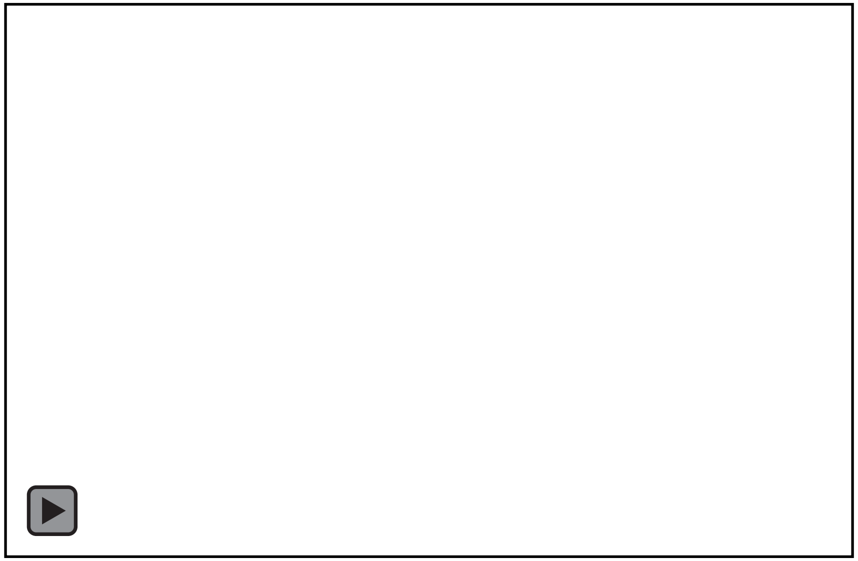
Question	UT Examiner Responses
What aspects of training could be improved and how?	"… look at more flawed samples." "Training needs to be on good mockups,…" "….just scanning samples is very valuable."
Opportunity – Examiners are requesting accessibility to practice samples	

- A solution for this opportunity is the EPRI Virtual Nondestructive Evaluation (VNDE) 2.0 ultrasonic simulator.
  - During 2018 VNDE 2.0 was undergoing development.
  - Excellent opportunity for applying human factors practices.

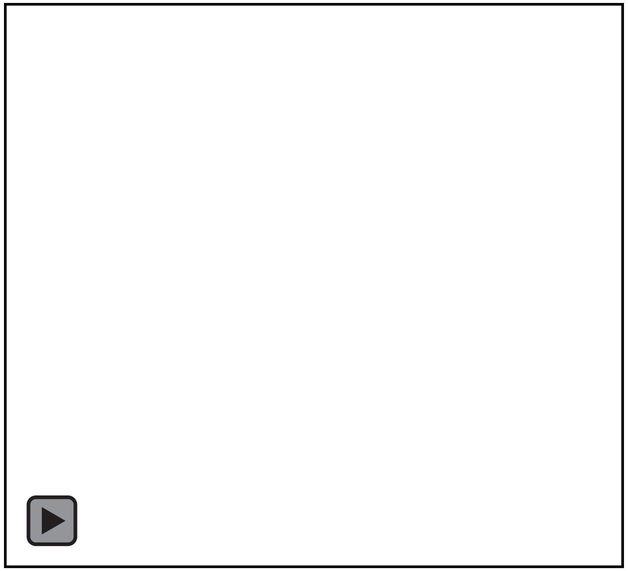
Virtual NDE (VNDE) 2.0 and Human Factors

- Simulated hardware contains a 3D printed plastic specimen and probe.
  - Gives a realistic look and feel when scanning.

Hardware Scan: Half Pipe



Hardware Scan: Rompas Block

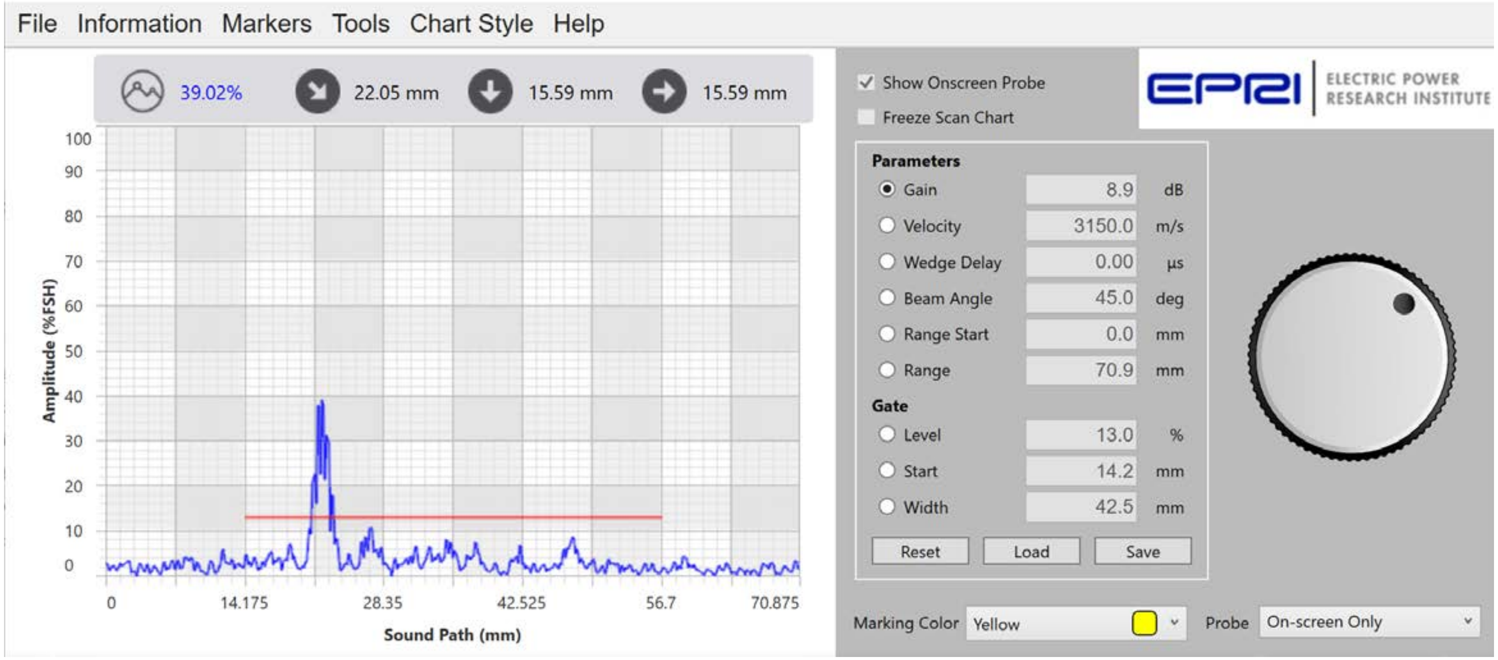


Product ID: 3002013243

Virtual Non-Destructive Evaluation (VNDE), v2.0

Usability Testing

- A test procedure was developed and ultrasonic examiners were asked to:
  - Load data files.
  - Apply ultrasonic calibration settings.
  - Scan for indications.
- The user interface and its operation were designed based on testing results.



2019 Research

- Interviews are planned with international ultrasonic examiners.
- This data will sever as a comparison against the 2017 US based interviews.
- A final technical report will be published that covers all research and activities.

Conclusions and Takeaways

- MOU tasks between EPRI and NRC are complete.
  - This was an excellent opportunity for the two organizations to collaborate and mutually expand human factors research in NDE.
- Interviews with ultrasonic examiners brought forth an assessment of the most critical tasks and the challenges and opportunities to effectively perform their job.
  - This was the first study to speak directly to a large body of ultrasonic examiners and document their perspective on important job tasks.
- In 2018, workshops showcased industry's awareness of these tasks.
  - Best practices have been established for a significant amount of the human factors heard during 2017 interviews.
  - Industry has produced other works that address many of these factors such as DMW guidelines, informative pre-job briefs, ultrasonic simulators, etc.
- A final report will be published in 2019 documenting the findings from this research.

discussion

Together…Shaping the Future of Electricity

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Analysis of Empirical Probability of Detection Data for Dissimilar Metal Welds

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NRC-Industry NDE Technical Information Exchange Meetings
Rockville, MD
January 15-17, 2019

WORK SPONSORED BY THE US NRC – OFFICE OF RESEARCH
CAROL NOVE, NRC COR

Outline

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- eXtremely Low Probability of Rupture (xLPR) Probabilistic Fracture Mechanics Code
- What is Probability of Detection (POD)?
- xLPR In-Service Inspection POD Model
- Sources of Empirical Data for POD Estimation
- False Call Probability (FCP)
- Presentation of Results
- Discussion and Conclusions

Background - What is xLPR?

- Motivation - assist users of the probabilistic fracture mechanics code called eXtremely Low Probability of Rupture (xLPR)

- xLPR is a modular-based probabilistic computational tool capable of determining probability of leakage and rupture for reactor coolant piping

- One of the modules in xLPR is the in-service inspection (ISI) module which models the probability of detection (POD) and sizing performance of nondestructive examination (NDE) performed during ISI

- Developed under a cooperative agreement between US NRC Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI)

What is Probability of Detection (POD)?

- POD is the de facto metric used in quantifying the performance of an inspection for detecting structural defects (usually cracks). POD reflects the stochastic nature of detection and has a value often expressed as a percentage (range from 0% to 100%) or fraction (range from 0 to 1). It is usually represented as a function of flaw size in this context.

- The ideal POD curve is a step function with perfect (POD = 1) detection of all flaws of $a>0$ and no detection (POD = 0) of flaws of $a=0$ (or $a \leq$ pre-defined minimum flaw size).

Representation of POD

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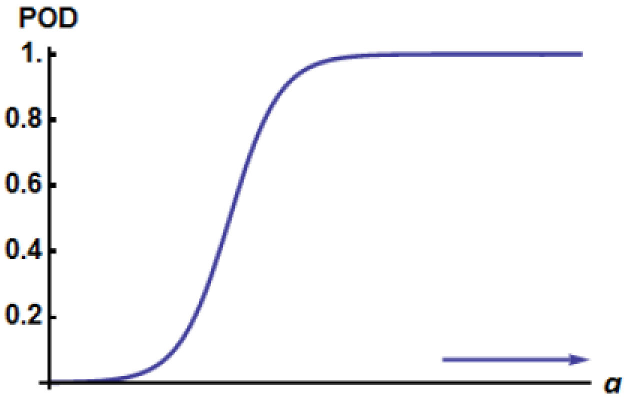
- The logistic function is often used for creating a continuous POD response from discrete binary (hit/miss) NDE response data

- Creates a mathematical expression of POD as a function of flaw variable (most often, flaw depth)

- The parameters, β_1 and β_2 , are determined using maximum likelihood estimation (MLE). Uncertainties in model parameters are represented by standard deviations in the parameters, σ_{β_1} and σ_{β_2}, and the covariance $\rho_{\beta_1\beta_2}$

$$\mathrm{POD}(a) = \frac{1}{1+\exp(-\beta_1 - \beta_2 a)} = \frac{\exp(\beta_1 + \beta_2 a)}{1+\exp(\beta_1 + \beta_2 a)}$$



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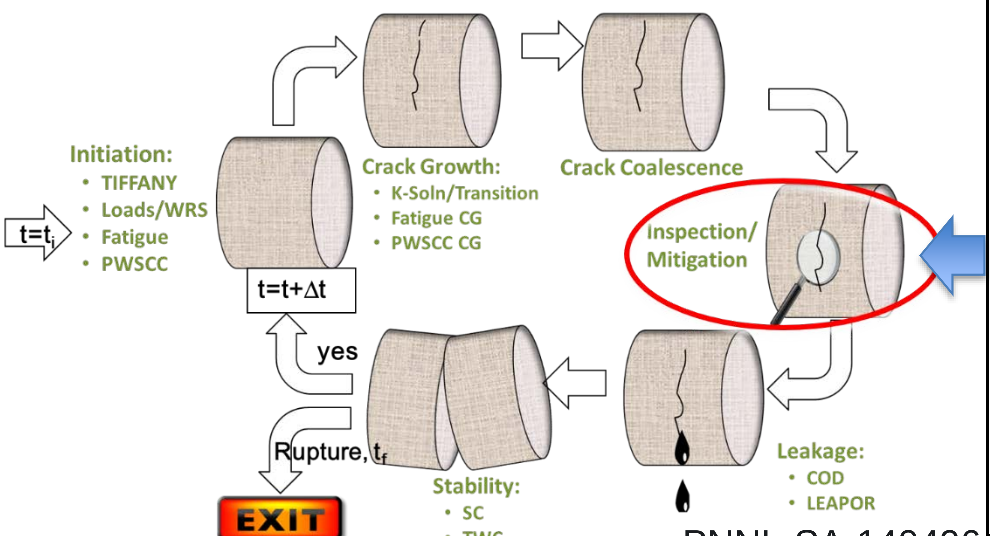
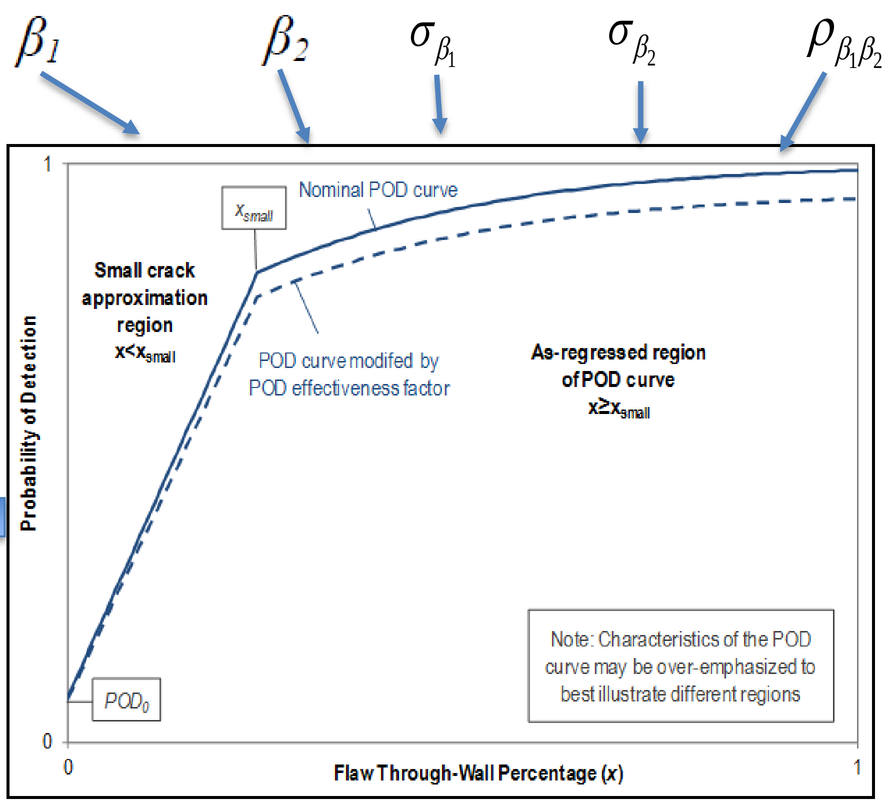
xLPR In-Service Inspection POD Model

- In xLPR, POD can be defined piecewise over the flaw size variable and can be expressed as a combination of a logistic function above a certain flaw size and simpler expression below a certain flaw size

- This model of POD is based on analysis of EPRI PDI data which included no flaws < 10% TW





Sources of Empirical NDE Performance Data

- **Program for Inspection of Nickel Alloy Components (PINC)**
  - Blind round-robin test on specimens containing simulated PWSCC cracks to determine the detection and sizing performance capabilities of various NDE techniques
  - Participants organized by the United States, Japan, Sweden, Finland, and South Korea
  - The PINC final report NUREG/CR-7019 (available at www.nrc.gov) [ML17159A466]

- **Program to Assess the Reliability of Emerging Nondestructive Techniques (PARENT)**
  - Open testing was conducted to evaluate the performance of emerging/novel NDE techniques
  - Blind testing was conducted to quantitatively evaluate the performance of commercially used NDE techniques
  - PARENT final reports NUREG/CRs 7235 (Blind) & 7236 (Open) (available at www.nrc.gov) [Blind - ML17159A466; Open - ML17223A700]

- **EPRI Performance Demonstration Initiative (PDI)**
  - Developed from EPRI Performance Demonstration Initiative data
  - POD analysis of PDI data is summarized in EPRI report: 3002010988 [MRP-262 Rev. 3]

Sources of Empirical NDE Performance Data - Considerations

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- **PINC AND PARENT**
  - Smaller sample sizes (30 to 183 attempts)
  - Both UT and ECT procedures
  - Most, but not all, procedures qualified
  - Data collected over limited time period (< 2 years)
  - For some scenarios, flaw sizes < 10% TW included in sample
  - False call data utilized in POD Analysis
  - Lower pressure – test outcome will not affect qualification status

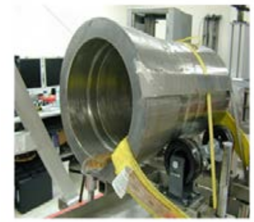
- **EPRI PDI**
  - Largest source of NDE performance data (288 to 1675 attempts)
  - Only includes UT performance data
  - All qualified procedures
  - Database built over period of ~20 years
  - No flaws < 10% TW
  - False call data not utilized in POD Analysis
  - High pressure – passing qualification is necessary to perform job function

Scope of Test Blocks

SBDMW = Small Bore Dissimilar Metal Weld
LBDMW = Large Bore Dissimilar Metal Weld

PINC - SBDMW

PARENT - SBDMW



PARENT - LBDMW

	PDI			PINC	PARENT	
	Pressurizer Surge (Category A)	Reactor Pressure Vessel (Category B1)	Steam Generator Nozzle (Category B2)	SBDMW	SBDMW	LBDMW
Outer Diameter (mm)	305–356	686–787	685–787	386–390	289 and 815	852–895
Wall Thickness (mm)	30–58	64–76	127–132	42–46	35 and 39.5	68–78
Access	OD	ID	OD	OD and ID	OD	OD and ID
ID = inner diameter; OD = outer diameter						

Sample Sizes

		PDI			PINC	PARENT	
		Pressurizer Surge (Category A)	Reactor Pressure Vessel (Category B1)	Steam Generator Nozzle (Category B2)	SBDMW	SBDMW	LBDMW
OD	Axial	611[A]	---	---	100	45	45
	Circumferential	1675[A]	---	184[B]	150	183	50
ID	Axial	---	288[A]	---	30	---	34
	Circumferential	---	553[A]	---	45	---	38

[A]Table 6-1 in MRP 262 Rev. 3
[B]Table G-2 in MRP 262 Rev. 3

Flaw Size Ranges

		PDI			PINC	PARENT	
		Pressurizer Surge (Category A)	Reactor Pressure Vessel (Category B1)	Steam Generator Nozzle (Category B2)	SBDMW	SBDMW	LBDMW
OD	Axial	10% - 100%*			11% - 71%	11% - 74%	1% - 36%
	Circumferential				10% - 83%	3% - 72%	
ID	Axial				11% - 71%	---	
	Circumferential				10% - 83%	---	

*Flaw size distribution in PDI meets the requirements of ASME Boiler and Pressure Vessel Code Section XI, Appendix VIII, Supplement 10

Flaw Depth (% Wall Thickness)	Minimum Number of Flaws
10–30%	20%
31–60%	20%
61–100%	20%

At least 75% of the flaws shall be in the range of 10% to 60% of wall thickness.

False Call Probability (FCP)

- False Call Probability (FCP) – the likelihood that an inspection will provide an indication of detection when no structural defect is present

- In PINC and PARENT, FCP is a data point obtained by converting the observed false call rate (FCR) where FCR is the # of false calls observed per length of inspected material

$$FCR = \frac{\#\ of\ False\ Calls}{Length\ of\ Material\ Inspected}$$

- Assuming that false calls are randomly distributed, FCP can be calculated from FCR

$$FCP = 1 - \exp\left(-FCR\left(L_{gu} + L_{fc}\right)\right)$$

$$L_{gu} = Length\ of\ blank\ grading\ unit$$
$$L_{fc} = Length\ of\ false\ call$$

POD(a=0)

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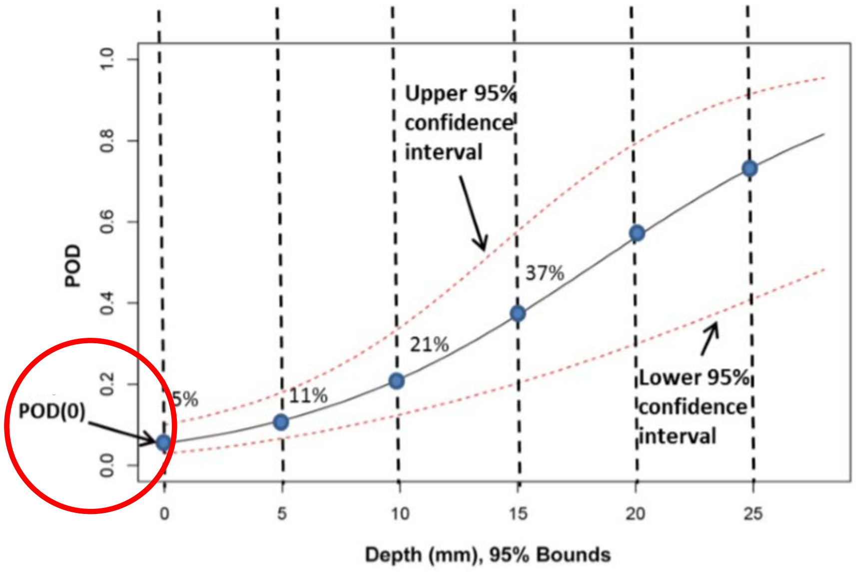
- POD(a = 0) is the value of POD curve fit at a = 0
- Similar concept to FCP, but not exactly the same
- POD(0) is influenced by FCP and data for a > 0



$$POD(a=0) = \frac{\exp(\beta_1 + \beta_2 * 0)}{1+\exp(\beta_1 + \beta_2 * 0)} = \frac{\exp(\beta_1)}{1+\exp(\beta_1)}$$

$\beta_1 \ll 0$	$POD(0) \rightarrow 0$
$\beta_1 = -2.20$	$POD(0) = 0.1$
$\beta_1 = 0$	$POD(0) = 0.5$
$\beta_1 = 2.20$	$POD(0) = 0.9$
$\beta_1 \gg 0$	$POD(0) \rightarrow 1$

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Small Bore Dissimilar Metal Weld (SBDMW) Outer Diameter (OD) Access - Procedures

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PINC procedures

Team	Techniques	Data Collection	Procedure ID
13	PAUT	Automated	PAUT.13
22	UT	Automated	UT.22
28	UT	Automated	UT.28
30	UT	Manual	UT.30
39	PAUT	Automated	PAUT.39
48	UT	Manual	UT.48
63	UT	Automated	UT.63
66	UT and PAUT	Manual+Encoded	UT.PAUT.66
72	PAUT	Automated	UT.72
82	UT and TOFD	Automated	UT.TOFD.82

UT = conventional UT, PAUT = phased array UT, TOFD = time-of-flight diffraction UT

PARENT procedures

Team	Techniques	Data Collection	Procedure ID
25	UT	Automated	UT.25
115	PAUT	Manual	PAUT.115
128	PAUT	Automated	PAUT.128
117	UT and TOFD	Automated	UT.TOFD.117
108	UT	Manual	UT.108
108	PAUT	Manual	PAUT.108.1
134	UT	Manual	UT.134.2
126	UT	Manual	UT.126
126	PAUT	Manual	PAUT.126.1

UT = conventional UT, PAUT = phased array UT, TOFD = time-of-flight diffraction UT

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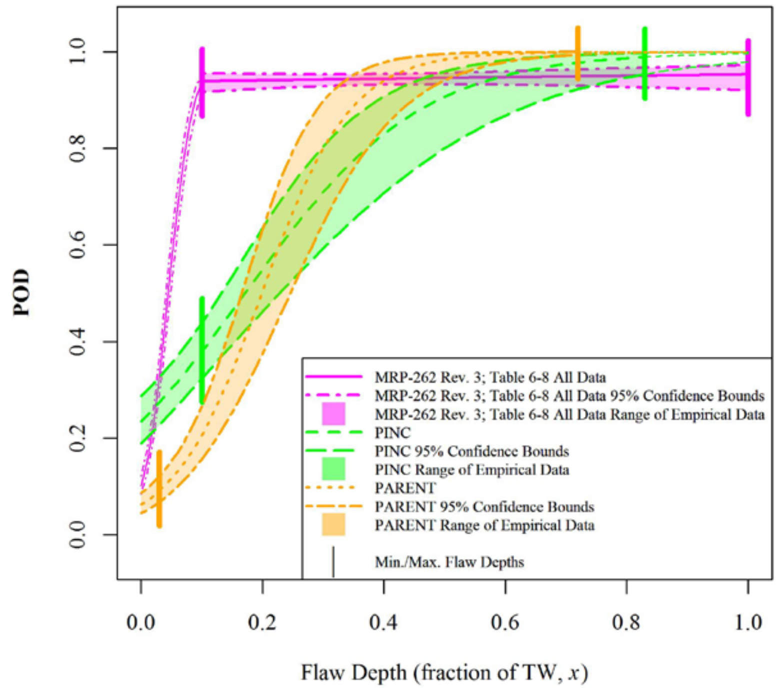
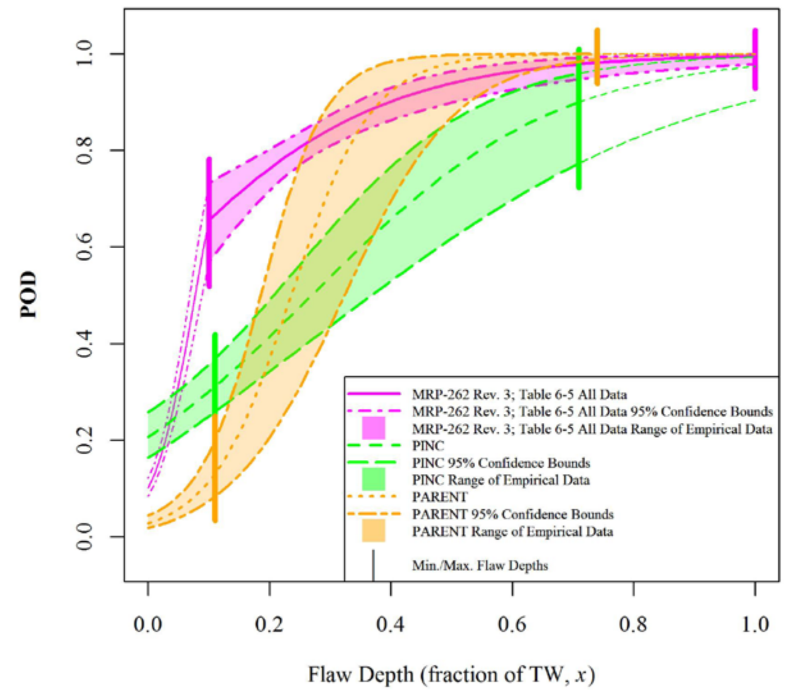
Small Bore Dissimilar Metal Weld (SBDMW) Outer Diameter (OD) Access - Results

Circumferential Flaws



Axial Flaws



Shading below "Min" flaw size to indicate that empirically derived false call data is used in the logistic curve fit for PINC and PARENT

Small Bore Dissimilar Metal Weld (SBDMW) Inner Diameter (ID) Access - Results

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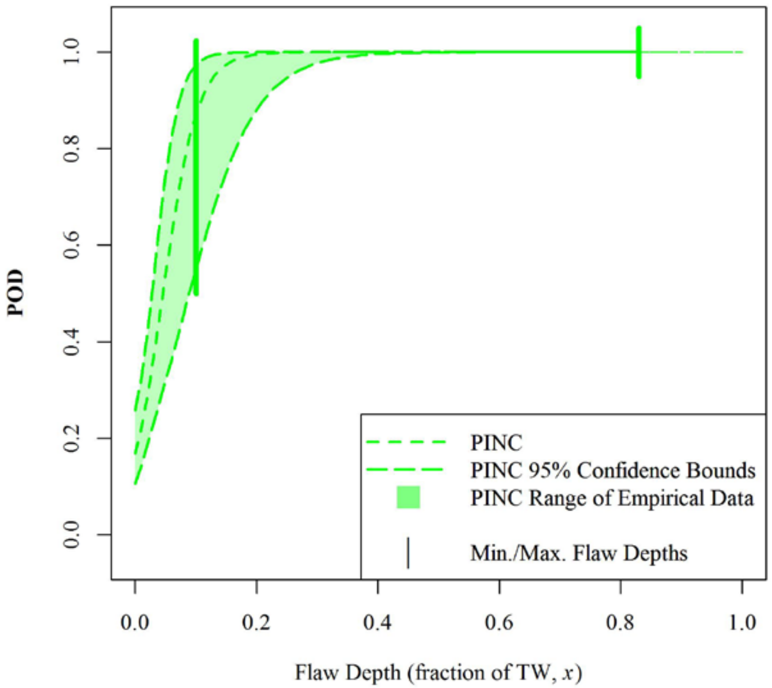
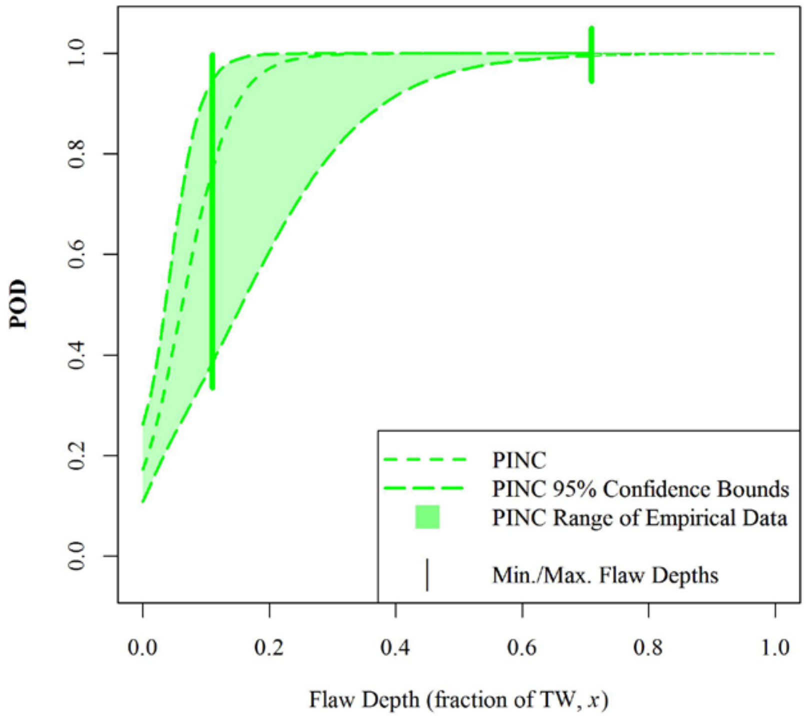
Circumferential Flaws



Axial Flaws



Team	Techniques	Data Collection	Procedure ID
38	ECT	Manual+Encoded	ECT.38
70	ECT	Manual+Encoded	ECT.70
96	ECT	Automated	ECT.96
ECT = eddy current testing			

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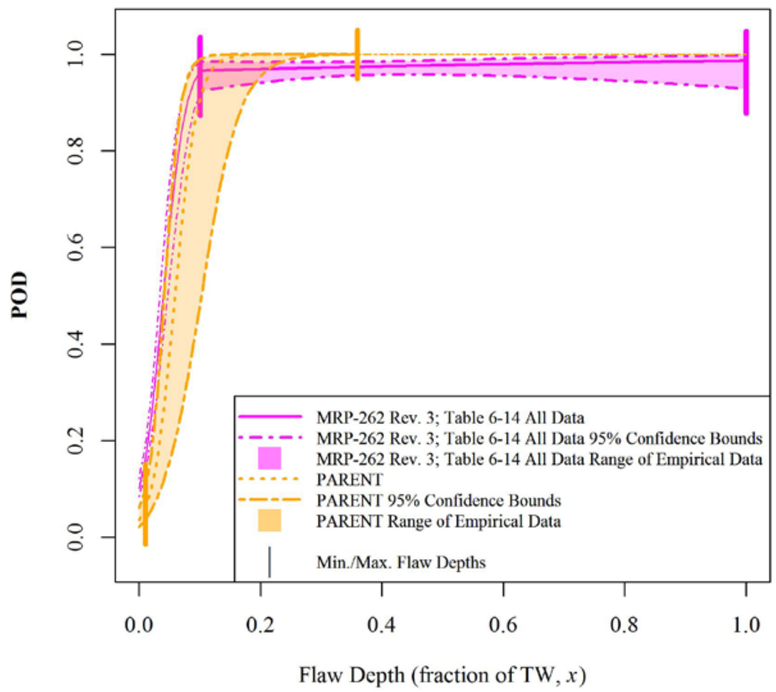
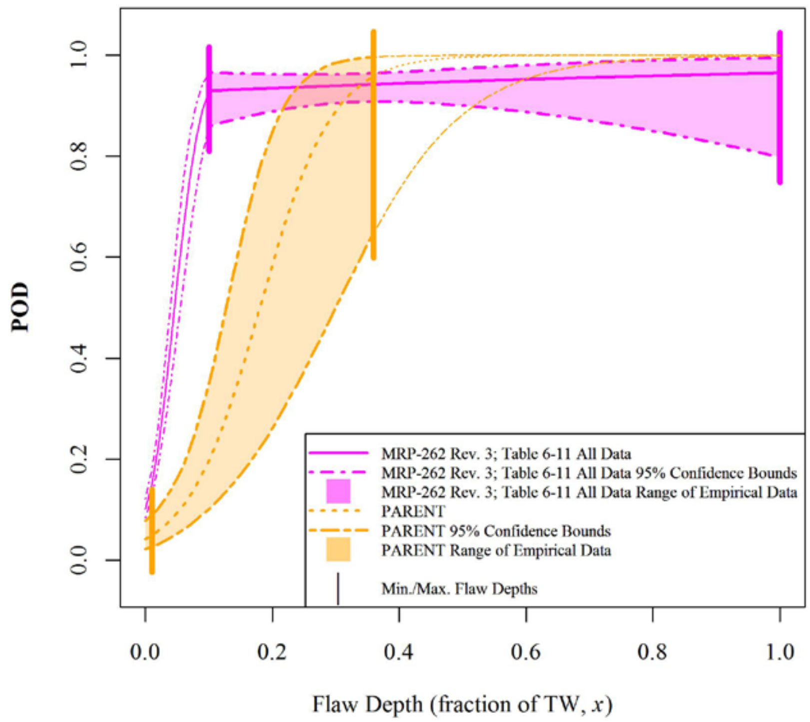
Large Bore Dissimilar Metal Weld (LBDMW) Inner Diameter (ID) Access - Results

Circumferential Flaws



Axial Flaws

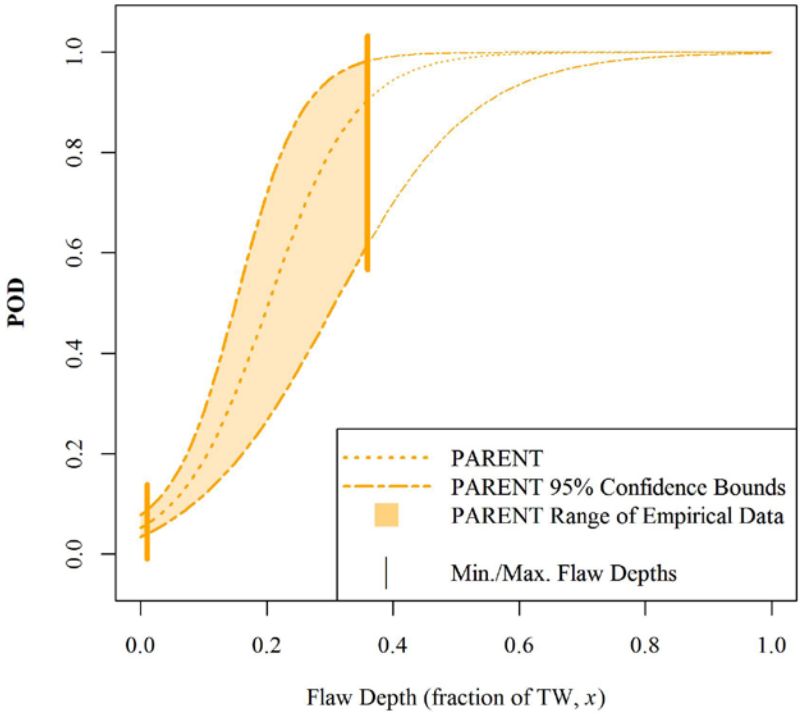


Team	Techniques	Data Collection	Procedure ID
101	ECT, UT, and TOFD	Automated	UT.TOFD.ECT.101
144	ECT and UT	Automated	UT.ECT.144
113	UT and PAUT	Automated	UT.PAUT.113
135	ECT	Manual+Encoded	ECT.135

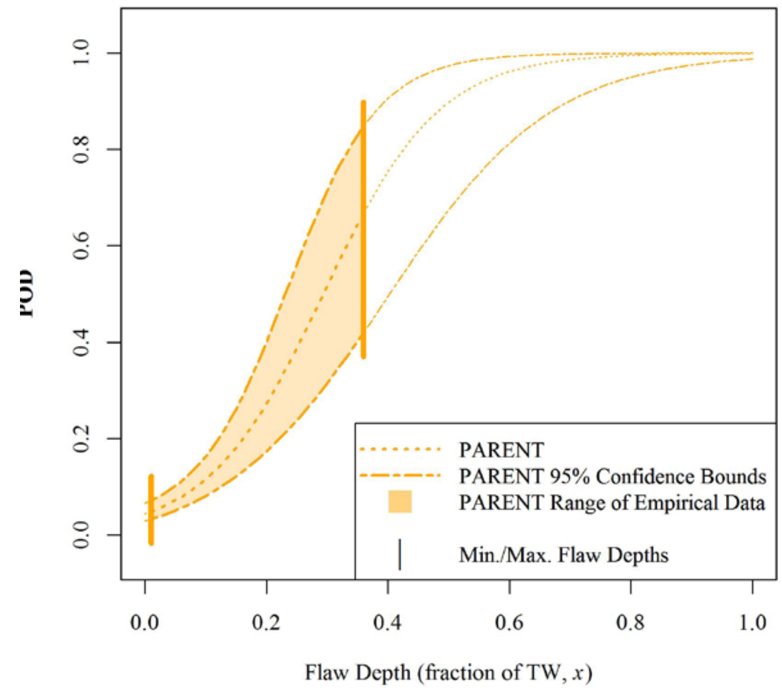
UT = conventional UT, TOFD = time-of-flight diffraction UT, ECT = eddy current testing, PAUT = phased array UT

Large Bore Dissimilar Metal Weld (LBDMW) Outer Diameter (OD) Access - Results

Circumferential Flaws



Axial Flaws



Team	Techniques	Data Collection	Procedure ID
108	UT	Manual	UT.108
108	PAUT	Manual	PAUT.108.1
134	UT	Manual	UT.134.2
126	UT	Manual	UT.126
126	PAUT	Manual+Encoded	PAUT.126.1
UT = conventional UT, PAUT = phased array UT			

Summary of Model Parameters

Category	Flaw Orientation	Data Source	β_1	β_2	σ_{β_1}	σ_{β_2}	$\rho_{\beta_1\beta_2}$	Min. Flaw Depth, x	Max. Flaw Depth, x
SBDMW (OD Access)	Circumferential	PDI – Category A (MRP-262 Rev. 3; Table 6-8)	2.71	0.31	0.21	0.45	−0.86	0.10	1.00
		PINC	−1.18	6.9	0.14	1.0	−0.49	0.10	0.83
		PARENT	−2.71	13.7	0.18	1.5	−0.48	0.03	0.72
SBDMW (OD Access)	Axial	PDI – Category A (MRP-262 Rev. 3; Table 6-5)	0.12	5.24	0.27	1.02	−0.91	0.10	1.00
		PINC	−1.34	4.99	0.15	0.77	−0.46	0.11	0.71
		PARENT	−3.56	15.1	0.23	2.3	−0.43	0.11	0.74
SBDMW (ID Access)	Circumferential	PINC	-1.6	35.1	0.28	8.9	−0.23	0.10	0.83
SBDMW (ID Access)	Axial	PINC	-1.57	25.4	0.27	8.0	−0.24	0.11	0.71
LBDMW (ID Access)	Circumferential	PDI – Category B2 (MRP-262 Rev. 3; Table 6-14)	3.24	1.06	0.55	1.32	−0.87	0.10	1.00
		PARENT	−3.31	56	0.29	13	−0.33	0.01	0.36
LBDMW (ID Access)	Axial	PDI – Category B1 (MRP-262 Rev. 3; Table 6-11)	2.50	0.82	0.51	1.40	−0.87	0.10	1.00
		PARENT	−3.14	17.4	0.35	3.9	−0.40	0.01	0.36
LBDMW (OD Access)	Circumferential	PARENT	−2.91	14.3	0.22	2.7	−0.37	0.01	0.36
LBDMW (OD Access)	Axial	PARENT	−3.08	10.5	0.22	1.6	−0.46	0.01	0.36

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Some Sources of Variation Among Studies

- Flaw size distribution and manufacturing technique for flaws…
- Test format and objectives
  - PDI intent is to determine if performance is "good enough," not meant to fully characterize performance
  - PARENT and PINC results more likely to represent performance that is possible
- Period of time for data collection
  - PINC and PARENT data each collected over 1-2 year time frame
  - PDI data accumulated over 20 years (estimated performance represents an average over this period)
- Variation in the procedures/techniques represented in each dataset and the relative distribution of procedures (e.g. # of PAUT and # of UT procedures)
- Variation in how data analysis is performed (i.e. how is false call data utilized?)

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Conclusions/Recommendations

- Empirically derived POD data from PINC, PARENT, and PDI studies are excellent resources for basing POD inputs to xLPR code
- Sensitivity analyses can be useful to estimate importance of accurate knowledge of POD for small flaw sizes where large variability exists
- Treatment of POD at 0 TW size may have a significant influence on POD, especially for smaller flaw sizes
- A standardized set of guidelines for performing POD analysis would be useful to facilitating comparison of POD results from different data sets

Questions?

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