Industry/NRC NDE Technical Information Exchange Meeting

January 2020

NRC Offices
Rockville, MD

ELECTRIC POWER RESEARCH INSTITUTE

www.epri.com

Opening

- Welcome
- Safety
- Logistics
- Announcements

Announcements

- MRP’s in-vessel inspection Virtual Reality application, used in the MRP-228 IVI training course, will be available for demonstration in the Auditorium Lobby all day Wednesday
  - Supports only one viewer at a time
  - Please feel free to (quietly) go to the lobby at any time in order to try it out

Opening remarks

NRC opening remarks

Industry opening remarks

Action item review

Action item review – actions recently closed

Action number	Topic	Action owner	Action	Date opened	Date closed
2018-01-03	RPV upper head bare metal visual	Industry	Provide progress updates on quarterly calls, for: 1) MRP project expediting updating head penetration BMV guidance to reflect recent OE and Code activity, and 2) development of technical basis for ET qualifications and Code Cases.	1/18/2018	10/2/2019
2019-01-02	2020 meeting venue	NRC	Identify venue for 2020 NDE Technical Information Exchange Meeting.	1/17/2019	10/2/2019
2019-10-01	Agenda for January 2020	Both	Prepare draft agenda for January 14-16, 2020 Industry-NRC NDE Technical Information Exchange Meeting	10/2/2019	11/5/2019

Action item review – open actions

Action number	Topic	Action owner	Action	Date opened	Date due
2017-01-04	CASS timeline	NRC	Evaluate regulatory aspects; will the stated 2022 put regulator and licensees into a position from which they can't recover. Request additional public comments. Report progress on quarterly calls.	1/19/2017	undefined
2019-01-01	Coverage relief requests	NRC	Expand guidance on coverage relief requests to include how licensees might address reasonable assurance of continued structural integrity. Report on quarterly calls.	1/17/2019	report quarterly

Agenda review

Agenda review - Tuesday

1:00	Opening	NRC
1:10	NRC and Industry opening remarks	NRC
1:20	Section XI update: NDE-related actions	Industry
1:35	Update on Code Case N-711-2	Industry
1:50	Supplement 15 update	Industry
2:05	Technical basis for eddy current code cases, qualification, acceptance criteria - Update	Industry
2:20	CASS research update	Industry
2:40	CASS timeline update	NRC
2:55	Break	
3:15	Coverage relief requests guidance	NRC
3:30	Training and Practice for NDE	NRC
4:00	Technical basis for Section XI Appendix VII	Industry
4:20	UT Simulator update	Industry
4:35	Public comment period, daily wrapup and adjourn	NRC

Agenda review - Wednesday

8:00	Announcements	NRC
8:05	PDI update	Industry
8:20	Qualified procedure modifications	Industry
8:40	Hyperspectral imaging	Industry
8:55	MRP NDE update	Industry
9:15	BWRVIP NDE update	Industry
9:35	Concrete NDE	Industry
10:05	Break	
10:25	Automated data analysis update	Industry
10:50	Assessment of Eddy Current Testing for PWSCC Susceptible Materials	NRC
11:20	Evaluating Flaw Detectability under Limited Coverage Conditions	NRC

1:00	Human Factors for Encoded Exams	NRC
1:20	Development of technical bases for optimization of examination requirements	Industry
1:50	Update on reactor vessel upper head volumetric exam OE	Industry
2:20	Update on MRP-60	Industry
2:40	Update on RV UT procedure change OE	Industry
3:00	Break	
3:20	Discussion: NDE for advanced manufacturing	NRC, Industry
4:00	Public comment, wrapup, adjourn	NRC

Agenda review - Thursday

8:00	Announcements	NRC
8:05	Update on Virtual Mockups/eflaws	Industry
8:35	Modeling & Simulation update	Industry
9:05	Progress in Assessing CIVA for NDE Modeling and Simulation	NRC
9:50	Break	
10:10	NDE for composite repairs	Industry
10:25	Open discussion	
11:40	Closing, action items	NRC
11:50	Public comment period	NRC
12:00	Adjourn	NRC

Section XI Update

NDE Related Actions

Gary Lofthus
Southern Nuclear

Carl Latiolais
EPRI

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Recent Code Activities

- Revision to VIII-1000
  - Added definition of responsibilities of the PDA
  - Board approved

- Revision of Appendix VIII, Supplement 8
  - Code change to replace the existing wording of Supplement 8 with the contents of ASME Board approved Code Case N-845
  - Board approved
  - In Reg Guide 1.147

Ongoing Activities

- Supporting development of Code Case N-780-1
  - *Alternative Requirements for Upgrade, Substitution, or Reconfiguration of Examination Equipment when using Appendix VIII Qualified Ultrasonic Examination Systems, Section XI, Division 1*
    - Revised Code Case due to be presented at February 2020 Code meeting
    - Code Case will be limited to equipment used with encoded procedures

Ongoing Activities (continued)

- Revision to VIII-4000 and Supplement 1 (ASME Section XI Task Team - Defining Essential Characteristics of UT Systems)
  - The current Appendix VIII requirements are in need of revision to define essential characteristics for modern equipment
    - Current requirements are focused on traditional analog conventional equipment
  - Working to update the requirements and provide guidance for substituting digital and phased array equipment
  - In the process, this Task Team will better define the terminology used when describing the critical parameters which must be considered when performing equipment substitutions
  - The Task Team meets Tuesday afternoons at the Section XI BPV Code Weeks
  - Considering using/modifying existing ENIQ standards as a template

Ongoing Activities (continued)

- Revision to Article VIII-2000 “General Examination System Requirements”
  - The lessons learned from the EPRI PD Program and input from the equipment vendors were used to generate a list of critical instrument essential variables
  - The report “Nondestructive Evaluation: Phased Array Technologies: Essential Variables Defined” (Product ID:3002008768) was published in 2016 as a technical basis document for Code actions
  - The material was presented to the ASME Section XI Task Team
    - Defining and incorporating essential characteristics of UT systems in Section XI falls within the charter of this committee
  - Additional actions will be initiated to revise this Article

Ongoing Activities (continued)

- Need to revise Table VIII-3110-1 to address Supplement 14 and component to component dissimilar metal welds
  - Standards Committee Approved

Table VIII-3110-1
Component Qualification Supplements

Component Type	Applicable Supplement
Piping Welds	
Wrought austenitic	2
Ferritic	3
Cast austenitic	[Note (1)]
Structural weld inlay (corrosion- resistant clad) austenitic	[Note (1)]
Dissimilar metal	10
Overlay	11
Coordinated implementation	12
Vessels	
Clad/base metal interface region	4
Nozzle examinations from the outside surface	5
Reactor vessel welds other than clad/base metal interface	6
Nozzle examinations from the inside surface	7
Bolts and Studs	8

NOTE:
(1) In the course of preparation.

Ongoing Activities (continued)

- Appendix VIII
  - Supplement 5 (Examination of nozzles from the outside surface)
    - Currently the program does not work to ASME Section XI, Appendix VIII, Supplement 5; instead operates to CC-552-1
    - CC-552-1 describes the processes we use for qualification and should be referenced in the licensee's program and is currently endorsed with conditions in RG 1.147
    - Additional Code work is needed to bring Code in alignment

Ongoing Activities (continued)

- Reactor Upper Head Penetration Qualification Program
  - August 2017 issuance of 10CFR50.55a removes previous conditions to CC-N-729-1 and mandates the use of CC-N-729-4
  - CC-N-729-4 lacks some of the criteria covered by the MRP protocol that will require Code action
    - Diameter tolerances
    - Other administrative items
  - MRP has formed a focus group to address the differences

Ongoing Activities (continued)

- Reactor Upper Head Penetration Qualification Program (continued)
  - Supplement 15 has been developed and includes requirements currently defined in CC-729-4 and other criteria that is required to make it consistent with other Supplements
    - Parallel Code actions have begun
      - Code Case that contains the requirements of Supplement 15
        - Sent out for letter ballot from Standards Committee
          - Received several negatives (nothing technical)
        - Two separate actions to follow
          - Remove volumetric qualification requirements from CC-729-X
          - Incorporate Supplement 15 Code Case into Code

Ongoing Activities (continued)

- Revision to Section XI, Division 1, Appendix IV, eddy current examination demonstration requirements
  - Creating Supplement 5
  - Will be addressed in another agenda item later today

Ongoing Activities (continued)

- Revision to Appendix VII
  - Address required examiner training and experience hours
  - Will be addressed in another agenda item later today

Ongoing Activities (continued)

- Code Case N-711-2 is being processed
  - Passed Working Group Risk Informed and Sub-group Water Cooled Systems
  - Scheduled for February 2020 Standards Committee Section XI meeting
  - Will be addressed in another agenda item later today

RPV Threads in Flange

- Code Case N-864 approved by ASME, July 2017
- Large number of plant-specific approvals
  - BWRs and PWRs
  - Including subsequent intervals
  - Including period of extended operation
- Code Change was initially modified to address New Build (action **BC17-1666)**
- Additional revisions to address NRC input attempted, but could not pass ASME consensus process
- Code change, with New Build modification, should clear ASME Section XI Standards Committee at the February meeting

RPV Threads in Flange (Continued)

CASE
N-864

ASME BPVC.CC.NC.S2-2017

Approval Date: July 28, 2017

Code Cases will remain available for use until annulled by the applicable Standards Committee.

Case N-864
Reactor Vessel Threads in Flange Examinations
Section XI, Division 1

Inquiry: What alternative to the examination requirements of Examination Category B-G-1, Item Number B6.40, may be used?

Reply: It is the opinion of the Committee that examination requirements of Examination Category B-G-1, Item Number B6.40, are not required.

RPV Threads in Flange (Continued)

BC17-1666

Table IWB-2500-1 (B-G-1)
Examination Category B-G-1, Pressure-Retaining Bolting, Greater Than 2 in. (50 mm) in Diameter (Cont'd)

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Piping						
B6.150	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)], [Note (5)]	Same as for 1st interval	Permissible
B6.160	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface [Note (5)]		
B6.170	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)], [Note (5)]		
	Pumps						
B6.180	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)], [Note (3)]	Same as for 1st interval	Permissible
B6.190	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface [Note (4)]		
B6.200	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)], [Note (4)]		
	Valves						
B6.210	Bolts and Studs						
B6.220	Flange Surface, [Note disassembled						
B6.230	Nuts, Bushings, and V						

GENERAL NOTE: Bolting di

NOTES:
(1) Bolting may be examined
(a) in place under ten
(b) when the connectic
(c) when the bolting is
(2) Bushings are required to be examined only when the bolting is removed. Bushings may be examined in place.

Note 8

New Note (8) For item number B6.40. for second and subsequent intervals, successive examinations are not required provided no flaws have been previously detected.

Code Case N-885 (B-N-1 Examinations) Update

- Original ASME Code Action 10-123 (Active 2010 – 2018)
  - Unanimously passed Section XI Standards Committee December 2018
  - Adopted new **Case N-885** to clarify and simplify the examination requirements associated with existing Code Examination Categories B-N-1, B-N-2, and B-N-3 and eliminate inconsistencies in application of requirements
  - ASME Code Case N-885, published in July 2019
  - Combined Categories B-N-1, B-N-2, and B-N-3 into a single B-N category and eliminated the category B-N-1 requirements

Code Case N-885 (B-N-1 Examinations) Update

- EPRI Report 3002012966: "Evaluation of Basis for Periodic Visual Examination of Accessible Areas of Reactor Vessel Interior per Examination Category B-N-1 of ASME Section XI, Division 1" (Publicly available; download at www.epri.com)
  - Covers the historical evolution of Code Inspection (Cladding vs. Debris)
  - Performs engineering analysis for Low Alloy Steel (LAS) Corrosion and Cracking Cracking
  - Technical basis supporting ASME Code, Section XI Action 10-123

Code Case N-885 (B-N-1 Examinations) Update

Current Code Table

Table IWB-2500-1 (B-N-1, B-N-2, B-N-3)
Examination Categories B-N-1, Interior of Reactor Vessel; B-N-2, Welded Core Support Structures and Interior Attachments to Reactor Vessels; B-N-3, Removable Core Support Structures

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals	
	Reactor Vessel						
B13.10	Vessel interior (B-N-1)	Accessible areas [Note (1)]	Visual, VT-3	IWB-3520.2	Refueling outages [Note (3)]	Each inspection period	Not permissible
	Reactor Vessel (BWR)						
B13.20	Interior attachments within beltline region (B-N-2)	Accessible welds	Visual, VT-1	IWB-3520.1	Welds	Same as for first interval	Permissible
B13.30	Interior attachments beyond beltline region (B-N-2)	Accessible welds	Visual, VT-3	IWB-3520.2	Welds	Same as for first interval	Permissible
B13.40	Core support structure (B-N-2)	Accessible surfaces	Visual, VT-3	IWB-3520.2	Surfaces	Same as for first interval	Permissible
	Reactor Vessel (PWR)						
B13.50	Interior attachments within beltline region (B-N-2)	Accessible welds	Visual, VT-1	IWB-3520.1	Welds	Same as for first interval	Permissible
B13.60	Interior attachments beyond beltline region (B-N-2)	Accessible welds	Visual, VT-3	IWB-3520.2	Welds	Same as for first interval	Permissible
B13.70	Core support structure [Note (2)] (B-N-3)	Accessible surfaces	Visual, VT-3	IWB-3520.2	Surfaces	Same as for first interval	Permissible

NOTES:
(1) Areas to be examined shall include the spaces above and below the reactor core that are made accessible for examination by removal of components during normal refueling outages.
(2) The structure shall be removed from the reactor vessel for examination.
(3) At 1st refueling outage, and subsequent refueling outages at approximately 3-yr intervals.

Code Case N-885 (B-N-1 Examinations) Update

Code Case Table

Table 1
Examination Category B-N, Interior Welded Attachments to Reactor Vessels and Segments of Core Support Structures Having a Safety Function

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Reactor Vessel						
B13.10	Interior welded attachments within beltline region [Note (1)]	Accessible welds	Visual, VT-1	-3520.1	Welds	Same as for first interval	Permissible
B13.20	Interior welded attachments beyond beltline region [Note (1)]	Accessible welds	Visual, VT-3	-3520.2	Welds	Same as for first interval	Permissible
B13.30	Welded core support structure [Note (2)]	Accessible surfaces	Visual, VT-3	-3520.2	Surfaces	Same as for first interval	Permissible
B13.40	Removable core support structure [Note (2)]	Accessible surfaces	Visual, VT-3	-3520.2	Surfaces	Same as for first interval	Permissible

GENERAL NOTE: Safety function is defined in Article IWA-9000.

NOTES:
(1) Areas to be examined shall include those that are made accessible for examination by removal of components during normal refueling outages.
(2) For PWRs, structures shall be removed from the reactor vessel for examination.

Risk Informed ISI Code Case Approval

RI-ISI Timeline

1996-1997	1998-1999	1999-2006	2006-Present
		U.S. & Worldwide Industry Implementation	
ASME Section XI	USNRC Approves Industry Reports	25-30 US Reactors Several Countries in Europe / Asia	Several Countries in Europe/Asia
Code Case N577 RI-ISI Method A	WOG Topical #14572-A "ASME Appendix R Method A"	60 US Reactors Several countries in Europe	~50 US Reactors, Canada, China, Europe, Mexico, S. Africa
Code Case N-578 RI-ISI Method B	EPRI Topical #112657, Rev B-A "ASME Appendix R Method B"	Code Case N-716 EPRI Report #3002003029 "Streamlined RI-ISI"	~50 US Reactors

Current Status

- EPRI Streamlined RI-ISI Methodology
  - ASME Code Case N716-1
  - Endorsed in Regulatory Guide 1.147, revision 14
  - Relief request / Request for alternative no longer required
  - Focuses limited NRC / industry resources on more important issues / components
- EPRI Traditional RI-ISI Methodology
  - Latest version of 10CFR50.55a still requires plant-specific submittals as well as NRC review and approval

Path Forward

- ASME Section XI - Appendix R
  - NRC / Industry meeting held April 17, 2018
  - ASME Letter requesting NRC endorsement of Appendix R, Supplement 2 (Method B), dated October 31, 2019
  - What is the best process for assuring timely changes are made, if needed, to Appendix R to allow efficient endorsement by NRC in 10CFR50.55a?

Together…Shaping the Future of Electricity

Update on ASME Code Case N-711-1 / N-711-2

Gary Lofthus
Southern Nuclear

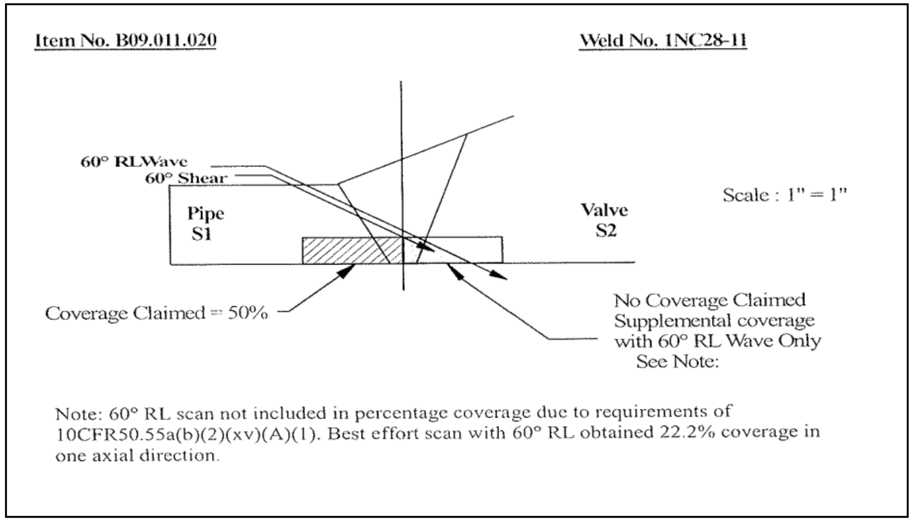
Carl Latiolais
EPRI

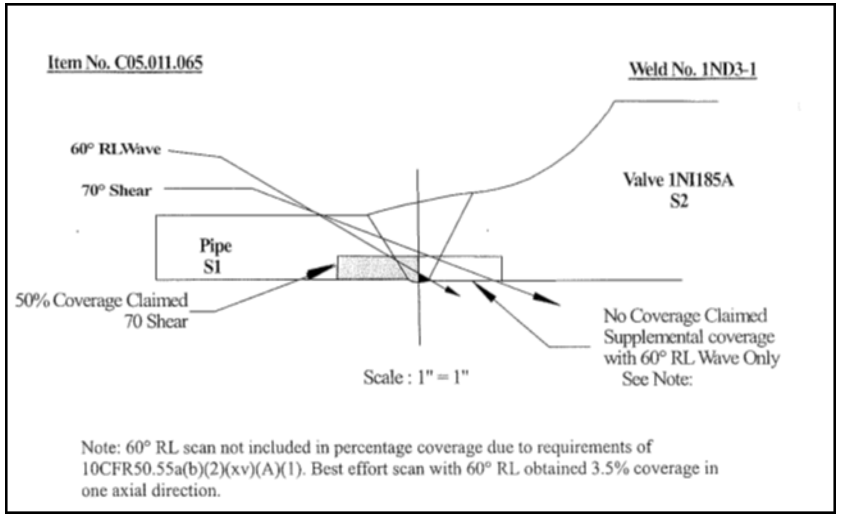
NRC/Industry NDE Technical Information Exchange Meeting
January 2020

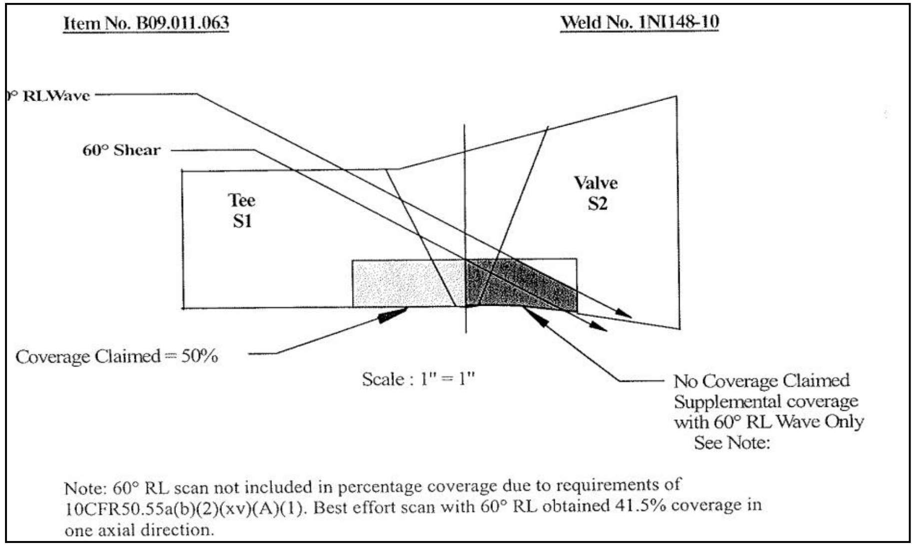
What is Case N-711?

- N-711 provides a method to define a more informed examination volume as compared to current ASME SXI practices. That is;
  - ➢ The method is a safety based approach that focuses on the areas where service induced flaws are most likely to occur
  - ➢ The method provides alternative examination coverage requirements for Category B-F, B-J, C-F-1 and C-F-2
- N-711 can also be used to better define RI-ISI examination volumes (e.g. examination category R-A)
- N-711 provides a mechanism to reduce undue burden on the NRC and Industry by eliminating "requests for alternative":
  - When a robust inspection has already been completed
  - Related to missed examination coverage from single sided examinations

Examples of Typical Single Side Examination Configurations







- Single sided examinations are most often caused by:
  - OD Mismatch
  - Component Geometry (e.g. nozzle boss or machined land)
  - Component Material Properties (e.g. CASS)
  - Diametric Shrinkage
  - Weld Crown Reinforcement

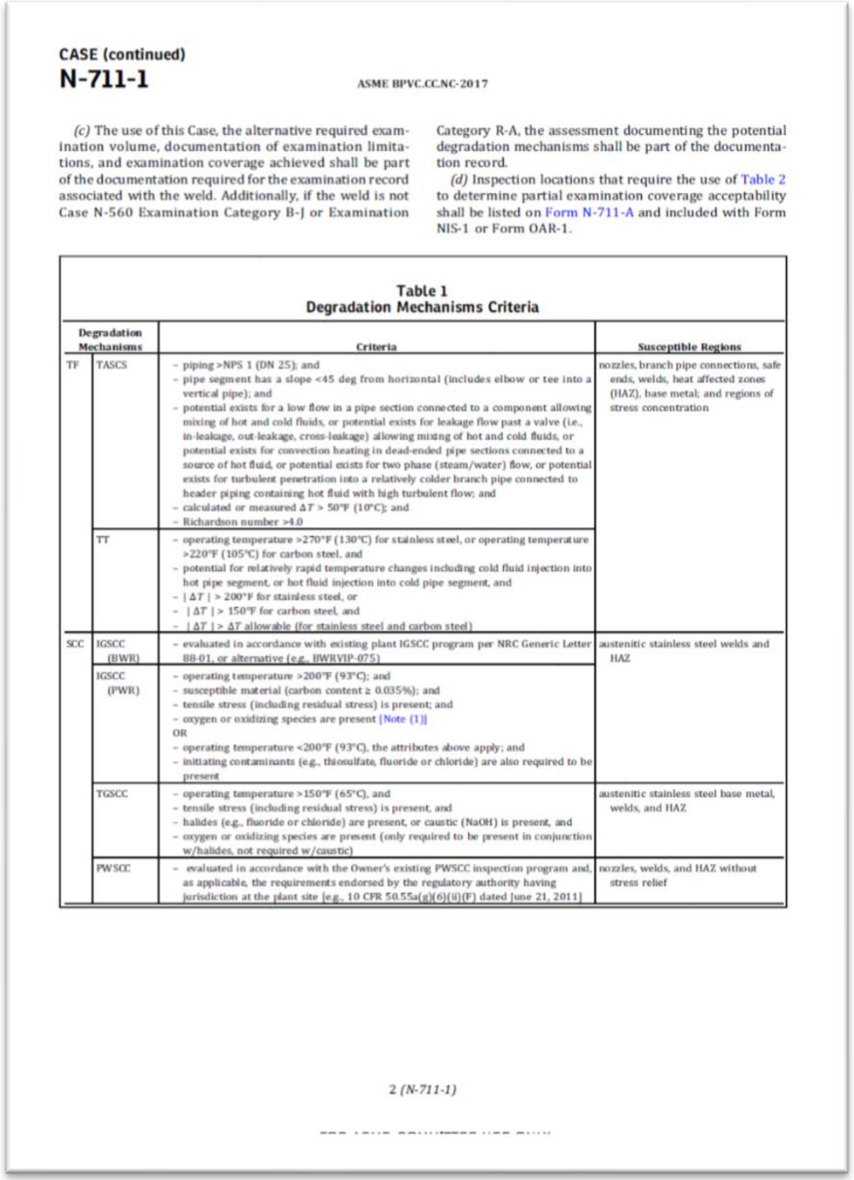
Challenges

- Most single sided examination piping welds are joined to a component that limits the examination coverage
  - Flange
  - Pump (Cast)
  - Valve (Cast)
- Components have larger outside diameter than pipe, thus causing a transition that cannot be removed
- Component geometry does not complete allow coverage of the examination volume
- Component material properties challenge the effectiveness of the examination (Cast)
- Welds have irregular surface conditions due to mismatch that cannot be improved to an level where effective examinations can be performed
- Most piping welds have diametric shrinkage that if removed would violate minimum wall requirements
  - More prevalent on thin piping welds
- In many cases removal of weld crown reinforcement would violate minimum wall thickness
  - Counterbore has reduced thickness of pipe

Code Case N-711-1 Process

Step 1 – Establish Probable Degradation Mechanisms

- The licensee determines the degradation mechanisms associated with the weld
  - For examination category R-A, the degradation mechanism assessments have already been completed using NRC approved process
  - For the other examination categories, not in the risk program, an assessment must be performed to determine potential degradation mechanisms
    - Table 1 in Code Case N-711-1 provides the criteria for the degradation mechanism assessment
    - Table 1 in Code Case N-711-1 is identical to NRC approved process (e.g. TR-112657, Rev B-A, Case N-716-1)



CASE (continued)

N-711-1

ASME BPVC.CC.NC-2017

(c) The use of this Case, the alternative required examination volume, documentation of examination limitations, and examination coverage achieved shall be part of the documentation required for the examination record associated with the weld. Additionally, if the weld is not Case N-560 Examination Category B-J or Examination Category R-A, the assessment documenting the potential degradation mechanisms shall be part of the documentation record.

(d) Inspection locations that require the use of Table 2 to determine partial examination coverage acceptability shall be listed on Form N-711-A and included with Form NIS-1 or Form OAR-1.

Table 1
Degradation Mechanisms Criteria

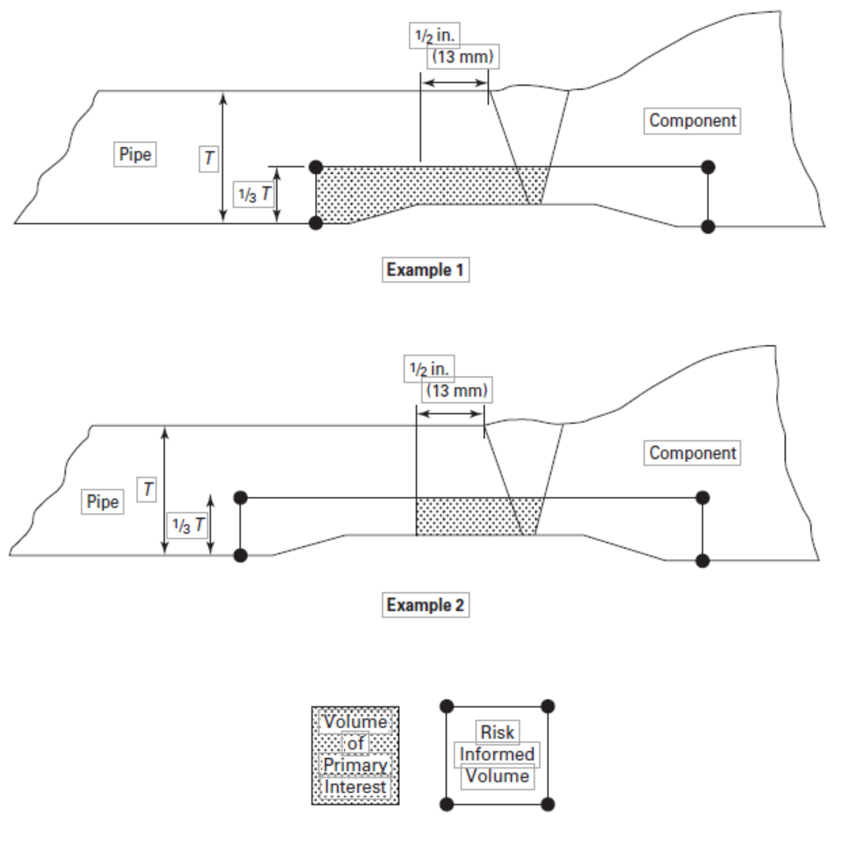
Degradation Mechanisms		Criteria	Susceptible Regions
TF	TASCS	– piping >NPS 1 (DN 25); and – pipe segment has a slope <45 deg from horizontal (includes elbow or tee into a vertical pipe); and – potential exists for a low flow in a pipe section connected to a component allowing mixing of hot and cold fluids, or potential exists for leakage flow past a valve (i.e., in-leakage, out-leakage, cross-leakage) allowing mixing of hot and cold fluids, or potential exists for convection heating in dead-ended pipe sections connected to a source of hot fluid, or potential exists for two phase (steam/water) flow, or potential exists for turbulent penetration into a relatively colder branch pipe connected to header piping containing hot fluid with high turbulent flow; and – calculated or measured ΔT > 50°F (10°C); and – Richardson number >4.0	nozzles, branch pipe connections, safe ends, welds, heat affected zones (HAZ), base metal; and regions of stress concentration
	TT	– operating temperature >270°F (130°C) for stainless steel, or operating temperature >220°F (105°C) for carbon steel, and – potential for relatively rapid temperature changes including cold fluid injection into hot pipe segment, or hot fluid injection into cold pipe segment, and – $\lvert \Delta T \rvert$ > 200°F for stainless steel, or – $\lvert \Delta T \rvert$ > 150°F for carbon steel, and – $\lvert \Delta T \rvert$ > ΔT allowable (for stainless steel and carbon steel)	
SCC	IGSCC (BWR)	– evaluated in accordance with existing plant IGSCC program per NRC Generic Letter 88-01, or alternative (e.g., BWRVIP-075)	austenitic stainless steel welds and HAZ
	IGSCC (PWR)	– operating temperature >200°F (93°C); and – susceptible material (carbon content ≥ 0.035%); and – tensile stress (including residual stress) is present; and – oxygen or oxidizing species are present [Note (1)] OR – operating temperature <200°F (93°C), the attributes above apply; and – initiating contaminants (e.g., thiosulfate, fluoride or chloride) are also required to be present	
	TGSCC	– operating temperature >150°F (65°C), and – tensile stress (including residual stress) is present, and – halides (e.g., fluoride or chloride) are present, or caustic (NaOH) is present, and – oxygen or oxidizing species are present (only required to be present in conjunction w/halides, not required w/caustic)	austenitic stainless steel base metal, welds, and HAZ
	PWSCC	– evaluated in accordance with the Owner's existing PWSCC inspection program and, as applicable, the requirements endorsed by the regulatory authority having jurisdiction at the plant site [e.g., 10 CFR 50.55a(g)(6)(ii)(F) dated June 21, 2011]	nozzles, welds, and HAZ without stress relief

2 (N-711-1)

Code Case N-711-1 Process

Step 2 – Determine Volume of Primary Interest

- The licensee next must determine the volume of primary interest (VPI) using the postulated degradation mechanism along with Table 2 from Case N-711



TASCS, TT; Component Configuration, Pipe-to-Component

CASE (continued)
N-711-1

ASME BPVC.CC.NC-2017

Table 2
Partial Examination Coverage Evaluation Process

Degradation Mechanisms	Process Decision Point [Note (1)]	If Decision Point is "Yes"	If Decision Point is "No"	Risk Characterization [Note (2)], [Note (3)] Method A	Method B
FAC	Requirements governed by plant FAC program.	...	...	Region 1A Region 1B Region 2 Non RI-ISI Examination	Category 1 Category 3 Category 5 Non RI-ISI Examination
WH + other DM VF (assumed)	(a) Is water hammer or vibratory fatigue still applicable?	–correct design deficiency –re-risk-rank system without water hammer or vibratory fatigue	–re-risk-rank system without water hammer or vibratory fatigue		
	(b) Is the examination still required?	–partition by applicable degradation mechanism as shown below	–no further action required		
TASCS TT	(c) Is the inspection location on a horizontal run to a steam generator or BWR vessel, including feedwater nozzle?	–see decision point (d)	–see decision point (e)	Region 1A Region 1B Region 2 Non RI-ISI Examination	Category 2 Category 5 Non RI-ISI Examination
	(d) Was the weld, pipe side heat affected zone and pipe side counterbore transition region captured?	– document examination limitation and coverage achieved and verify examination performed to the examination requirements of B-F, B-J, C-F-1, C-F-2 or R-A, as applicable	–volume of primary interest not sufficiently examined –coverage requirement not met		
	(e) Is the inspection location a pipe component weld? Included pipe to pumps, valves, nozzles and branch connections.	–see decision point (f)	– see decision point (g) if the examination limitation is a counterbore issue – if the examination limitation is a weld or heat affected zone issue, then the volume of primary interest was not sufficiently examined and the coverage requirement was not met		
	(f) Was the weld, pipe side heat affected zone and pipe side counterbore transition region captured?	–document examination limitation and coverage achieve and verify examination performed to the examination requirements of B-F, B-J, C-F-1, C-F-2 or R-A, as applicable	– see decision point (h) if the examination limitation is a counterbore issue – if the examination limitation is a weld or heat affected zone issue, then the volume of primary interest was not sufficiently examined and the coverage requirement was not met		

4 (N-711-1)

Code Case N-711-1 Process

Step 3 - Documentation

- Once the examination is complete, the licensee documents it by assembling an examination record which will contain the results along with any scan limitations and achieved examination coverage
  - If the weld is not examination category B-J (CC N-560) or examination category R-A, the degradation mechanisms assessment will also be included in the examination record
  - The inspection locations that require the use of Table 2 to determine partial examination coverage acceptability shall be listed on Form N-711-A and included with Form NIS-1 or Form OAR-1
  - Best effort examination is required for the volume outside the volume of primary interest

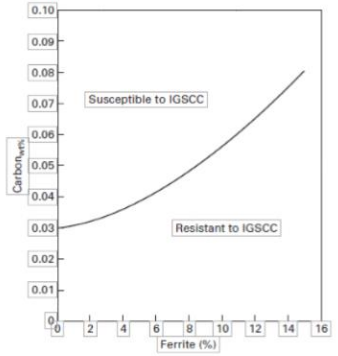
Table 2
Partial Examination Coverage Evaluation Process (Cont'd)

NOTES (CONT'D):
(3) Method A applies to plants implementing risk-informed inservice inspection programs through the use of Case N-577 and associated revisions or of Section XI, Nonmandatory Appendix R, Supplement 1. Method B applies to plants implementing risk-informed inservice inspection programs through the use of Case N-578 and associated revisions of Section XI, Nonmandatory Appendix R, Supplement 2. Applicable terms (e.g., Region 1A) are define therein. The risk characterization of Method B also applies to Case N-560.

Form N-711-A
Abstract of Welds Satisfying Alternate Examination Coverage Requirements of Case N-711

Examination Category	Weld Number	Weld Description	Percent Coverage	Description of Limitation

Figure 1
Carbon Content and Ferrite Content Combination for Cast Stainless Steels — IGSCC Resistance



GENERAL NOTES:
(a) Applicable to oxidizing environments only.
(b) Does not apply to castings that have been furnace sensitized.
(c) Ferrite carbon content NOT within resistant region of Figure 1.

Code Case N-711-1 / N711-2 Work Plans

- A multiyear project will publish the technical basis (2017), gain ASME approval of revision to N-711 (2018 - 2019) and develop a series of tools and training for the implementation of N-711 (2018 - 2020)
  - Convert the N-711 evaluation process into a step by step flowchart
  - Generate examples using missed coverage relief requests previously submitted by industry
    - Gain insights on in what cases and how often using N-711 will eliminate the need for a relief request
  - Support training classes focused on teaching licensees how to navigate the process (2020)
  - Develop a software tool to automate and document the N-711 evaluation process as discussed above

Code Case N-711-1 / N-711-2 Work Plans
(Continued)

- Qualified UT procedures to support New Plants (Vogtle 3 & 4)
  - Fabricated NDE specimens with flaws in the extremities of the applicable volume of primary interest
  - Evaluated existing generic NDE procedures to determine if they are capable of detecting and characterizing flaws in the new specimens
  - Conducted blind trials with the new specimens to expand existing procedures or qualify new procedures to include the applicable volumes of primary interest
  - Supported Vogtle 3 & 4 with a Request for Alternative and any Requests for Additional Information

Industry Actions Going Forward

- While a process has been outlined for the new plants, a number of limitations prevent the industry from fully benefiting from Code Case N-711-1
  - NDE technology is not available to interrogate the weld root for the presence of small axial flaws from the adjacent base material
  - Some component configurations cannot be conditioned to an acceptable surface to allow scan access on top of the weld
    - Minimum wall thickness and counterbore requirements
  - Licensees unable to condition existing components due to dose and time constraints

Industry Actions Going Forward (Continued)

- A revision of Code Case N-711-1 is needed to address the above concerns and may incorporate the following solutions:
  - Adjust the VPI for certain damage mechanisms for axial flaws (e.g. flaw will not propagate outside the VPI)
  - Adjust the VPI for certain damage mechanisms for circumferential (e.g. examination of essentially 100% of VPI will capture all significant flaws)
  - Require best effort examination of entire examination volume regardless of VPI, that is
    - ➢ entire B-J volume, or R-A volume, still needs to be interrogated
  - Scanning shall be performed from all accessible surfaces (i.e., weld crowns if ground flush)

Industry Actions Going Forward (Continued)

- Code Case N-711-2 is being processed via ASME Section XI consensus process
  - Passed WG Risk-Informed and SG Water-Cooled Systems
  - Scheduled for February 2020, Standards Committee Section XI meeting
- N-711-1 to N-711-2 changes
  - The acceptable coverage is **essentially** 100% of the volume of primary interest as defined in Table 2
  - **i.e. essentially 100% coverage is achieved when the applicable examination coverage is greater than 90%; however, in no case shall the examination be terminated when greater than 90% coverage is achieved, if additional coverage of the required examination surface or volume is practical**

Path Forward

- Case N-711-2 approved by ASME, ~ 2nd quarter 2020
- Case N-711-2 lead plant submittal, ~ 3rd quarter 2020
- Case N-711-1 incorporated into RG1.147, with essentially 100% wording, ~ Xth quarter 2020
- Case N-711-2 incorporated into RG1.147, ~ Xth quarter 202X

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Appendix VIII, Supplement 15 Update

Carl Latiolais
Senior Program Manager
NDE Reliability

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Background

- A revision to the Code of Federal Regulations (CFR) 50CFR50.55a effective August 17, 2017 requires that examination performed after the effective date be performed in accordance with the requirements of CC-N-729-4 titled *"Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds Section XI, Division 1"* as conditioned by the rule
- Prior to this 10 CFR 50.55a required the use Code Case N-729-1 with conditions to be used for qualification of procedures, personnel and equipment that are used for the examination of reactor upper head penetrations

Background

- In order to ensure uniform implementation of the requirements, the Materials Reliability Program developed a protocol published in EPRI report (1012856) Materials Reliability Program: Qualification Protocol for Pressurized Water Reactor Upper Head Penetration Ultrasonic Examinations—2011 Update (MRP-311).
- This document, in conjunction with the endorsed Code Case N-729-1 (including NRC conditions), served as the implementation requirements for pressurized water reactor (PWR) upper head penetration examinations and addressed essential elements that were not covered by the Rule or the Code Case such as diameter tolerances for field implementation and processes to quantify the effects of geometry on the examination techniques and other administrative requirements

Background

- Code Case N-729-4 was approved on by ASME on June 22, 2012 and this revision addressed many of the 10CFR50.55a conditions placed on Code Case N-729-1 and attempted to incorporate the additional elements addressed in MRP-311 Revision 1, but several of the key technical elements did not make it into this revision
  - Currently, CC-729-4 contains some key criteria, but heavily references selected sections of Appendix VIII for implementation (Not All)
- To address this issue the MRP Inspection Technical Advisory Committee reinstituted the Reactor Pressure Vessel Head Penetration Focus Group which consists of utility members and EPRI staff
- The focus group took the lead on mapping the course for recovery
- Based on discussion with all applicable parties it was determined that the qualification requirements should be consolidated in one location and that location should be in ASME Section XI, Appendix VIII

Supplement 15 *(Content)*

- Qualification Requirements For PWR Reactor Vessel Upper Head Penetrations (Record # 19-2501)
- Scope
  - PWR reactor vessel upper heads fabricated from one of the following:
  - (a) UNS N06600 material with UNS N06082 or UNS W86182 partial penetration welds,
    or
  - (b) Primary Water Stress Corrosion Cracking (PWSCC) resistant materials, such as UNS N06690 base metal with UNS N06052 or UNS W86152 partial-penetration welds.

Supplement 15 *(Content)*

- Current Code Case is structured similar to other Appendix VIII Supplements with 5 main sections
  - 1.0 Scope
  - 2.0 Specimen Requirements
    - General
    - Flaw location
    - Flaw type
    - Flaw Depth
    - Length sizing
    - Depth sizing
    - Flaw orientation
  - 3.0 Performance Demonstration
    - Detection Tests
    - Length Sizing Tests
    - Depth Sizing Tests
  - 4.0 Procedure Qualification
  - 5.0 Grading Criteria

Supplement 15 (*Advantages*)

- Consolidates all qualification requirements into one location
- Future revisions will be reviewed by the most qualified groups within the Code
  - Task Group – High Strength Nickel Alloy
  - Task Group - Appendix VIII
  - Working Group - Procedure Qualification & Volumetric Examination
  - Sub Group – NDE
- Groups include implementors (PDA), Utilities, Vendors, and NRC

Supplement 15 (*Status*)

- Code Case has been approved unanimously by
  - Task Group - Appendix VIII
  - Working Group - Procedure Qualification & Volumetric Examination
  - Sub Group - NDE
- Is currently out for Standards Committee Section XI First Consideration Ballot
  - Has received three negatives related to the inquiry statement and proposed reply **(No technical comments)**
  - Commenters take issue with a Code Case referencing a Code Case
  - We are currently working on a proposed response to the negatives

- *Inquiry: What alternative provisions may be used for qualification of equipment, procedures, and personnel for volumetric examination and leak path assessments of PWR reactor vessel upper head penetrations, other than those of Case N-729, -2500(a) through (j)?*
- *Reply: It is the opinion of the Committee that, as an alternative to the provisions of Case N-729, -2500(a) through (j), qualification of equipment, procedures, and personnel for volumetric examination and leak path assessments of PWR reactor vessel upper head penetrations may be performed in accordance with the following provisions*

Supplement 15 (*Additional Code Actions*)

- 2 additional actions will be processed once Code Case is approved
  - 18-1690 – Revise CC-N-729 to remove qualification requirements for volumetric examination and replace them with a reference to the new requirements
  - 18-1691 – Incorporate Code Case into Code as Supplement 15
- Several other actions will be needed to address this addition into Appendix VIII such as
  - Mandatory Appendix I
  - Article VIII-3000 “Qualification Requirements” Table VIII-3110-1

Supplement 15 (*Actions Required for Implementation*)

- Once Code Case is approved additional actions are required to allow implementation
  - Request for Alternative to 10CFR50.55a requirements (Not preferred approach)
  - Code Case incorporated into RG 1.147 (Time issue)
    - Change to 10CFR50.55a to remove the requirement for use of CC-N-729-4 would be required
  - A regulatory position would be desirable, allowing use of the Supplement 15 Code Case in lieu of CC-N-729-4 (acceptable alternative to CC-N-729) until such time Code Case is endorsed in RG 1.147
  - Other?

Summary

- Industry has developed Appendix VIII, Supplement 15
  - Provides a technical valid process for qualification of procedures, personnel and equipment for the examination of PWR reactor upper head penetrations
    - Exceeds the requirements of CC-N-729
    - Provides a consolidated approach
    - Includes missing requirements needed for an effective implementation
  - Once approved industry needs a way to effectively implement in a timely fashion

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Technical basis for eddy current code cases, qualification, acceptance criteria - Update

Kevin Hacker
Dominion Energy

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Outline

- Background
- Focus Group
- Status
- Actions

Background

- In 2017, a technical basis document (MRP-423) was developed to be used as guidance to revise Section XI, Division 1, Appendix IV, Eddy Current Examination demonstration requirements
  - Adjust current "short defect" requirements that have driven some ET equipment designers to develop probes with high sensitivity that are prone to false calls
  - Demonstration test sets should include defects with subsurface morphologies instead of small shallow surface flaws or notches
- This technical basis document will also be used to revise relevant Code documents that provide acceptance criteria for ET surface examinations in the context of newly available surface examination results
  - Current requirements are an incomplete representation of Stress Corrosion Cracking (SCC)
  - Some requirements are based on Liquid Penetrant Testing (PT) techniques

MRP-423 Report


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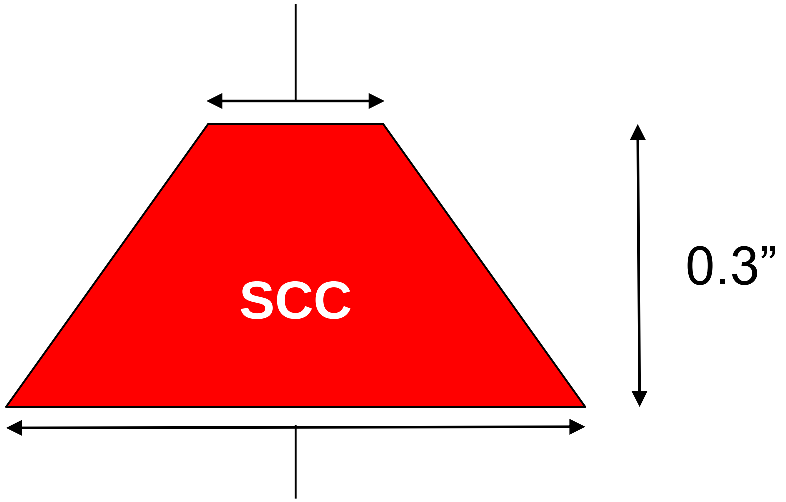
Materials Reliability Program: Technical Basis for Surface Eddy Current Demonstration in Materials Susceptible to Stress Corrosion Cracking (MRP-423)

2017 TECHNICAL REPORT

"Small flaws with large subsurface features"

- Flaws of interest – SCC Example

0.2" long at wetted surface



1" long below surface (subsurface)

Focus Group

- Formed a focus group to provide input into the development of Appendix IV, Supplement 5, “Qualification Requirements for Surface Examination of Piping and Vessels Welds in Service Fabricated With Austenitic Stainless Steels or Nickel Alloys Susceptible to Stress Corrosion Cracking”
- Focus Group Volunteers
  - Kevin Hacker – Dominion Energy
  - Tim Thulien – Duke Energy
  - Conrad Wyffels – Westinghouse
  - Mark Kirby –Westinghouse
  - CJ Conner – Framatome
  - Barry Everett - Framatome

Status

- Presented basis for the need to revise Appendix IV Supplement of Section XI in 2017 Section XI Working Groups (WG) and the NDE Sub Group

- Submitted draft of new Supplement 5 for Appendix IV at the May 2018 Working Group for Personnel Qualification, Surface, Visual, and Eddy Current meeting

  – Record No. 18-1186: *APPENDIX IV, SUPPLEMENT 5 QUALIFICATION REQUIREMENTS FOR SURFACE EXAMINATION OF PIPING AND VESSELS WELDS IN SERVICE FABRICATED WITH AUSTENITIC STAINLESS STEELS OR NICKEL ALLOYS SUSCEPTIBLE TO STRESS CORROSION CRACKING*

Actions

- Short Term Actions
  - Address comments and provide revised technical basis to support approval of Supplement 5
    - Material to be distributed to WG-PQSVECE in between Code meetings to facilitate action
  - Create a Code Case that parallels Supplement 5 to promote early adoption of the surface examination requirements
  - Approval at Sub-Group NDE (Targeting in August 2020)
- Future Actions
  - Develop technical basis documentation to revise Code Cases relevant to Alloy 600 Examinations and initiate Code actions (2020)
    - Revise references and acceptance criteria
    - N-729 (upper head penetrations)
    - N-770 (DM Welds)
    - N-766 (Onlay and Inlay mitigation)

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CASS Research Update

Carl Latiolais
Senior Program Manager
NDE Reliability

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Overview

Multi-faceted Approach for CASS Materials

Approaches to Manage Welds with CASS

NDE — Nondestructive Evaluation

- Inspection technologies/methodologies to perform periodic volumetric ISI
  - Traditional Techniques
  - Advanced NDE methods/analyses
  - Continuous Structural Health Monitoring

EES — Engineering Evaluation Solutions

- Risk informed inspection practices
- Engineering solution (s)
- Material characterization
- Probabilistic Fracture Mechanics (PFM)

MM — Manage by Mitigation

- Full/Optimized structural weld overlay
- Component replacement
- Excavate Weld Repair (EWR)
- New mitigation technique (s)

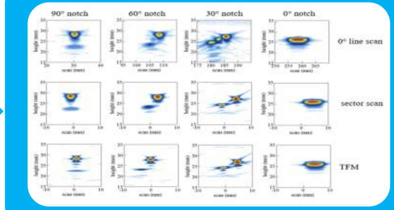
Defense in Depth Safety Route

Goal for Managing Welds with CASS

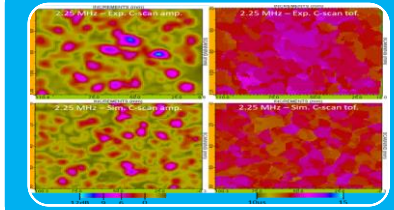
Goal

Continued Safe and Reliable Operation of Nuclear Power Plants with Safety Related CASS Components

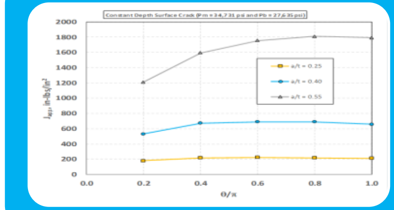
Ongoing CASS Projects



Technique Enhancements for CASS Examination Techniques



Ultrasonic Characterization and Acoustical Equivalency of CASS



Probabilistic Fracture Mechanics Evaluation of CASS PWR Piping Components

Technique Enhancements for CASS Examinations

Background

- This project utilized the data library developed during the EPRI CASS Round Robin Study
  - 5 Organizations (3 Different Countries)
  - 6 Different Techniques
  - 7 Data Sets (20 Specimens/set)
- **Phase 1** – Perform an independent review of the three data sets with the best performance in the EPRI CASS Round Robin Study
- **Phase 2** – Use observations from the review to develop guidelines for optimizing NDE techniques on CASS materials
- **Phase 3** – Collect data to evaluate performance of additional NDE techniques
- **Phase 4** – Evaluate non-NDE related factors
  - Flaw morphology (Destructive Analysis)
  - Weld crown conditioning

Technique Enhancements for CASS Examinations
Results

- Optimizing the techniques resulted in:
  - Improvements were noted on 12” and 28” series specimens
    - 100% detection of circumferential flaws with weld crown in place
    - Flaw sizing remains challenging
  - No major improvements to 36” series specimens
    - Undetected flaws remain
    - Sizing unreliable in most cases
    - Destructive testing recommended for this series / flaw condition

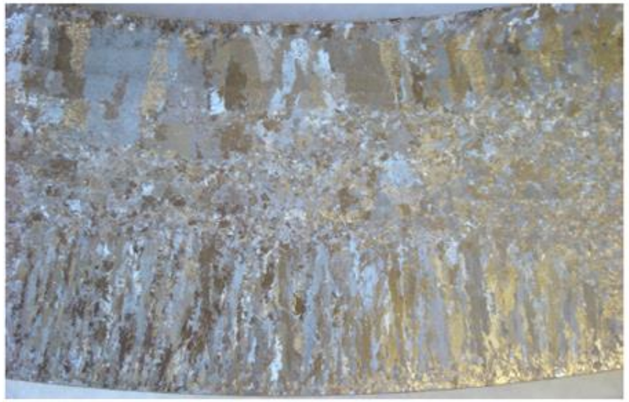


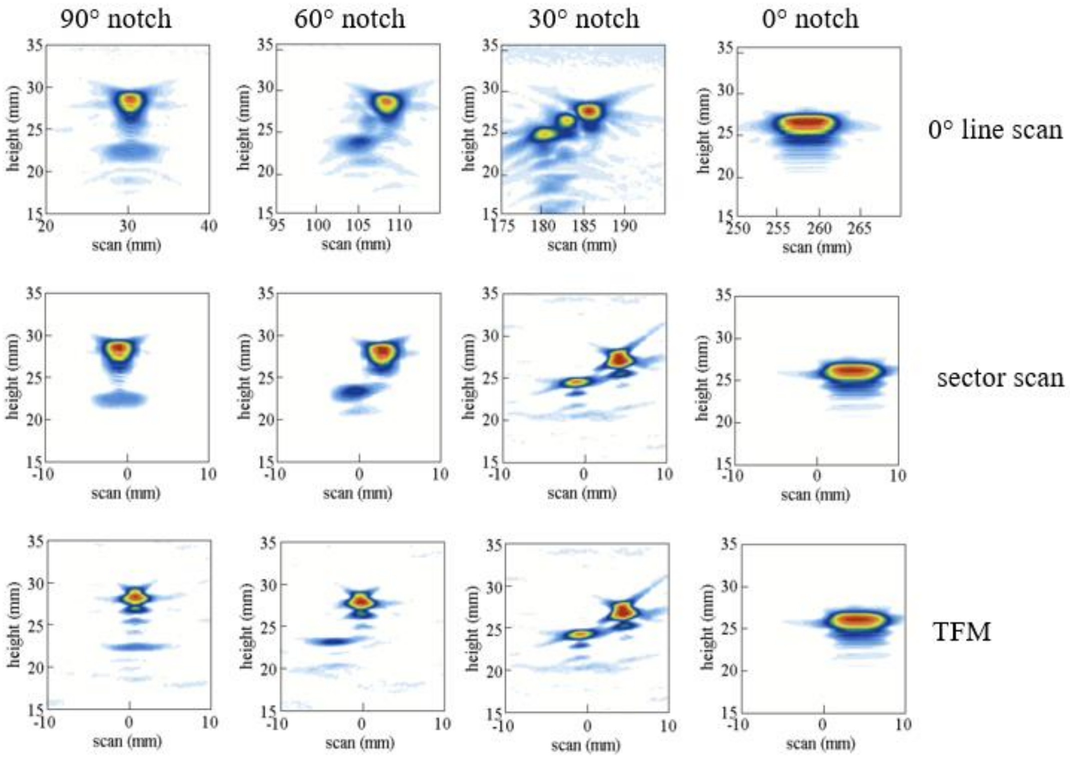
Figure 2-6
Microstructure from Downstream Side of 28-in. Specimen Material (vintage material from pipe manufacturer)

Figure 2-7
Microstructure from 36-in. Specimen Material (vintage material from canceled plant)

Technique Enhancements for CASS Examinations

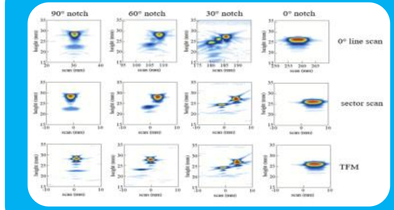
Next Steps

- Evaluation of beam interaction in the CASS material
- Compare reactions of various probes in beam interaction studies
- Evaluate Advanced techniques (e.g. TFM, FMC, High Voltage UT)
  - TFM & FMC efforts have been performed with little or no identifiable improvement to RR results
  - Initial efforts with High Voltage UT showed little to no identifiable improvement in detection capability

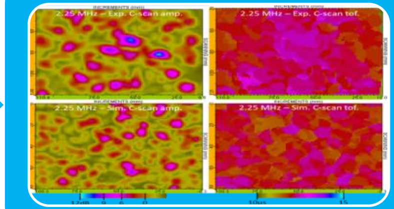


- Apply techniques to entire sample set to determine if performance has improved
- Destructive evaluation of 2 circumferential flaws in the 36" specimen set
- Determine if conditioning or removal of weld crowns will significantly improve sizing and characterization performance

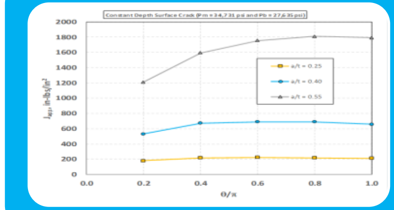
Ongoing CASS Projects



Technique Enhancements for CASS Examination Techniques



Ultrasonic Characterization and Acoustical Equivalency of CASS

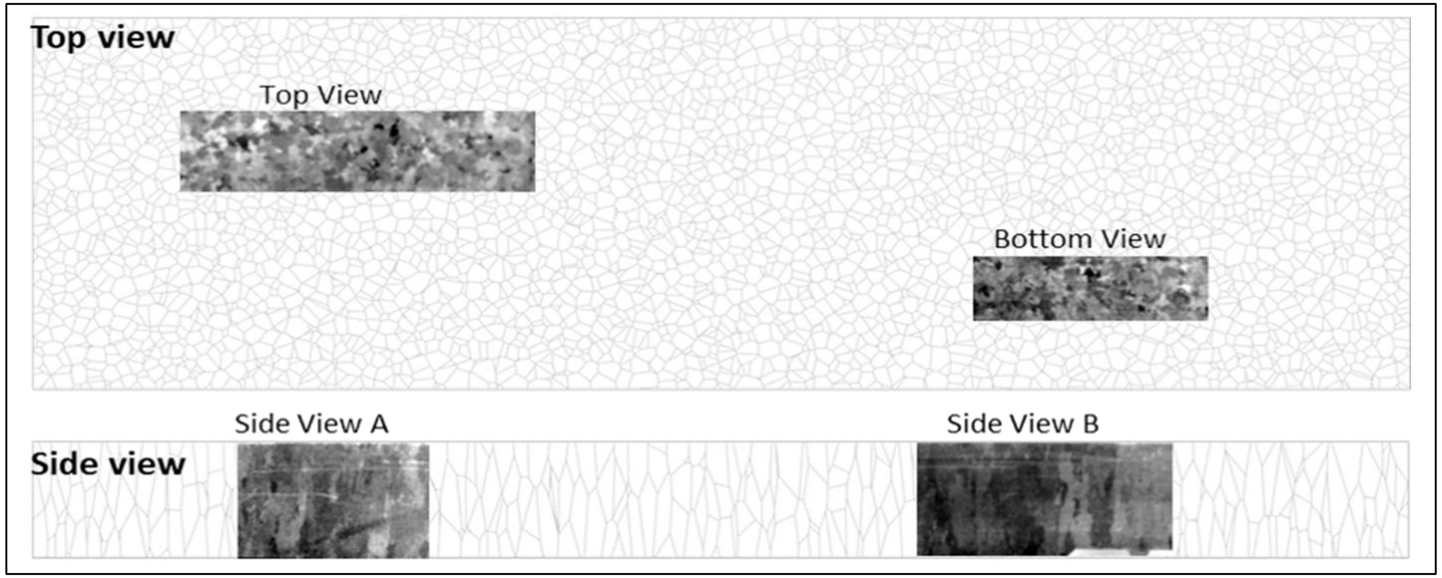


Probabilistic Fracture Mechanics Evaluation of CASS PWR Piping Components

Ultrasonic Characterization & Acoustical Equivalency of CASS

Background

- Ultrasonic wave interaction within coarse grained material is subject to scattering and attenuation
  - This leads to reduced signal-to-noise ratios (SNR) and challenging analysis and interpretation of results
- This research proposes an experimental based strategy to setup ultrasonic models and simulations aiming at accurately replicating Ultrasonic Testing (UT) in a coarse grain material such as Cast Austenitic Stainless Steel (CASS)
- The goal of this project is to develop a proposed workflow and set of recommended practices to use when modeling coarse grain materials

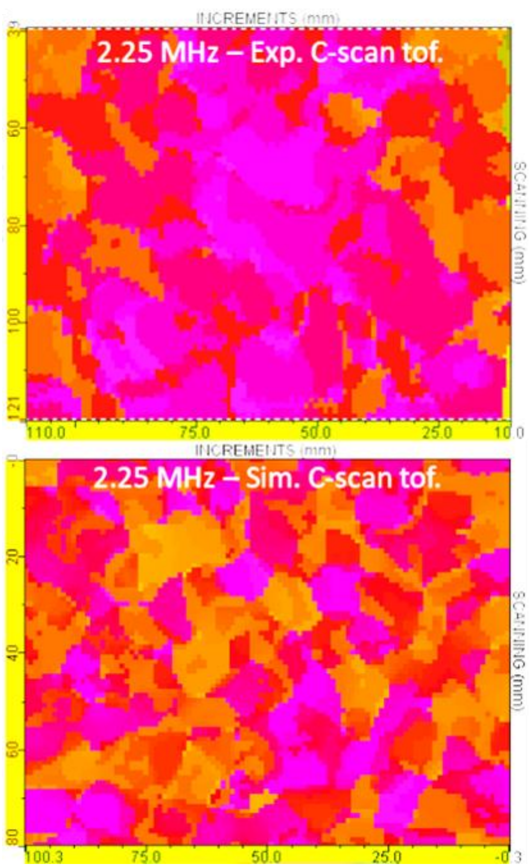


Ultrasonic Characterization & Acoustical Equivalency of CASS

Results

- Prior to developing models it was necessary to properly characterize the ultrasonic probes being used in the study
  - Used a homogeneous well-known material to define CIVA probe settings, amplitude references, and to evaluate experimental error and uncertainty
- The process of developing coarse grain models along with detailed descriptions of the primary modeling inputs are included in the latest report – **EPRI Product ID #: 3002013160**
- The study used a 45°LW, 1MHz contact dual matrix phased array probe for the experimental and simulated results
  - Experimental and simulated results were similar in amplitude response
  - Signal-to-noise ratio (SNR) was noticeably lower in the experimental results
  - Simulation times vary significantly depending on the model's complexity (33s to 137hr)

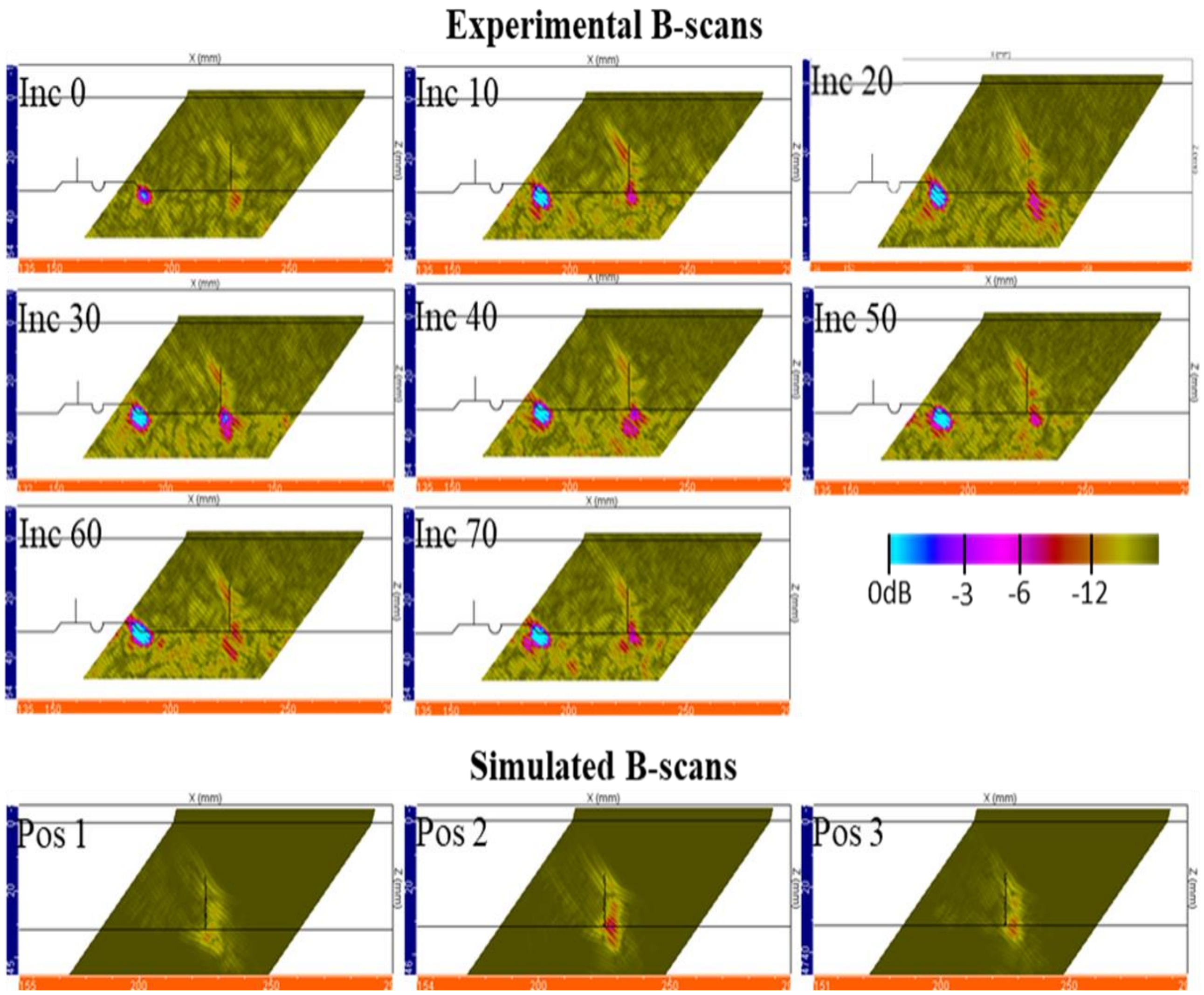
Time (velocity)



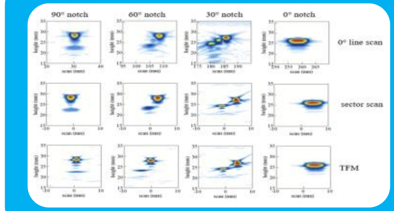
Ultrasonic Characterization & Acoustical Equivalency of CASS

Next Steps

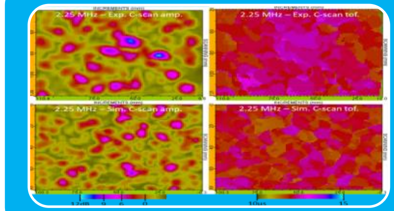
- Future work should focus on:
  - Developing efficient techniques for incorporating noise into the simulations
  - Reducing computation times
  - Expand the modeling process to include large grain materials with welds



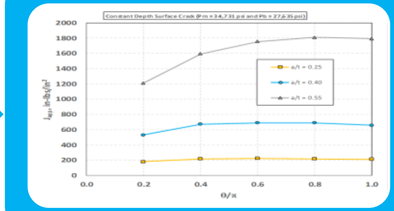
Ongoing CASS Projects



Technique Enhancements for CASS Examination Techniques



Ultrasonic Characterization and Acoustical Equivalency of CASS



Probabilistic Fracture Mechanics Evaluation of CASS PWR Piping Components

Probabilistic Fracture Mechanics (PFM) Evaluations of CASS PWR Piping Components

Background

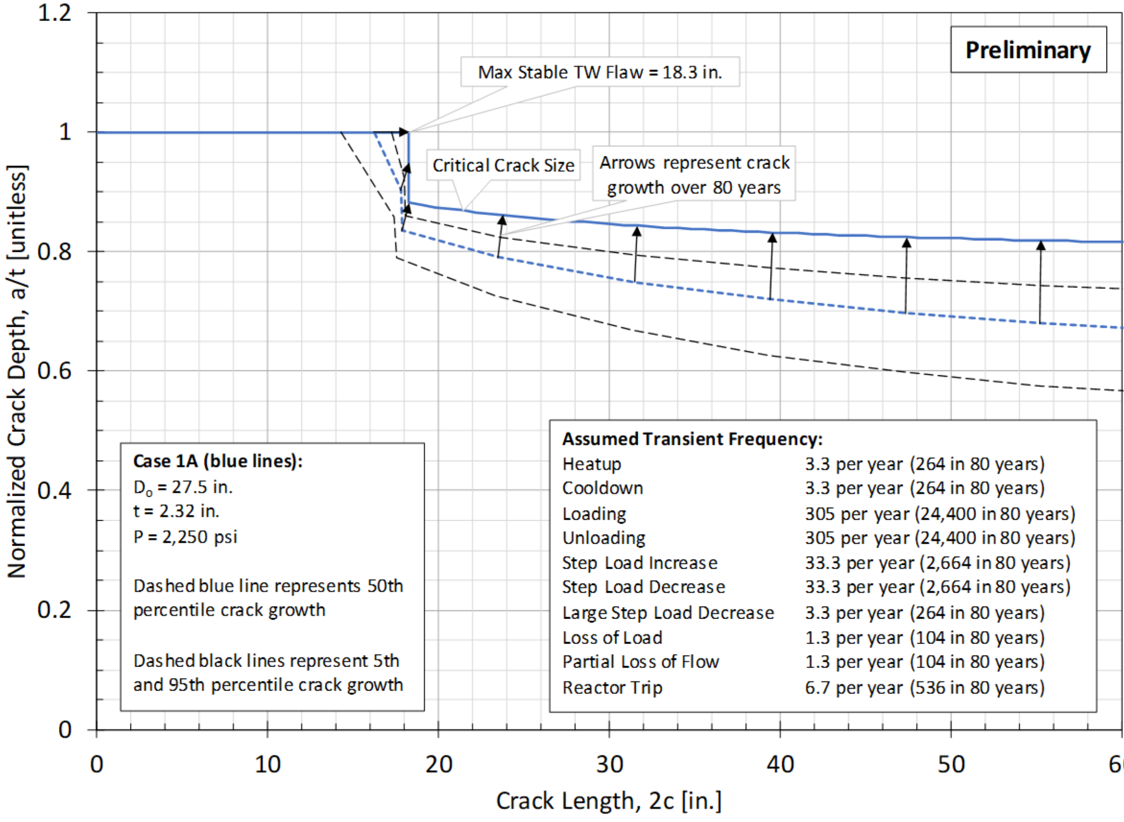
- Current UT technology applied to CASS components is not currently capable of meeting PDI qualification standards for other piping weld materials
- Key challenges for UT Techniques in CASS material include:
  - Detection of axial cracks
  - Depth sizing of circumferential cracks
- The goal of this project is to determine if analytical evaluation could be used in concert with the limited CASS NDE capabilities to support a comprehensive revision to ASME Code, Section XI, Appendix VIII, Supplement 9

PFM Evaluations of CASS PWR Piping Components

Results - *Axial Cracks*

- CASS piping is tolerant of large flaws
  - The only load relevant to axial crack stability is internal pressure
- Example fatigue crack growth calculations show tolerance for long period of subcritical growth
  - Example cases show that subcritical growth may be more significant for CE surge line than Westinghouse main loop piping due to differences in cyclic loading
  - Probabilistic growth and coalescence modeling shows substantial margin when considering effect of multiple axial flaws on the same plane
- Phase 1 results indicates that a full probabilistic analysis would likely show that periodic UT is not necessary to maintain nuclear safety

Main Loop Piping – Single Axial Crack
Stability and Fatigue Crack Growth



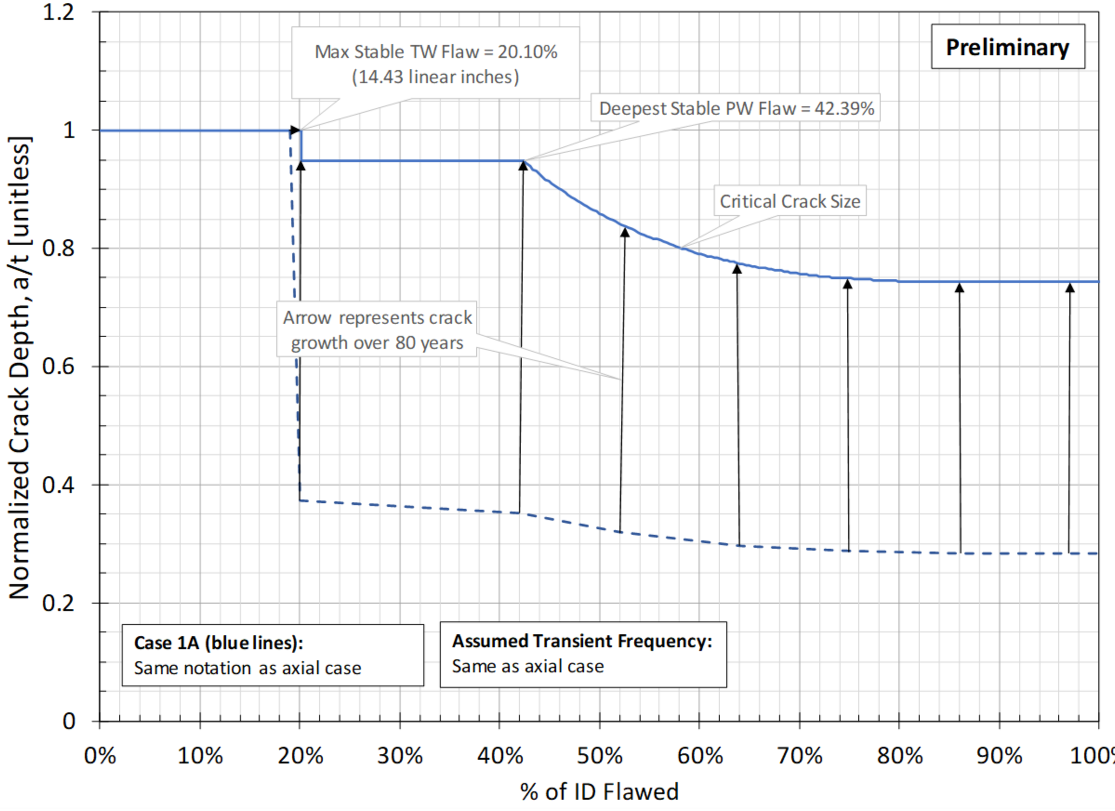
PFM Evaluations of CASS PWR Piping Components

Results - *Circumferential Cracks*

- Example results for Westinghouse main loop piping assuming loading at stress ratio show reduced critical size length compared to axial flaw cases, but still of relatively large size
- A Phase 2 effort is needed to investigate whether qualified UT detection absent qualified UT depth-sizing would be sufficient to maintain nuclear safety and leak tightness (i.e., defense in depth) within acceptable limits

Main Loop Piping – Single Circumferential Crack

Stability Example Case



PFM Evaluations of CASS PWR Piping Components

Next Steps

- Phase 2 (underway; to be completed by ~10/31/2020)
  - Produce a reasonably complete PFM analysis
    - Complete the case matrix developed in Phase 1
    - Consider probability of initiation, probability of leakage
    - Full Monte Carlo simulation with all analysis aspects linked
- Phase 3 (after Phase 2; to be completed by 4/30/2021)
  - Complete all needed supporting analyses, sensitivity analyses, V&V, and documentation expected for a PFM submittal to regulators
  - Content will be consistent with NRC's planned PFM Regulatory Guide and EPRI's White Paper on PFM Submittals

Completed CASS Projects

Other EPRI Projects of Interest Related to CASS Material

Single Source Cast Austenitic Stainless Steel Research

This report contains CASS research material from more than 100 reports that has been summarized and organized by topic in one convenient location

Report also contains a bibliography of references spanning more than 50 years

Single Source Cast Austenitic Stainless Steel Research: Summary of EPRI Research and Relevant Sources

Product ID:3002010315

Date Published:20-Dec-2017

Single Source Cast Austenitic Stainless Steel Research: Summary of EPRI Research and Relevant Sources **(Japanese Translation)**

Product ID:3002013949

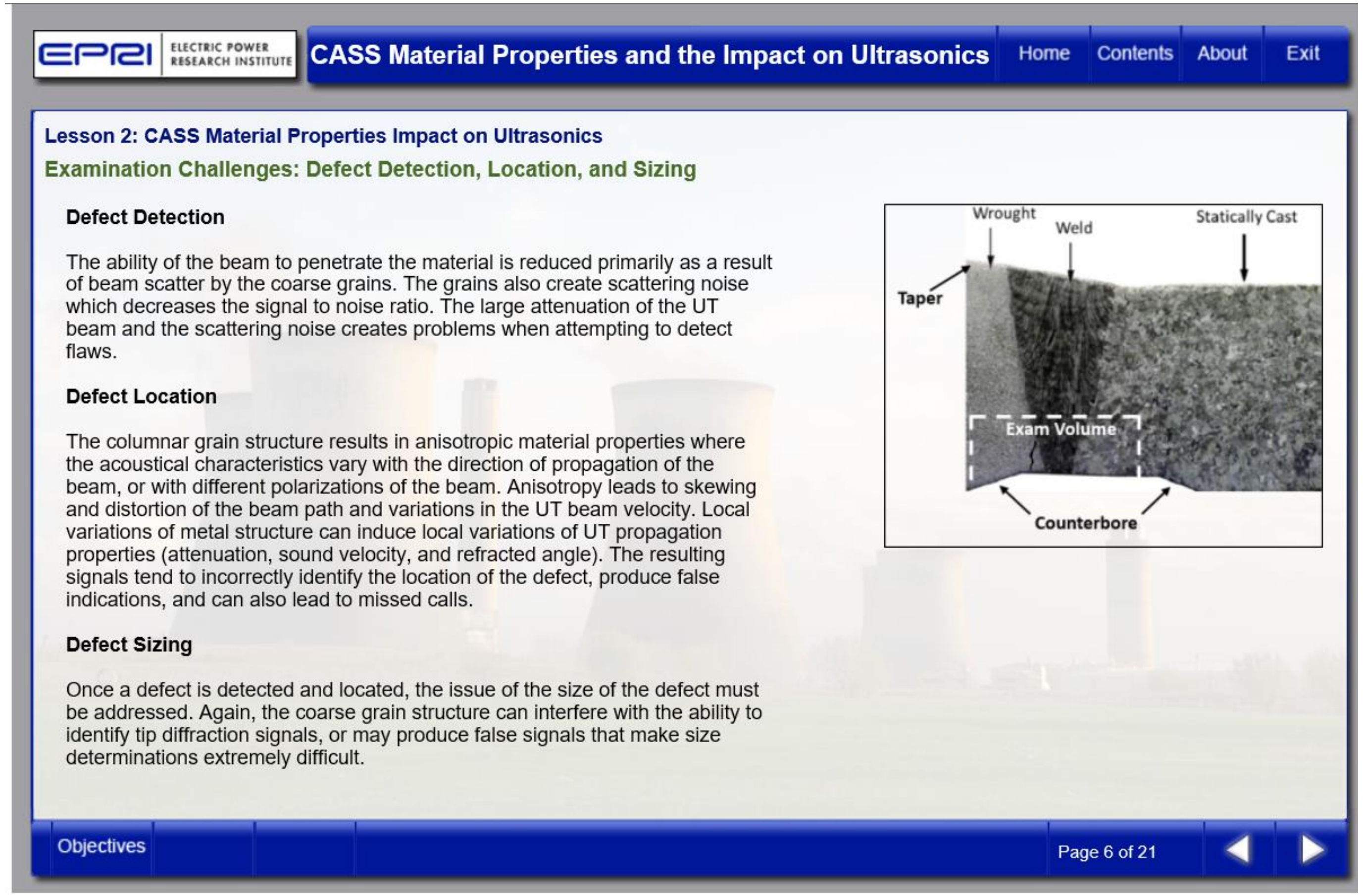
Date Published:15-June-2018

Computer Based Training (CBT) for the Ultrasonic Examination of Cast Austenitic Stainless Steel Welds (UTCASS-CBT), v1.0

Computer Based Training (CBT) for the Ultrasonic Examination of Cast Austenitic Stainless Steel Welds (UTCASS-CBT), v1.0

Product ID	Sector Name	Document Type
3002014180	Nuclear	Software
Date Published	**File size**	**File Type**
29-Aug-2018	291.02 MB	Windows Executable (.exe)

Online version of an overview of ultrasonic inspection of cast austenitic stainless steel (CASS) pipe welds. Benefits & Values Online version of UT of CASS materials allows for the following: Self-paced learning opportunity Reduced cost of travel and time outside the plant enabled by computer-based delivery Ability to revisit the material at-will for learning and verification purposes Platform Requirements Browser: Internet Explorer 11+ Operating System: Windows 7 (32-bit and 64-bit), Windows 8.1, and W...

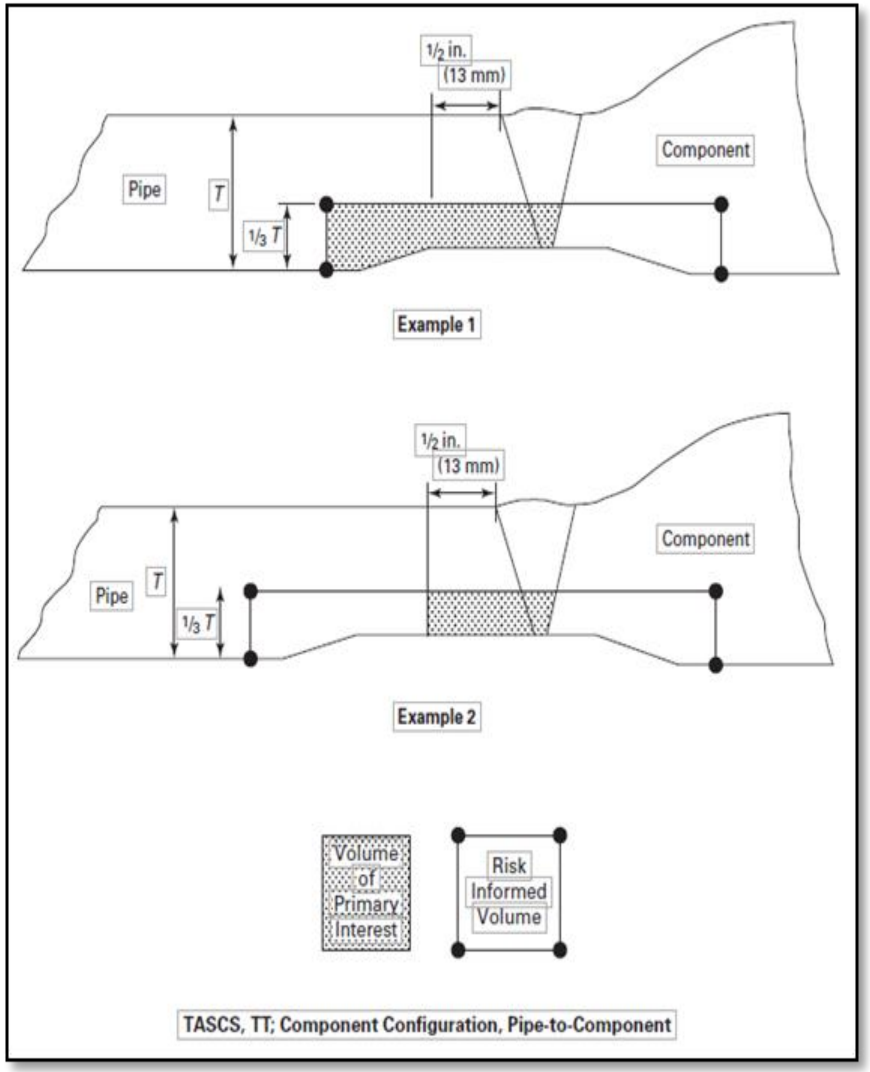


Development and Implementation support for ASME Code Case N-711 Alternative Examination Coverage Requirements for Select Piping Welds

The process provides alternative examination coverage requirements for Category B-F, B-J, CF-2, and R-A piping welds

This Code Case is a risk based approach that focuses on the areas where service induced flaws are most likely to occur

Intended to reduce burden on the regulators and Industry by decreasing the number of relief requests related to missed examination coverage from single sided examinations



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CASS Timeline Update

Stephen Cumblidge

2020 Industry/NRC NDE Technical Information Exchange Public Meeting

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

Coverage Relief Request Update

Stephen Cumblidge

2020 Industry/NRC NDE Technical Information Exchange Public Meeting

U.S.NRC
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2015 Presentation on Impractical Relief Requests

In 2015 the NRC prepared a presentation that covered issues that commonly resulted in Requests for Additional Information (RAIs)

It can be found in ADAMS under Accession Number ML15013A266

What has changed since 2015?

The quality of impractical relief requests has improved substantially

This improvement has resulted in fewer RAIs, but has not eliminated them

Many RAIs are based on missing information or errors the submittal

Some RAIs are related to issues that makes justifying reasonable assurance of leak tightness and structural integrity more challenging

Themes in RAIs Since 2015

Welds with low coverage may get extra scrutiny

Some RAIs are in response to operating experience- welds with new issues may get more questions

Some RAIs address inconsistencies in submittals, such as including information on some welds but not others

A review of recent RAIs did not find a strong common issue that resulted in many RAIs

What Information is Helpful?

Recent examples of RAIs have asked for the following additional information to help provide reasonable assurance in difficult cases:

A summary of the evaluation for accepting the proposed limited coverages required by ASME Code Case N-716 “Alternative Classification and Examination Requirements Section XI”

A discussion of measures that could ensure or monitor the structural integrity of the subject welds, including the reactor coolant system leakage detection systems, routine system leakage tests in accordance with IWA/B-5000 of the ASME Code, Section XI, boric acid monitoring programs, operator walkdowns, and any augmented examinations.

Discussion

What have we missed?

Implications of the Science of Learning for Qualification of Personnel for Ultrasonic Examination

Thomas F. Sanquist, Ph.D., Research Scientist

NRC/Industry NDE TIE

January 14, 2020

Work sponsored by US NRC Office of Research

Carol A. Nove, COR

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Preview of Recommendations

1 – Increase lab practice

2 – Objectively define experience time

3 – Provide sufficient field experience

4 – Use distributed practice learning principle for lab practice

5 – Provide structured learning opportunities and feedback for lab practice and field experience

Introduction

- Changes in ASME Code Section XI, Appendix VII (2011) reduced experience hours required for Level II certification from 800 to 400, permitting 320 of those hours to be laboratory training. (Table VII-4110-1, Required Experience for Initial Certification for Ultrasonic Examination (Hours)). Currently, 10CFR 50.55a prohibits the use of reduced experience hours.
- NRC initiated research to investigate the technical basis for training requirements through a scientific literature review of studies concerning human learning, retention, training, and application of knowledge.
- Product – integrative literature review and recommendations concerning technical basis for NDE training hours and types.
- Issues:
  - Reduced size of workforce
  - Lack of opportunities to detect flaws in operational plants
  - Fewer opportunities for training during inservice inspections than earlier periods
- Outcome: there is latitude to reduce experience hours with increase in lab practice
  - We address five recommendations for how to implement this, based on fundamental learning principles

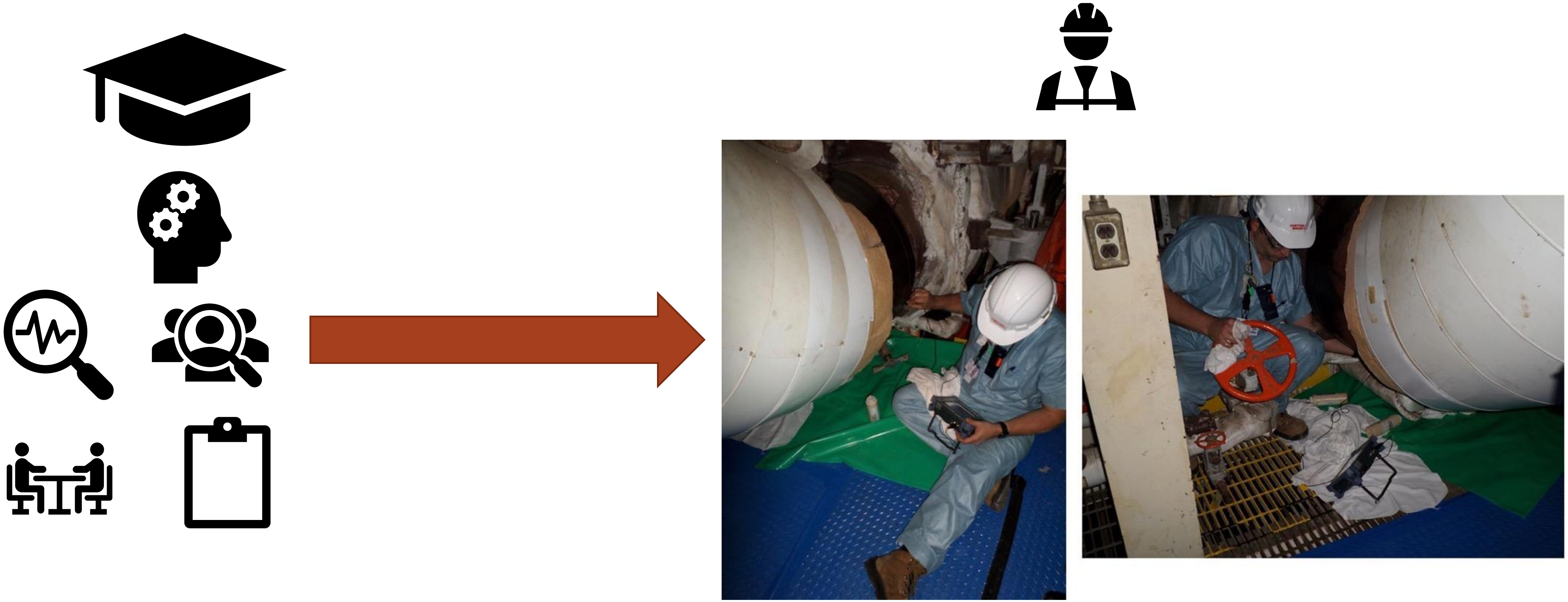
Background

- Supervised experience time requirements common in many skill-based jobs, e.g.,
  - Flying hours for pilots
  - Clinical practice for doctors
- Goal of training and field experience
  - Develop applicable knowledge and skill
  - Perform job task at a level of proficiency to work unsupervised (“journeyman” level)
  - “Proficiency” currently based on passing a performance test (Appendix VIII) after required amount of field experience (Appendix VII)
  - Performance testing not intended as method to assess systematic training and experience needed for personnel to acquire skills to successfully perform NDE (Doctor, 2013).
- Changes in experience time requirements generally involve considerable debate

Fundamental Principles

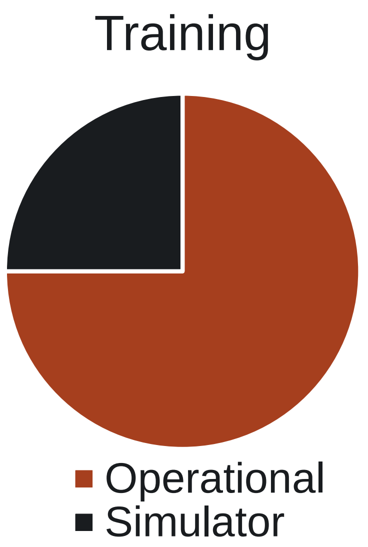
- Total Time: more learning time results in better performance
- Incidental Learning: Learning can occur in the absence of overt behavioral change
- Distributed Practice: Learning time that is distributed across intervals rather than massed together yields better retention
- Knowledge Testing: Testing can enhance retention, independent of further study
- Feedback: Feedback that informs the learner as to the correct answer on a test, presented after the test is completed, enhances retention and can be used to correct errors.
- Transfer of Training: Practice on parts of tasks that are similar or identical to elements of the task being learned results in positive transfer of learning, i.e., the new task is performed better than if practice on related tasks had not occurred.
- On-the-Job Training (OJT): OJT is a systematic process based on analysis of the task to be performed, development of instructional situations from the operational environment, employment of instructional techniques such as demonstration and observation as warranted, and evaluation of performance based on increasing competence in operational tasks.
- Proficiency and Expert Performance: Proficiency and eventual expertise develops over a long period of time, requiring deliberate practice of component tasks at increasing levels of difficulty to challenge the current skill level.
- Perceptual Learning: Experience can change how people perceive visual patterns, increasing the ability to extract information from the environment.
- Active Learning: Learning material that is processed more “deeply,” i.e., with elaboration of content though meaningful engagement – as distinct from passive activity such as rote repetition or verbatim note-taking – will be retained better.

Translational Science – from research to application. What should we do about practice and field experience?



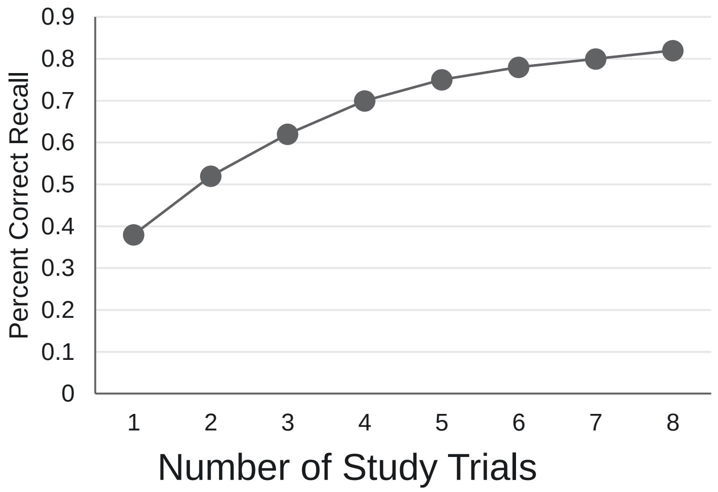
Recommendation 1

- Increase opportunities to practice detection and flaw characterization by use of laboratory practice exercises that simulate the types of examinations that would be done in the field.
  - Provide sufficient time and feedback to ensure mastery of the relevant techniques
- **Applicable Learning Principles**: Total Time, Transfer of Training, Perceptual Learning, Feedback



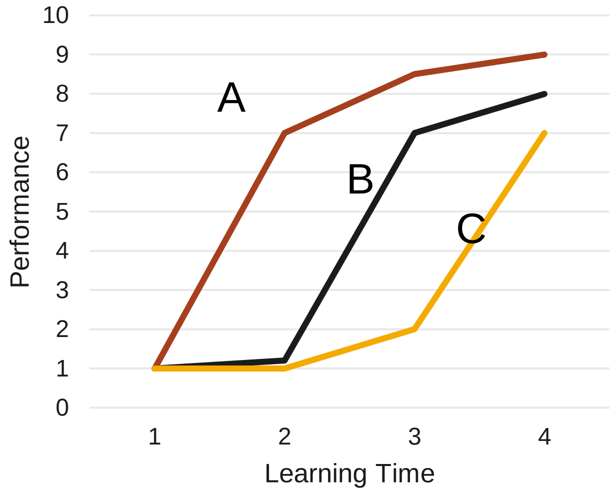
Recommendation 1, Considerations

- Consistent with current Appendix VII allowing increased hours of lab practice on UT techniques and components likely to be encountered in field conditions.
- Time provided for exercises should be based on objective criteria for demonstrating mastery, such as supervisor ratings, performance scores in practice tests, and overall likelihood of passing PDI tests.
- Not a substitute for field experience; instead it is *augmentation*
- Implement provisional Level II certifications to ensure effectiveness



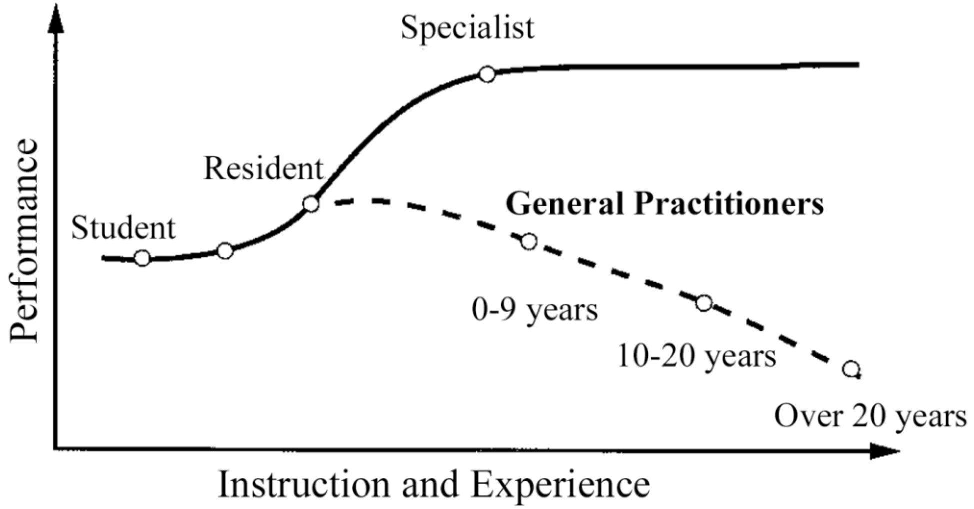
Recommendation 2

- Define the relationship between hours of experience and frequency of UT task performance.
  - Current proposals for lab practice and field experience hours use a table of frequency X hours per task (lab practice) or total time in hours (field experience) to yield total experience time.
  - A more detailed basis for what tasks and subtasks contribute to the time estimates will provide supervisors and regulators with a better understanding of how to implement and evaluate Code modification proposals.
- **Applicable Learning Principles**: Total Time, OJT, Distributed Practice



Recommendation 2, Considerations

- An issue with basing qualifications on experience time is the specific definition of "time."
- Time and frequency of task are related, but unclear whether the number of times the task is performed, or the duration of the task is the key variable in developing proficiency.
- **On-the-Job Training (OJT):** Specific criteria for what is to be observed and then demonstrated by the trainee. Full demonstrations of tasks, as well as parts of tasks by instructors, should form the basis for student demonstration of proficiency.
- Simple "experience accrual" is not sufficient.
- Amount of time and allocation can be better defined through systematic estimates by subject matter experts.



Recommendation 3

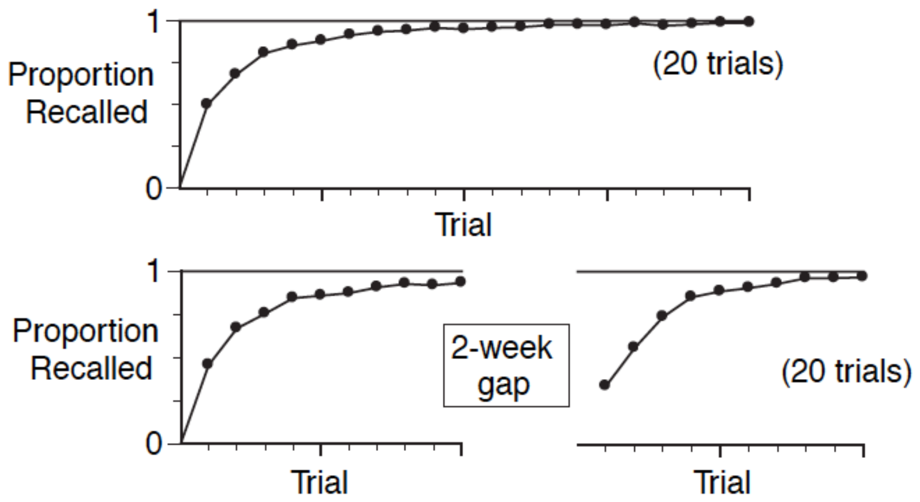
- Provide *sufficient* field experience in nuclear plant inservice inspections to develop proficiency of the knowledge and skills necessary to conduct examinations in realistic operational settings.
  - Time in field experience should complement laboratory practice such that total experience time is equivalent with Code requirements currently accepted by the NRC (800 hours)
  - Field experience should be based on a structured approach to on-the-job training to ensure that all techniques addressed in laboratory practice are observed, demonstrated in the field under supervision, and feedback provided to the trainee concerning their performance.
- **Applicable Learning Principles**: Total Time, Incidental Learning, Distributed Practice, On-the-job Training, Proficiency and Expertise, Active Learning.

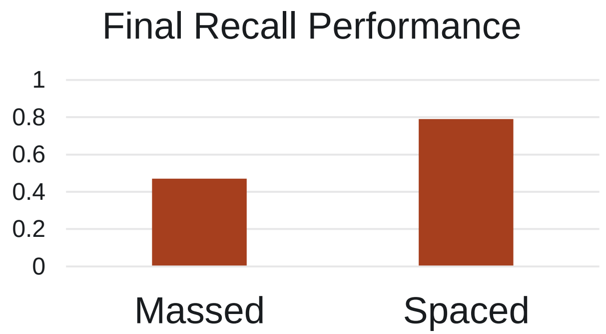
Recommendation 3, Considerations

- Could reduce field experience hours substantially, recognizing the potential contribution of laboratory practice.
- Many aspects required to develop proficiency for skill application in operational environments besides detection and characterization of flaws
  - ✓ learning how to navigate through containment/inspection areas,
  - ✓ executing procedures in complex circumstances,
  - ✓ observing multiple geometries,
  - ✓ addressing issues of coverage limitations, and
  - ✓ generally learning flexibility to adapt the examination process while maintaining compliance with the qualified procedure,
  - ✓ experience in diverse operational cultures and expectations
- Code reduction to 80 hours of field experience is unacceptably low
- Proficiency and eventual expertise has been shown to require as much as 10,000 hours to develop.
- Potential “provisional” certification

Recommendation 4

- Develop a schedule for laboratory practice that distributes the practice sessions for various techniques over intervals separated in time, e.g., a week or a month, based on what is feasible for trainees, oversight supervisors and lab facilities. Incorporate testing of previously practiced material.
- **Applicable Learning Principles**: Distributed practice

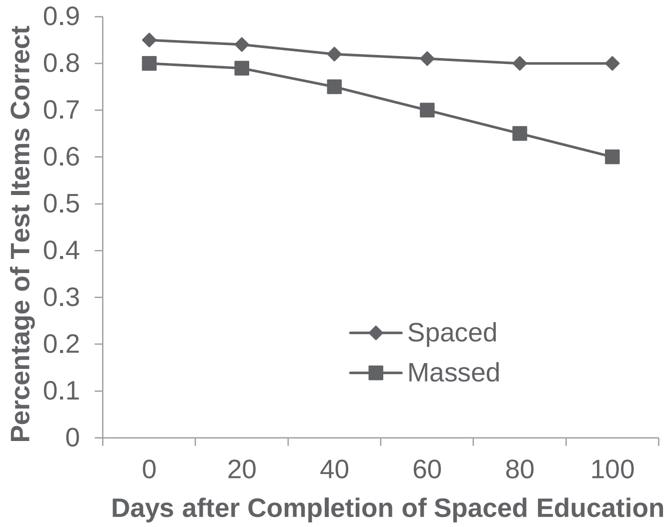




Recommendation 4, Considerations

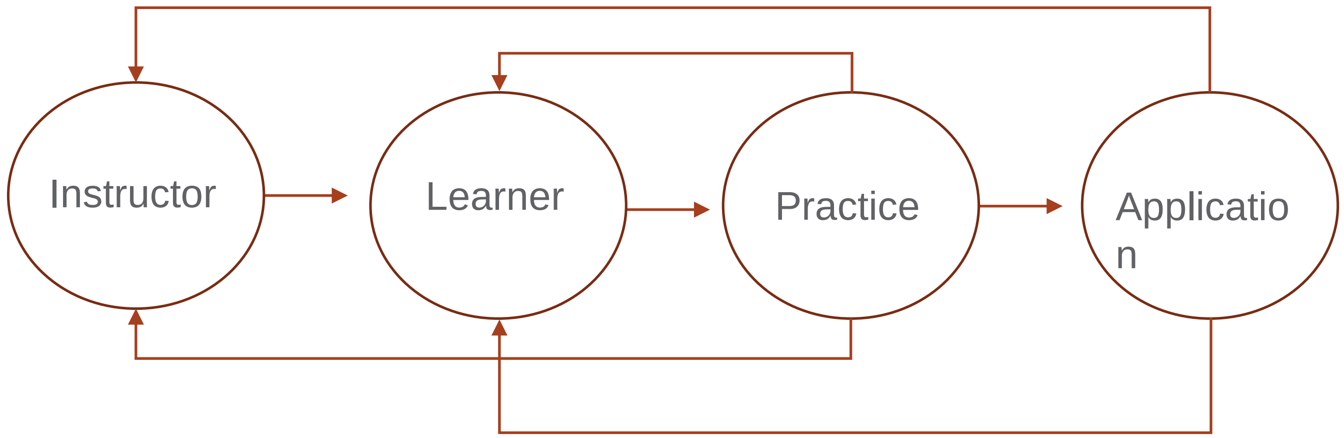
- Spacing of lab exercises over time so that more durable learning takes place.
- Several hours of practice on alternate days
- Current approaches to prepare for performance testing involves massed practice on samples in the time period immediately preceding the test
- Feasibility – practice sample availability, location, oversight

Medical Students: Better long-term retention with spaced practice



Recommendation 5

- Develop a protocol for laboratory practice that incorporates feedback to the trainee concerning their performance addressing (1) performance accuracy, (2) process of examination, (3) how the trainee can monitor their own performance, and (4) increasingly difficult problems to challenge the current trainee skill level.
- **Applicable Learning Principles**: Feedback, Proficiency and Expertise



Recommendation 5, Considerations

- Considerations
  - Laboratory practice for UT procedures permits the opportunity to provide more feedback concerning performance
  - Feedback not only about performance accuracy – whether the flaw was correctly detected and sized – but also about how the trainee performed the task, and how they can monitor their own performance to ensure proper task completion
  - More intensive for early trainees who will require considerable oversight, while in the latter periods of lab practice, less scrutiny would be necessary
  - Feedback provided by Level III supervisors might address how such examination procedures would be performed in the field, and practical considerations that are typically encountered in operational settings
  - Graduated levels of difficulty for the practice specimens will permit the trainer to challenge the current skill level of the trainee, so that current knowledge is pushed and extended

Summary

- Time requirements exist to ensure that trainees have sufficient opportunity to experience and perform their job tasks at an acceptable level of proficiency so that they can work unsupervised – the “journeyman” level of performance
- Difficulty with NDE Level II experience is defining exactly what “proficiency” means
  - Currently, passing the performance demonstration test after the required amount of field experience is one way to demonstrate proficiency.
- Changing one of the core aspects of proficiency development – e.g., field experience hours, should be carefully evaluated and addressed conservatively
- Increased laboratory practice is commensurate with guidance from the literature

Summary, continued

- Reducing field experience, however, is a more challenging issue
- Reducing field experience to 80 hours provides only a token amount of time
- More appropriate would be to ensure that field experience actually does provide adequate time to observe and execute UT examinations under supervision, and that this is done frequently enough to develop operational proficiency
- There is latitude to reduce the overall number of experience hours with a corresponding increase in lab practice
  - Proposals should be evidence-based and include a rationale for accumulating adequate experience to develop proficient examiners

Thank you

Technical Basis for Section XI, Appendix VII

Kevin Hacker
Dominion Energy

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Outline

- Objectives
- Background
- History of Section XI Requirements
- Process
- Proposed Changes to Appendix VII (2019 Edition)
- Status
- Schedule

Objectives

- Develop guidance and recommendations for training and certification programs addressing NDE personnel
- Develop a technical basis for the training and experience hours for Level II UT examiners

Background

- UT personnel are certified based on ASME Section XI, Appendix VII
  - As modified through 10 CFR 50.55a
- Certification at Level II requires 800 hours of experience
  - Requirements have evolved since 1960s
  - “Experience” is defined only loosely in Appendix VII
- The 2011 Addenda includes an option to replace this requirement
  - Code Case N-784
    - Minimum 80 hours of field experience and 320 hours of laboratory practice
    - Candidate must also pass a Section XI Appendix VIII, Supplement 2
      - Performance demonstration for flaw detection and length sizing
- NRC conditioned the use of Section XI
  - Requires that the earlier experience provisions be applied

History of Section XI Requirements

Timeline	Requirement for Qualification of Examiners
From 1963	Examiner must be "competent" with 20/20 vision
Winter 1968 Addenda	Examiner must be qualified per SNT-TC-1A in IX-400 (equivalent to modern-day Section XI, IWA-2300)
1975	SNT-TC-1A adds first rigorous experience recommendations: Level I: 525 hours Level II: 1,575 hours
1986	Section XI, Appendix VII adds separate experience requirements for UT examiners: Level I: 250 hours Level II: 800 hours
1991	ANSI/ASNT CP-189 is first issued to provide requirements that replace and/or supplement provisions in SNT-TC-1A. For NDE: Level I: 210 hrs; Level II: 600 hrs
1992	SNT-TC-1A revised to be consistent with CP-189
1995	CP-189 replaces SNT-TC-1A in Section XI, IWA-2300
2010	CC-N-784 published
2018	NRC review and disapproval of CC-N-784

Experience Requirements of Various Industry Standards

Source	UT Level I	UT Level II
Section XI	250	800†
SNT-TC-1A-2006*	210	630
ANSI/ASNT CP-189	200	630
ACCP 8/9/2009	N/A	800
ISO 9712: 2005	525	1,575
EN 473: 2008	525	1,575
NAS 410 Rev. 4 (2014)	200	600
AC 65-31B*	480	1,440

†Updated in 2011 addenda to allow reduction to 400 hours with conditions (CC-N-784), but not permitted by NRC

*These standards are recommendations

Process

- In the process of developing:
  - A technical basis for training and experience requirements for UT personnel
  - Related guidance and recommendations for NDE training program
  - Improved efficiency and effectiveness
    - Required for the NDE training and qualification process
- The technical basis will determine:
  - The number of hours of field experience that is considered "sufficient"
  - The relative importance of field experience vs. laboratory practice across the range of personnel
  - The benefit of field experience and laboratory practice hours
    - Compared to the knowledge gained through training

Process

- Recommendations for the technical basis and NDE training program guidance
  - These items are being considered
    - Latest findings and information from NDE human factors research program
    - Precedents and lessons learned from systematically developed training programs
    - Available results of industry and NRC review of NDE field performance issues
    - ASNT guidance
    - ANDE program developments
    - Relevant EPRI reports
    - Discussions with industry NDE experts and instructors
    - Practices and requirements for nuclear NDE in other countries
    - NDE training and qualification in other industries
      - Aerospace, petrochemical, etc.
    - Atkins Systematic Approach to Training (SAT)
      - Considers experience with training in other areas of the nuclear power industry

Proposed Changes to Appendix VII (2019 Edition)

Table VII-4110-1
Required Experience for Initial Certification for Ultrasonic Examination (Hours)

Trainee	Level I	Level II	Level III
None	250	800	4,200 (Option 1) 6,300 (Option 2) 8,400 (Option 3)

GENERAL NOTES:

(a) For Level II certification, the experience shall consist of time at Level I. To certify a candidate directly to Level II with no time at Level I, the total experience hours required for Level I plus Level II shall apply.

(b) Prior certification as a Level I or Level II is not required.

(c) All or part of the Level I experience hours may be satisfied by laboratory practice hours beyond those required for training in accordance with VII-4220, provided those practice hours are dedicated to the Level I or Level II skill areas as described in ANSI/ASNT CP-189.

(d) The 800 hr of Level II experience time may be reduced to 400 hr, which shall include a minimum of 80 hr of field experience and a minimum of 320 hr of laboratory practice, provided that ~~the practice is dedicated to scanning specimens containing flaws in materials representative of those in actual power plant components and the candidate passes a Mandatory Appendix VIII, Supplement 2 performance demonstration for detection and length sizing.~~ Insert A

Insert A

(1) the laboratory practice is dedicated to scanning specimens containing flaws in materials representative of those in actual power plant components,

(2) the candidate performs a sufficient number of examinations (with a sufficient number of flaws detected and correctly identified without prior knowledge of flaw location or type) and a sufficient number of calibrations as judged by the supervising Level III to assure candidate proficiency:

(-a) to detect, size, and identify flaws such as slag, lack of fusion, lack of penetration, porosity, and cracks, and

(-b) to identify and discriminate geometric reflectors,

(3) the laboratory practice includes scanning of pipe weld specimens covering the following at a minimum:

(-a) single-sided and double-sided examinations,

(-b) axial and circumferential scan directions,

(-c) small diameter (> NPS 1½ (DN 40) to NPS 4 (DN 100)), medium diameter (> NPS 4 (DN 100) to NPS 12 (DN 300)), and large diameter (> NPS 12 (DN 300)) specimens, and

(-d) thin wall joints (schedule 40 or below) and thick wall joints (schedule 60 or above),

(4) the laboratory practice includes straight beam testing and multiple angled beam testing,

(5) the laboratory practice includes longitudinal and shear waveforms, and

(6) the candidate passes a Mandatory Appendix VIII, Supplement 2 performance demonstration for detection and length sizing.

Proposed Changes to Appendix VII (2019 Edition)

Suggested additional caveats to Table VII-4110-1 Note (d), as shown on previous slide

(1) the laboratory practice is dedicated to scanning specimens containing flaws in materials representative of those in actual power plant components,

(2) the candidate performs a sufficient number of examinations (with a sufficient number of flaws detected and correctly identified without prior knowledge of flaw location or type) and a sufficient number of calibrations as judged by the supervising Level III to assure candidate proficiency:

(-a) to detect, size, and identify flaws such as slag, lack of fusion, lack of penetration, porosity, and cracks, and

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(5) The laboratory practice includes longitudinal and shear waveforms, and

(6) The candidate passes a Mandatory Appendix VIII, Supplement 2 performance demonstration for detection and length sizing.

Proposed Changes to Appendix VII (2019 Edition)

- The technical basis supports reduction of UT Level II experience hours requirements from 800 to 400, if the caveats proposed on the prior slide are met; these caveats:
  - Ensure the most pertinent relevant conditions are included
  - Ensure the candidate has successfully examined flawed components prior to taking the Appendix qualification examination
  - Make explicit that the supervising Level III is responsible to ensure that the experience is sufficient
  - Ensures proficiency
  - Qualification examination per Appendix VIII Supplement 2 has been shown to be an effective discriminator of examiner competence
- Caveats are based on discussion with experts and the approach being implemented within ASME to adopt the ANDE standard

Status

- Submitted proposed revisions to CC-N-784
  - Record 10-1074
  - Address regulatory concerns
- An industry expert panel is being established
  - Input and guidance on the direction of the technical basis
  - Expert opinion on the best approaches to optimize NDE training and certification programs
- Members of the panel
  - Section XI Appendix VIII volunteers
  - NDE human factors researchers
  - NDE researchers
  - NDE instructors
  - NDE training personnel
  - NDE vendor personnel
  - NDE utility personnel

Schedule

- 2018/2019
  - Completed initial data collection
- 2019-2020
  - Submitted proposed revisions to CC-N-784
  - Established expert panel objectives
    - Sought volunteers for panel
  - Organize expert panel
    - Incorporate expert feedback in guidance
  - Draft and finalize reports
    - Technical basis white paper supporting UT Level II experience requirements
    - Guidance document for NDE UT training and certification
- 2021
  - Support implementation
    - Work with ASME and NRC

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UT Simulator update

Mark Dennis
Program Manager, EPRI

Kevin Hacker
Dominion Energy

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Outline

- UT Simulator Status
- Scanning with the Simulator
- User Interface
- UT Simulator Components and How They Work Together
- Mockups
- Data Collection
- UT Simulator Data Files
- Future Plans
- Benefits and Uses

UT Simulator Status

- In December 2019 the ultrasonic simulator, VNDE 2.1 is delivered
- VNDE 2.1 is capable of simulating ultrasonic testing through the use of mockup hardware - probes, specimens, and reference blocks
  - The software can also be used without hardware objects

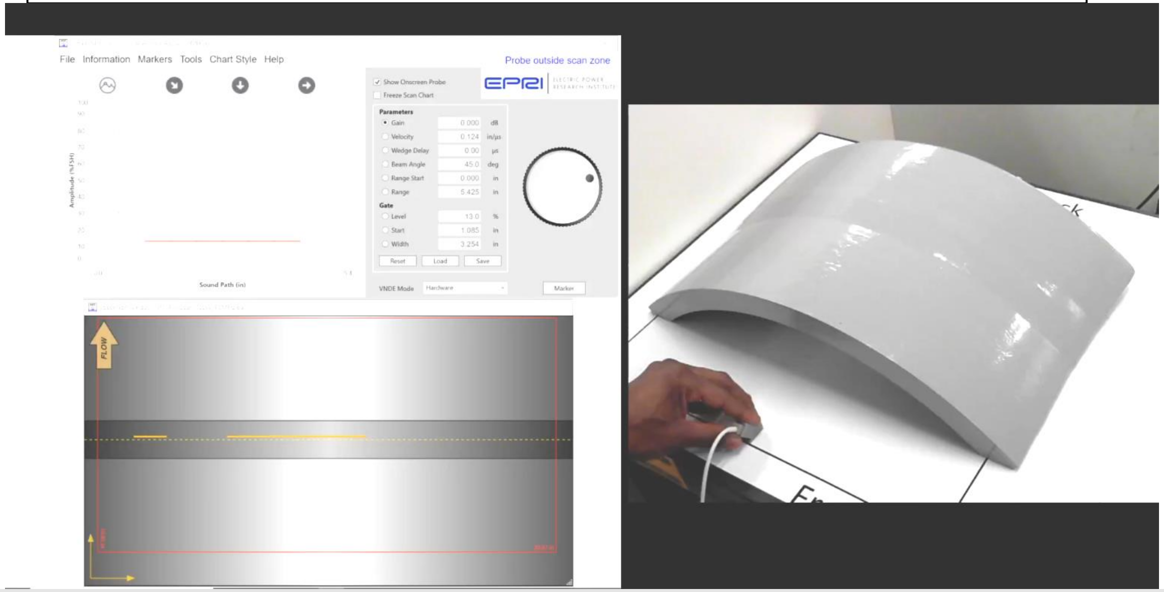
Virtual Non-Destructive Evaluation (VNDE), 2.1

Product Id: 3002015977

Scanning with the Simulator

- Simulated hardware contains a plastic specimen and probe
  - Gives a realistic look and feel when scanning
- The specimen and probe contain an electromagnetic (EM) sensor that is tracking all 6 degrees-of-freedom with respect to each other
  - The specimen and probe can be moved relative to each other
- Ultrasonic data collected on real samples is played back by the simulator

Hardware Scan: IGSCC Pipe



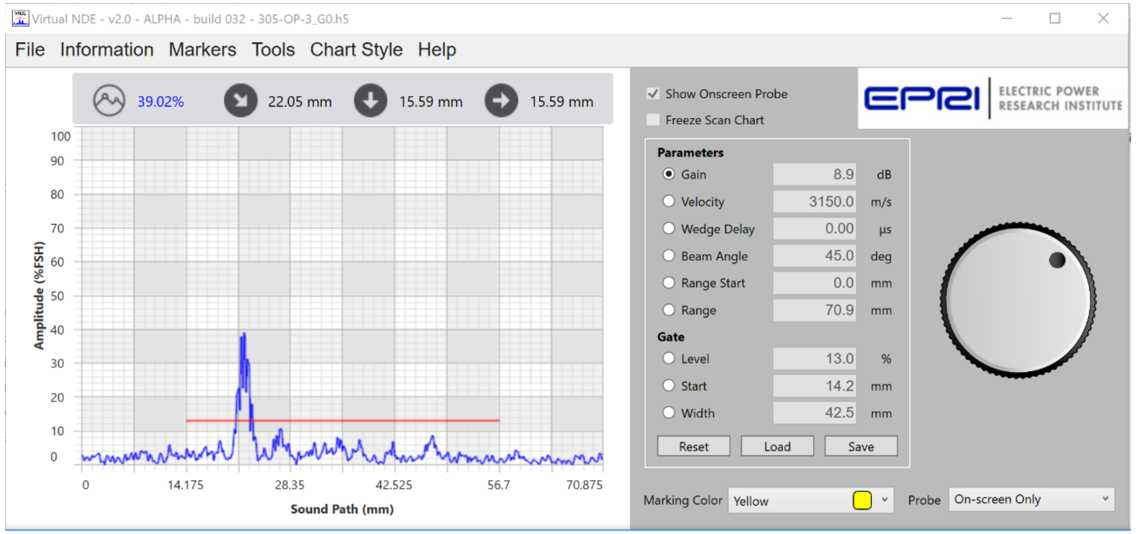
Hardware Scan: Rompas Block

 www.epri.com

User Interface

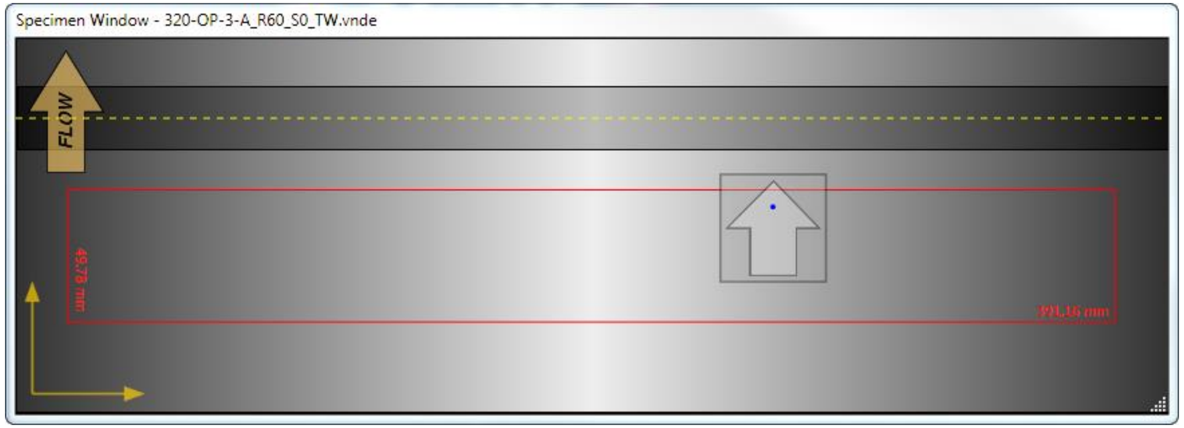
Main Window

- Software control interface (menus)
- Live A-Scan
- Display read outs
- Parameter & gate control



Specimen Window

- Represents top, roll-out view of virtual specimen with a virtual weld if applicable
- Only visible when a file is open
- Contains a virtual probe
- Scan data is available in red box



UT Simulator Components and How They Work Together

- The components work together as follows:
  - EM tracking system – this device lets the system know where the probe and specimen are relative to one another
  - Computer and VNDE software – the computer and software use the positional information from the EM tracking system and essentially "lookup" previously recorded ultrasonic data at the corresponding position
  - Mockups – these are non-magnetic objects that look and feel similar to real UT probes and metallic specimens

Category	Component
Computer and Electronic Hardware	Computer with VNDE software
	Touchscreen monitor
	EM tracking system
	EM transmitter
	EM receivers
Mockups	Specimens
	Probes
	Reference blocks
	Removable weld crowns
	Pipe covers

Mockups

- Simulator mockups are made of non-magnetic materials such as plastic or molding materials
- Mockups can be made to capture fine surface details as well as macroscale features
- Two methods are currently used to make mockups:
  - 3D printing
    - A real specimen is laser scanned, or previous drawings can be used, and this information forms a CAD file for 3D printing
  - Molding
    - A pliable material is placed on the real specimen and supported with a backing framework
    - The final product is a replicated specimen with very detailed surface features
    - This technique is in its earlier stages of testing

Mockups – DMW Nozzle Example

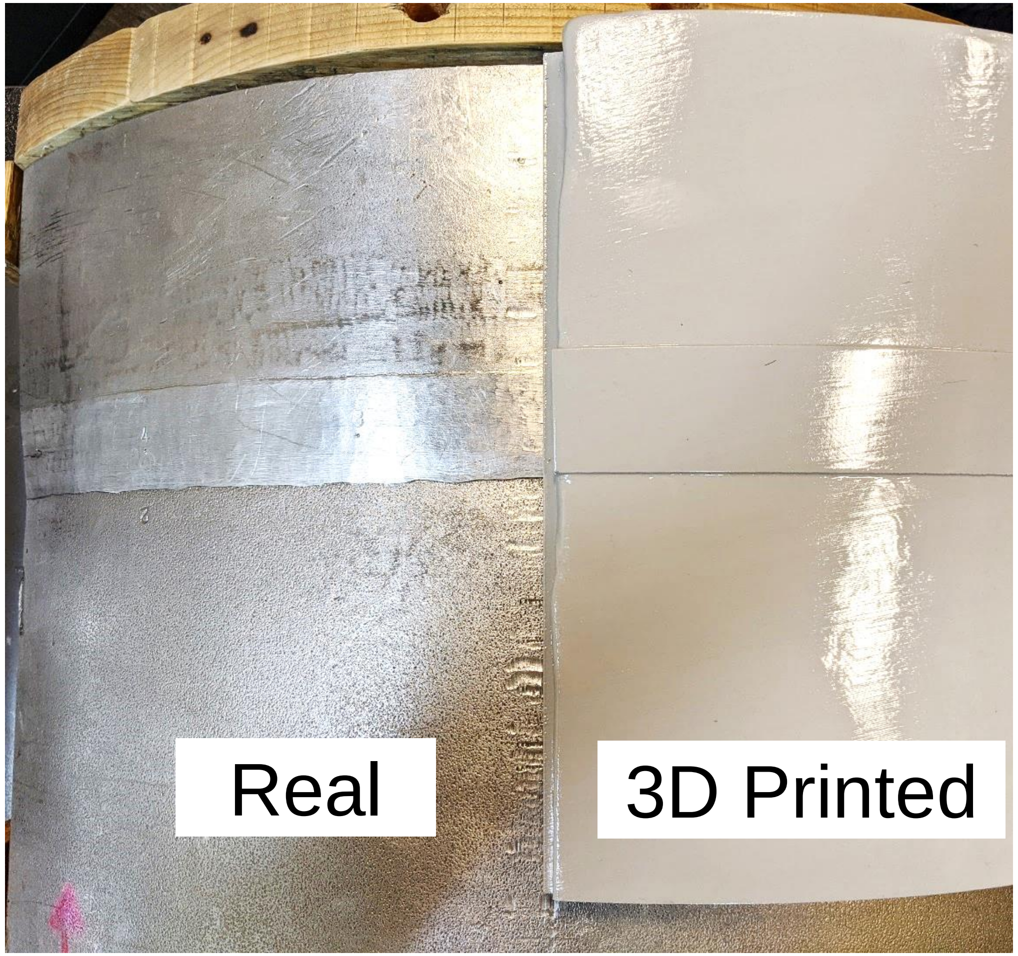
Real

3D Printed

Mockups – IGSCC Example

- Pipe features and weld crowns are similar

Top View



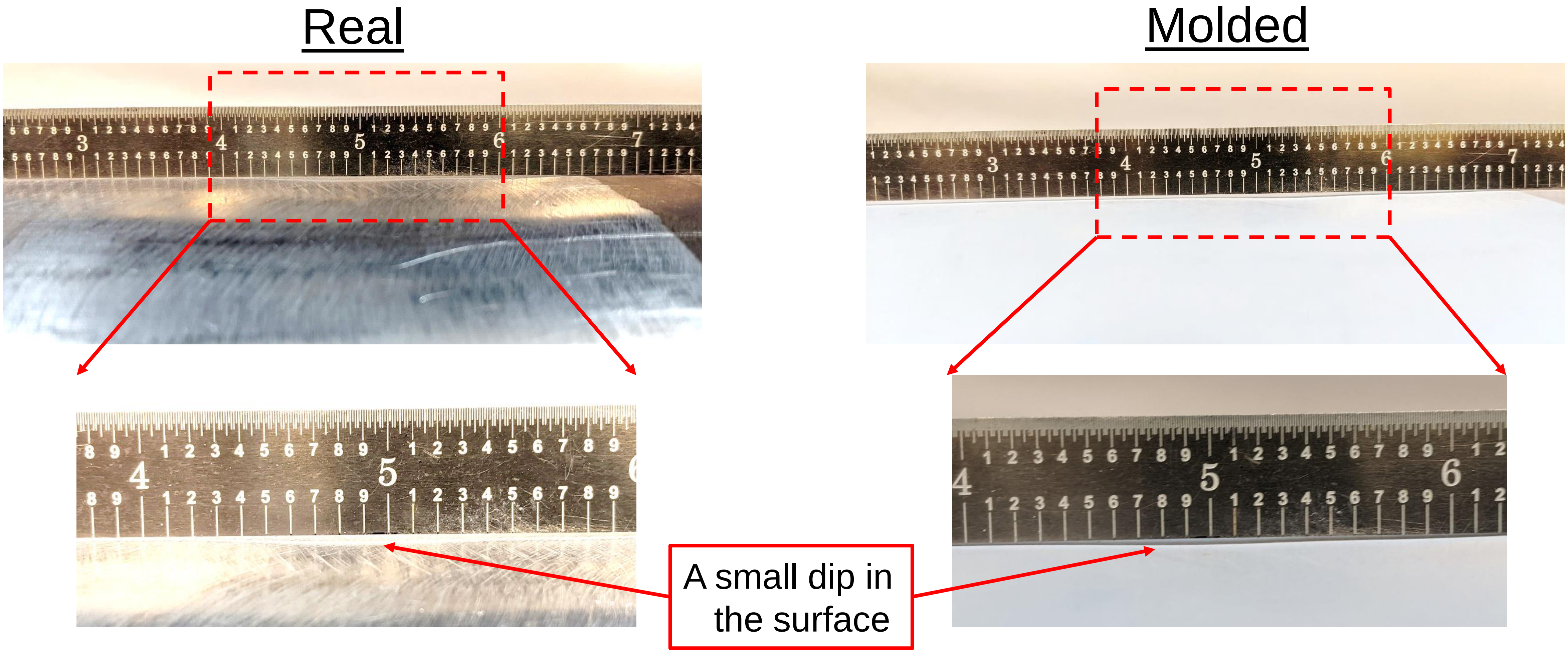
Side View

Real

3D Printed

Mockups – DMW Pipe Example

- Molding techniques can capture features that are difficult to see, but examiners can feel these features during scanning; such as hoop shrinkage in DM piping



Data Collection

- Data is collected so it represents non-encoded UT procedures
- This is accomplished by:
  - Collecting UT data with scan and index increments of 1 mm and 1-2mm, respectively
  - A three-axis scanner is used to collect skewed data at skew angles of 2° increments
  - Multiple gain levels are collected to help avoid data saturation
  - The time range for data collection exceeds that of procedures so that UT calibrations can be performed later
  - Data is collected with zero wedge delay so that UT calibrations can be performed later
- Collected data is then combined together into a simulator compatible datafile
  - For example, a circumferential scan datafile collected at 0° skew on the downstream side of a pipe is combined with the 180° skew datafile from the upstream side of the pipe
- Reference blocks are collected with the same UT instrument settings
  - This allows for UT calibrations to be applied to specimen datasets

UT Simulator Data Files

- Initial release of the simulator contained a total of 18 mockups covering PDI Generic Procedures for Appendix VIII Supplements 2, 3, and 10; plus seven reference blocks

Supplement Category	Number of Samples	Samples
Dissimilar Metal	5	703-8 706P1/P2 707P1/P2
Ferritic	4	16C-076 18C-195-1/2 423-P
Austenitic	3	305-OP-3 306-V 308-OP-2-C
IGSCC – Detection	4	305-C8 P1-3 P1-4 P1-7
IGSCC – Sizing	2	PT1/PT6
Total	18	N/A

Category	Number of Samples	Samples
Reference /Calibration Blocks	7	SS-Rompas CS-Rompas SS-AltBlock 6-Ax-02 6-Circ-03 12-AX-02 13-Circ-03

Future Plans

- Support member needs with VNDE systems
  - EPRI has multiple systems available to members and will continue to support members

- Collecting more UT Simulator data sets
  - Continue to focus on building the number of available datasets
  - Data collection takes significant effort and produces large data files
  - More data is being taken for austenitic, ferritic, IGSCC, WOL, etc. components

Benefits and Uses

- UT simulator can be used to support initial UT training, just-in-time training prior to examiners performing field examinations, maintaining examiner proficiency, hands-on practice, etc.
- Cost effective process to obtain data from existing specimens and share data with many users
  - Major benefit where only limited number of mockups are available, i.e., TF, IGSCC, DMW, or WOL specimens
  - Current focus has been on collecting data to represent industry generic procedures but data can be collected to represent any procedures
  - Can continue to add data files to expand data file library
- Portable and light weight system that can be easily shipped and handled

Together…Shaping the Future of Electricity

Closing the day

Public comment period

End-of-day announcements

- Wednesday session begins 8:00

Wednesday

Announcements

Announcements

- MRP's in-vessel inspection Virtual Reality application, used in the MRP-228 IVI training course, will be available for demonstration in the Auditorium Lobby all day Wednesday
  - Supports only one viewer at a time
  - Please feel free to (quietly) go to the lobby at any time in order to try it out

2019 Performance Demonstration Program Update

Dave Anthony
Exelon
Performance Demonstration Focus Group Chair

Leif Esp
EPRI
Principal Project Manager
Performance Demonstration Applications

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

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www.epri.com

2019 Qualification Activities

Piping Program Personnel Qualification Activities 2019

- Personnel Qualifications (General Statistics)
  - 136 Non-Encoded

Test Type	Detection	Length	TWS
Austenitic w/ IGSCC	9	7	6
Austenitic w/o IGSCC	13	12	6
Ferritic (Supplement 12)	13	16	12
Ferritic Only	0	0	0
Weld Overlay	0	0	0
Dissimilar Metal Welds	10	11	3
IGSCC Requalification	10	6	2
WOL Requalification	0	0	0

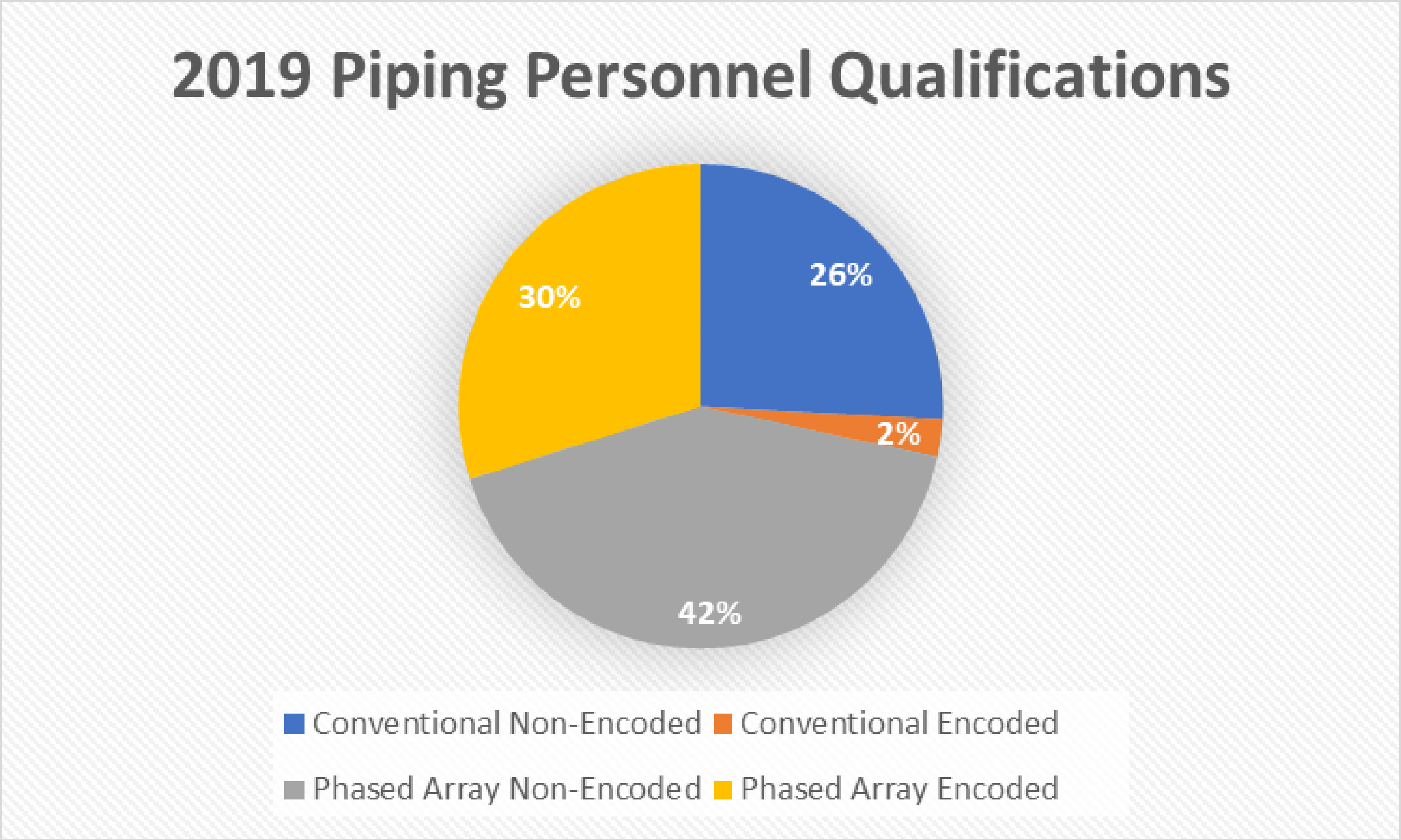
Piping Program Personnel Qualification Activities 2019

- Personnel Qualifications (General Statistics)
  - 65 Encoded

Test Type	Detection	Length	TWS
Austenitic w/ IGSCC	0	0	0
Austenitic w/o IGSCC	0	0	0
Ferritic (Supplement 12)	0	0	0
Ferritic Only	4	5	4
Weld Overlay	0	0	0
Dissimilar Metal Welds	17	17	18
IGSCC Requalification	0	0	0
WOL Requalification	0	0	0

Piping Program Personnel Qualification Activities 2019

- Personnel Qualifications (General Statistics)
  - **72%** (144/201) of piping personnel qualifications used phased array
    - **Non-Encoded** qualifications = **62%** (84/136)
    - **Encoded** qualifications = **92%** (60/65)



RPV Personnel Qualifications Activities Year to Date 2019

- Personnel Qualifications
  - Non-Encoded
    - 5 Candidates, Supplement 8 (Bolting)
    - 11 Candidates, Supplement 5 (RPV Nozzles from the OD)
    - 16 Candidates, Supplement 4 & 6 (RPV Welds)
  - Encoded
    - 7 Candidates, Supplement 7 (RPV Nozzles from the ID)
    - 0 Candidates, Supplement 5 (RPV Nozzles from the OD)
    - 16 Candidates, Supplement 4 & 6 (RPV Welds)
    - 3 Candidates, Upper Head Penetration

Procedure Qualifications - RPV Year to Date 2019

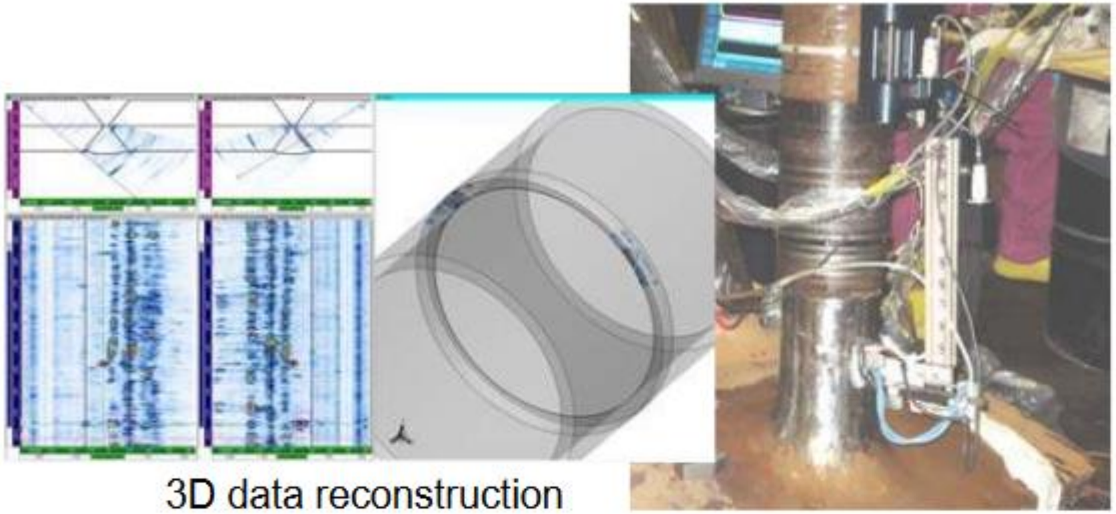
- RPV – (Encoded – Automated)
  - Supplement 4 & 6 from the ID
    - New PA Procedure Qualification
  - Supplement 6
    - Procedure Modification / Equivalency Qualification
  - Supplement 4, 5, 6, & 7 from the ID
    - New PA Procedure Qualification (in process)

Procedure Qualifications - Piping Year to Date 2019

- Piping – (Encoded – Automated)
  - Supplement 10 from the OD
    - New PA Procedure Qualification
  - Supplements 2, 3, & 10 from the ID
    - New PA Procedure Qualification
  - Supplements 2 & 10 from the ID
    - Expansion of previously qualified conventional UT vendor procedure to include AP1000 Reactor Vessel Nozzle (RVNZ) configuration
  - Supplement 10 from the OD
    - Addition of New Technique Sheets to EPRI-ENC-DMW-PA-1
      - KKB SG Configuration
      - Koeberg Replacement Steam Generator Configuration
      - AP1000 Steam Generator Inlet Configuration (in process)

Procedure Qualifications - Piping Year to Date 2019 cont....

- Piping – (Encoded – Automated)
  - CASS AP1000 Reactor Coolant Pump Procedure and Personnel Capability Demonstration from the OD
  - Supplement 10 from the OD
    - New PA Procedure Qualification (in process)
  - Supplements 2 & 3 from the OD
    - New PA Procedure Qualification (in process)
- Piping – (Non-Encoded – Manual)
  - Supplement 2 from the OD
    - PDI-UT-2 expansion for AP1K-SGINZ configuration (expanded thickness)
  - Supplement 10 from the OD
    - PDI-UT-10 configuration add-on for AP1K-PRHR & AP1K-PSNZ configurations

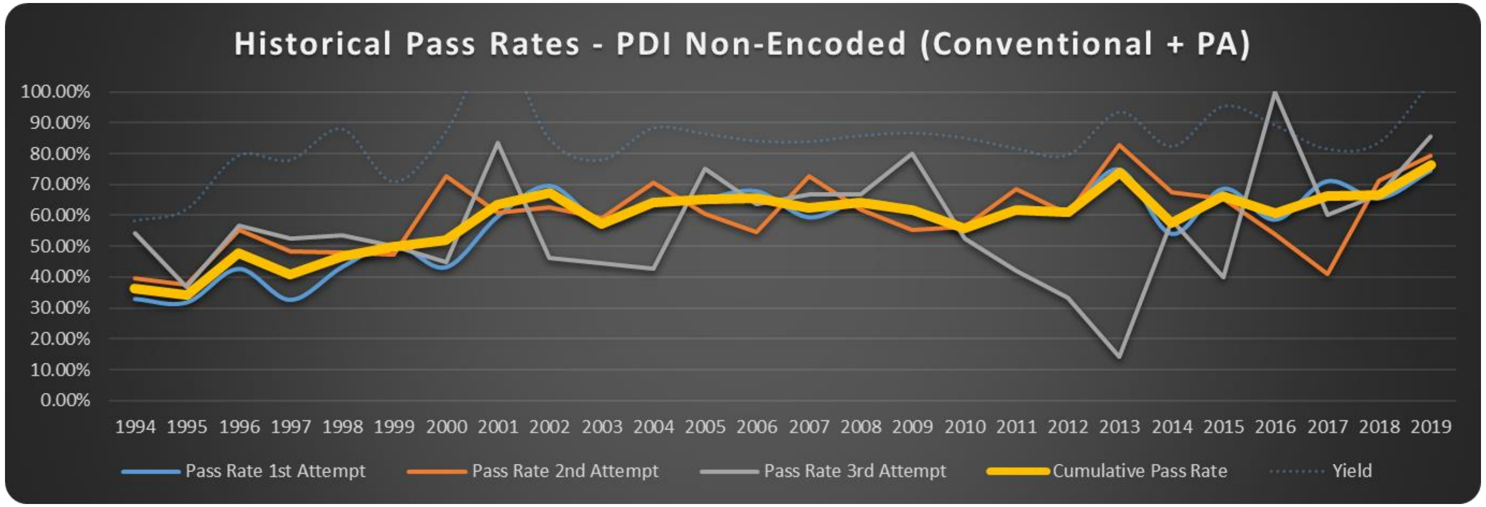


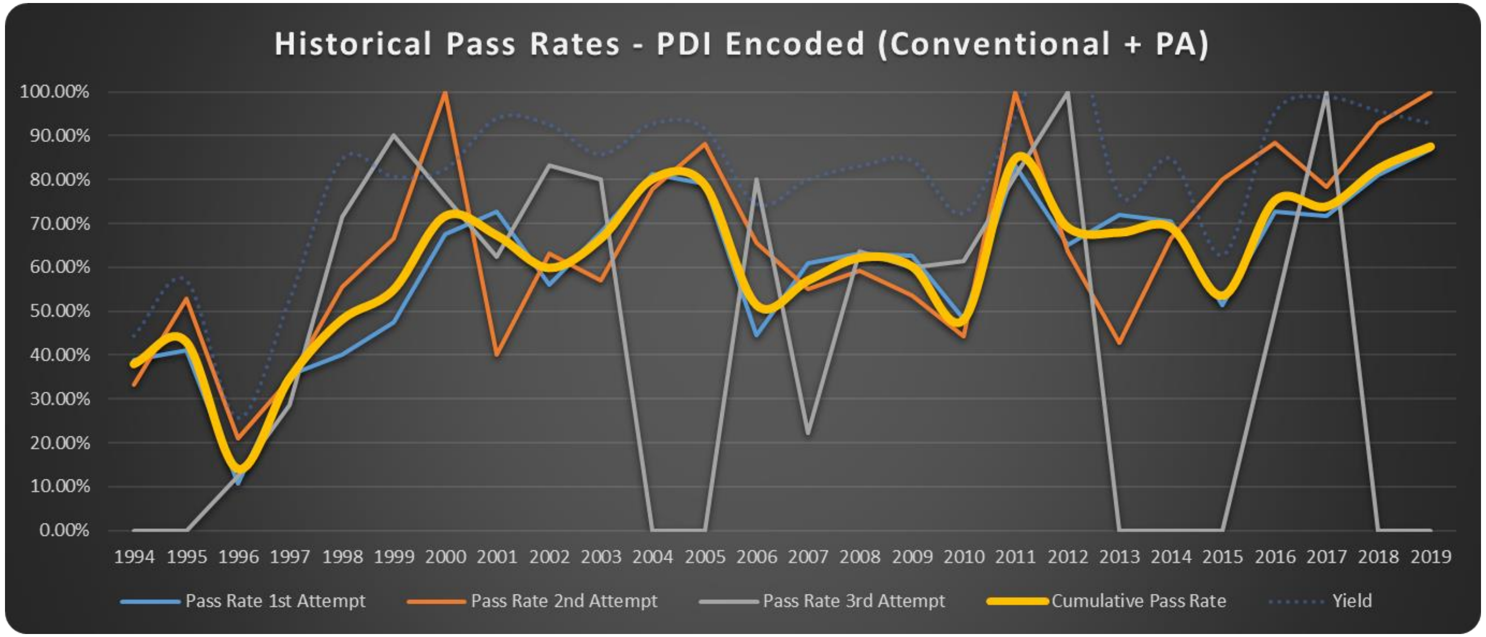
3D data reconstruction

Performance Demonstration Statistics

PDI Non-Encoded and Encoded Pass Rates

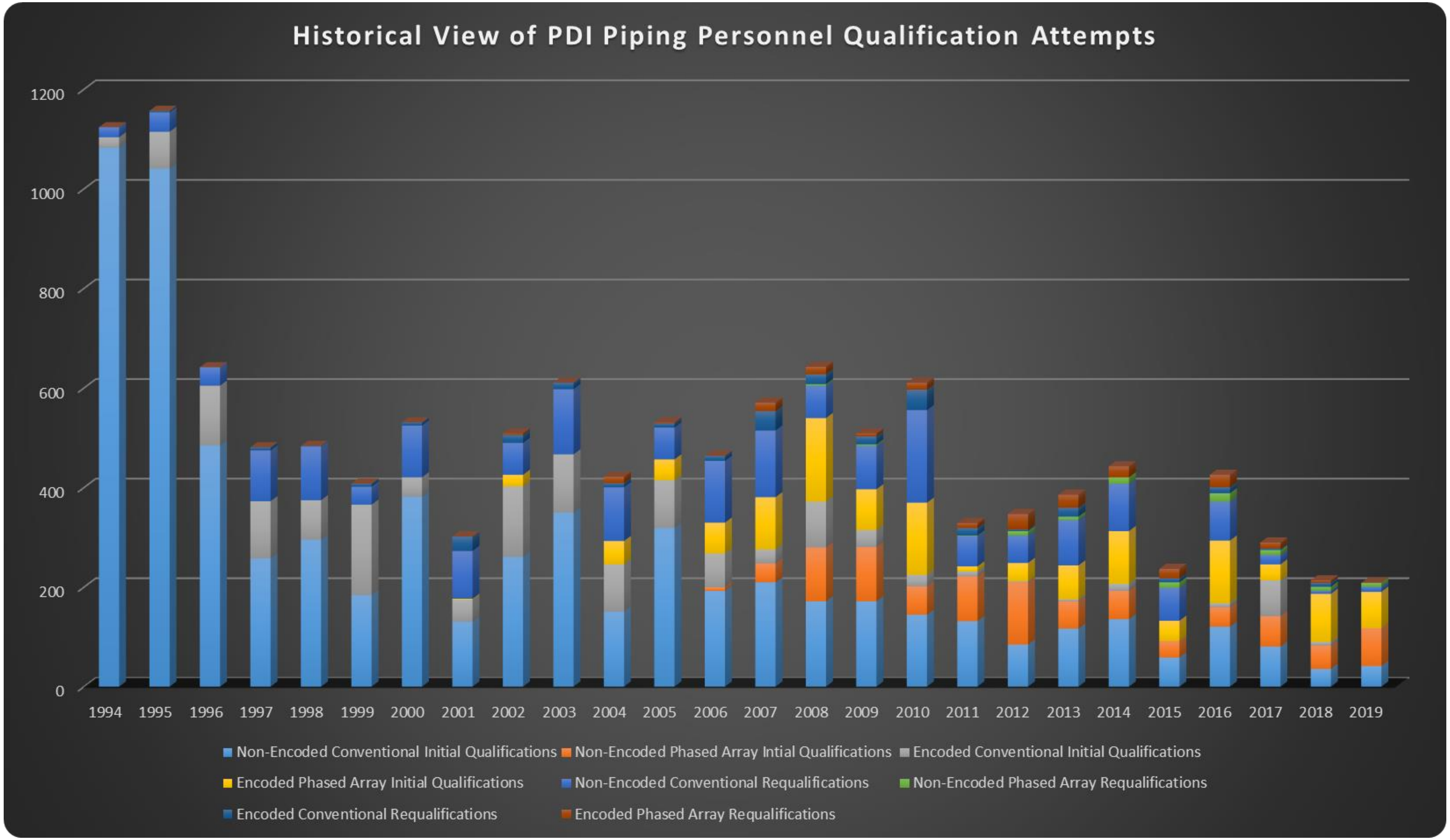
- Pass Rates for 2019 in line with historical trends / normal operating range
- No significant changes to Pass Rates in 2019



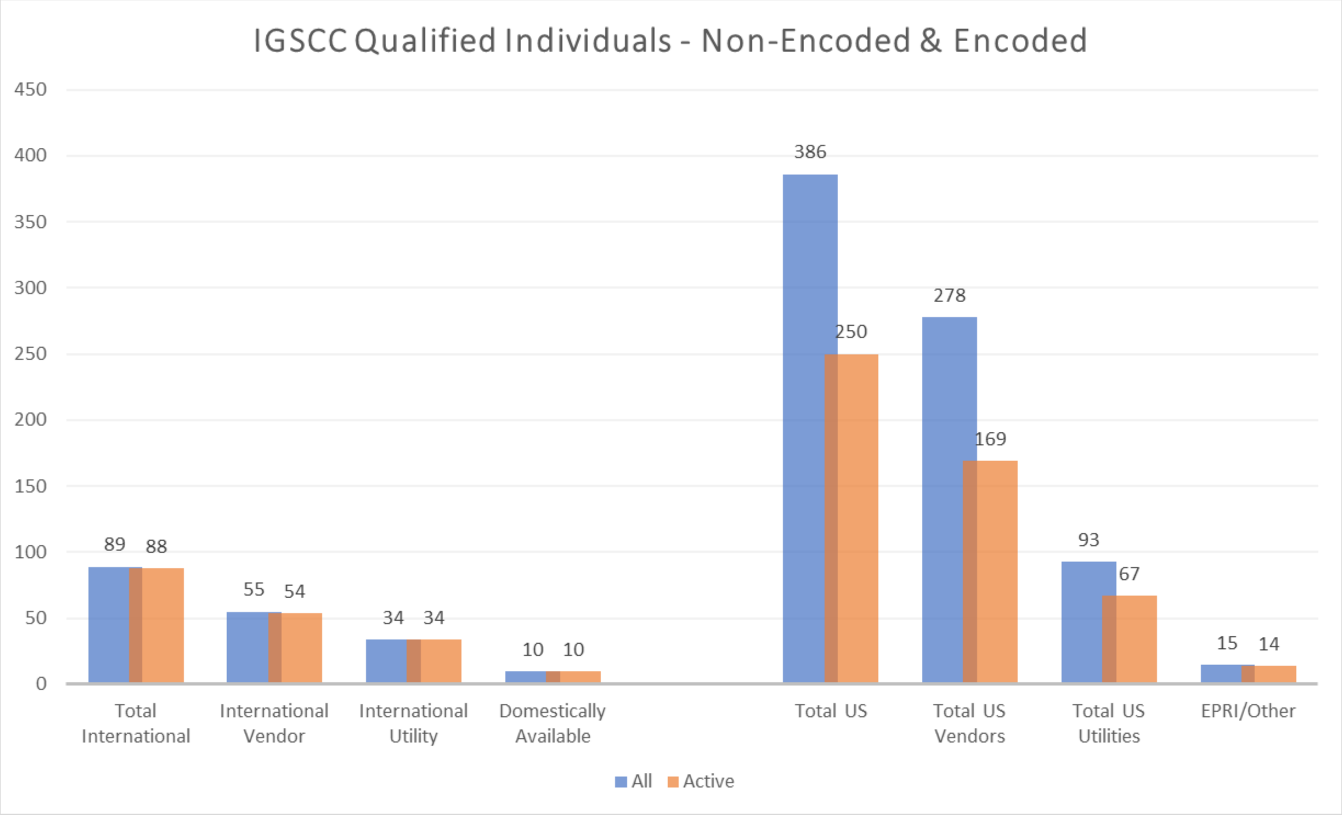


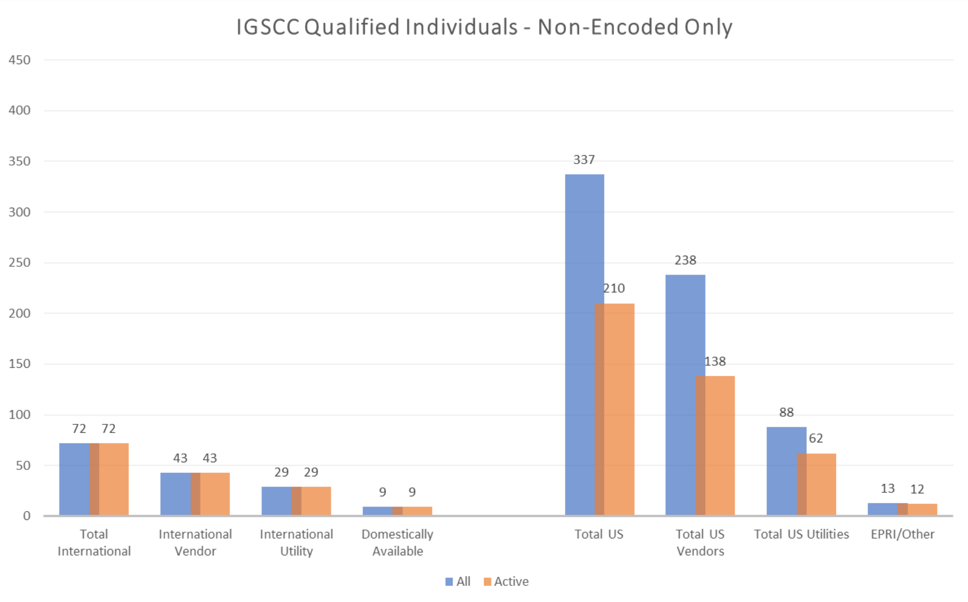
Personnel Qualifications – A Historical View

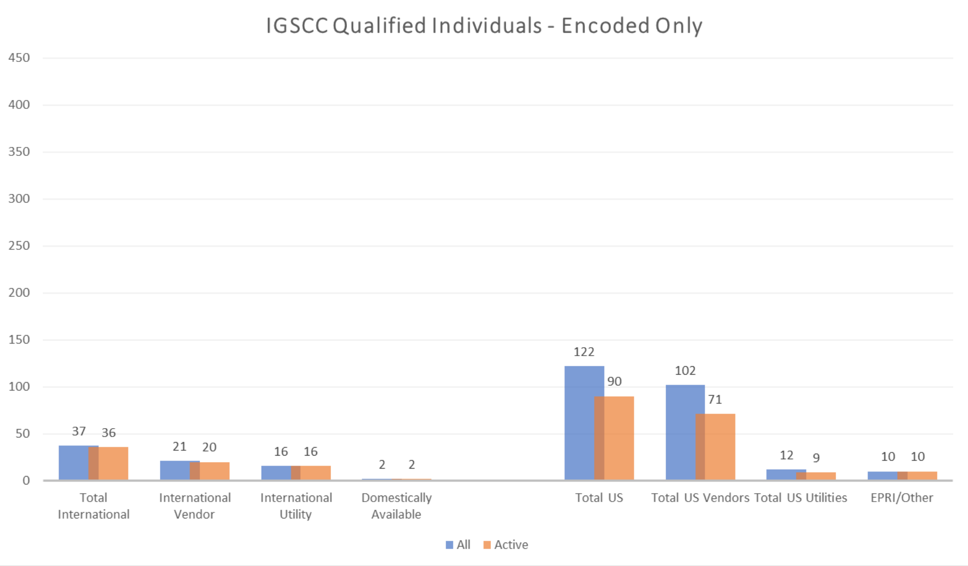
Volume of qualification attempts has approached a "new normal" of about 200/yr



IGSCC Qualified Individuals – All Procedures





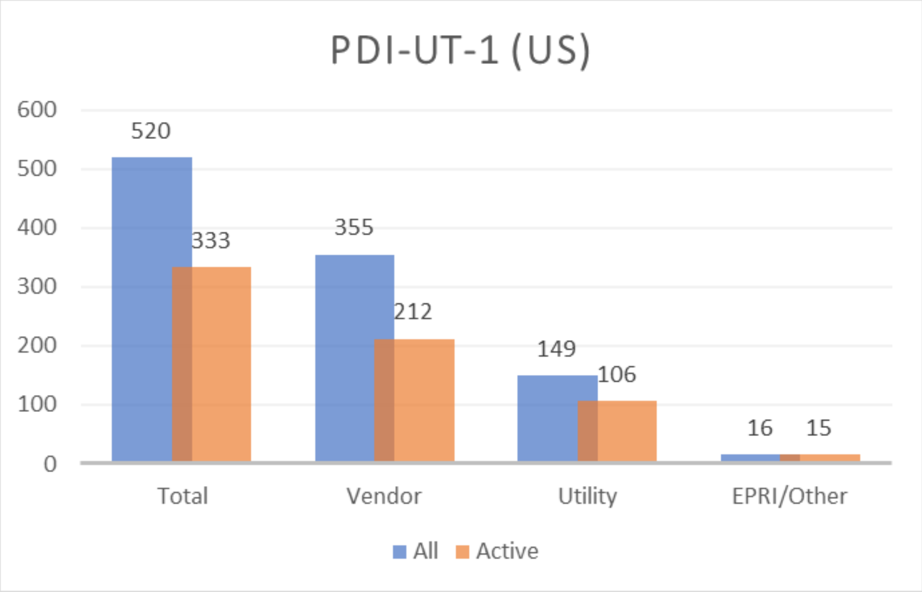


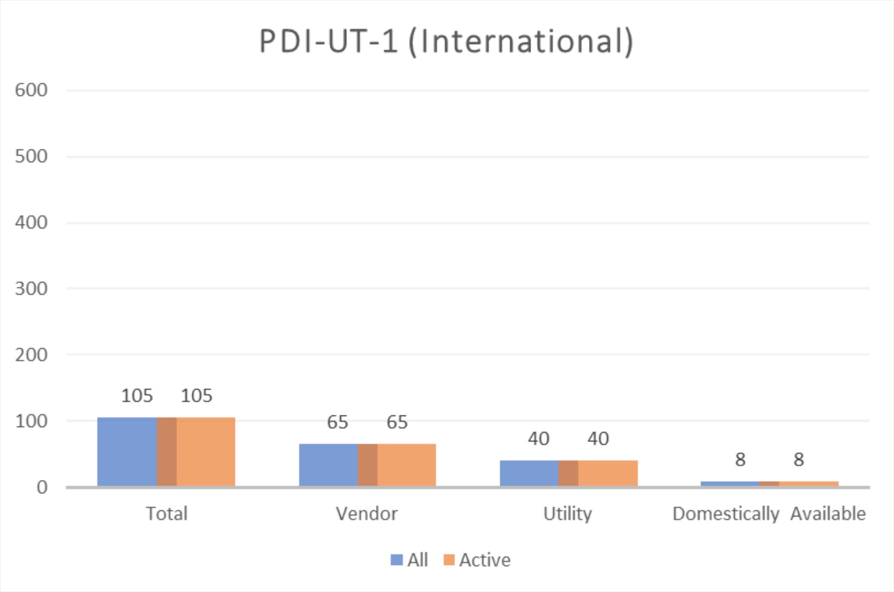
* Note – Some individuals appear in both the Non-Encoded Only and Encoded Only stats as they hold PDQSs for both

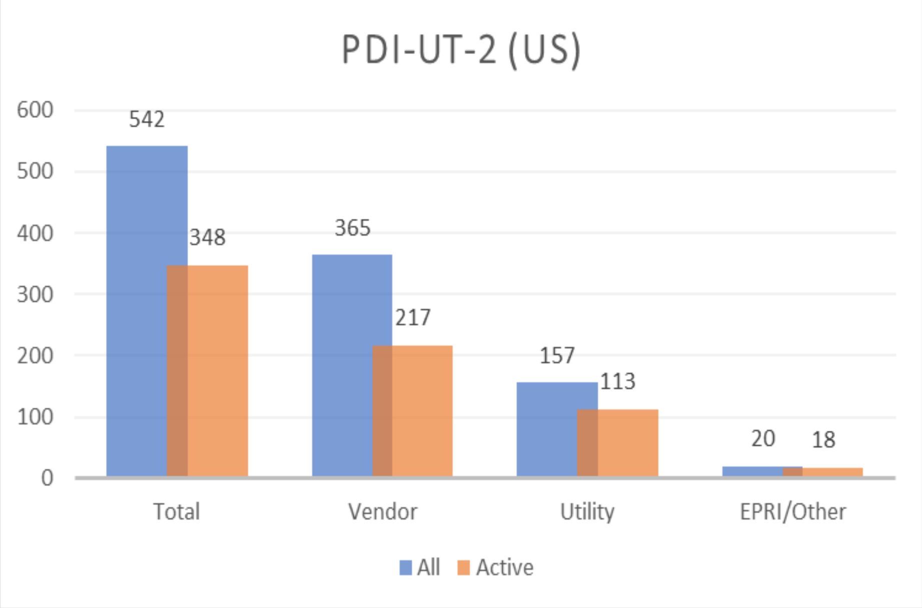
PDI-UT-1 & PDI-UT-2 – Qualified Individuals

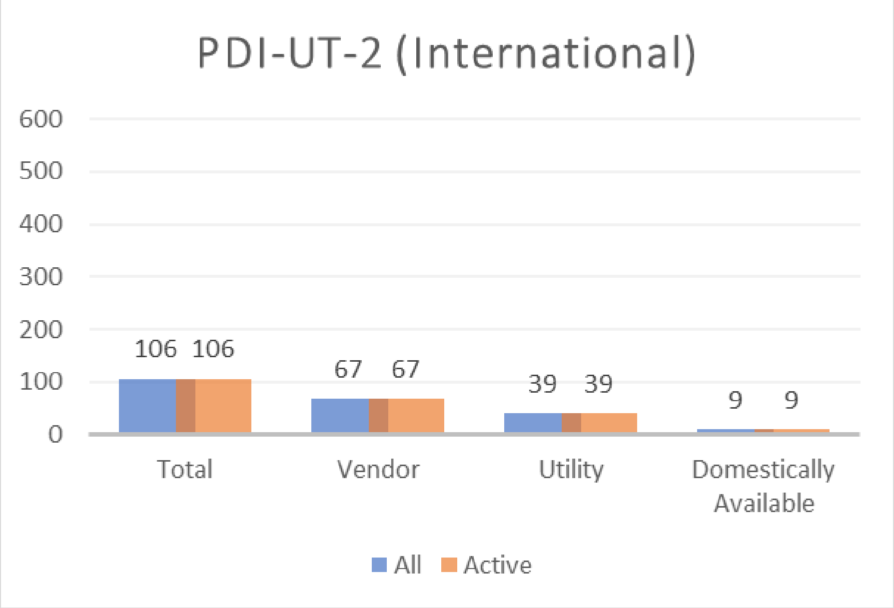
- PDI-UT-1
  PDI Generic Procedure for Ultrasonic Examination of Ferritic Pipe Welds

- PDI-UT-2
  PDI Generic Procedure for Ultrasonic Examination of Austenitic Pipe Welds

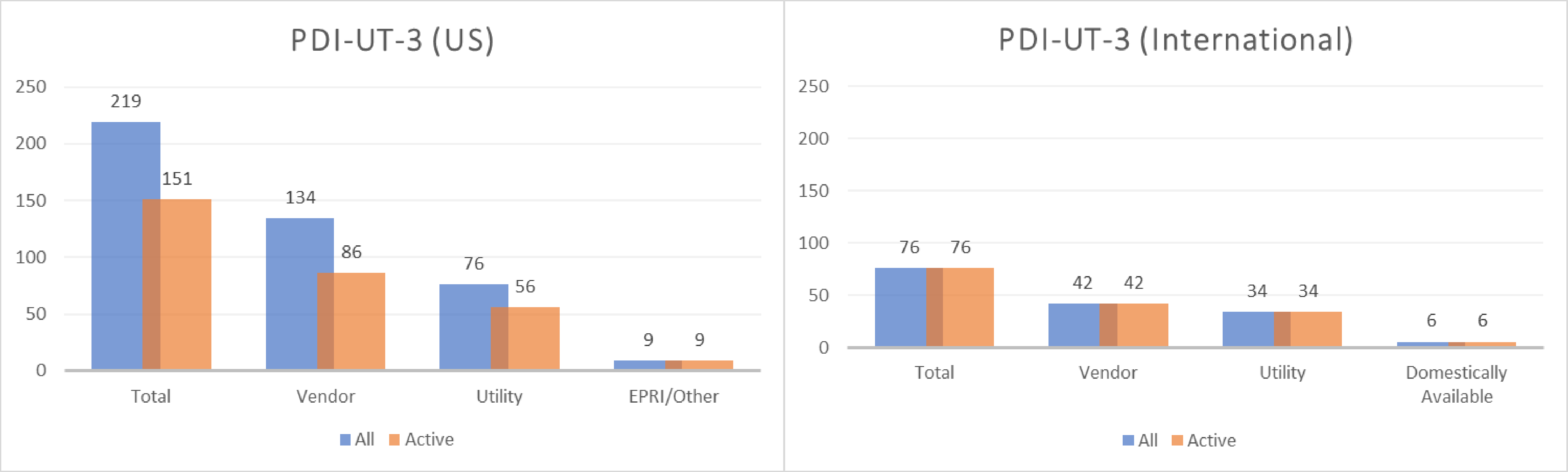








PDI-UT-3 – Qualified Individuals

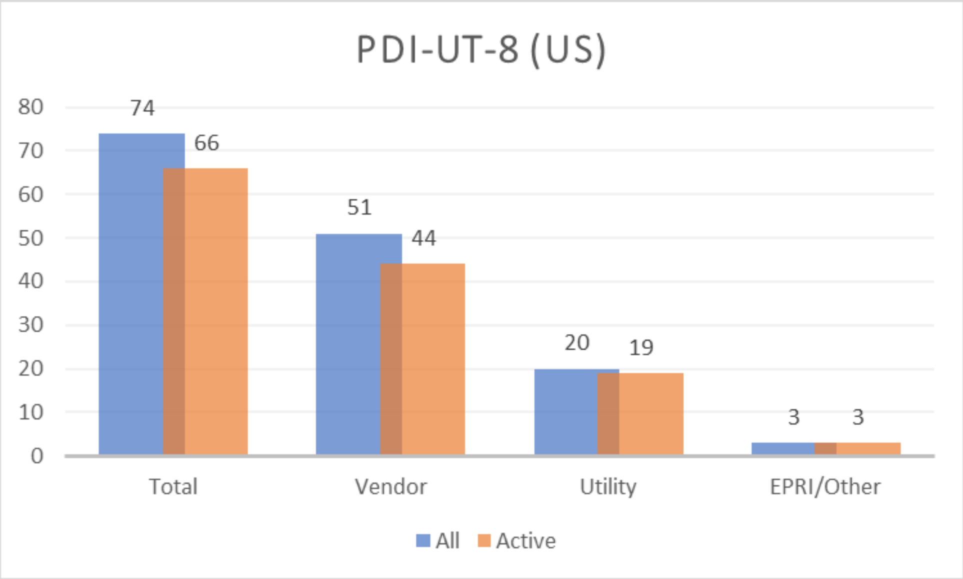


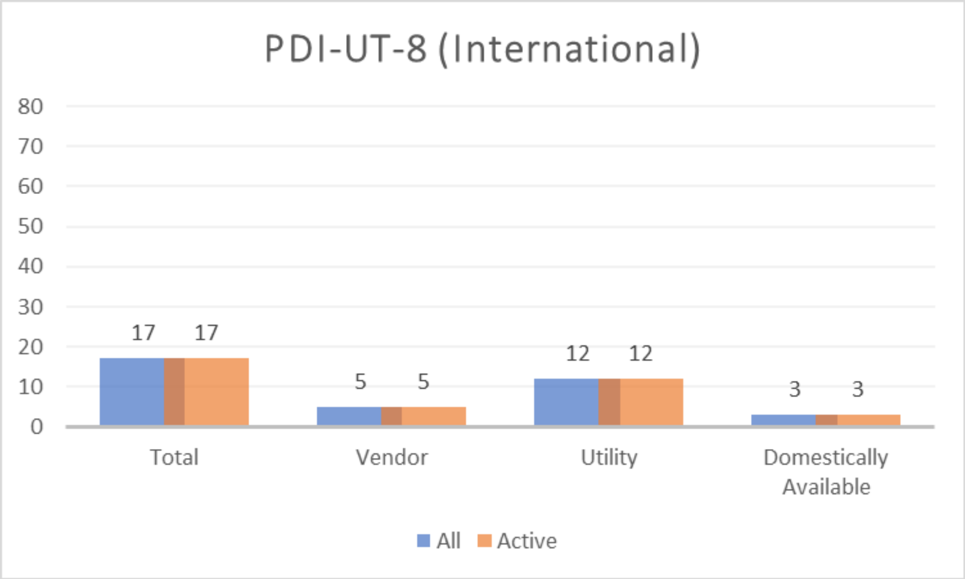
- PDI-UT-3
  PDI Generic Procedure for Ultrasonic Through-Wall Sizing in Pipe Welds

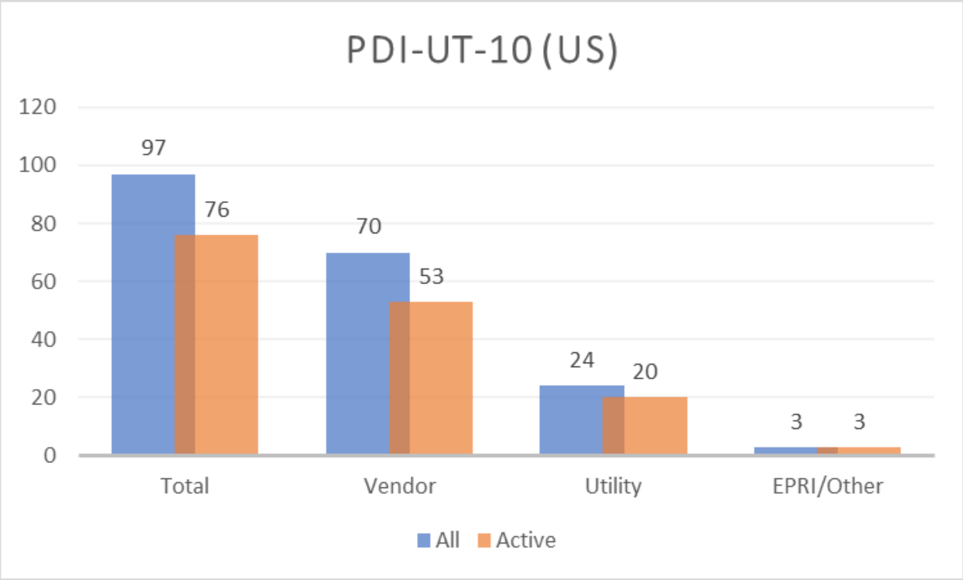
PDI-UT-8 & PDI-UT-10 – Qualified Individuals

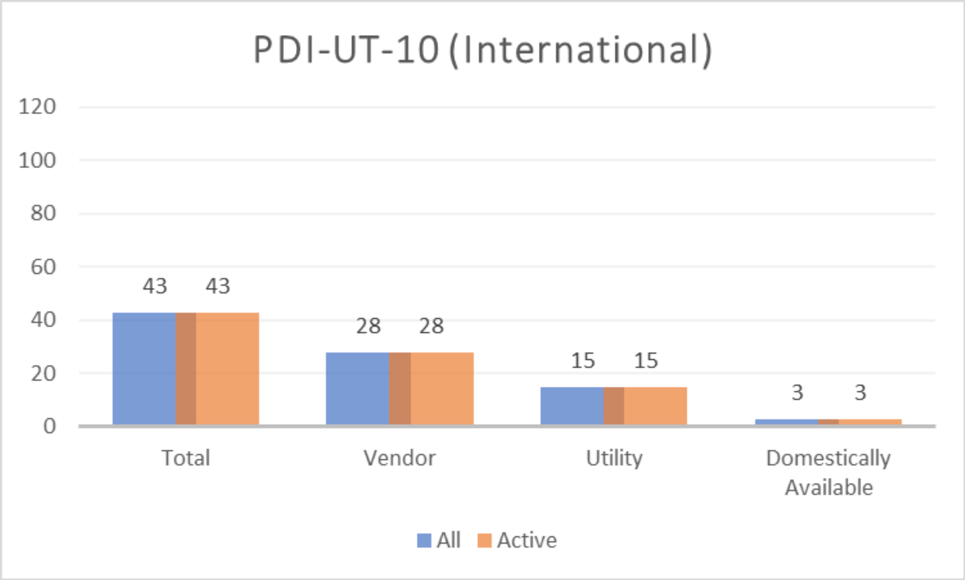
- PDI-UT-8
  PDI Generic Procedure for the Ultrasonic Examination of Weld Overlaid Similar and Dissimilar Metal Welds

- PDI-UT-10
  PDI Generic Procedure for the Ultrasonic Examination of Dissimilar Metal Welds





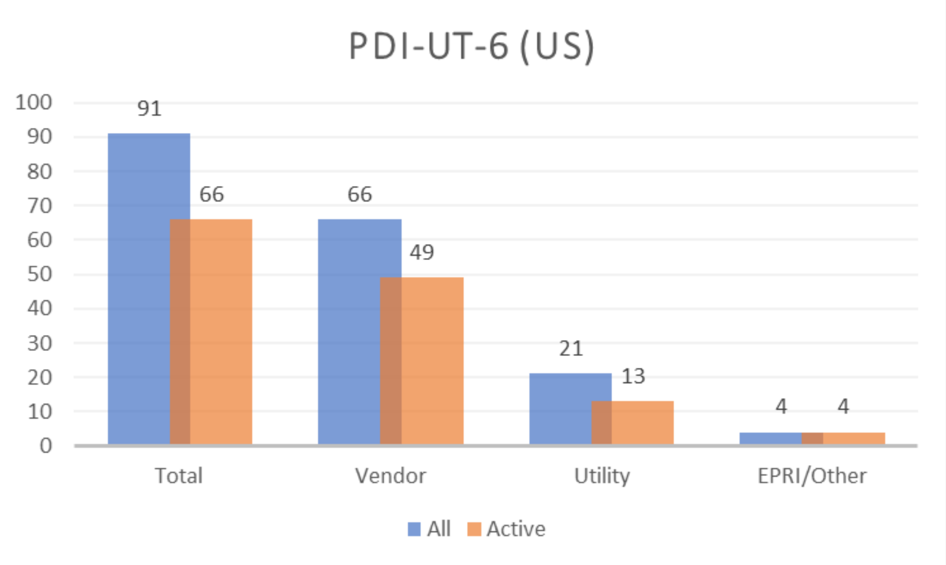


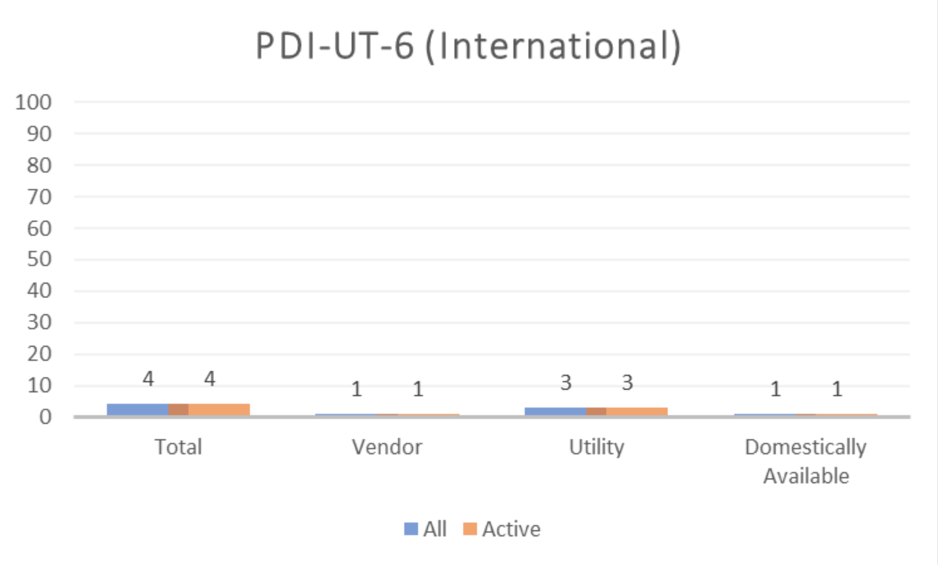


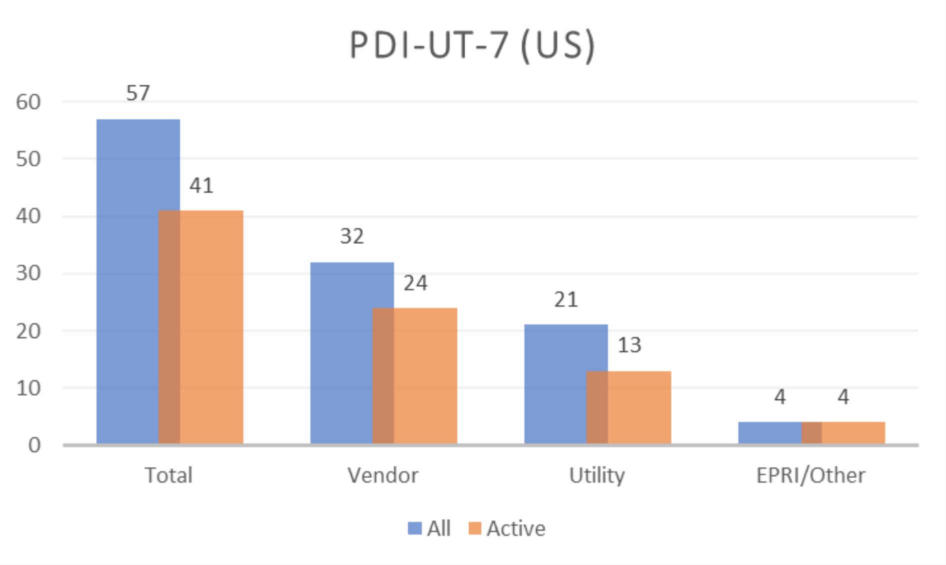
PDI-UT-6 & PDI-UT-7 – Qualified Individuals

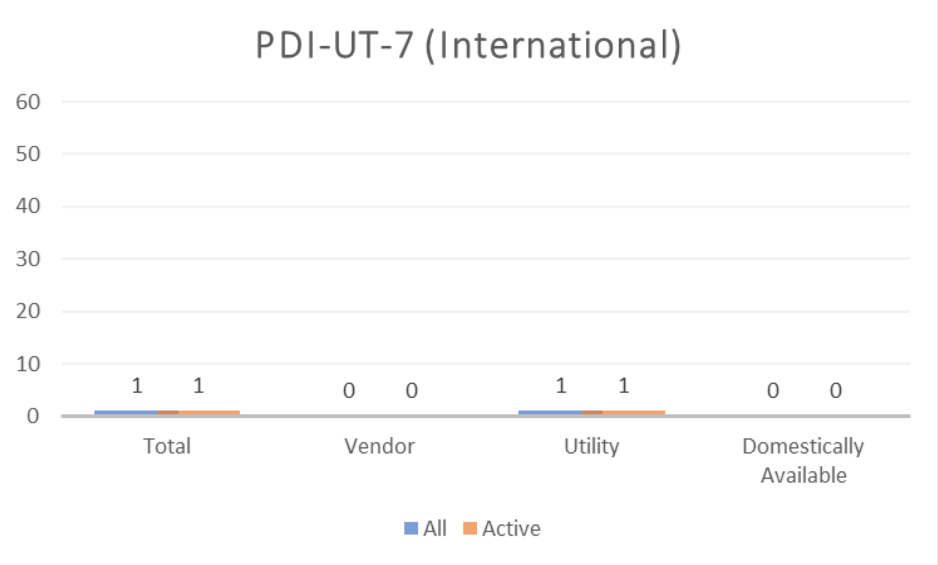
- PDI-UT-6
  PDI Generic Procedure for Ultrasonic Examination of Reactor Pressure Vessel Welds

- PDI-UT-7
  PDI Generic Procedure for the Manual Ultrasonic Through Wall and Length Sizing of Ultrasonic Indications in Reactor Pressure Vessel Welds





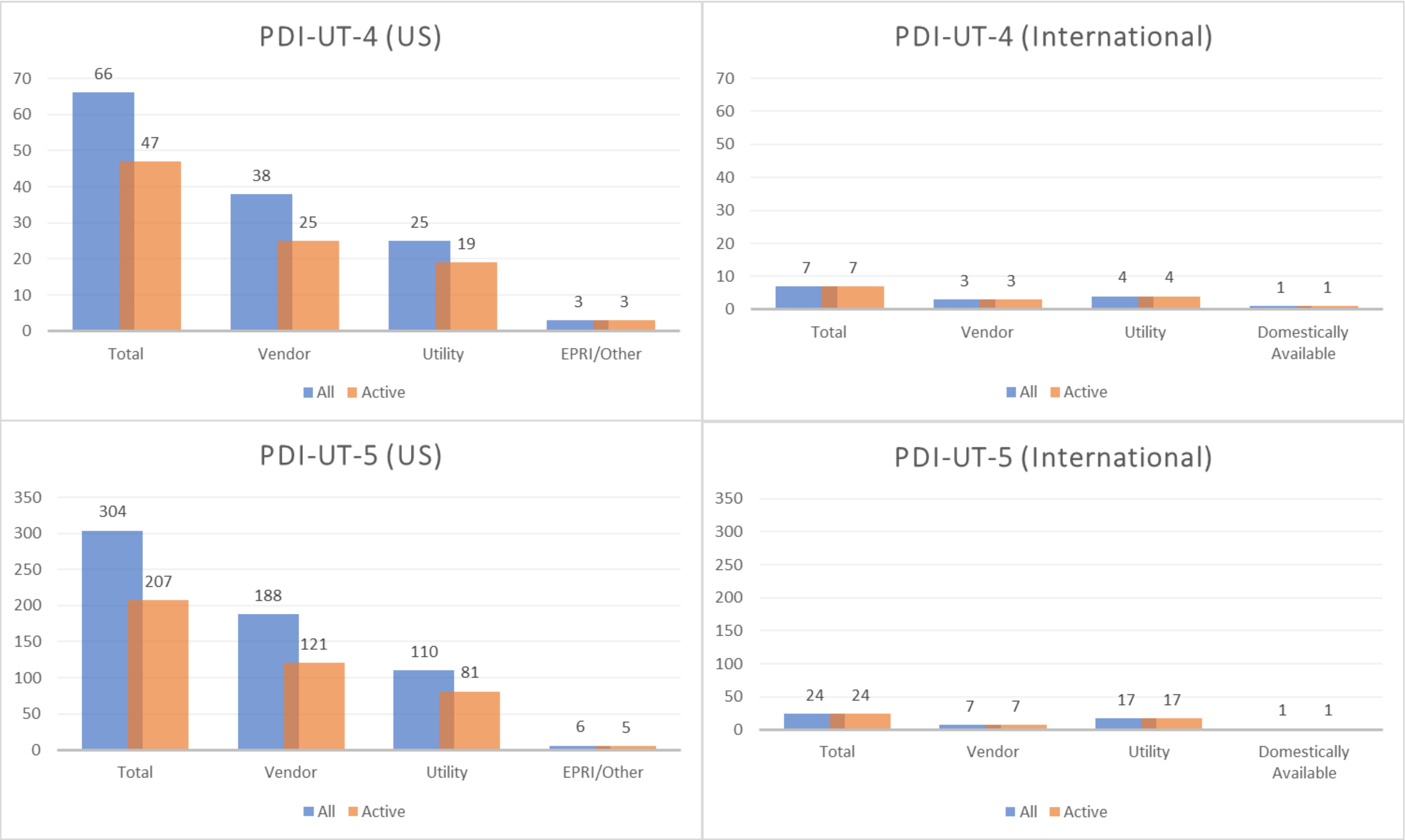




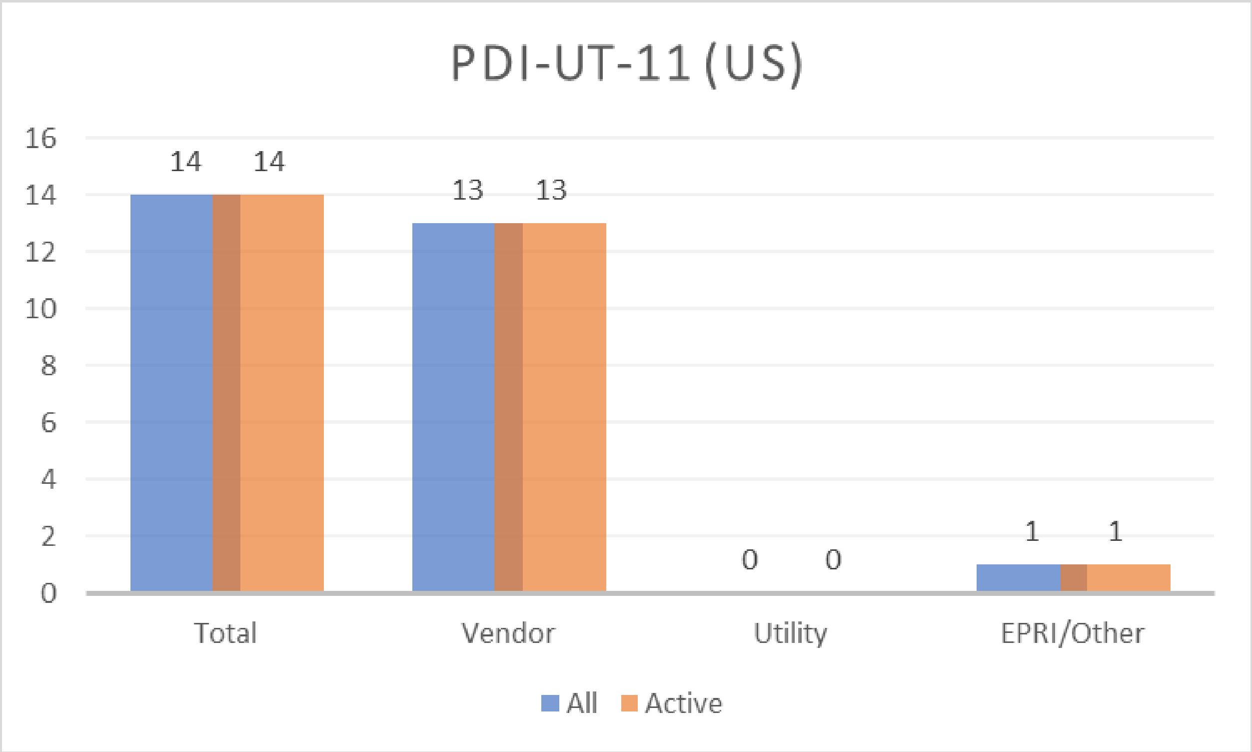
PDI-UT-4 & PDI-UT-5 – Qualified Individuals

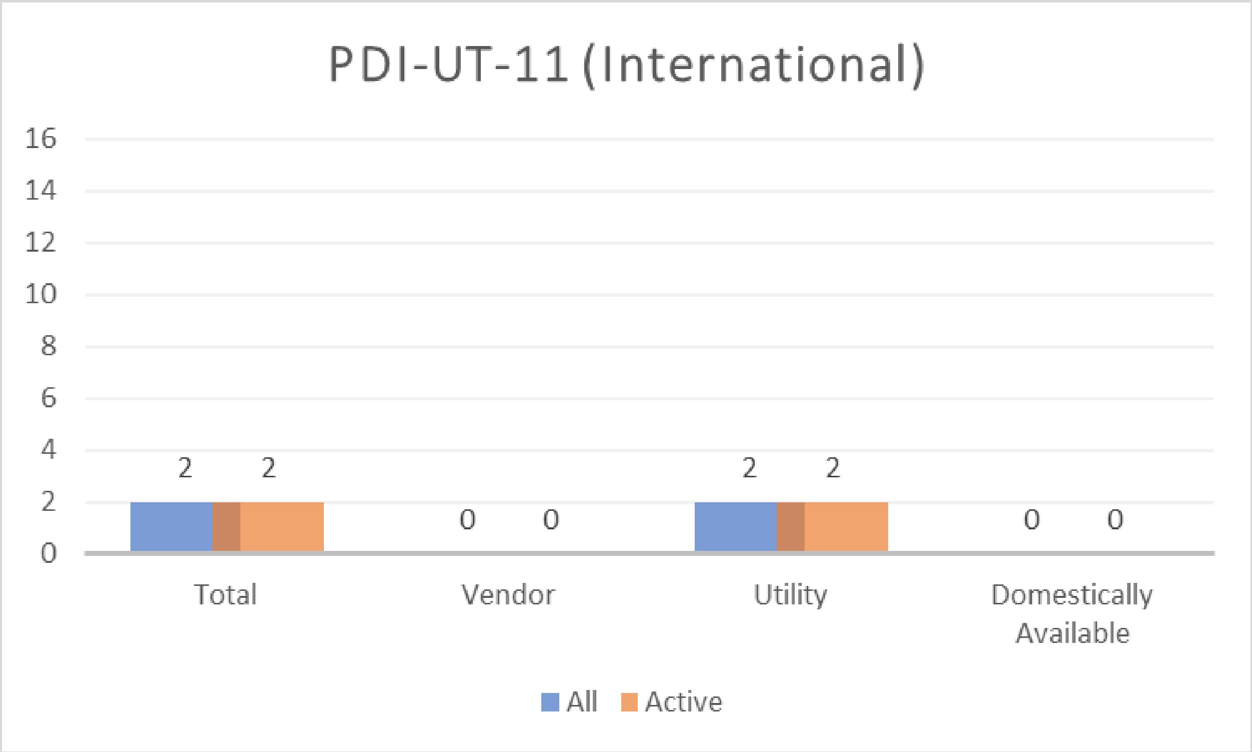
- PDI-UT-4
  PDI Generic Procedure for Ultrasonic Examination of Bolts and Studs from the Bore

- PDI-UT-5
  PDI Generic Procedure for Straight Beam Ultrasonic Examination of Bolts and Studs



PDI-UT-11 – Qualified Individuals

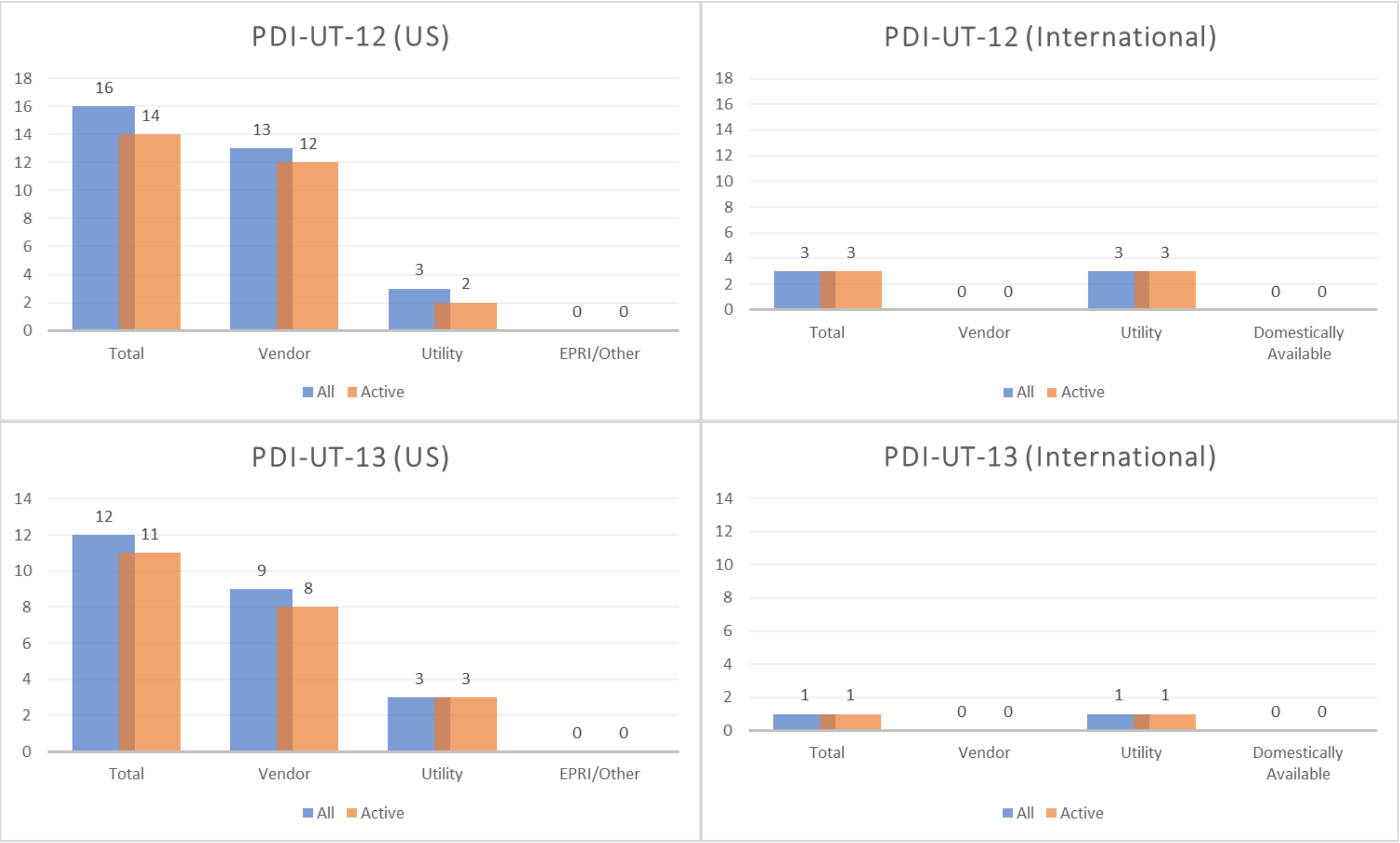




- PDI-UT-11
  PDI Generic Procedure for the Ultrasonic Detection and Sizing of Reactor Pressure Vessel Nozzle to Shell Welds and Nozzle Inner Radius

PDI-UT-12 & PDI-UT-13 – Qualified Individuals

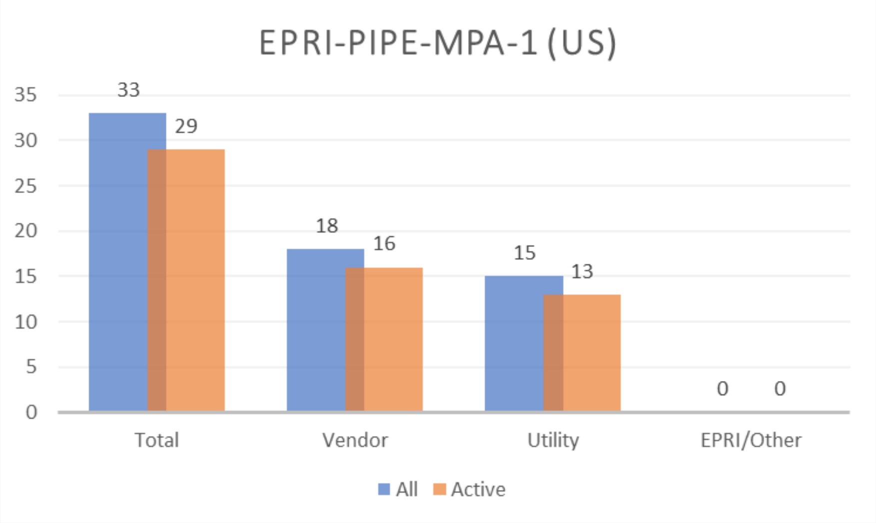
- PDI-UT-12
  PDI Generic Procedure for Manual Phased Array Ultrasonic Examination of Reactor Pressure Vessel Welds
- PDI-UT-13
  PDI Generic Procedure for Manual Phased Array Ultrasonic Examination of Reactor Pressure Vessel Nozzle to Shell Welds and Nozzle Inner Radius Regions

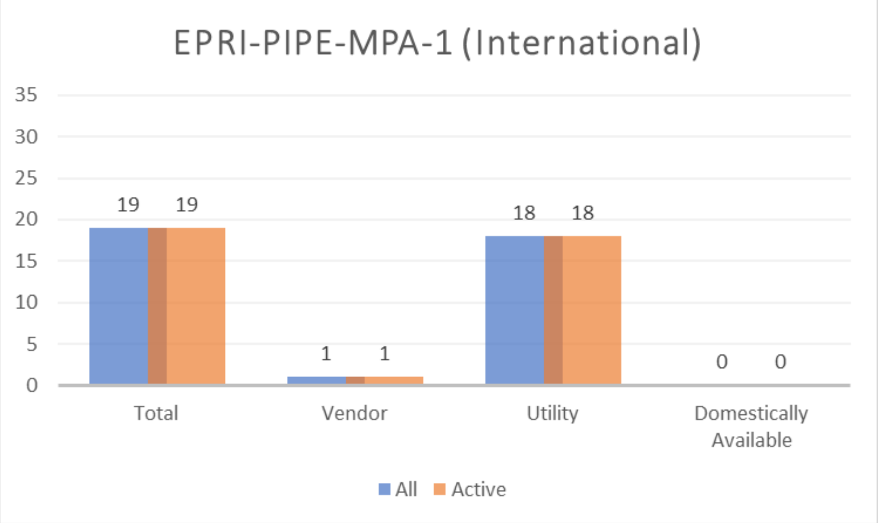


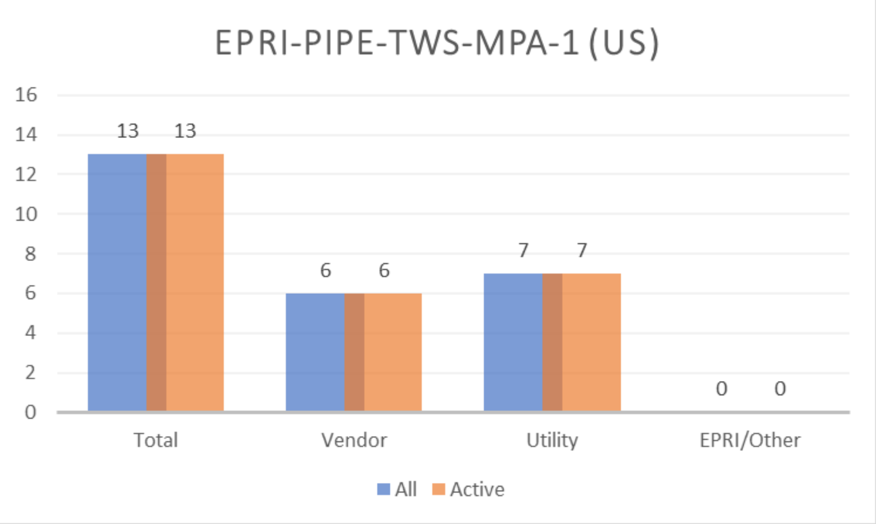
EPRI-PIPE-MPA-1 & EPRI-PIPE-TWS-MPA-1 – Qualified Individuals

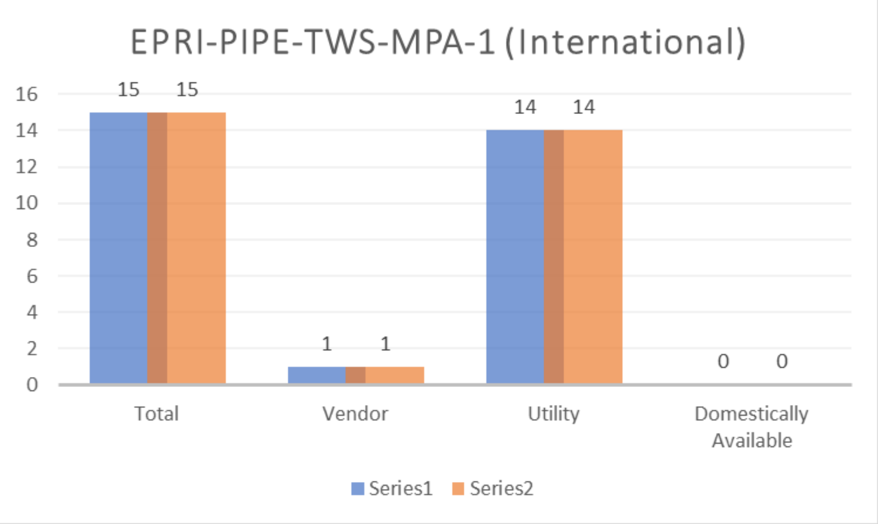
- EPRI-PIPE-MPA-1 *Procedure for Manual Phased Array Ultrasonic Examination of Austenitic and Ferritic Pipe Welds*

- EPRI-PIPE-TWS-MPA-1 *Procedure for Manual Phased Array Ultrasonic Through Wall Sizing in Pipe Welds*





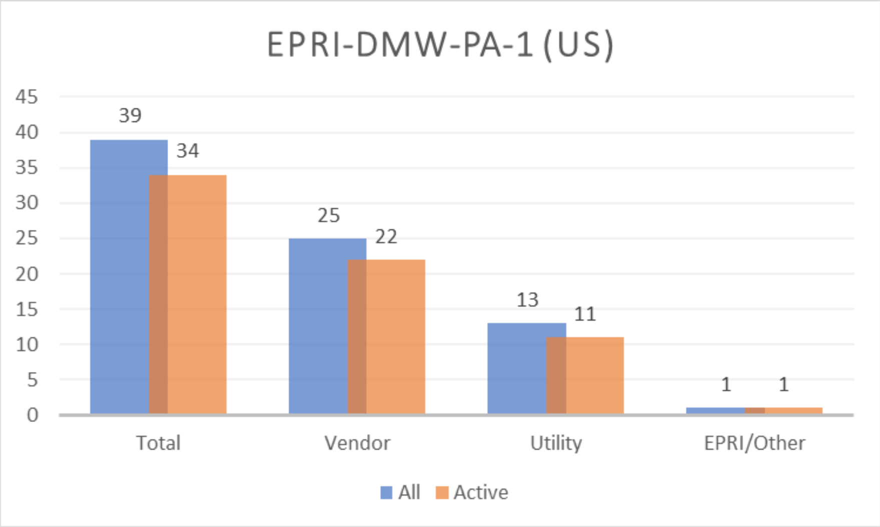


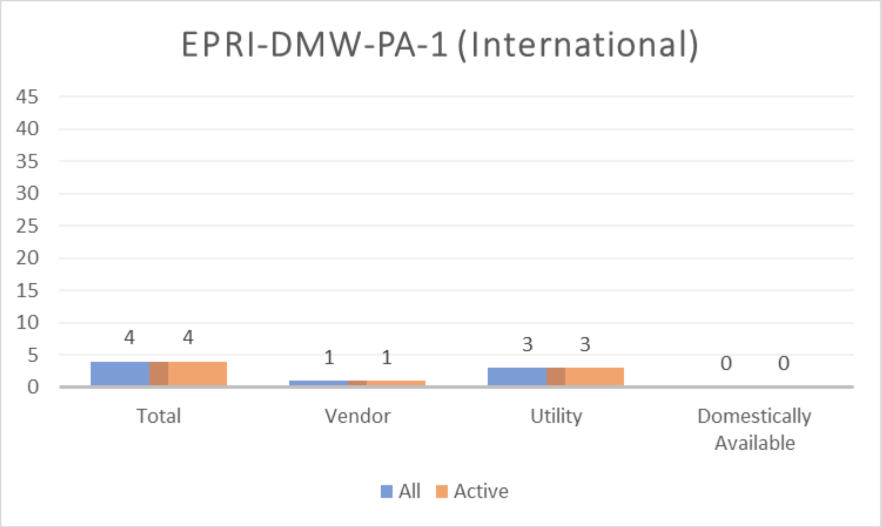


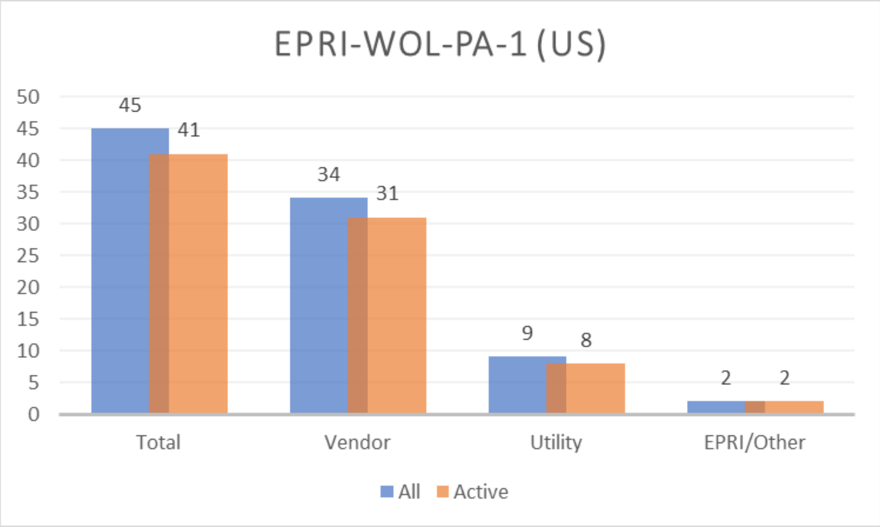
EPRI-DMW-PA-1 & EPRI-WOL-PA-1 – Qualified Individuals

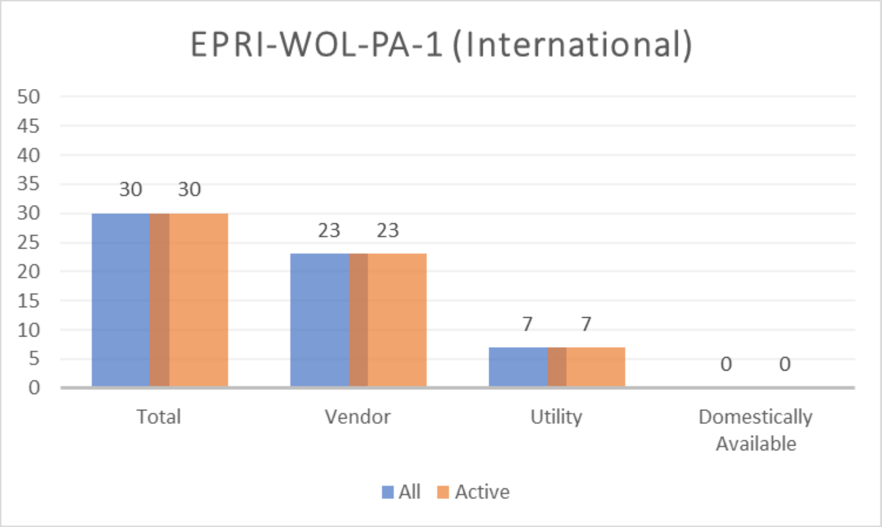
- EPRI-DMW-PA-1 *Procedure for Manual Phased Array Ultrasonic Examination of Dissimilar Metal Welds*

- EPRI-WOL-PA-1 *Procedure for Manual Phased Array Ultrasonic Examination of Weld Overlaid Similar and Dissimilar Metal Welds*

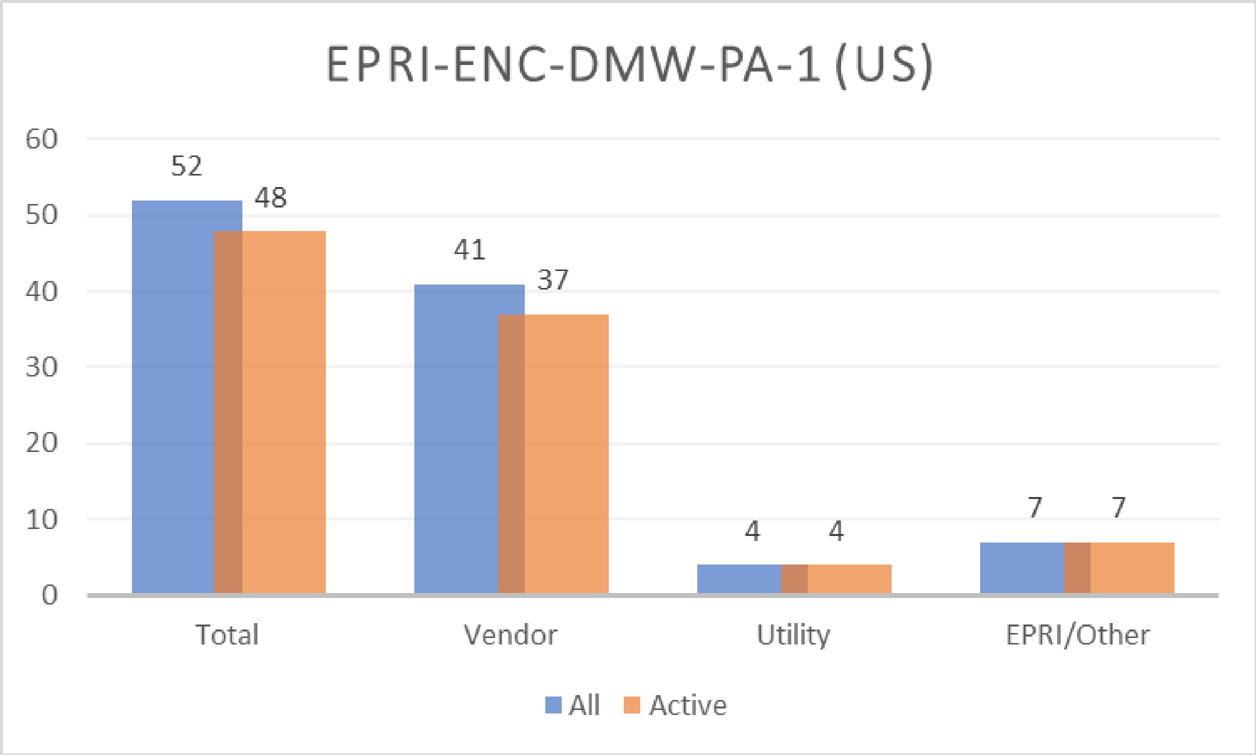


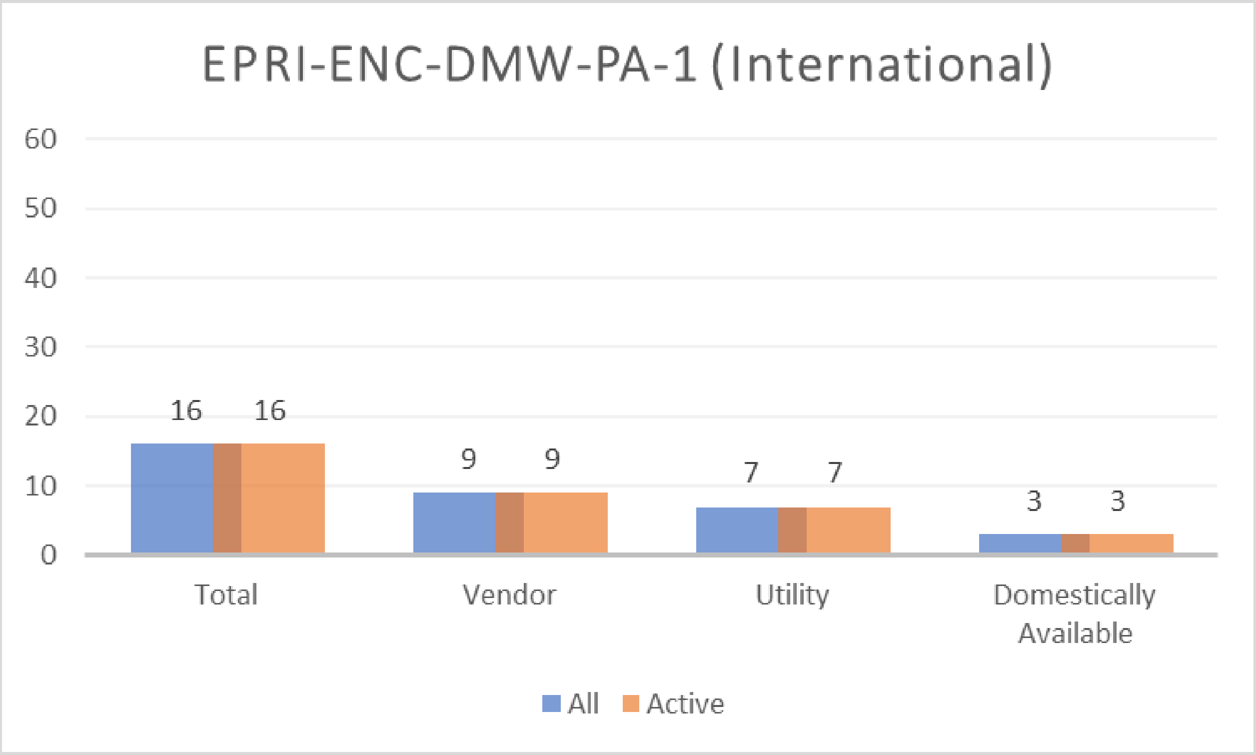






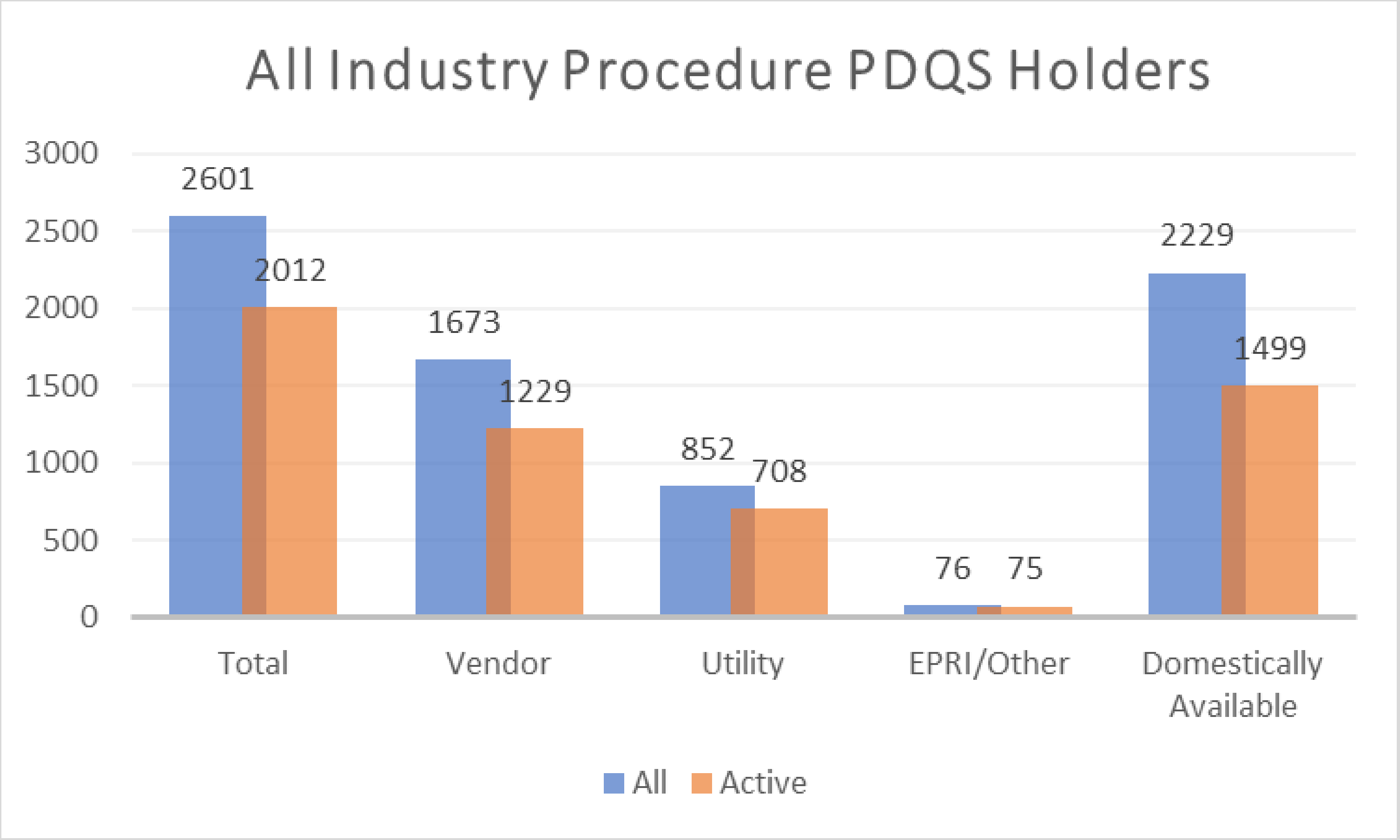
EPRI-ENC-DMW-PA-1 – Qualified Individuals





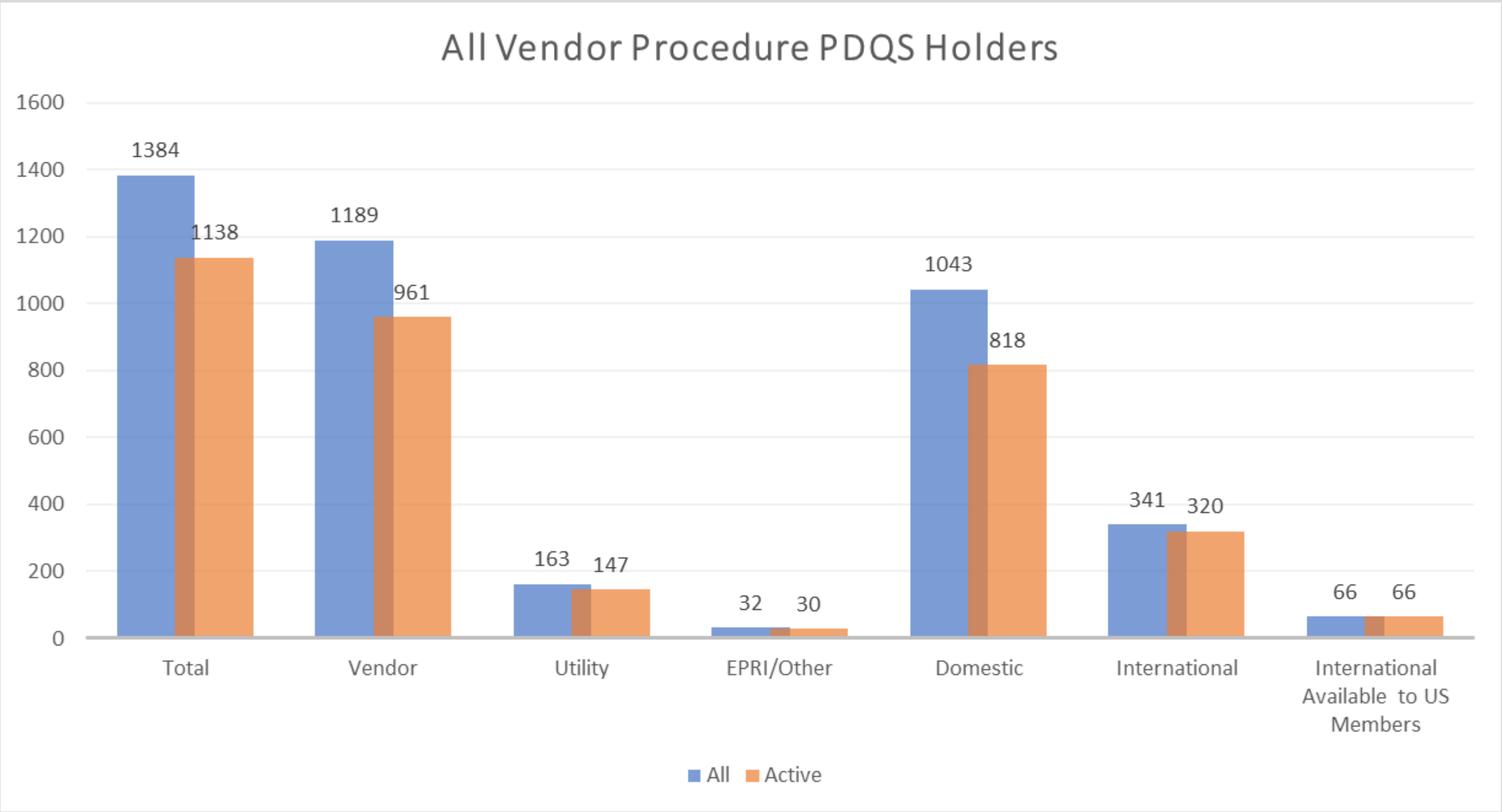
- EPRI-ENC-DMW-PA-1
  Procedure for Encoded Phased Array Ultrasonic Examination of Dissimilar Metal Piping Welds

Qualified Individuals – All Industry Procedures Combined



- 736 Qualified Individuals hold 2601 PDQSs for the industry procedures
  - 524 Active PDQS holders
    - 365 in the US
      - 230 vendor personnel
      - 112 utility personnel
      - 23 EPRI or other personnel
    - 159 internationally
      - 107 vendor personnel
        - 9 available to US utilities
      - 52 utility personnel

Qualified Individuals – Vendor Procedures



- 433 Qualified Individuals hold 1384 PDQSs for vendor procedures
  - 335 Active Personnel
    - 206 in the US
    - 129 internationally
      - 26 available to US utilities
    - 267 active vendor personnel
    - 59 active utility personnel
    - 9 active EPRI/Other personnel

Review of Recent Compliance Issue Related to Qualified Equipment

USN60 Component Changes

- The USN60ND was brought to market as a replacement for the USN60SW instrument in 2013
  - Screen and power supply updated – potential effect on pulser side of the instrument
  - 2016 - equivalency in accordance with ASME Section XI, Appendix VIII, Article 4000 performed by manufacturer
    - Concluded the pulser circuitry between the USN60SW and USN60ND were equivalent
    - Manufacturer provided the documentation to EPRI staff who then performed confirmatory testing in accordance with Performance Demonstration Initiative (PDI) Program QPI-202 and added the instruments to PDI Table 3 Revision 3 on 08/16/2016
  - 2019 – multiplexer portion of instrument updated / replaced – potential effect on the receiver side of the instrument
    - Manufacturer provided EPRI with new data and documentation to support the replacement of the multiplexor in the USN60ND instrument
    - Data provided did not meet the acceptance criteria for instrument receiver replacement which is found in ASME Section XI, Appendix VIII, Article 4000

USN60 Component Changes (continued)

- Issue:
  - The multiplexer (receiver) modification was completed in 2018 and a number of the USN60ND instruments with non-equivalent hardware have been manufactured and distributed to various organizations
  - The affected instruments include those with manufacture dates of October 2018 and later. The manufacturer has informed EPRI by email on 9/30/2019 that the serial numbers of the affected units start with 18J, 18K, 18L, or 19
  - In addition to the units manufactured in and after October 2018, there have also been a number of instruments repaired that could contain the non-equivalent hardware

USN60 Component Changes (continued)

- Recommended Industry Actions
  - EPRI issued letter (NDE 20191001-001) to industry on October 4, 2019 recommending the following actions
    - Review the examination reports for examinations performed in 2018 and 2019 to determine if USN60ND instruments with non-equivalent hardware have been used for ASME Appendix VIII examinations
    - Those organizations with USN60ND instruments recently sent to the manufacturer for repair need to contact the manufacturer to determine if the non-equivalent hardware has been installed
    - Until this issue is resolved, licensees should ensure they are not performing any Appendix VIII examinations using the instruments suspected to contain non-equivalent hardware

USN60 Component Changes (continued)

- EPRI Actions
  - At this time, the USN60SW and USN60ND equivalency has been removed from the PDI Table 3
  - The instrument has been evaluated and its performance is acceptable
  - The instrument is qualified for use with PDI-UT-1 and PDI-UT-2 with a limited number of search unit combinations
  - 19 specific search unit-instrument combinations that had been used for examination of various welds are now qualified
  - This issue has been entered (for tracking) in EPRI's Correction Action Program (CAR 2019-0119).

USN60 Component Changes – future actions

- Manufacturer
  - Will send out letter to everyone that has purchased the modified instruments instructing them to place a sticker next to the name plate that provides a unique identification
  - Newly manufactured instruments will be shipped with sticker already in place
  - Any instrument requiring replacement of the boards will have the sticker placed on the instrument prior to shipping instrument back to the owner
  - Will provide support to qualify additional instrument search unit combinations with various Generic Procedures

- EPRI
  - EPRI has started a new Table 1 for these modified instruments [USN60SWND A18]
  - Table 3 will be revised to provide instructions on use
    - Older instruments without A18 can use Table 1 for USN60SW
    - Modified instruments with A18 sticker will need to use new table
  - EPRI will send out a letter to industry informing them of the actions taken

Discussion

Qualified procedure modifications

Carl Latiolais
Senior Program Manager
NDE Reliability

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

ELECTRIC POWER RESEARCH INSTITUTE

Purpose

- Revisions to qualified procedures are sometimes required to
  - Address operating experience
  - Update administrative information
  - Incorporate lessons learned
  - Incorporate plant specific requirements
  - Correct typos or other errors
  - Improve format
- It is important to understand what changes can be made without requiring requalification

Current Code Requirements

- Appendix VIII requires qualification of procedures, personnel, and equipment that are used to detect and size flaws
- Both documents require the use Appendix VIII, Article VIII-2000 *"General Examination System Requirements"*
- These requirements specify that essential variables must be identified in the procedure and that all the variables are qualified
  - It is important to note that the variables listed in VIII-2000 are not limited to instrument settings, scan parameters and equipment selection
  - These variables include the required analysis process demonstrated during the initial procedure qualification and by subsequent personnel qualifications
- Revisions to previously qualified procedures are allowed, without requalification, provided no changes to essential variables are made or the changes satisfy the requirements defined in Appendix VIII, Article VIII-3000 *"Qualification Requirements"* and Appendix VIII, Article VIII-4000 *"Essential Variable Tolerances"*

Evaluation of Requirements

- The essential variables and requalification requirements are defined in the various sections of Appendix VIII, and in some cases are defined broadly and incompletely
  - Numerous types of instruments and equipment exist
  - Many of these instruments are software driven and the settings and parameters vary from instrument to instrument
  - Many variables exist that may have an effect on other variables that are defined as essential
  - Certain techniques have unique essential variables
    - TOFD
    - Phased Array
  - Analysis processes can be very specific and applicable only to the specific technique or procedure

VIII-2100 Procedure Requirements

- *(a)* The examination procedure shall contain a statement of scope that specifically defines the limits of procedure applicability (e.g., materials, thickness, diameter, product form)

- *(b)* The examination procedure shall specify a single value or a range of values for the variables listed in (d).

- *(c)* Any calibration method may be used provided it is described and complies with (d)(5).

VIII-2100 Procedure Requirements (Continued)

- *(d)* The examination procedure shall specify the following essential variables:
  - *(1)* instrument or system, including manufacturer, and model or series, of pulser, receiver, and amplifier;
  - *(2)* search units, including manufacturer, and model or series, and the following:
    - *(-a)* nominal frequency or, if Supplement 1 is used, the center frequency and either bandwidth or waveform duration as defined in Article VIII-4000;
    - *(-b)* mode of propagation and nominal inspection angles;
    - *(-c)* number, size, shape, and configuration of active elements and wedges or shoes;
  - *(3)* search unit cable, including the following:
    - *(-a)* type;
    - *(-b)* maximum length, +1 ft (300 mm) to allow for manufacturing tolerances;
    - *(-c)* maximum number of connectors;

VIII-2100 Procedure Requirements (Continued)

- *(4)* detection and sizing techniques, including the following:
  - *(-a)* scan pattern and beam directions;
  - *(-b)* maximum scan speed;
  - *(-c)* minimum and maximum pulse repetition rate;
  - *(-d)* minimum sampling rate (automatic recording systems);
  - *(-e)* extent of scanning and action to be taken for access restrictions;

VIII-2100 Procedure Requirements (Continued)

- *(5)* methods of calibration for detection and sizing (e.g., actions required to insure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeated from examination to examination);
- *(6)* inspection and calibration data to be recorded;
- *(7)* method of data recording;
- *(8)* recording equipment (e.g., strip chart, analog tape, digitizing) when used;
- *(9)* method and criteria for the discrimination of indications (e.g., geometric versus flaw indications and for length and depth sizing of flaws);
- *(10)* surface preparation requirements

Article VIII-3000 Qualification Requirements

- **VIII-3130 ESSENTIAL VARIABLE RANGES**
- *(a)* Any two procedures with the same essential variables **[VIII-2100(d)]** are considered equivalent. Pulsers, search units, and receivers that vary within the tolerances specified in VIII-4100 are considered equivalent
  - When the pulsers, search units, and receivers vary beyond the tolerances of VIII-4100, or when the examination procedure allows more than one value or range for an essential variable, the qualification test shall be repeated at the minimum and maximum value for each essential variable with all other variables remaining at nominal values
  - Changing the essential variable may be accomplished during successive personnel performance demonstrations.
  - Each examiner need not demonstrate qualification over the entire range of every essential variable
- *(b)* When the procedure does not specify a range for essential variables and establishes criteria for selecting values, the criteria shall be demonstrated

Article VIII-3000 Qualification Requirements (Continued)

- **VIII-3140 REQUALIFICATION**
- When a change in an examination procedure causes an essential variable to exceed a qualified range, the examination procedure shall be requalified for the revised range

Article VIII-4000 Essential Variable Tolerances

- **VIII-4100 PROCEDURE MODIFICATIONS**
  - Section describes the equipment substitution requirements
    - Very detailed measurement criteria that needs to be updated to address more modern equipment
- **VIII-4200 COMPUTERIZED SYSTEM ALGORITHMS**
  - When the performance demonstration uses prerecorded data, algorithms for automated decisions may be altered when the altered algorithms are demonstrated to be equivalent to those qualified. When the performance demonstration results meet the acceptance requirements of Article VIII-3000, the algorithm shall be considered qualified

Article VIII-4000 Essential Variable Tolerances (Continued)

- **VIII-4300 CALIBRATION METHODS**
- Alternative calibration methods may be demonstrated equivalent to those described in the qualified procedure without requalification. This demonstration of equivalence shall be conducted for each beam angle and mode of propagation to which it applies, as follows.
- *(a)* Calibrate the examination system in accordance with the alternative methods.
- *(b)* Compare the sensitivity of the alternative calibration method to that of the qualified calibration method.
- *(c)* The alternative calibration method is acceptable when the system sensitivity is no more than 2 dB below that obtained by the qualified method.

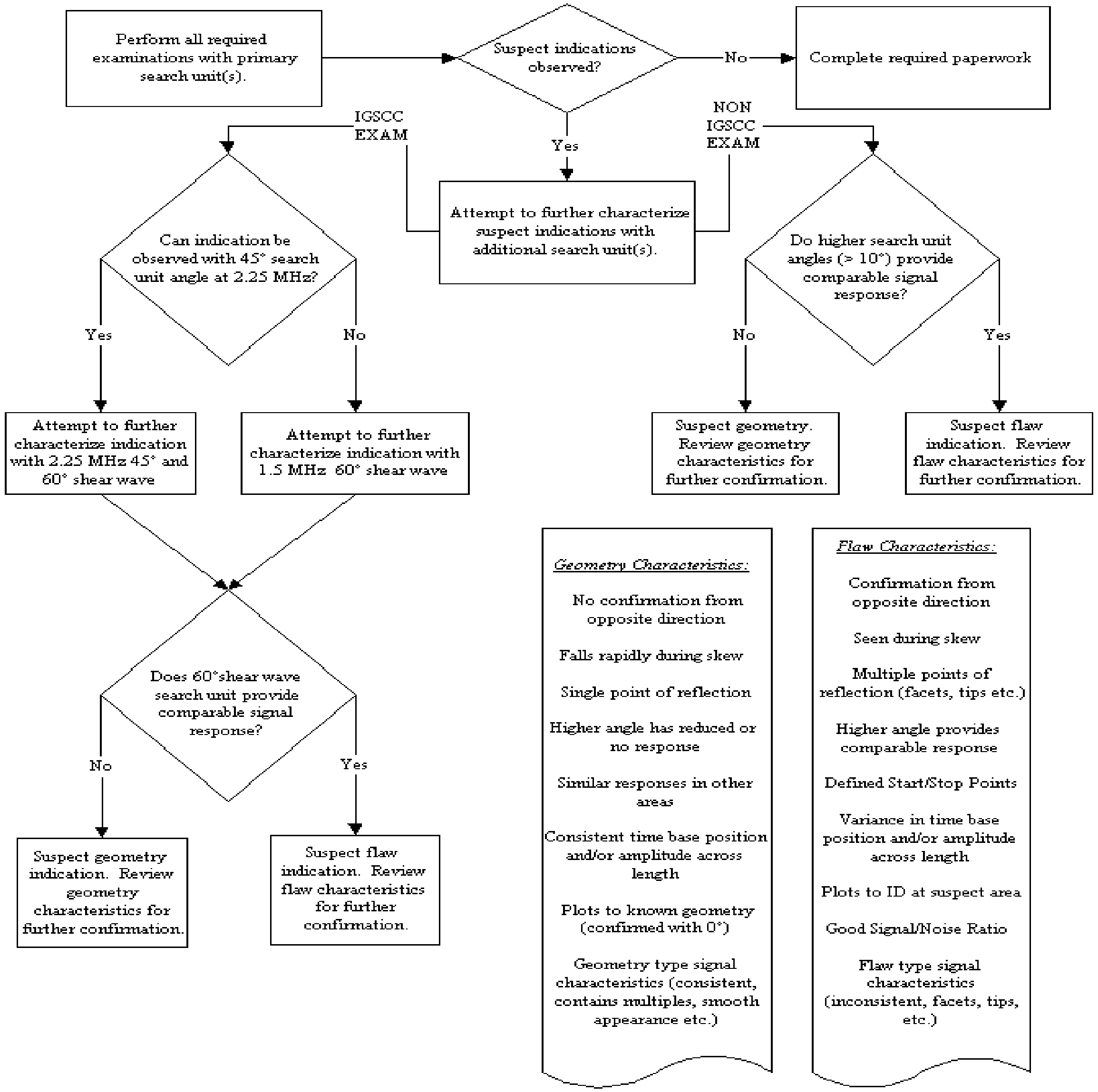
Review Considerations

- The procedure qualification process is essential in identifying the essential variables specific to the application and technique
- Some techniques have pages of essential variables such as;
  - Search unit and wedge parameters
  - Focal law inputs
  - Instrument settings
  - Probe center separation
- Once identified, demonstrated and documented they can easily be verified by knowledgeable personnel prior to and after examinations are performed
- Changes to these parameters are easily identified from one revision to another by comparing the two documents

Pulser			
	Pulser	1	Essential
	Tx/Rx mode	Imported from .LAW file	Essential
	Freq	2 or 1.5 (To Match Probe Frequency)	Essential
	Voltage	High	Essential
	PW	Imported from LAW file (Auto) (250 ns for 2 MHz, 333 ns for 1.5 MHz)	Essential
	PRF	Optimum	Essential
	*Note: The operator shall not proceed if the "Freq" is not correct as this may indicate an incorrect setup.		
Receiver			
	Receiver	Imported from .LAW file	Not applicable
	Filter	None	Essential
	Rectifier	FW	Essential
	Video Filter	Off	Not applicable
	Averaging	1	Essential
	Reject	0	Essential
Beam			
	Gain Offset	Imported from .LAW file	Essential
	Scan Offset	Imported from .LAW file	Essential
	Index Offset	Imported from .LAW file	Essential
	Angle	Imported from .LAW file	Essential
	Skew	Imported from .LAW file	Essential
	Beam Delay	Imported from .LAW file	Essential
Advanced			
	dB Ref	Off	Essential

Review Considerations

- Every procedure defines the process used for characterization of indications
  - Some process are quite complicated and if not followed could result in unacceptable performance
- Influential changes to a variable may not be easily identifiable
- Subtle changes could have an effect on the process and it may not be apparent to the person that is making the revision
- The effect of these changes are harder to measure
- Identifying these changes from one revision to another can be difficult



Future Actions

- Appendix VIII revisions should be made to update the list of essential variables defined in VIII-2000 (Currently being worked in Code)
  - Address modern equipment
  - Expand on the definitions
    - These changes may still need to remain broad because it will be impossible to address every parameter on all systems and every technique
- Update Article VIII-3000 to better address requalification requirements
  - Define thresholds for changes that would require requalification and better define what an essential variable is
    - *Essential variables*: a change in the examination system, which will affect the system's ability to perform in a satisfactory manner
    - *Influential parameter*: Change that can effect the desired result
- Update Article-4000 to address substitution of modern equipment and to address changes in calibration methods

Summary

- If changes were made to previously qualified procedures, the owner should assure that no changes to essential variables defined in VIII-2100 were made without requalification.
- These changes can include:
  - Changes in the procedure requirements defined in VIII-2100(a) through (c)
  - Changes in the essential variables listed in VIII-2100(d)
  - Any changes made to other variables that could have an influence on the aforementioned variables
- It is important to note that the variables listed in VIII-2000 are not limited to instrument settings, scan parameters and equipment selection
- These variables include the required analysis process demonstrated during the initial procedure qualification and by subsequent personnel qualifications

Summary

- In addition, VIII-2000 references other sections within Appendix VIII that must be followed, such as VIII-3000 *“Qualification Requirements”*, which includes definitions of essential variable ranges and requalification requirements and VIII- 4000 *“Essential Variable Tolerances”,* which includes criteria for equipment substitution and replacement, requalification for computerized system algorithms and criteria for changes in calibration methods
- When changes are made to procedures, it is important that all these sections be carefully reviewed, and the requirements addressed
- Changes are required in Appendix VIII to better define the requirements

Together…Shaping the Future of Electricity

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Hyperspectral Imaging

Bruce Greer
EPRI

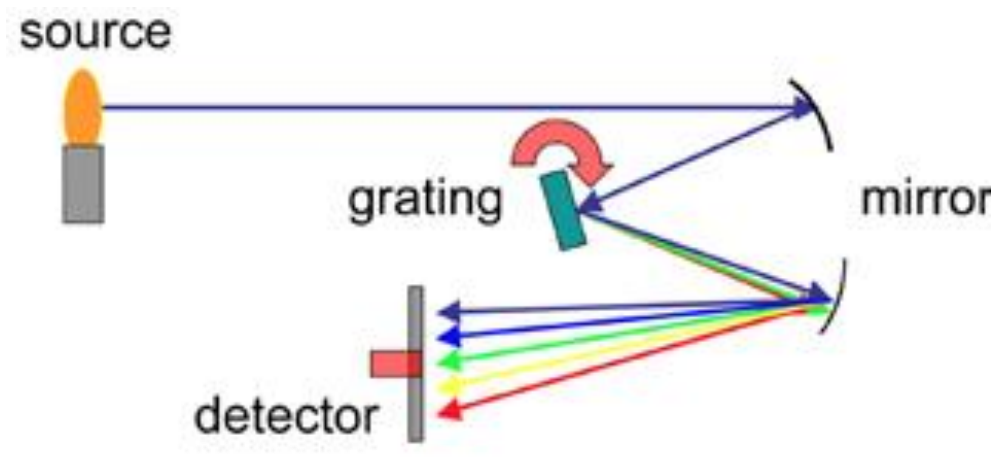
NRC/Industry NDE Technical Information Exchange Meeting
January 2020

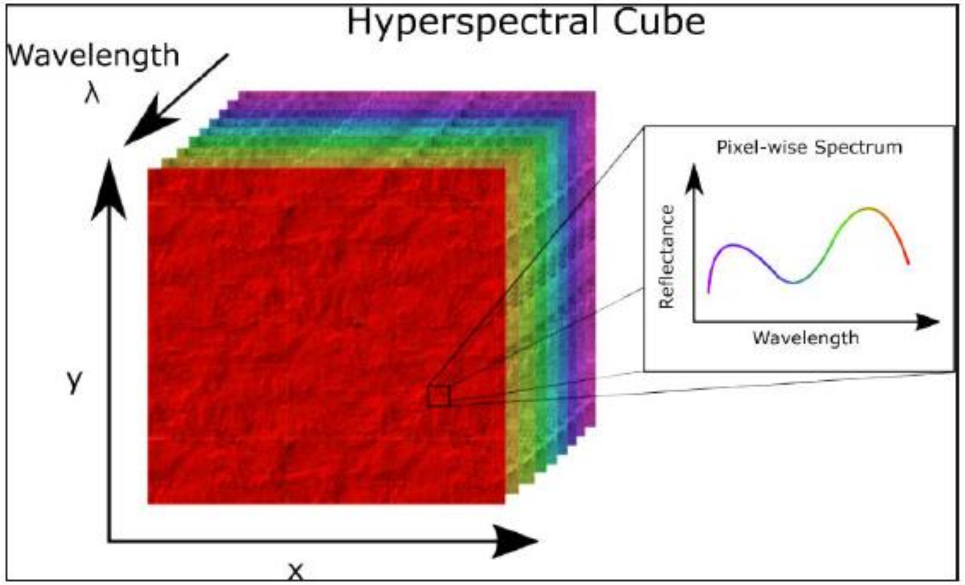
Agenda

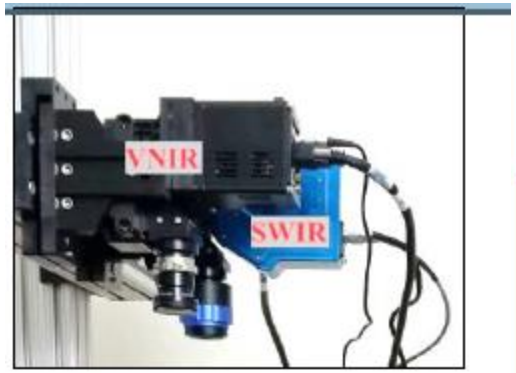
- Background
- 2019 Progress
- 2020 Planned Activities

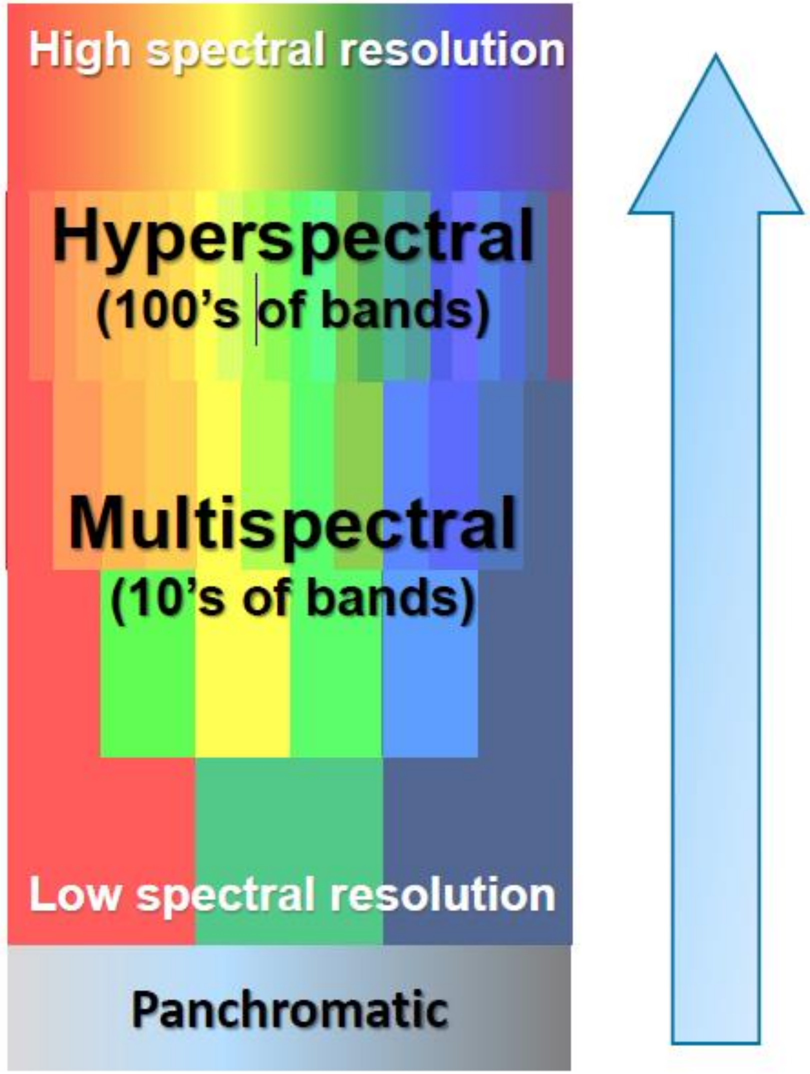
Hyperspectral Imaging Background

Basics of Reflectance Spectral Imaging





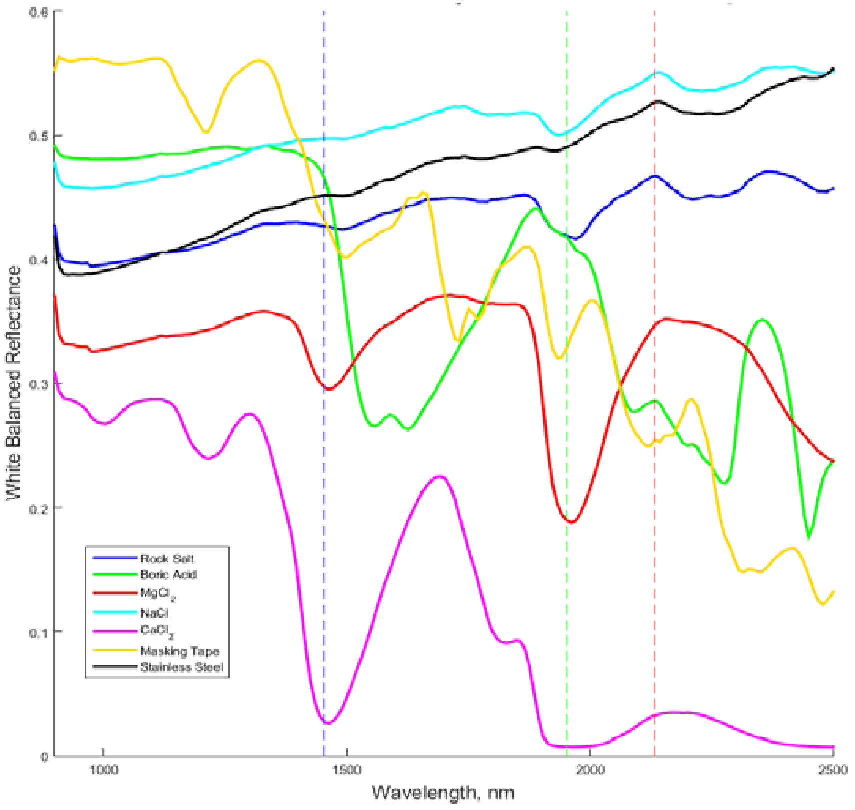


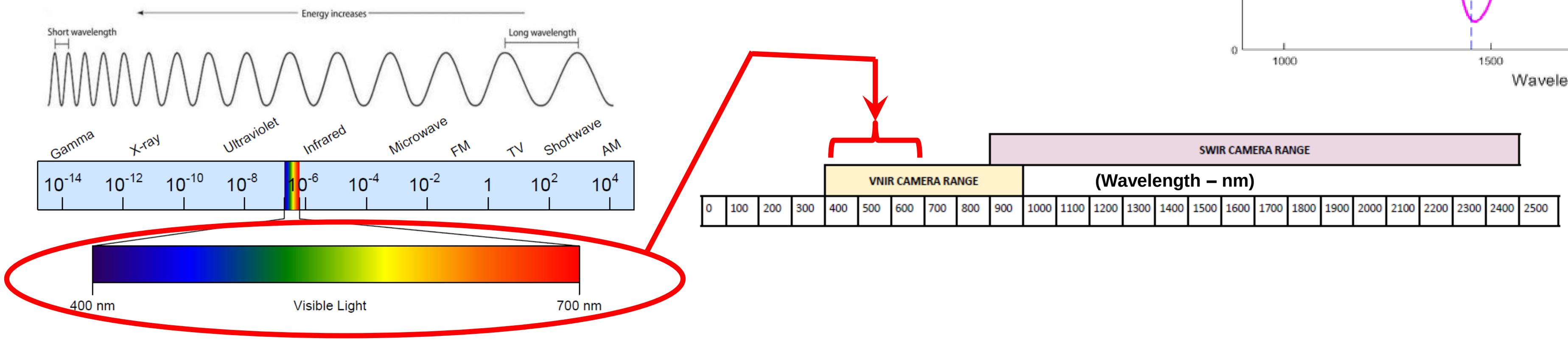


Hyperspectral Imaging

- Reflected spectral signatures are powerful discriminators
  - Materials (based on chemistry at the surface) reflect light differently
- Utilize visible (VNIR) and short wave infrared ranges (SWIR -beyond visible light spectrum)
- Used to classify substances that have similar 'visual' appearance
  - White residues/powders, other…

SWIR Data

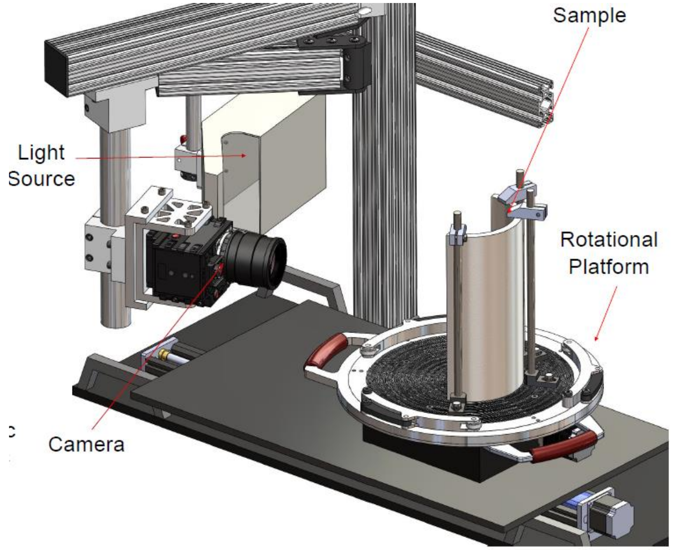


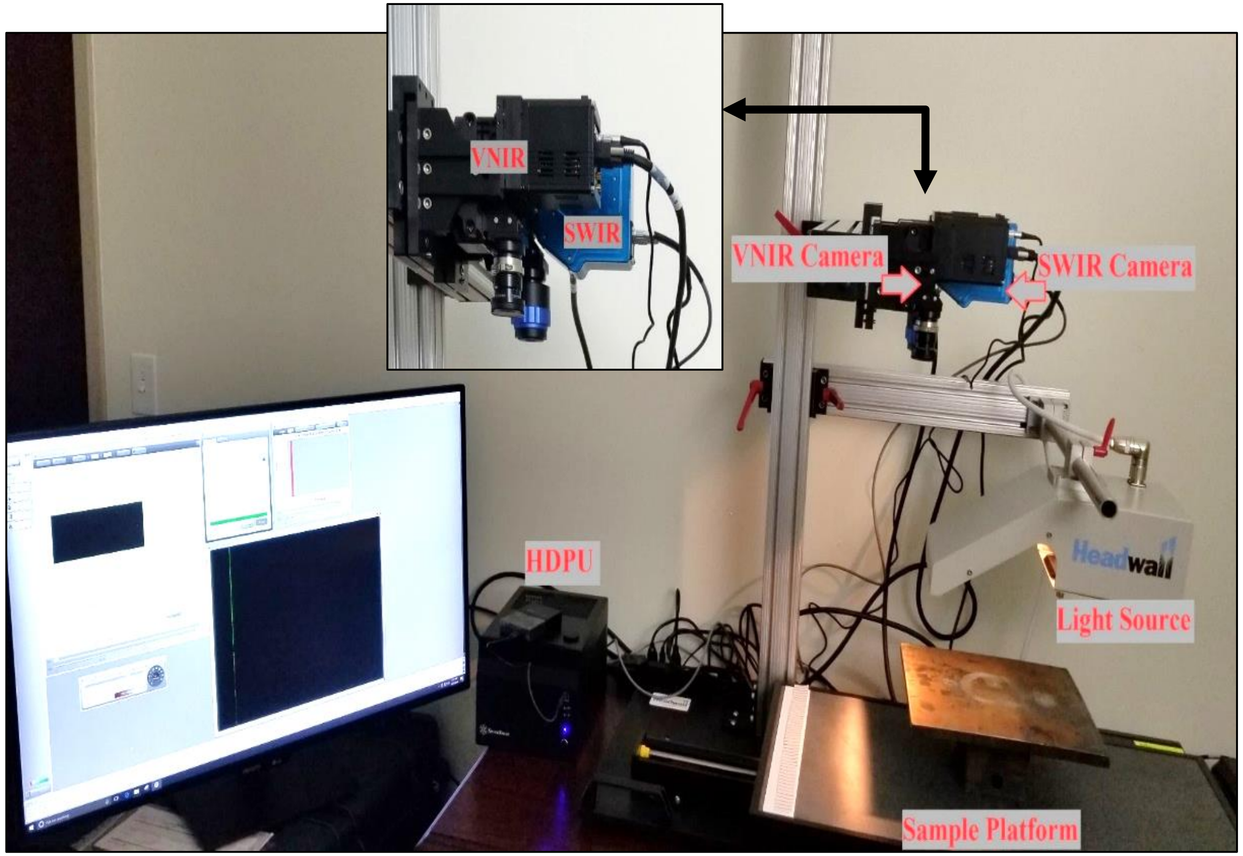


2019 Progress

Benchmarking Laboratory System

- Dual Camera Scanning System
  - VNIR (visual near infrared)
    400 - 1000 nm wavelengths
  - SWIR (short wave infrared)
    900 - 2500 nm wavelengths
- Data acquisition and analysis software
- Linear and rotational stages

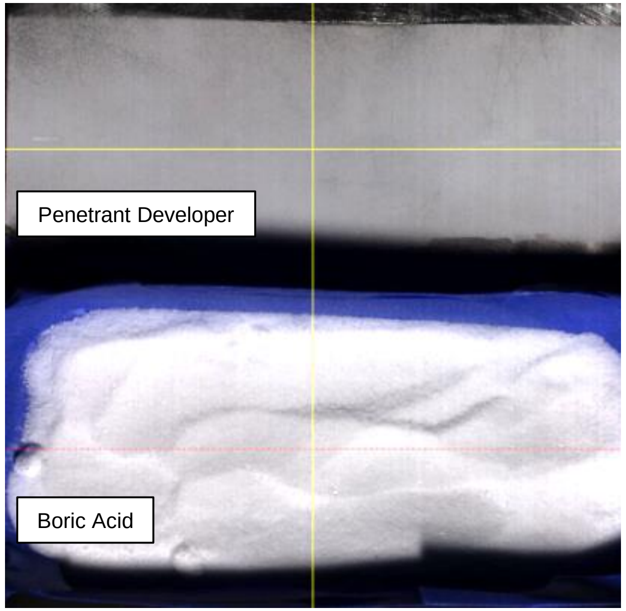




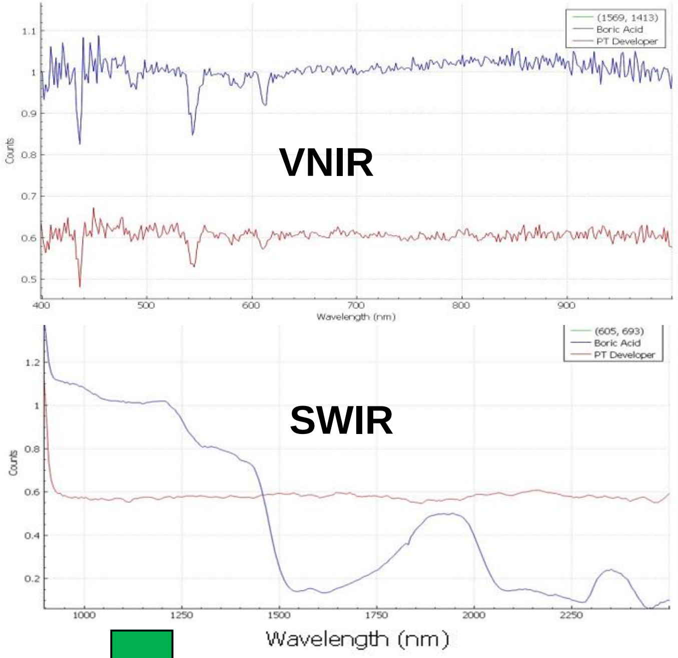
Benchmarking Data

- An example of HI classification of **dye penetrant developer**:

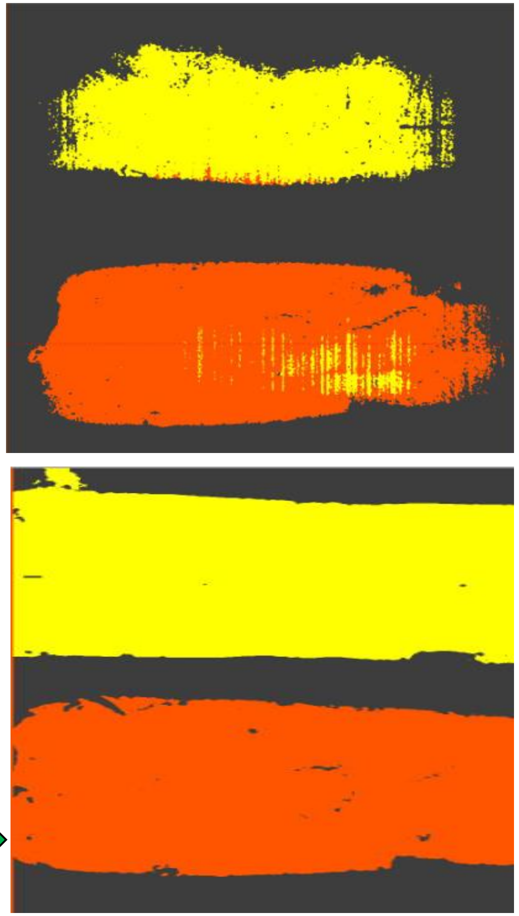
Raw Image



Spectral Data



Post Classification Image



The spectral data is used with application of a spectral angle mapping-based classifier to create a post-classification image.

Building Materials Specimen Library

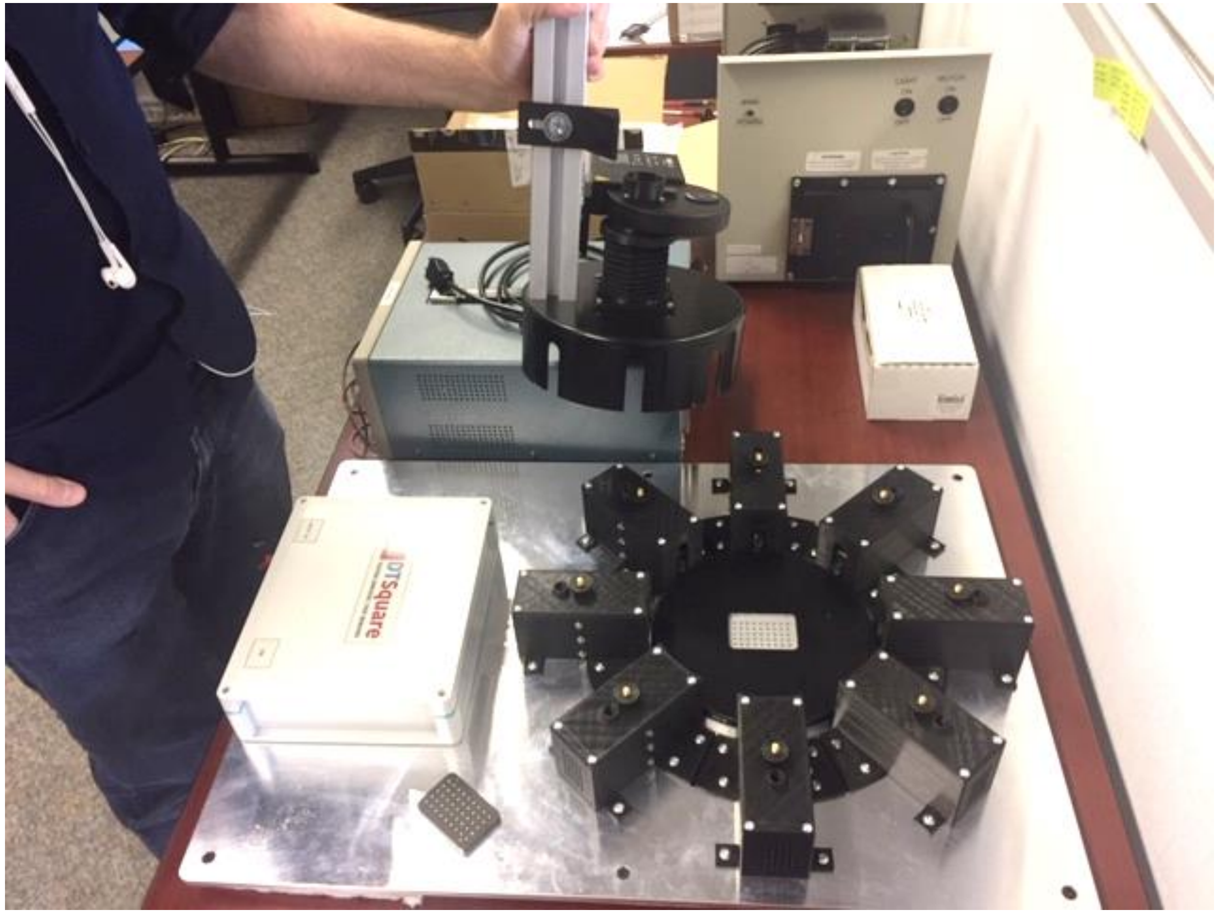
- Contacted both industry and EPRI water chemistry groups to build the library of materials and chemical species that are required to be included in the test matrix
- A vendor knowledgeable in boric acid inspection and corrosion programs at nuclear power plants has been contracted to manufacture the representative specimens
- Specimens will be used for training of material classifier algorithms

Sampling of Materials
(More than 50 will be evaluated)

Material for Analysis	Plant Source
Lithium/boron mixtures	Primary cooling water
Potassium/boron mixtures	Primary cooling water (potassium chemistry)
Sodium carbonate	Closed cooling water
Calcium carbonate	Raw water
Silicon dioxide (silica)	Construction material, Latent debris
Calcium carbonate with iron contamination	Mixture

Hyperspectral Imaging for SCC

- Approach
  - Combining Reflectance Transformation Imaging (RTI) with Hyperspectral imaging
  - RTI is a technique of imaging and interactively displaying objects under varying lighting conditions to reveal surface phenomena.
    - Uses a fixed camera position with multiple lighting locations
  - Hyperspectral imaging will be used to provide data from the corrosion products associated with the cracks
- Progress
  - Lab acquisition hardware has been procured
  - Awaiting delivery of stress corrosion crack specimens with corrosion products
    - Midyear 2020



2020 Planned Activity

Timeline

Key Activities and Milestones	Target Date
Procure mobile hyperspectral camera	12/2019
Produce samples and coupons for boric acid identification	02/2020
Acquire data on boric acid samples	03/2020
Produce SCC samples	03/2020
Acquire data on SCC samples	06/2020
Completion of Analytics Engine. Hold Point to finalize deliverable format	07/2020
Publish technical report for Capability Study on the Use of Hyperspectral Imaging for Boric Acid Detection and SCC Crack Detection	09/2020
Complete field studies with mobile hyperspectral camera (PWR upper head application in conjunction with MRP)	12/2020

Questions?

Together…Shaping the Future of Electricity

MRP NDE Update

Dale Brown, Southern Nuclear
Inspection TAC Chair

Todd Davis, Exelon
Inspection TAC Vice Chair

Robert Grizzi, EPRI
Inspection TAC PM

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

ELECTRIC POWER RESEARCH INSTITUTE

Outline

- Review of 2019 Deliverables
- 2020 Project Overview
- 2020 Priorities and Preliminary Deliverables
  - 2020 Reactor Internals Aging Management
  - 2020 Nickel-based Alloys
  - 2020 Fatigue

2019 Deliverables

- Reactor Internals Aging Management
  - Initial Virtual Reality (VR) modules of PWR Internals completed
    - Westinghouse primary inspection components
    - ½ B&W primary components
  - PWR IVI Course completed July 24-26
  - Report "Investigating EMAT and Ultrasonic Examination of Bolts" - EPRI Product ID #: 3002016017
    - A set of 18 bolts were engineered and fabricated with different defects for testing including 3 bolt types; internal hex with washer, internal hex with tie bar, & external hex with tie bar
    - Based on the results to-date no single technique was capable of identifying the defects within each bolt design.
    - Two different EMAT techniques (EMAS and EMAT Pulse-Echo) were evaluated in the laboratory and mixed results occurred for flaw detection. Reliable in-field results with these techniques would be much more challenging due to embrittlement, stress loading, material grain structures, bolt geometry, spot welds, etc.
    - Further research is recommended, including pursuit of multi-element ultrasonic techniques. The results found with ATFM and TFM were encouraging for Bolt Type A and with further probe and fixture design it is likely the results could be improved.

2019 Deliverables

- Nickel-based Alloys
  - Guideline for Nondestructive Examination of Reactor Vessel Upper Head Penetrations, Revision 1 (MRP-384)
    - EPRI Product ID #: 3002017288 (Available to public at epri.com)
- Fatigue
  - Revision to MRP-23, Technical Basis for TF Procedures and Techniques
    - EPRI Product ID #: 3002017285
      - Added (6) additional TF small bore specimens (2” & 3”)
      - Wedge contour comparison between PDI-UT-2 and EPRI-NDEC-UT
      - Updated/added technical basis supporting procedure revisions

2020 Project Overview

- **New** and **Ongoing** Project Tasks
  - IVI Course
  - Internals Visual Examination Support Task and MRP-228 Support
  - Reactor Vessel Upper Head Penetration Qualification Program
  - NDE Specimen Design and Fabrication in Support of MRP Inspections
  - Hyperspectral imaging – feasibility for field implementation, i.e. Bare Metal Visual Exams
  - Wet & Adjustable Leak Path Specimen project to address recent OE in support of training and TJs (TAC has asked to accelerate this project and bring into 2020)
  - NDE for Thermal Fatigue Damage in Small Bore Piping

2020 Priorities and Preliminary Deliverables

- Reactor Internals Aging Management
  - Updates to IVI training course based on latest guidance documents, OE and tooling
  - Complete VR application for Westinghouse, CE, and B&W primary components for PWR Internals
  - Plan and execute July 21-23 IVI Course
  - MRP-228, Revision 4 – Evaluate needs and solicit utility input for revision
- Nickel-based Alloys
  - Support ASME code work for Supplement 15, CC-N-729-X
  - Kick off new Wet & Adjustable Leak Path Specimen project
  - Revise MRP-311, Revision 2; Materials Reliability Program: Qualification Protocol for Pressurized Water Reactor Upper Head Penetration Ultrasonic Examinations; Historic Account—2020 Update
- Fatigue
  - MRP-36; CBT for NDE of Thermal Fatigue conversion and update in EPRI LMS
  - Finish QA acceptance of newly fabricated TF specimens
  - Manage TF inventory for members

2020 Reactor Internals Aging Management

IVI Course (Scope)

- Includes inspection requirements from the latest I&E Guidelines (MRP-227) and PWR Inspection Standard (MRP-228)
- Addresses the differences in the various PWR designs and ASME Section XI requirements
- Includes descriptions of critical vessel internals components
- Addresses the expected flaw locations and examination challenges
- Allows for hands-on use of remote inspection devices
- Participants will practice visual and ultrasonic examinations on realistic and virtual mockups; which allows for personnel to experience the challenge of manipulating remote inspection devices, either with physical equipment or in a virtual reality environment.
- The course will be revised as IVI examinations and equipment improvements are made
- Lessons learned and operational experience will also be incorporated into the materials
- The course will be offered at least once each year to utility personnel
- Scheduled course for July 21-23, 2020 in Lynchburg, VA

IVI Course (Applicability/Value)

- This course allows industry members the opportunity to improve their understanding of MRP-227/228 inspections for PWR IVI in the areas of:
  - Examination requirements
  - Component configurations
  - NDE techniques
- The course enhances the utility members' ability to ensure examinations are implemented efficiently, and with consistency, throughout the industry in accordance with industry requirements

Internals Visual Examination Support Task and MRP-228 Support (Scope)

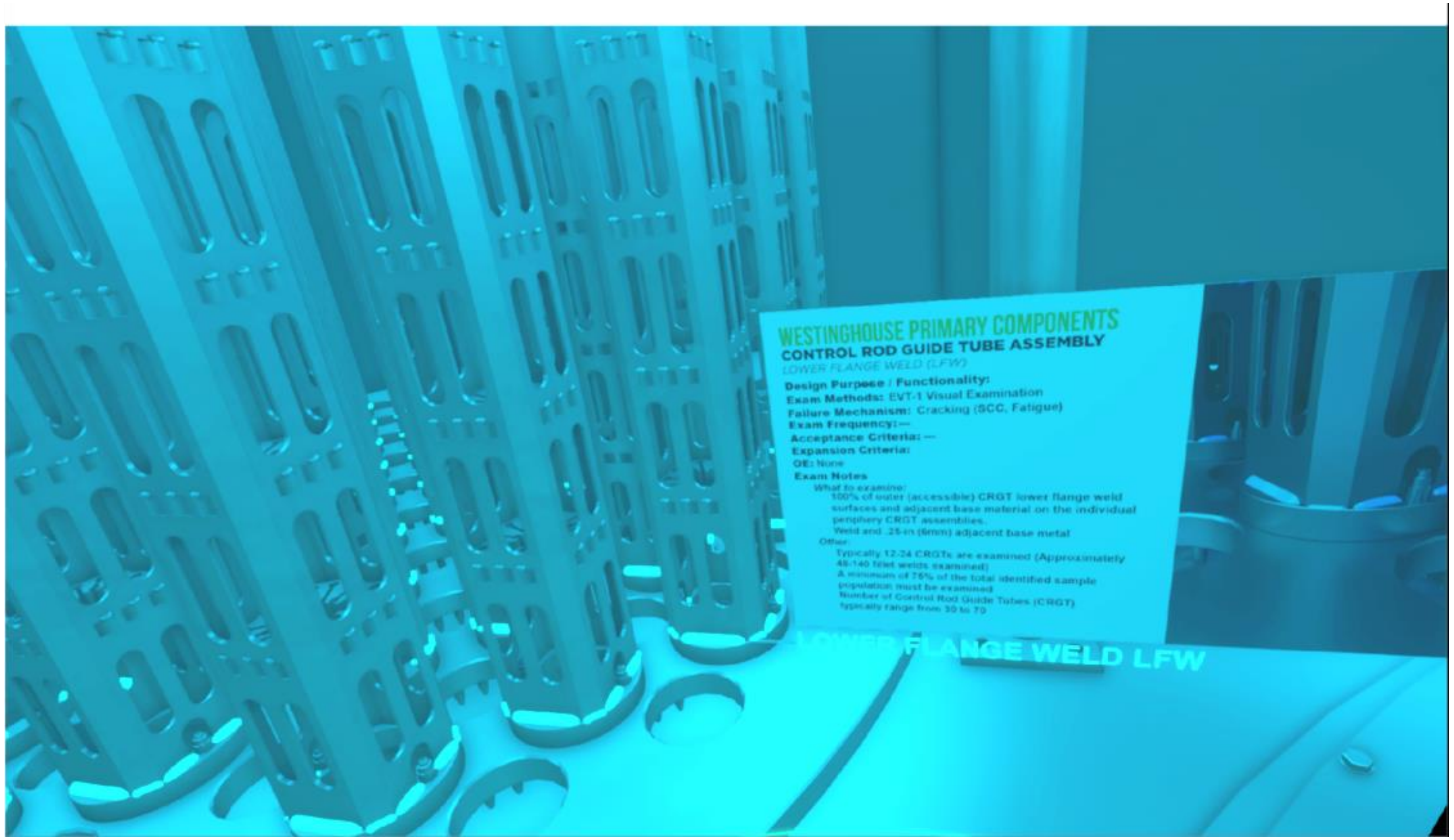
- Evaluate and enhance visual inspection methodologies for internals
- Support INPO vessel internals site visits
- Develop and fabricate visual inspection mockups, if applicable
- Support the Internals Core Team
- Support the Internals Focus Group
- Develop virtual reality applications for IVI components
- Evaluate operational experience and determine if revisions are necessary for the latest versions of MRP-227 and MRP-228 documents, assessment will identify areas where improvements are necessary to achieve reliable examination results

Internals Visual Examination Support Task and MRP-228 Support (Primary Tasks)

- Maintain and update MRP-228 (commitment to update NEI-03-08 documents every 2 years)
  - Make Revision 4 easier to navigate/read – potential re-format
  - Add results of EPRI NDE study on Evaluating Increased Distances for EVT-1 Exams Using Magnification
  - Incorporate Bolting Protocol requirements into document
  - Publish in December 2020

Internals Visual Examination Support Task and MRP-228 Support (Primary Tasks – continued)

- Continue development of VR application
- Complete remaining B&W Primary Components
- Complete CE Primary Components
- Investigate best method to deliver VR modules to members
- Explore gathering content to include international designs



Internals Visual Examination Support Task and MRP-228 Support (Applicability/Value)

- Support for and involvement with implementers of MRP-227 requirements to improve the effectiveness of IVI training and successive inspection campaigns
- Aids in the development of implementing IVI programs to satisfy license renewal, power up-rates and aging management for internals
- Provides basis for performance reliability of remote-visual examination and internals inspection; which continues to be of high interest to regulatory and industry oversight staff
- Collaboration between BWRVIP and MRP to leverage and ensure inspection vendors implement visual examinations with consistency and continue improvements in visual inspection technologies

2020 Nickel-based Alloys

RV Upper Head Qualification Program (Scope & Tasks)

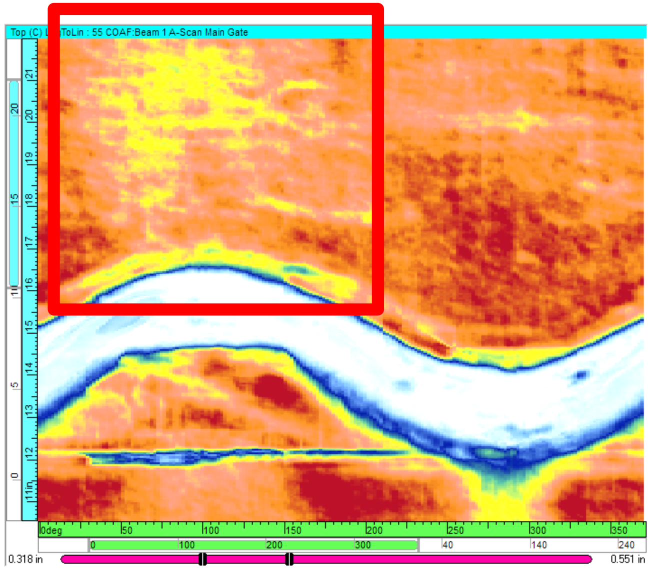
- Maintain the RVUH penetration tube qualification program in compliance with, and to fulfill the requirements of, the latest approved ASME Code Case and 10 CFR 50.55a for the PWR fleet
- Administer qualifications upon vendor or utility request
- Maintain NQA program documents by which the program is administered
  - Ensure reconciliation of program with ASME and regulatory standards
  - Maintain and Update
    - Quality Project Instructions
    - QA Servers and grading databases
    - QA archiving of qualifications and fabrication documents

NDE Specimen Design and Fabrication in Support of MRP Inspections (Scope)

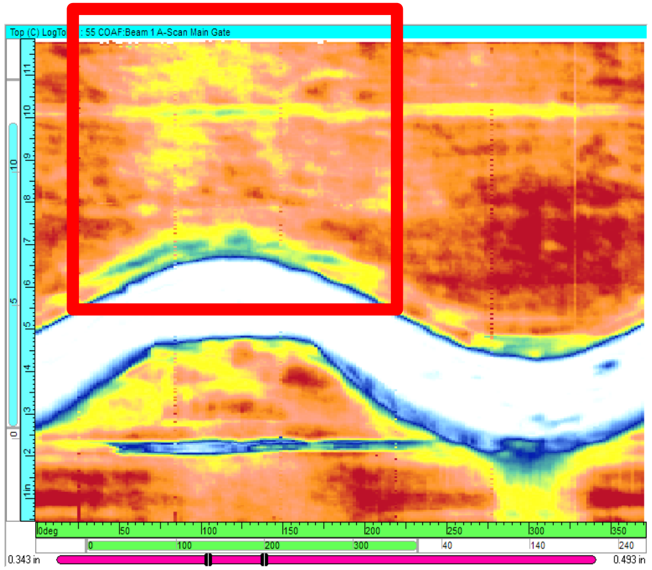
- Design and manufacture the necessary specimens to support NDE activities or Performance Demonstrations (PD) across all RFAs for the MRP
- Specimens will comply with applicable ASME Code or regulatory requirements
- Specimens will incorporate OE and SME inputs on a case by case basis to support industry needs
- All activities will be conducted under the EPRI QA PD Test Specimen Fabrication Program
- Annual or multi-year tasks are determined by the Inspection TAC members

NDE Specimen Design and Fabrication in Support of MRP Inspections (Tasks)

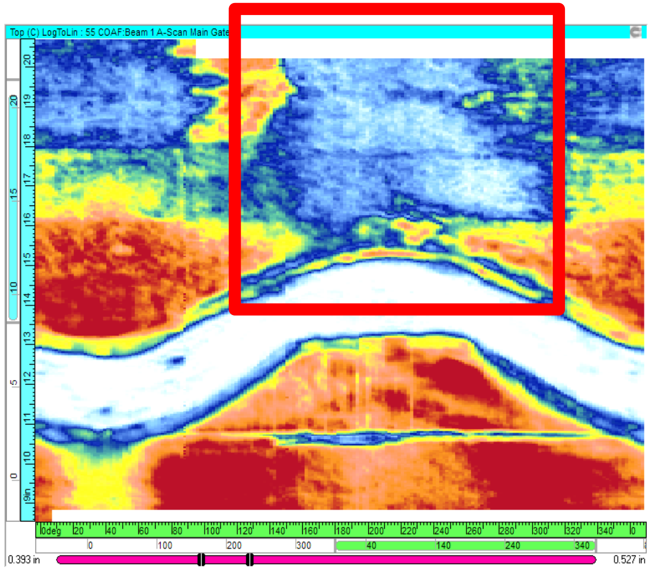
- Design and fabricate open specimens to represent early stage leak path; representing smaller, less uniform ultrasonic signatures
- Investigate a method to make leak path indications "wet" and "adjustable" in order to minimize the number of specimens that need to be fabricated



2015 Data



2017 Data



2018 Data

NDE Specimen Design and Fabrication in Support of MRP Inspections (Applicability/Value)

- Suitable NDE specimens, blind and open, are produced to support both the inspection vendors and utilities
- Provides representative field configurations of components to allow for vetting of inspection technique capabilities prior to deployment at utility sites
- Open specimens can be used to aid in vendor practice and familiarization of inspections prior to performing the inspection on the actual in-service component

Feasibility of Field Deployed Hyperspectral Imaging to Support Bare Metal Visual Examinations (Scope)

- This project leverages the NDE benchmarking work for hyperspectral imaging and moves the research dial towards technology transfer
- Perform a feasibility study to evaluate the use and implementation of hyperspectral imaging technology to improve bare metal visual examinations
- Investigate and evaluate form factors that could be used in field deployed situations
- Pilot plant study to determine limitations of deploying hyperspectral imaging technologies in various nuclear power plant environments

Feasibility of Field Deployed Hyperspectral Imaging to Support Bare Metal Visual Examinations (Tasks)

- Acquire hand held hyperspectral imaging system
- Benchmark hand held system with laboratory system
- Develop standards for classification of chemistries
- Identify and evaluate remote delivery systems, if applicable
- Integrate hand held system onto remote delivery systems
- Conduct field trials/demonstrations at plant
- Document results in EPRI Technical Report

InVision Top Innovation 2015

Sampling of Materials (More than 50 will be evaluated)

Material for Analysis	Plant Source
Lithium/boron mixtures	Primary cooling water
Potassium/boron mixtures	Primary cooling water (potassium chemistry)
Sodium carbonate	Closed cooling water
Calcium carbonate	Raw water
Silicon dioxide (silica)	Construction material, Latent debris
Calcium carbonate with iron contamination	Mixture

Feasibility of Field Deployed Hyperspectral Imaging to Support Bare Metal Visual Examinations (Availability/Value)

- Pilot plant implementation of hyperspectral imaging
- Real time (or near real time) differentiation of various surface residues, in-situ, to identify whether or not relevant conditions exist
- Add guidance to MRP-60 for implementation

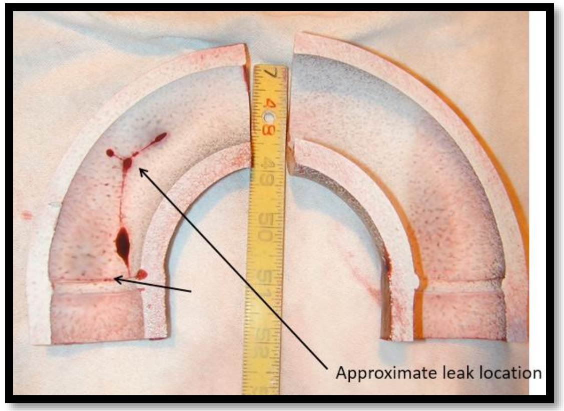
2020 Fatigue

NDE for Thermal Fatigue Damage in Small Bore Piping (Scope)

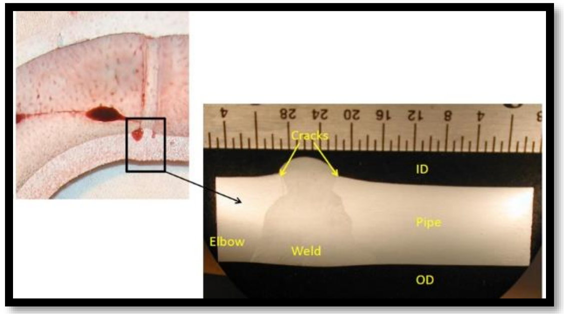
- Capture operating experience regarding thermal fatigue crack findings
- Capture lessons learned from an NDE perspective
- Expand specimen inventory to cover configurations not currently addressed
- Assess ultrasonic examination variables and record performance
- Covers small bore and socket weld configurations
- Revisions to the current generic examination procedures to enable utilities to address the thermal fatigue simultaneously with the Appendix VIII examination requirements
- Maintain and revise the thermal fatigue computer-based training program to capture the work perform herein and industry OE

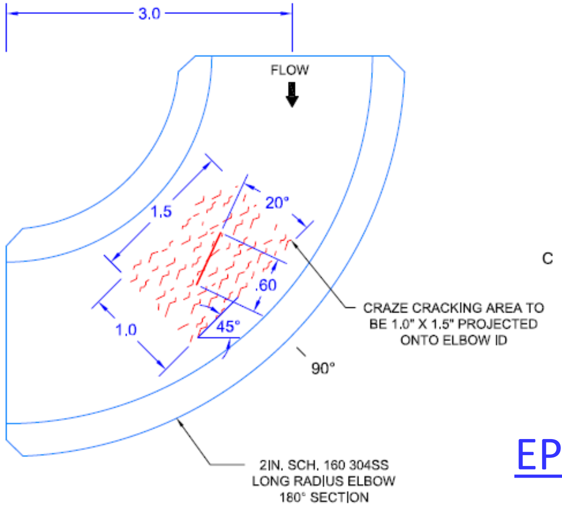
NDE for Thermal Fatigue Damage in Small Bore Piping (Tasks)

- Complete QA acceptance of (6) TF specimen

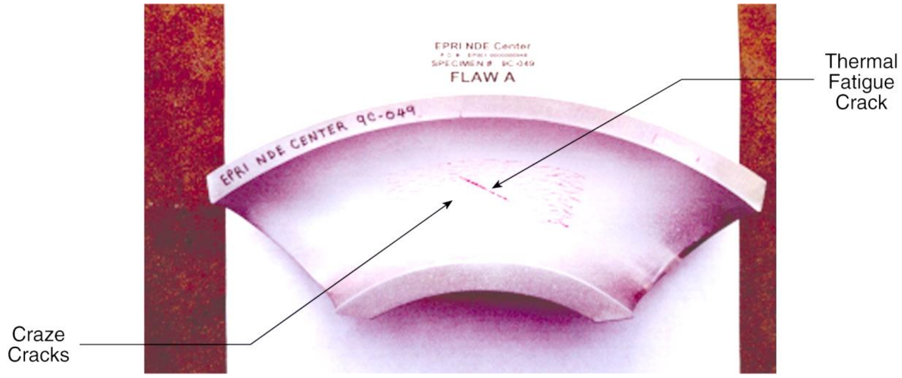


Field Removed





EPRI Specimen



Type of TF Specimen	Number of Specimens
Thermal Fatigue (pipe, elbow, SI nozzle, Mixing Tee, etc.)	25
Socket Weld (Vibration Fatigue)	18
Socket Weld (Thermal Fatigue)	15

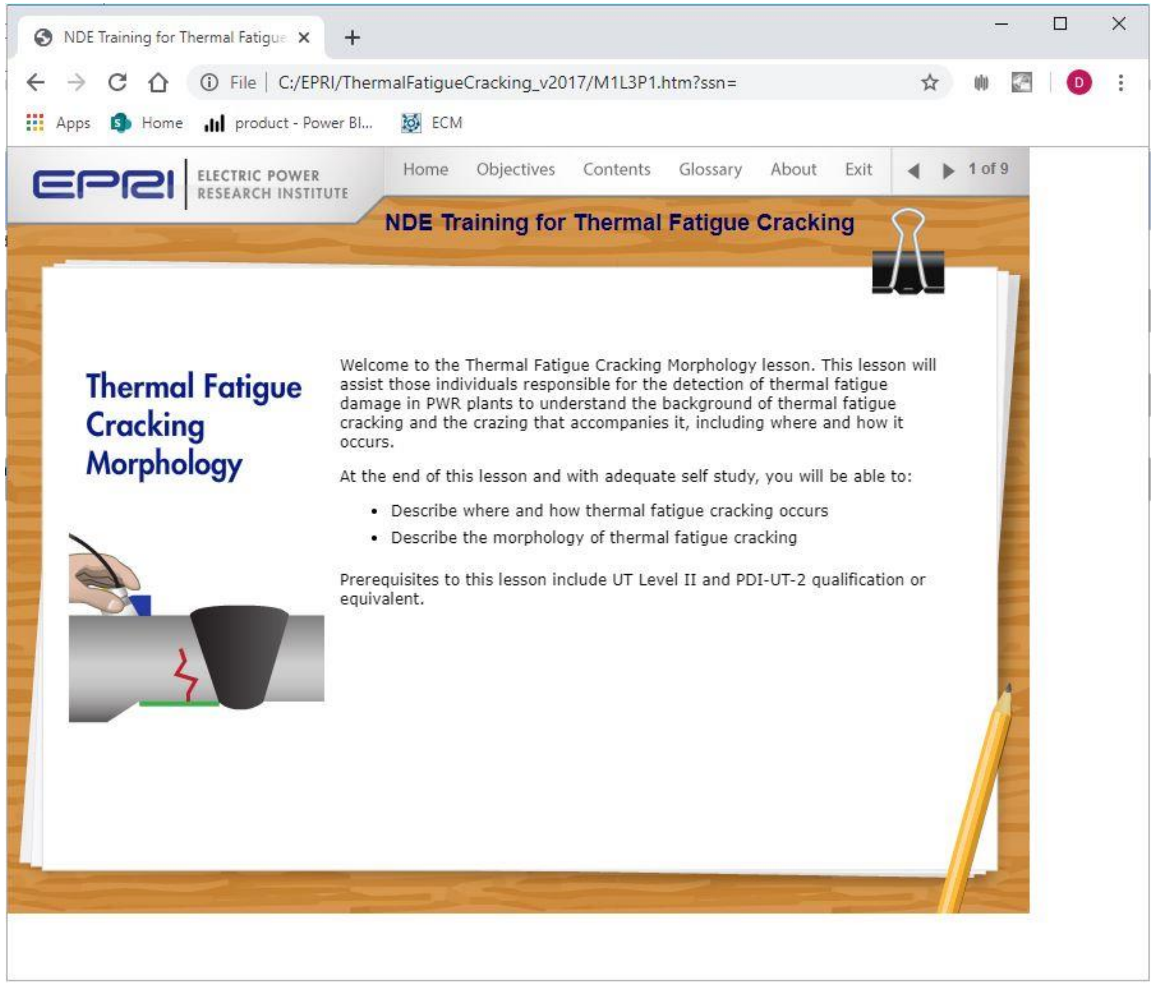
NDE for Thermal Fatigue Damage in Small Bore Piping (Tasks continued)

- Convert MRP-36, Thermal Fatigue Computer Based Training, into the updated EPRI learning management system format
- Issues
  - Revisions 1-3 were built in a software called Luminex that has been retired
  - EPRI|U guidelines now require all CBTs to be created in Articulate Storyline or Adobe Captivate to avoid these issues
  - Update to MRP referenced procedures
    - Guidance document when utilizing PDI-UT-2
    - EPRI-NDEC-UT

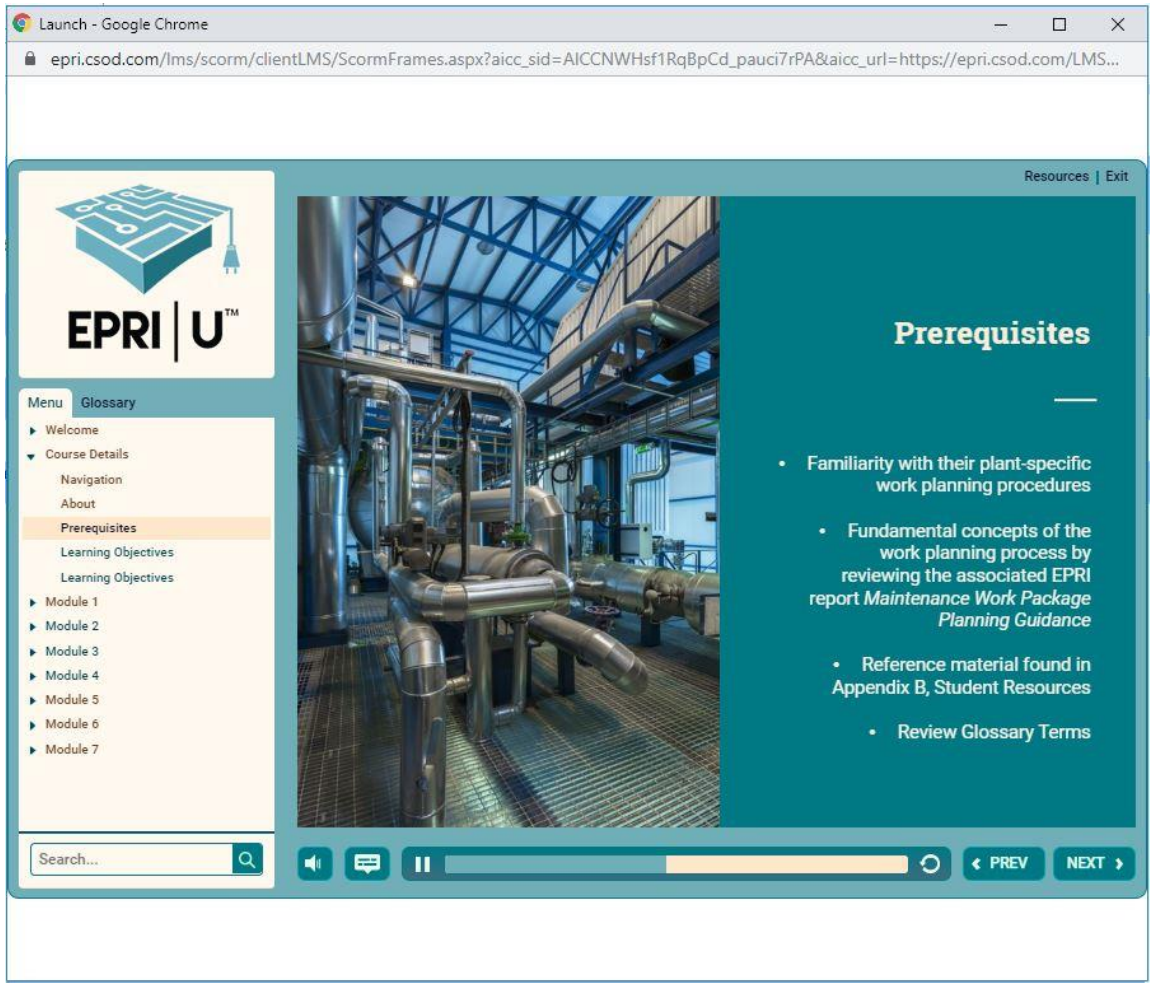
NDE for Thermal Fatigue Damage in Small Bore Piping (Tasks continued)

Luminex Player – Retired

(Flash Player embedded – no longer supported)



EPRI|U Learning Management System (LMS)



NDE for Thermal Fatigue Damage in Small Bore Piping (Applicability/Value)

- Provides means to characterize thermal fatigue indications with the purpose of minimizing false calls and targets discrimination between cracking and non-relevant indications
- Provides consistent implementation of NDE to support MRP-146 and MRP-192 inspection guidelines
- CBT training and UT procedures to promote consistent implementation across the industry

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BWRVIP NDE Update

Chris McKean, Exelon
Inspection TAC Chair

Jeff Landrum, EPRI
Inspection TAC PM

Bret Flesner, EPRI

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

ELECTRIC POWER RESEARCH INSTITUTE

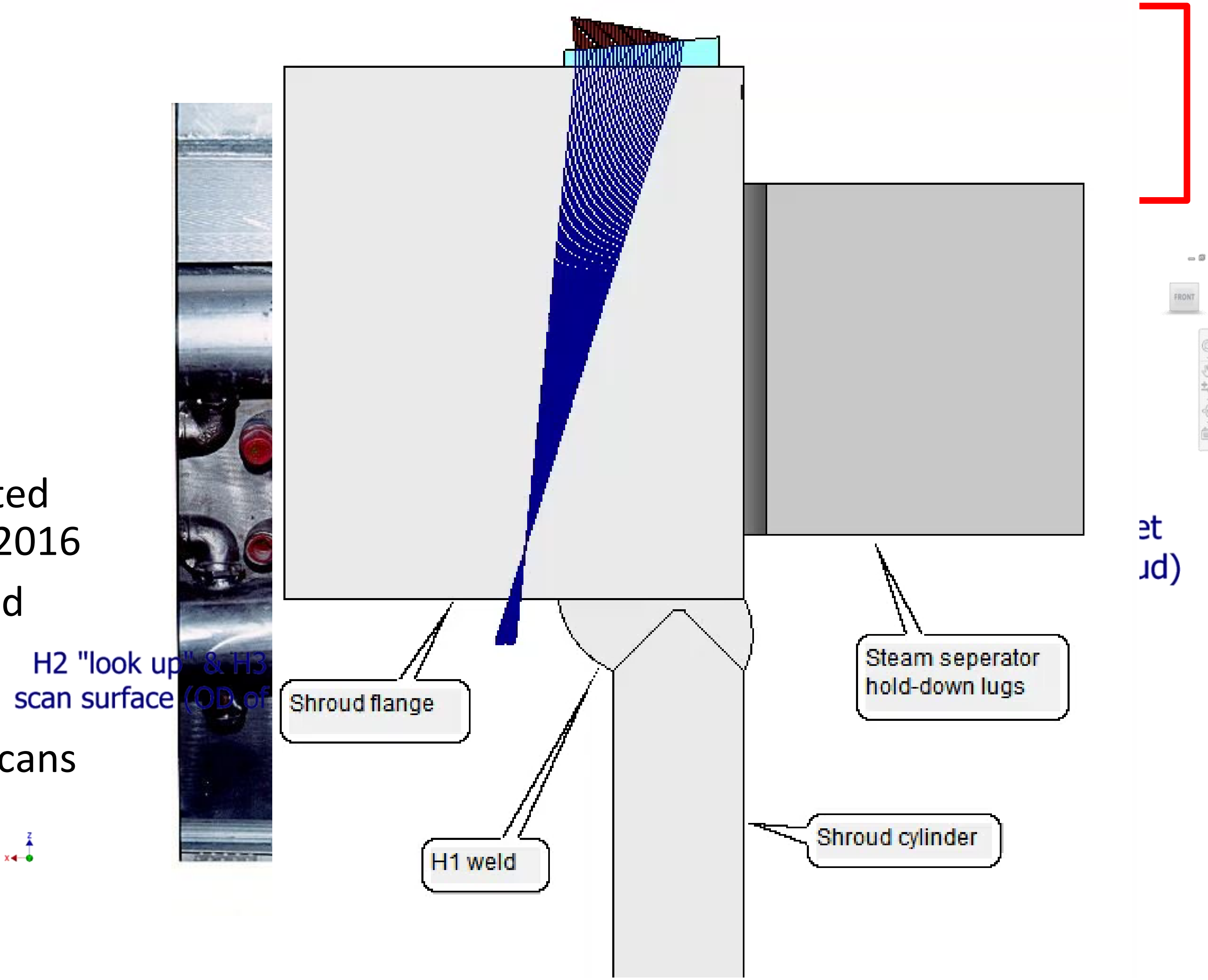
Contents

- Update on Inspection Vendor Demonstrations
  - Inspection vendor demonstrations activities in 2019
- Update on BWRVIP NDE Development Activities
  - New NDE mock-ups
  - Ongoing NDE technique development
  - Planned activities
- BWRVIP Reactor Internals Training

Update on Inspection Vendor Demonstrations

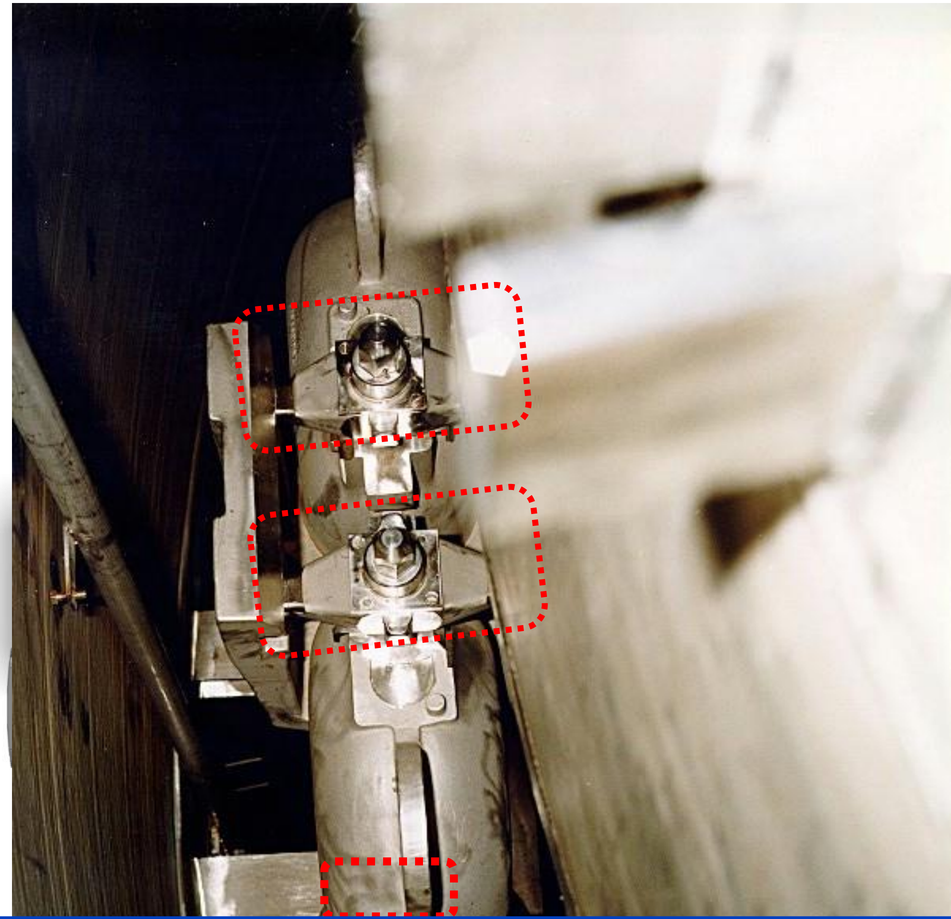
New Inspection Vendor Demonstrations

- Core shroud
  - Phased array H1 “looking down”
    - Shroud flange–to–plate weld
  - Phased array H2 & H3
    - Top guide support ring–to–plate
    - Two separate inspection vendors
      - RFQ from US BWR/4 required inspection techniques demonstrated on “new” mock-ups fabricated in 2016
  - Core spray sparger bracket to core shroud attachment welds
    - Areas can be interrogated during H1 “looking up” and H2 “looking down” scans to supplement remote-VT
    - Phased array UT



New Inspection Vendor Demonstrations (cont.)

- Jet-pump beams
  - Revision to new phased array technique used to examine the BB-1 inspection region
    - Incorporate lessons learned from initial deployment
    - Demonstrated to support Fall 2019 BWR/6 in Europe
- In-vessel core spray piping
  - BWR/6 flow divider
    - New configuration added to BWRVIP mock-up inventory
    - Conventional UT
    - Scans performed on reducer and tee geometry

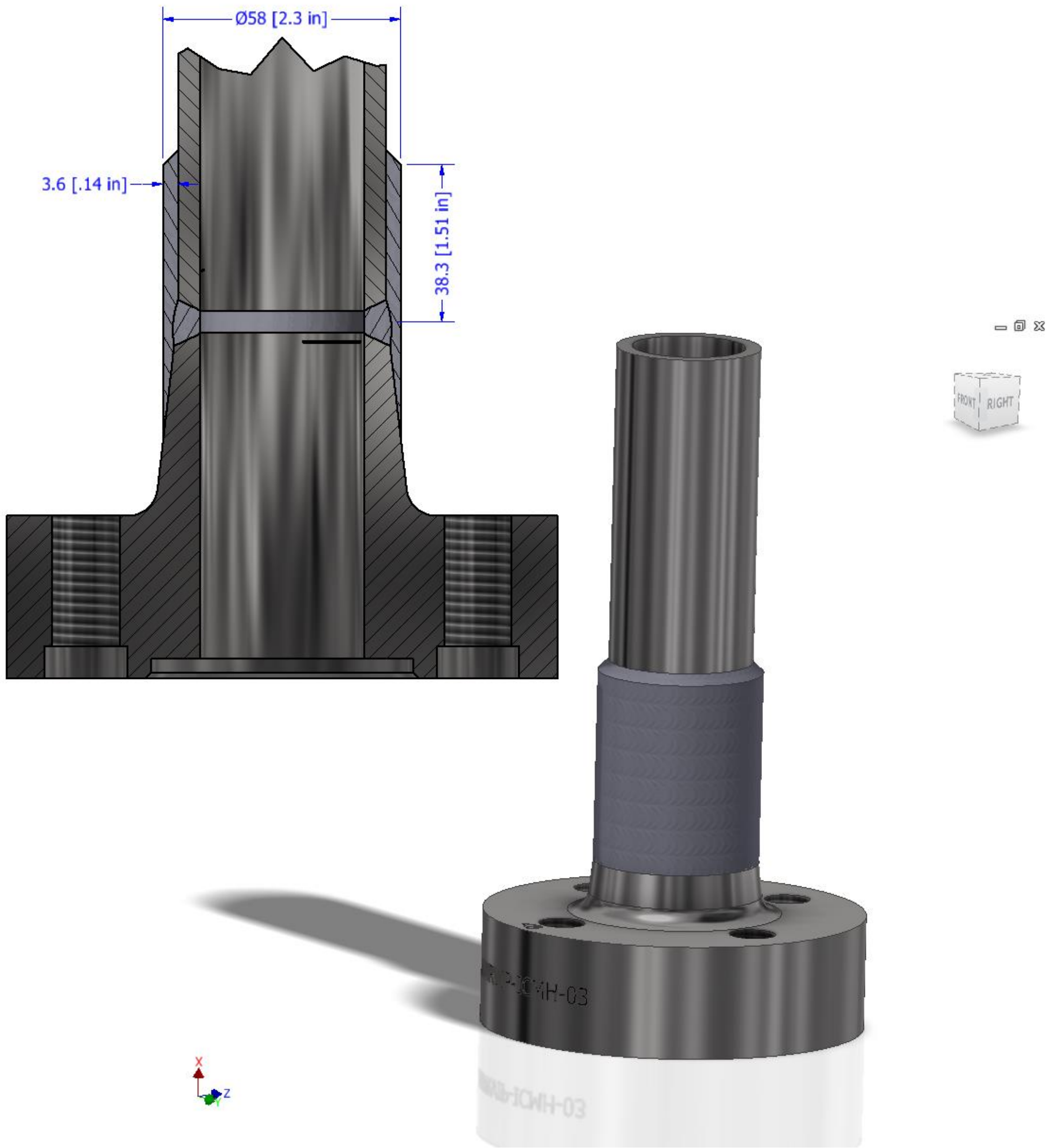


12 inspection vendor demonstrations in 2019
2 already in-progress to support 2020 examinations

ICMH mock-ups and NDE

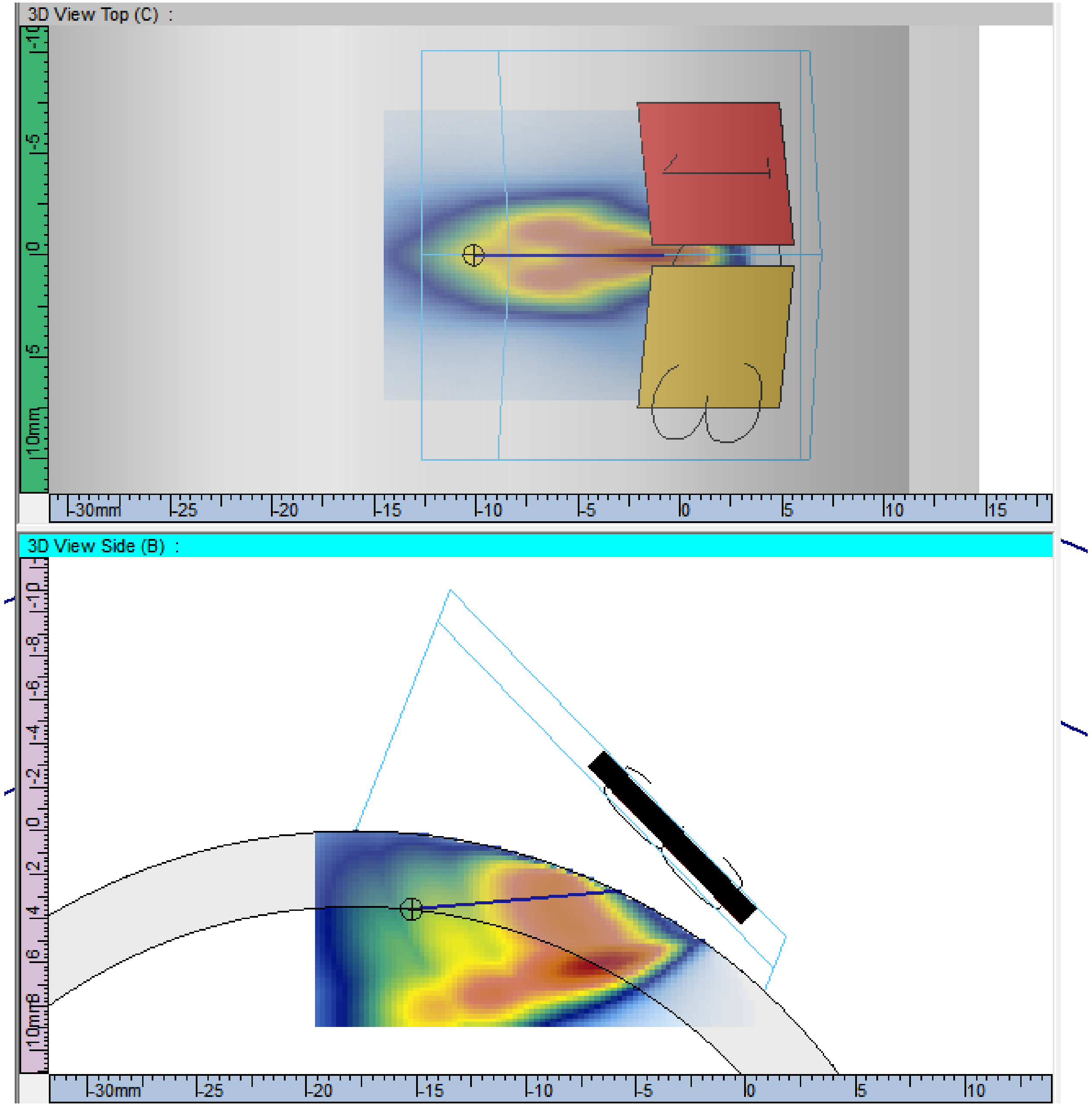
ICMH weld overlays

- ICMH mock-ups were not included in the PD inventory
  - <Ø2”[50mm] w/thin (0.1”) [2.5mm] overlays
  - Contain ID and OD initiating base material flaws
- Emergent BWR/4 overlay (summer-2016) welded to meet requirements of qualified probes versus design requirements for overlay design
- BWRVIP fabricating open/practice mock-ups and UT technique development
  - PD program fabricating blind qualification mock-ups and supporting procedure revision



ICMH weld overlay UT

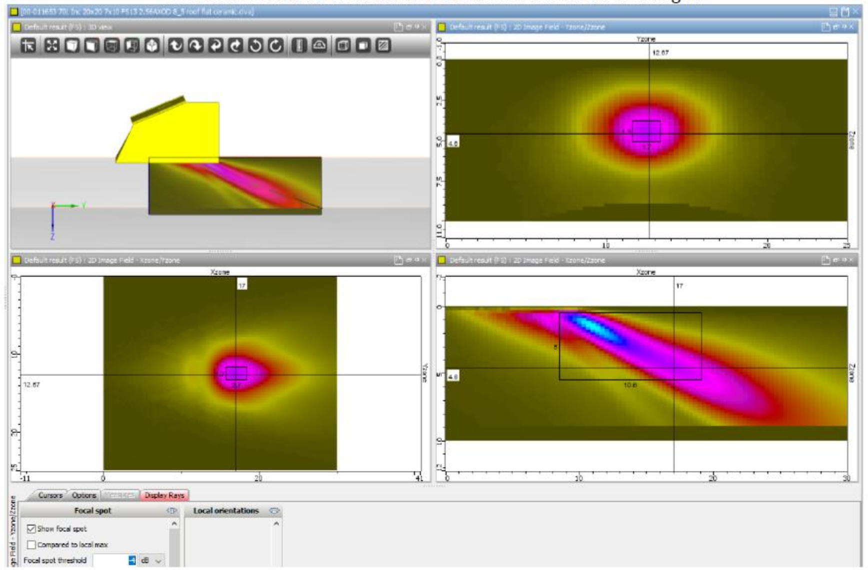
- Component curvature complicates probe design
  - Significantly defocuses ultrasonic beam
  - Example:
    - A 10mm wide element wide element requires an 17.9° incident angle to create a 60° refracted impingement angle at WOL interface
    - The back portion of the ultrasonic energy then impinges on the curvature with a 7.8° incident angle
      - 19.5° refracted angle
    - The front portion of the ultrasonic energy impinges on the curvature with a 28.7° incident angle
      - All of this energy is reflected off the surface (i.e. refracted angle exceeds 90°)



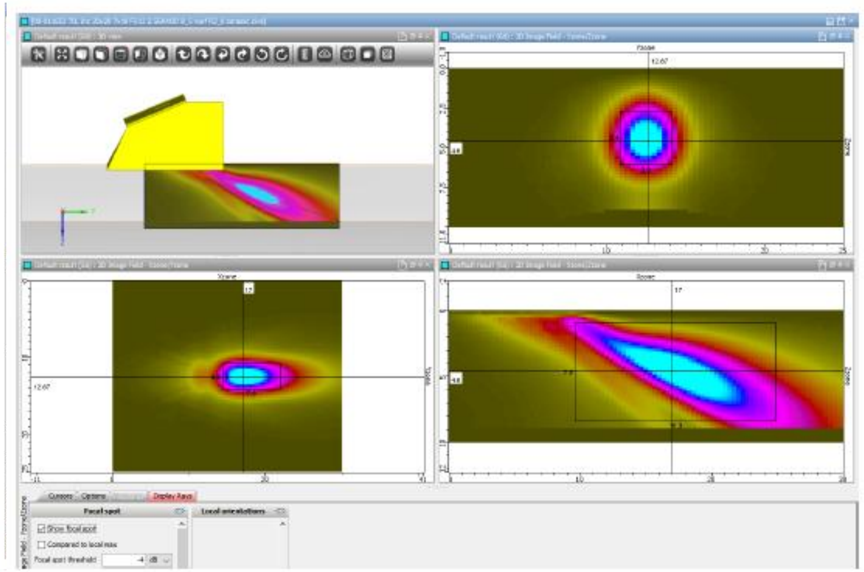
ICMH weld overlay UT

- Conventional probes being fabricated using curved crystals that compensate for curvature
  - Qualified phased array probes are too large to fit in this inspection location
    - Mechanically do what phased array does electronically to correct for curvature
    - Crystals will be diced like phased array crystals and then glued down to a curved mating surface
      - All elements then wired together
- Probe modeling in process
  - Some probes fabricated and tested before additional probes are designed and fabricated

Ceramic is flat and used as baseline reference for other designs

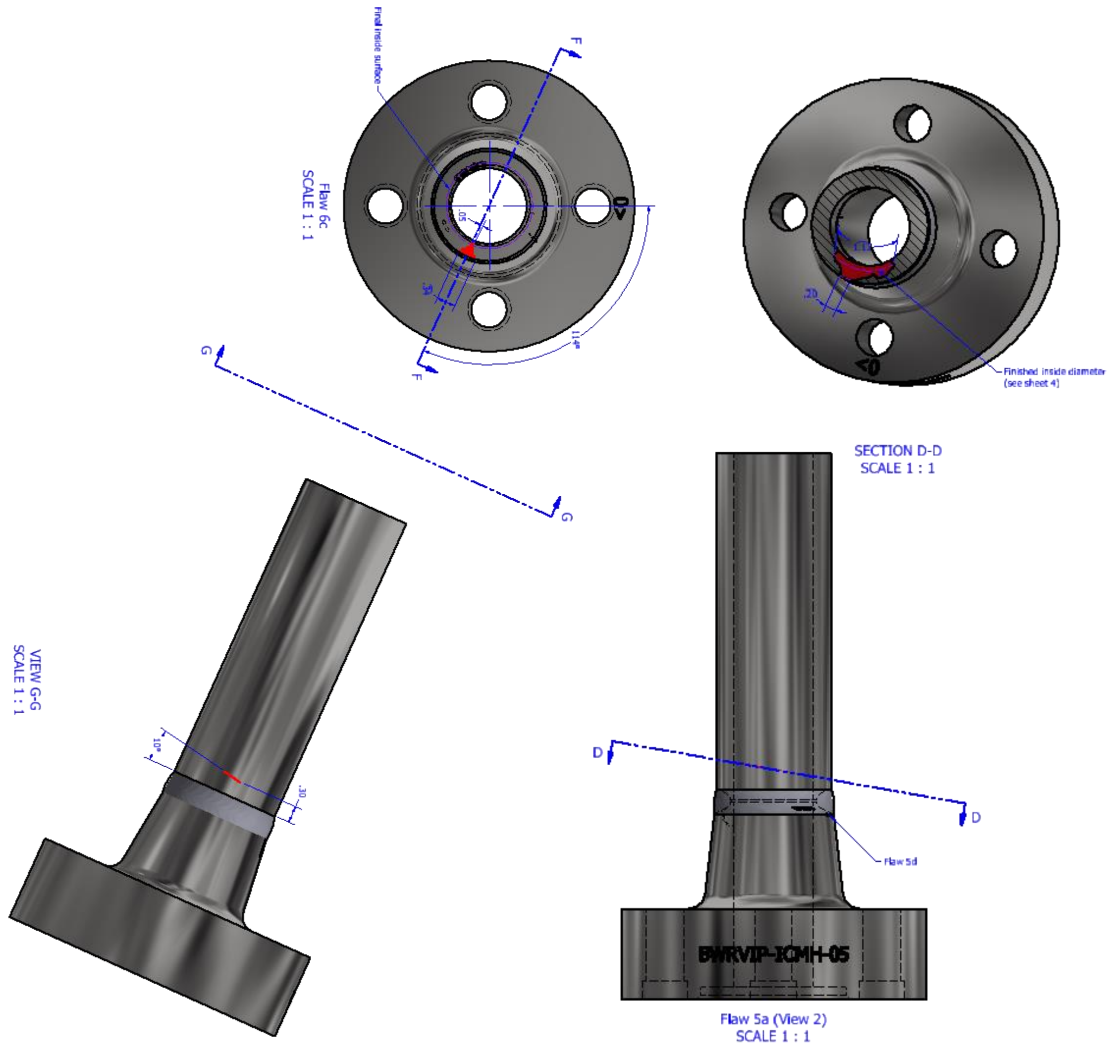


Ceramic has 2" radius in beam.



ICMH butt-weld mock-ups

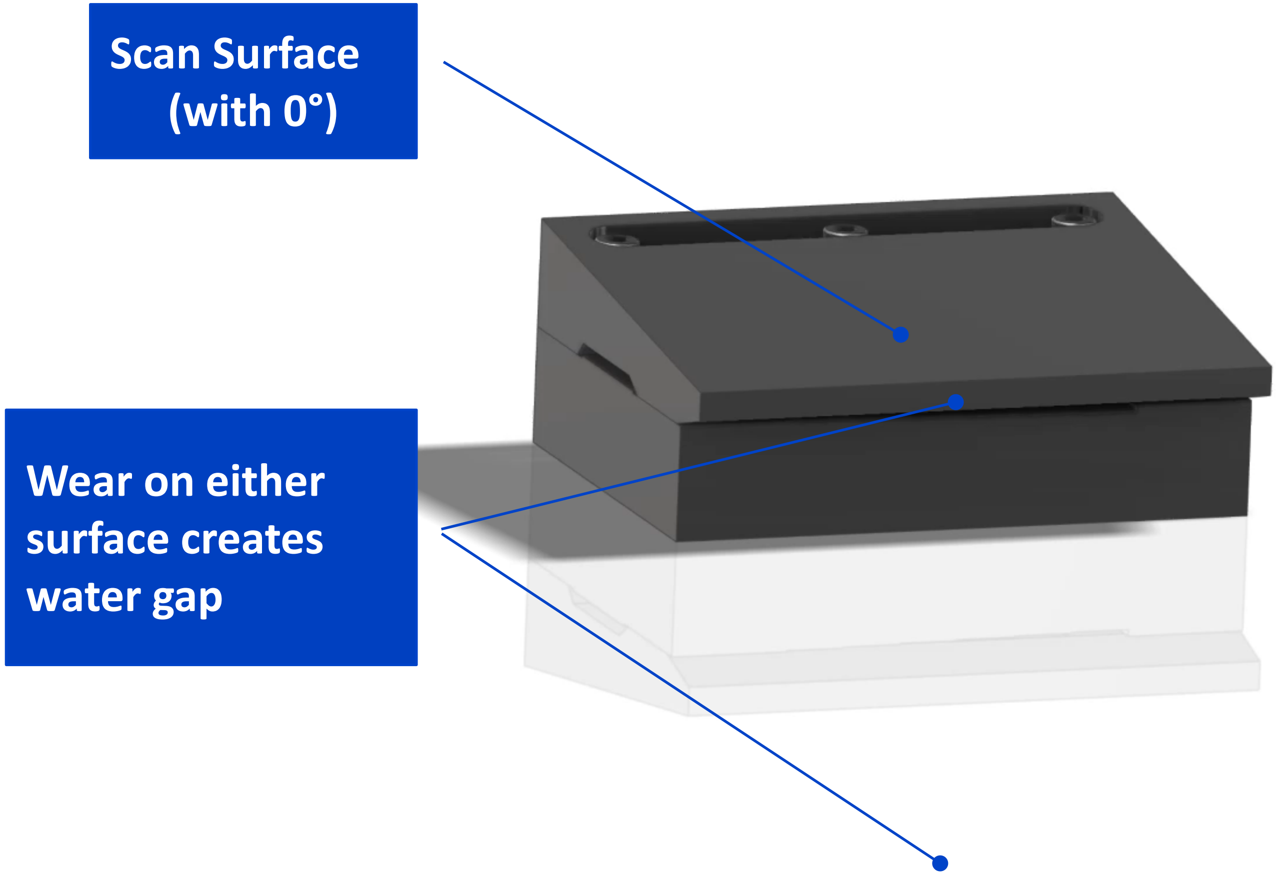
- Butt-weld mock-ups being fabricated along with WOL's
- ICMH exam volume includes the outside surface
  - PD qualified examiners may not be familiar with OD flaws
    - Existing piping/DMW procedures don't address the likelihood of OD initiating flaws
    - Mock-ups will be used to prepare ICMH UT guidelines
      - How to determine if flaw is ID or OD
      - How to measure ID length versus OD length
      - Determine characteristics of flaw response
- Mock-ups and guidelines will then be available to support emergent NDE should a 2nd leak occur
  - *We'll be prepared to gather even more information next time*



Jet-Pump diffuser slip-joint wear

Jet-pump diffuser slip-joint wear

- Efforts are progressing slowly
  - Finding time has been the issue
- Angle plates have been fabricated and high-frequency probes “tuned” for ~160’ [50m] cables have been evaluated
  - Remote pulsers close to probe may be necessary
    - Will need to be located underwater
- Prepared to design pitch-catch optimized probe design(s)
  - Will be reaching out to inspection vendors
  - Determine probe case size limitations for existing diffuser inspection tooling
- Goal is to measure ~1° of water gap using existing inspection tools with new UT technique
  - Angle steps in 0.5° gap increments



BWRVIP Reactor Internals Training

BWRVIP Reactor Internals Training

- The BWRVIP provides BWR reactor internals training to all BWRVIP members
  - Attendance has remained consistently high
    - Every class filled to capacity
  - Includes classroom training and hands-on activities
    - Held at full-scale BWR reactor internals mock-up in San Jose
    - Focused on the examination of BWR reactor internals and the various BWRVIP Inspection and Examination (I&E) documents
- One class in 2020 will be dedicated to support BWRVIP members from Japan
- Classes have been held for NRC staff in the past
  - Discussions are underway to make similar provisions in the future

Together…Shaping the Future of Electricity

Concrete NDE

Salvador Villalobos
Sam Johnson
Maria Guimaraes

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Some accomplishments

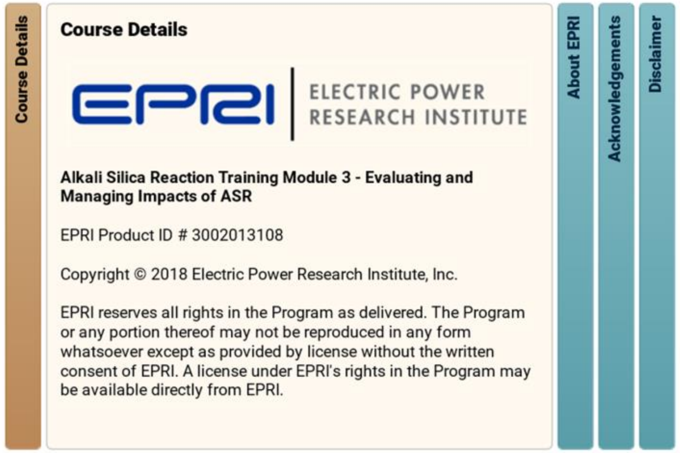
Strong collaboration with utilities, research Institutions and regulators.

Example: Joint project with MAI

Field demonstrations – Deployment

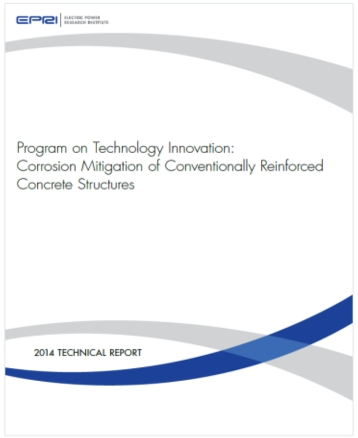
Workshops

On line courses



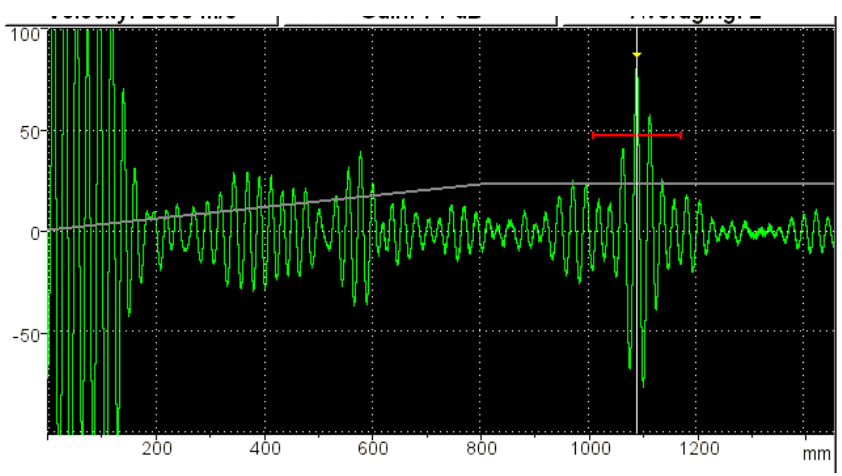
Field Guides

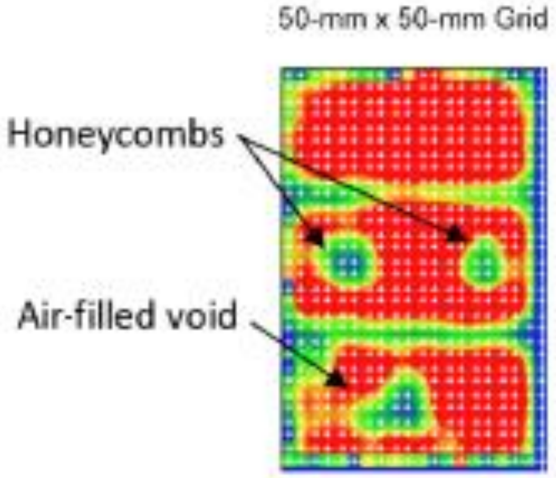
Reports



Overview of NDE of Concrete at EPRI

- Program initiated in 2009
- There are currently more than 70 published report for concrete
- Currently 18 published reports related to NDE of concrete
  - Six on feasibility and early application
  - One on modeling
  - One workshop
  - Three field guides
  - Seven on deployment





Content of presentation

- Update on concrete NDE research including the following topics discussed in May 2019 at EPRI with NRC personnel:
  - Blind testing on large mockups,
  - High energy X-ray for concrete behind liners,
  - Shear wave tomography,
  - Tendons project,
  - Strain-gage project,
  - Structures Monitoring Program,
  - UAV/drones

Capability Demonstration of NDE in Concrete with Blind Mockups

Project Objective and Benefits

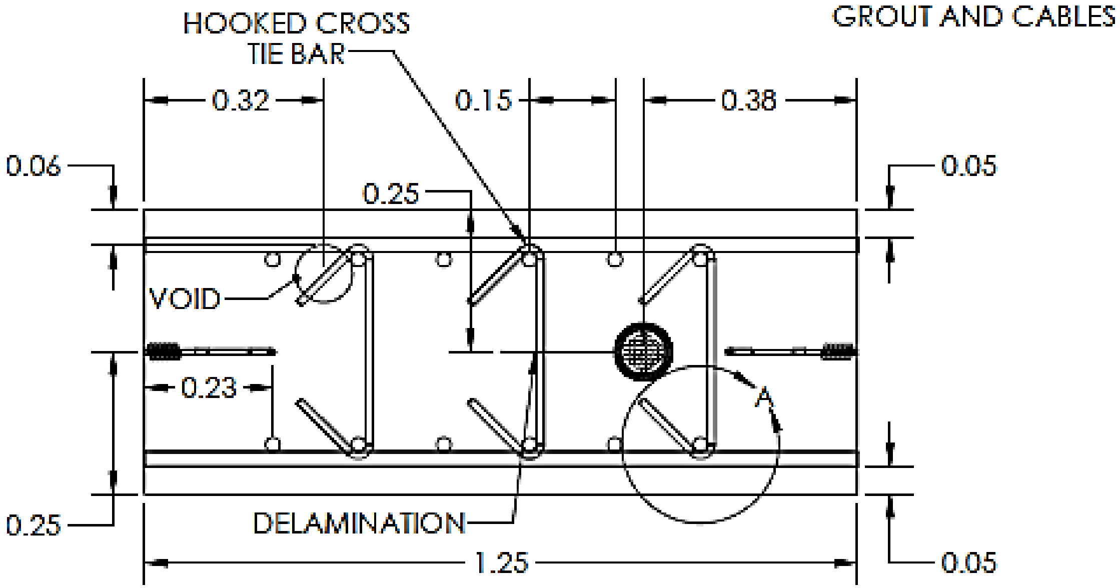
Objective - Document the capability of vendors to detect defects in concrete.

Benefits - Identify gaps in the following areas:

- Scope and equipment used for inspections
- Personnel qualifications
- Discrepancies in reporting
- Defects that cannot be accurately detected by vendors with commercially available systems

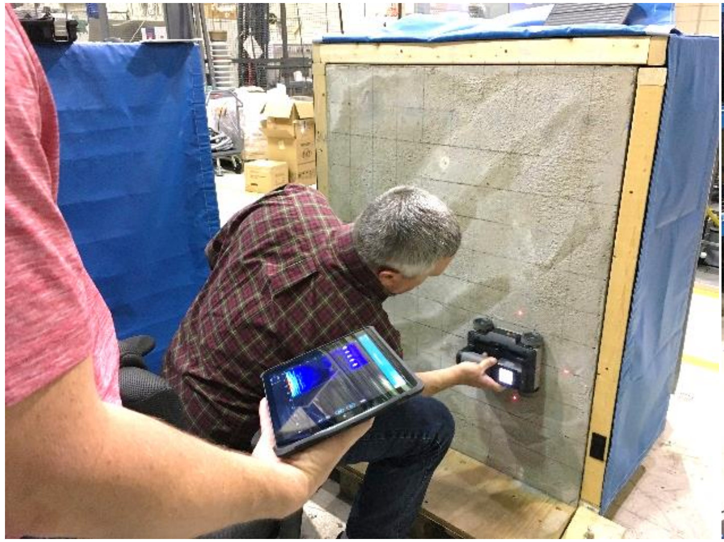
Project Schedule

- 2017 Mockup design
  - Conventionally reinforced concrete
  - Post-tensioned concrete
  - Concrete behind liner
- 2018 Mockup construction and fingerprinting
  - Fabrication of defects
  - In-house testing to ensure flaws are where they were intended to be
- 2019 Vendor testing
  - 2 Vendors and 2 equipment manufacturers
- 2020 Final Report



Observations during Vendor Testing

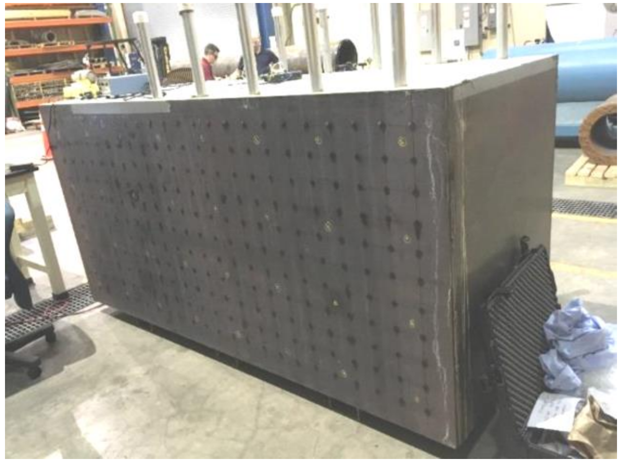
- Tests performed by 4 companies
- Differences in reporting
- False calls on defects and defect locations
- Honeycombs have not been accurately identified
- Not all techniques could be tested due to the size of the blocks
- Only one vendor tested the steel lined mockup
- Detection capabilities of embedments deeper than the first layer of steel highly dependent on frequency of equipment and qualifications of the operator



High Energy X-ray

Application: Steel-Concrete Construction

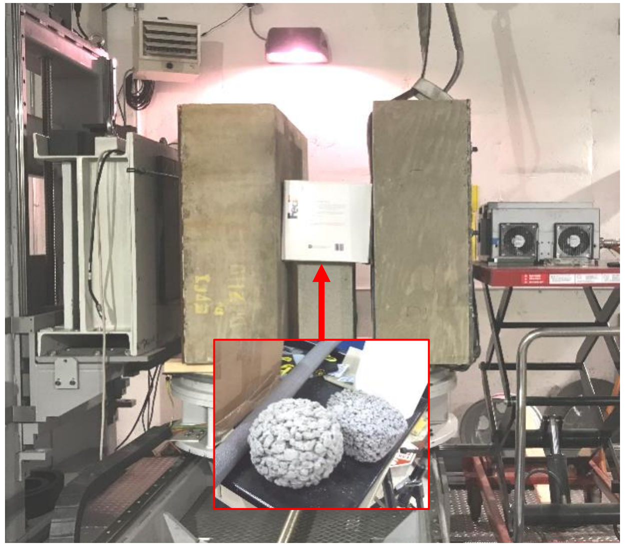
- Steel liners restrict direct access to concrete to perform a condition assessment
- High energy X-rays was identified as one of the techniques that could identify voids inside concrete behind a thick steel liner.



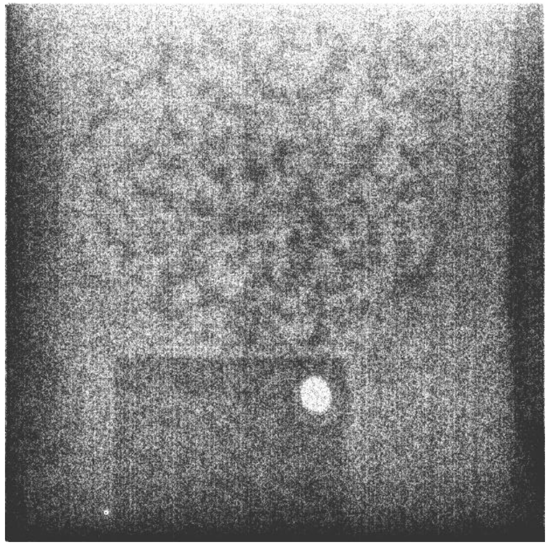
Technical Project Update

Current Status

- Testing high energy X-ray
- 2 mockups (Concrete blocks) (1 foot thick each). A box filled with sand was used to account for the additional ft.
- Inspection procedure to inspect through 3 feet of concrete using a Betatron (7.5 MeV @ 6-8 rad /min; 2.5 min per shot)



Setup



X-ray Image

Remaining Work

- Refine the inspection procedure
- Inspection of blind mockup at EPRI
  - Document results in a technical report and presentation

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Shear Wave Tomography
NDE Techniques to Detect the Edge of a Delamination

Motivation and Scope

Motivation

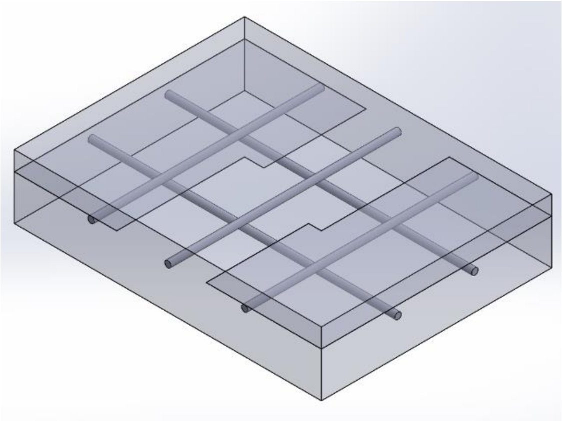
- NDE methods typically used to locate delaminations have **limited resolution** and can only be used to monitor the growth of a delamination if large changes occur.
- Shear wave methods have the potential to improve the resolution of NDE methods currently used.

Scope

- This project evaluates the capability of shear wave methods to detect changes in a delamination. The project covers the following tasks:
  - Design and fabrication of concrete mockups
  - Testing and evaluation of different NDE equipment
  - Evaluation of the resolution of the NDE equipment tested

Project schedule

- 2017 Design and fabrication of mockups
  - Determine reinforcement configuration
  - Defect fabrication and depth
  - Thickness of specimens
  - Fabrication of mockups

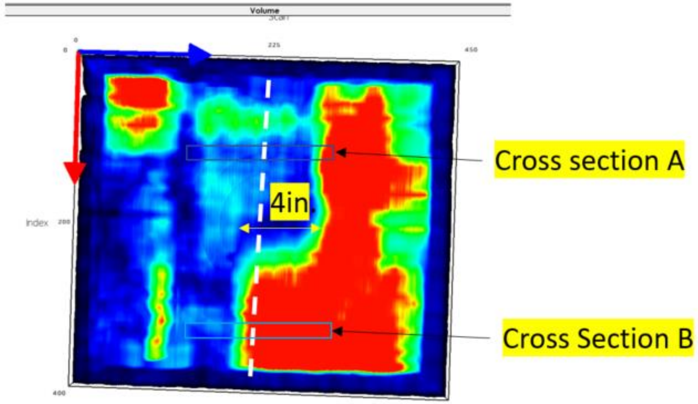


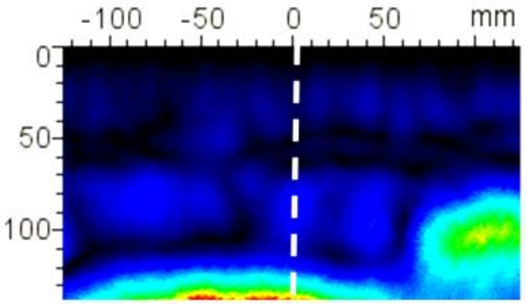
- 2018 – 2019 Perform testing and data analysis
  - Evaluate the shear wave and pulse echo techniques
  - Use systems from different manufacturers
  - Evaluate the resolution of the systems

- **Final Report 3002016082 – available in December 2019**

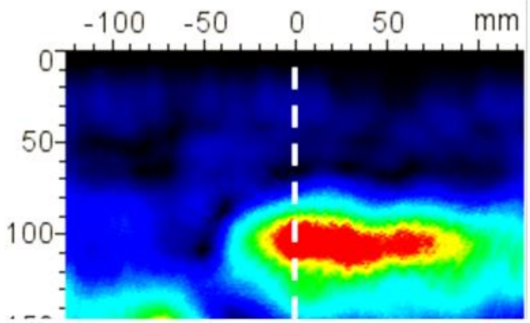
Observations During Testing with Shear Wave Techniques

- Preliminary testing indicated a 4 inch offset could be identified
- Changes as small as 1 inch can be detected versus a 12 inch resolution for typically used methods
- Pulse echo testing requires a small grid and is time consuming. The shear wave array is faster and provides better results
- Tests focused on monitoring the growth at a particular location rather than an area





Cross section A



Cross section B

Study of Lift-Off Tests and Data Trending for Post Tensioned Tendons

Key Research Question – Key Takeaways

Can the trend in lift-off test data support a new assessment of the tendon surveillance frequency for existing containments?

ANSWER

- This study showed that such analyses are case-specific.
- The methodology presented can be used to assess the adequacy of the tendon surveillance frequency.
- The analysis is applicable to individual tendon groups. Inspection period extensions would be limited to specific tendon groups unless the analysis from all tendon groups in the unit support an extension. The same reasoning applies for a multiunit plant.
- This reports focuses solely on tendon force loss. Analyses of other elements in the tendon surveillance program (such as grease testing, tendon strand testing, and moisture content testing) need to be performed to show that all of them are capable of performing their intended function for the duration of the extended period.

3002016331

Industry activities

- Two US utilities have submitted request reliefs to the regulator to extend the period between tendon surveillances.
  - One of these requests reliefs has been granted by the regulator
  - Both documents can be found in ADAMS

Southern Nuclear

Cheryl A. Gayheart
Regulatory Affairs Director

3535 Colonnade Parkway
Birmingham, AL 35243
205 992 5316 tel
205 992 7601 fax

cagayhea@southernco.com

FEB 1 8 2019

Docket Nos.: 50-424
50-425

NL-18-1571

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Vogtle Electric Generating Plant – Unit 1 and 2
Proposed ISI Alternative VEGP-ISI-ALT-19-01 for Tendon Inservice Inspection Extension

Ladies and Gentlemen:

Enclosed for your review is proposed Inservice Inspection (ISI) alternative VEGP-ISI-ALT-19-01 associated with the 4th ISI Interval for Vogtle Electric Generating Plant (VEGP), Unit 1 and 2. VEGP-ISI-RR-19-01 concerns requirements associated with the Containment ISI program. The 4th ISI Interval program complies with the 2007 Edition, 2008 Addenda of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code. The 4th ISI Interval began on May 31, 2017 and is currently scheduled to end May 30, 2027. We request your approval by February 19, 2020.

Exelon Generation.

200 Exelon Way
Kennett Square, PA 19348

www.exeloncorp.com

10 CFR 50.55a

TMI-18-094

October 16, 2018

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Three Mile Island Nuclear Station, Unit 1
Renewed Facility Operating License No. DPR-50
NRC Docket No. 50-289

Subject: Submittal of Relief Request RR-18-01 Concerning Containment Unbonded Post-Tensioning System Inservice Inspection Requirements

Attached for your review is a relief request associated with the fourth Inservice Inspection (ISI) interval for the Three Mile Island Nuclear Station (TMI), Unit 1. RR-18-01 concerns requirements associated with the containment inservice inspection program. The fourth interval program complies with the 2004 Edition, no Addenda of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code. The fourth ISI interval began on April 20, 2011 and is currently scheduled to end April 19, 2022. We request your approval by August 31, 2019.

There are no regulatory commitments in this letter.

Follow-up project - Tendon Monitoring (start 2020)

- Tendon tension can be monitored by attaching fiber optic strain gauges to the compression shims.
- Advantages:
  - It could allow further extending periods between tendon surveillances
  - It could eliminate lift-off tests
  - It allows a simple, low cost way to monitor suspect locations
- This approach has been demonstrated by EPRI at Ginna during a containment pressure test.
- Project Duration: 2 - 3 years

Looking for participants in focus group / potential pilots

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Structural Inspection and Monitoring – Best Practices

Structural Inspection and Monitoring – Best Practices

Objective

- Develop best practices for structural inspections and monitoring in an effort to have more consistent practices across the nuclear industry.

Scope

- Utilities perform inspections, analyze data, and record data differently. This project will look to determine the best practices from the industry and provide guidance on how to implement these practices.
- The guidance will focus on how data is collected and what is done with the data in terms of aging management.

- EPRI Collected:
  - SMP Procedure Documents
  - Inspection Procedures
  - Example Inspection Reports
  - Personnel Qualifications for Inspections
  - Underwater Inspection Procedures

- **87** documents collected
- **38** plants represented

Structures Monitoring Program Training Course

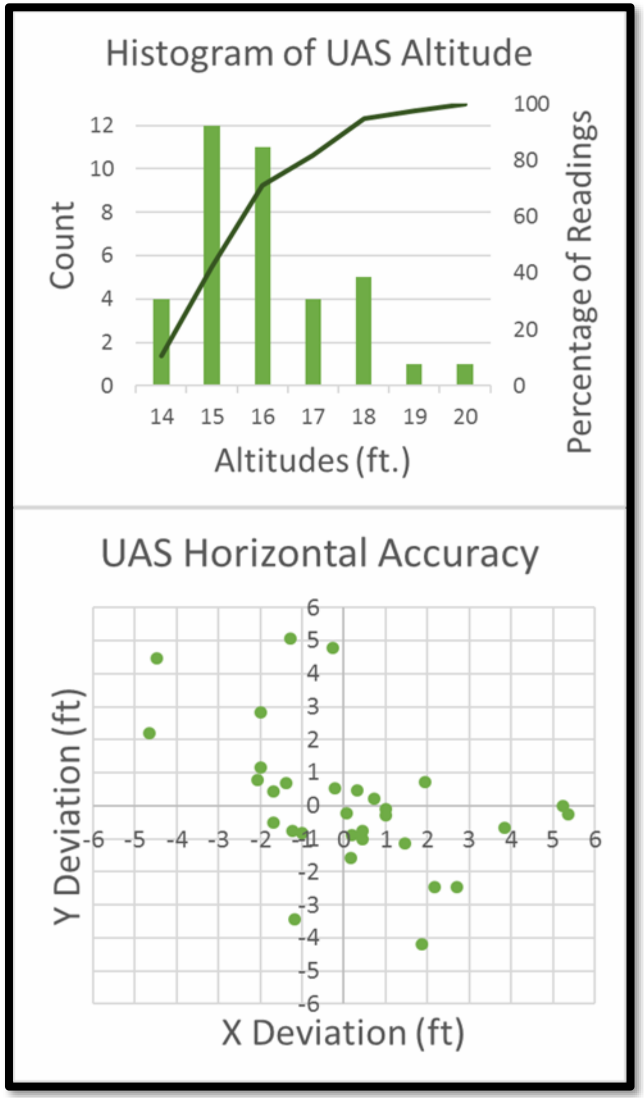
- EPRI is developing a new training course focused on the visual inspections performed for the Structures Monitoring Program (SMP)
- The 1.5 day classroom training will cover the following topics for four different materials: **Concrete, Steel, Masonry, and Polymers**
  - Scope of Components in SMP
  - Degradation Mechanisms of Material
  - Visual Identification of Defects
  - Acceptance Criteria/Evaluation
  - Utility Case Studies/OE
- Pilot training set to take place in Q1 2020 before official training course is developed

2019 UAV Activities

General UAS TI Initiatives

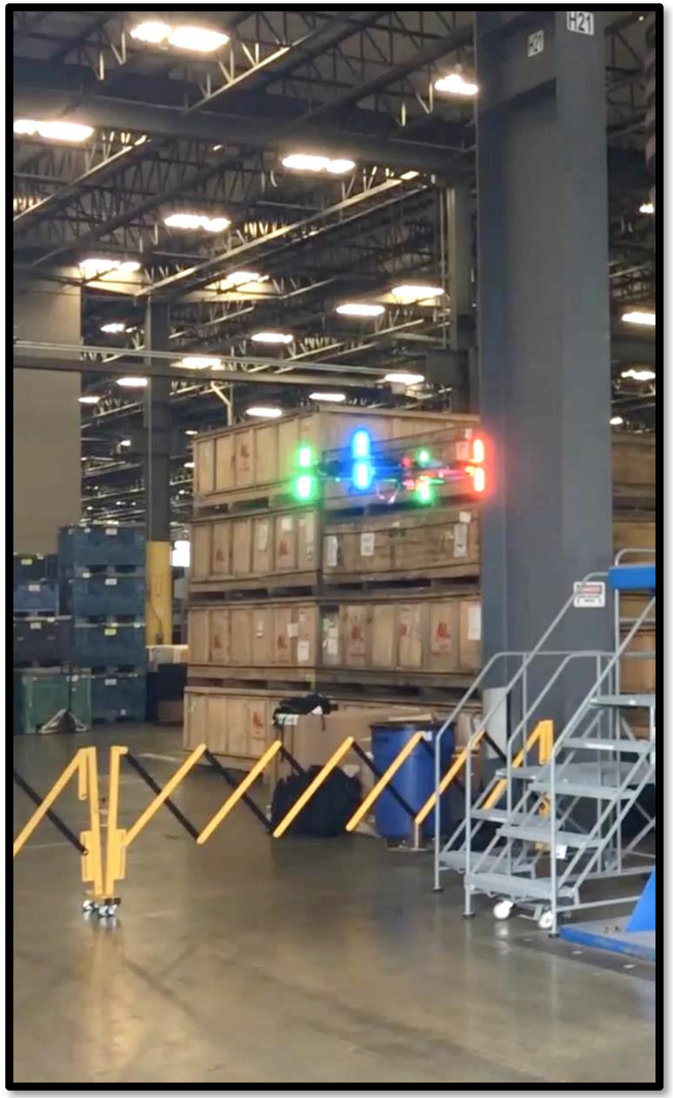
Machine Vision

Navigation Testing



Advanced UAS Payloads

Confined Space/Indoor Operations



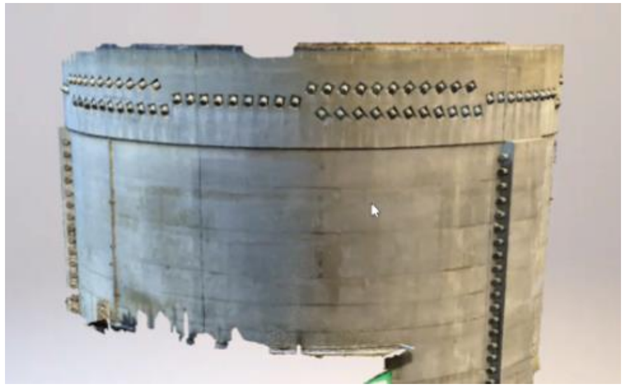
Remote Visual Inspections with Unmanned Aerial Systems

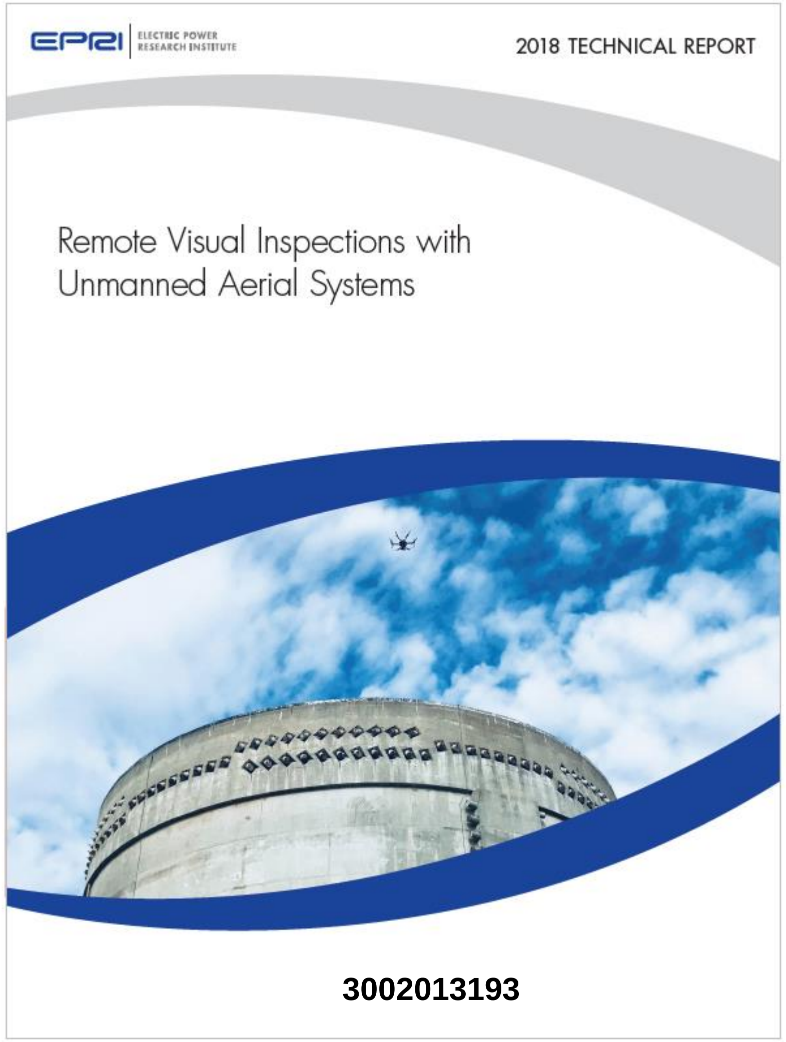
Who should read it?

- Utility personnel in charge of in-service inspections of infrastructure and personnel developing utility UAS programs

Key Findings

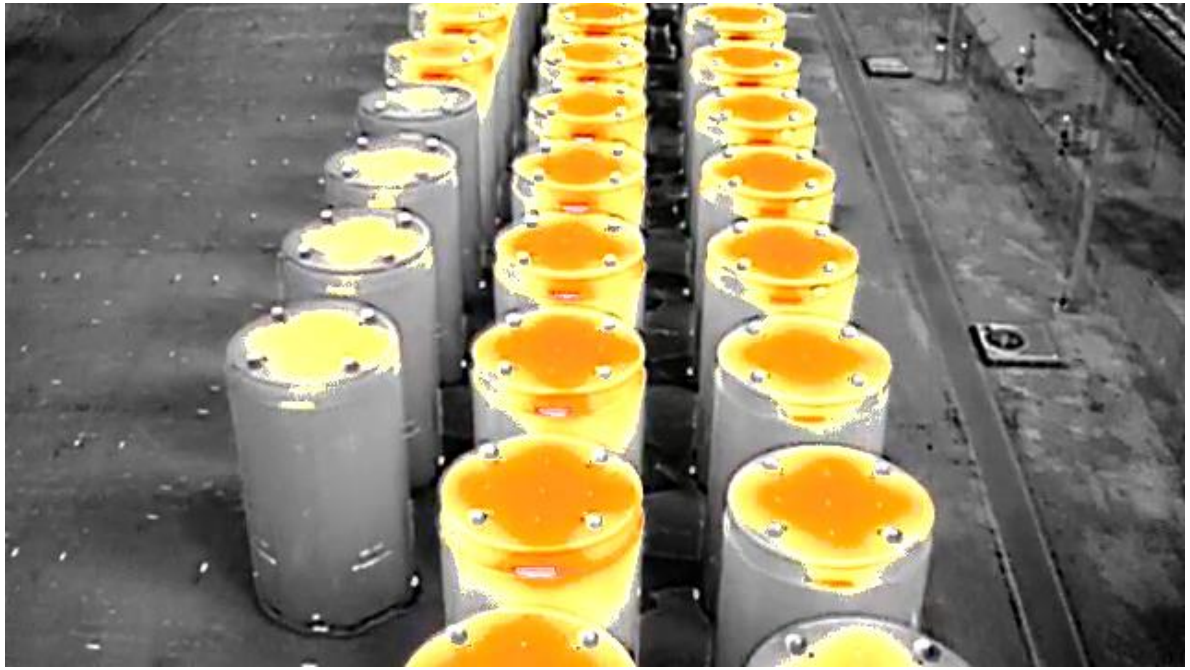
- UASs can perform external visual inspections of nuclear infrastructure to the same level of detail as traditional inspections with a lower risk to personnel and in less time.
- The data collected from inspections with UAS is beneficial for future trending and analysis of defects.
- Knowing visual acuity requirements is important in selecting a camera to be used as well as how far away from the structure you can fly.





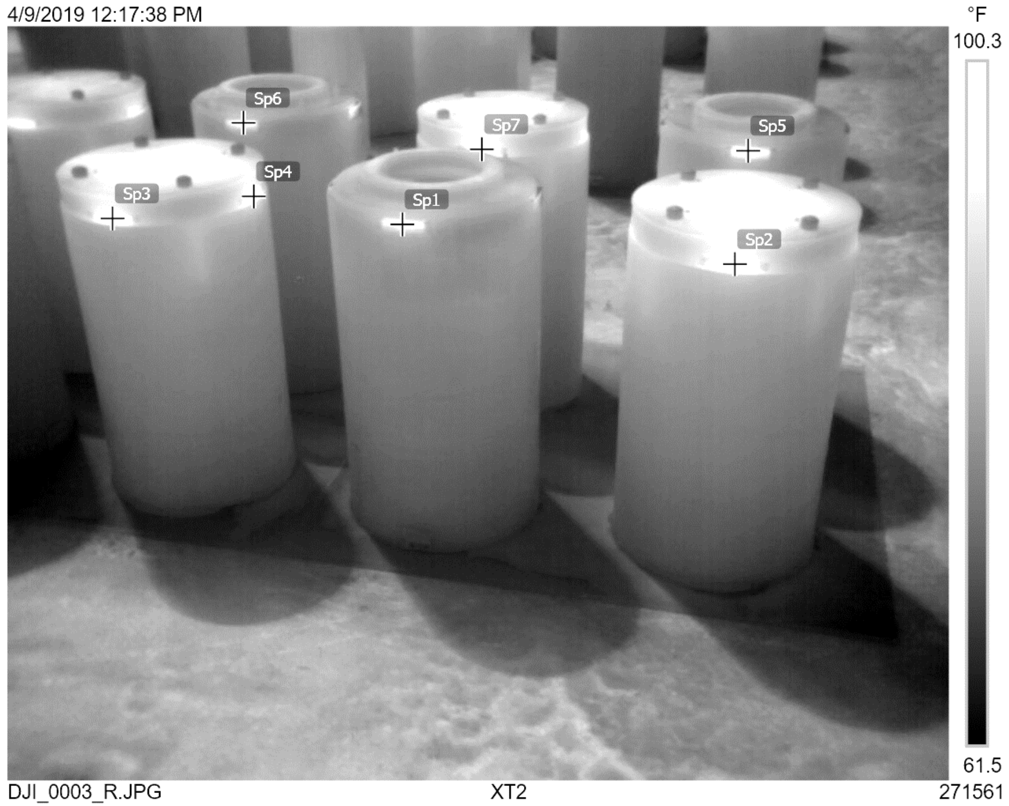
Video Taken from Field Demonstration

UAV for Dry Cask Storage System Inspections



Measurements	
Sp1	101.8 °F
Sp2	112.4 °F
Sp3	105.6 °F
Sp4	103.6 °F
Sp5	103.2 °F
Sp6	98.3 °F
Sp7	110.0 °F

Automated Analysis of Thermal Data from Drones



Measurements

Sp1	101.8 °F
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Sp4	103.6 °F
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Sp6	98.3 °F
Sp7	110.0 °F

2019 EPRI Annual UAS Conference

- Approx. 200 participants representing utilities, vendors, and other industry organizations
- 2 day conference
  - Break out sessions for Nuclear and Transmission on second day
  - Vendor Expo and Evening Reception

2020 Event will be in November – Exact Dates TBD

Together…Shaping the Future of Electricity

Automated data analysis update

John Lindberg
Thiago Seuaciuc Osorio

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Automated inspection of reactor internals

Remote Visual Inspection of Reactor Internals

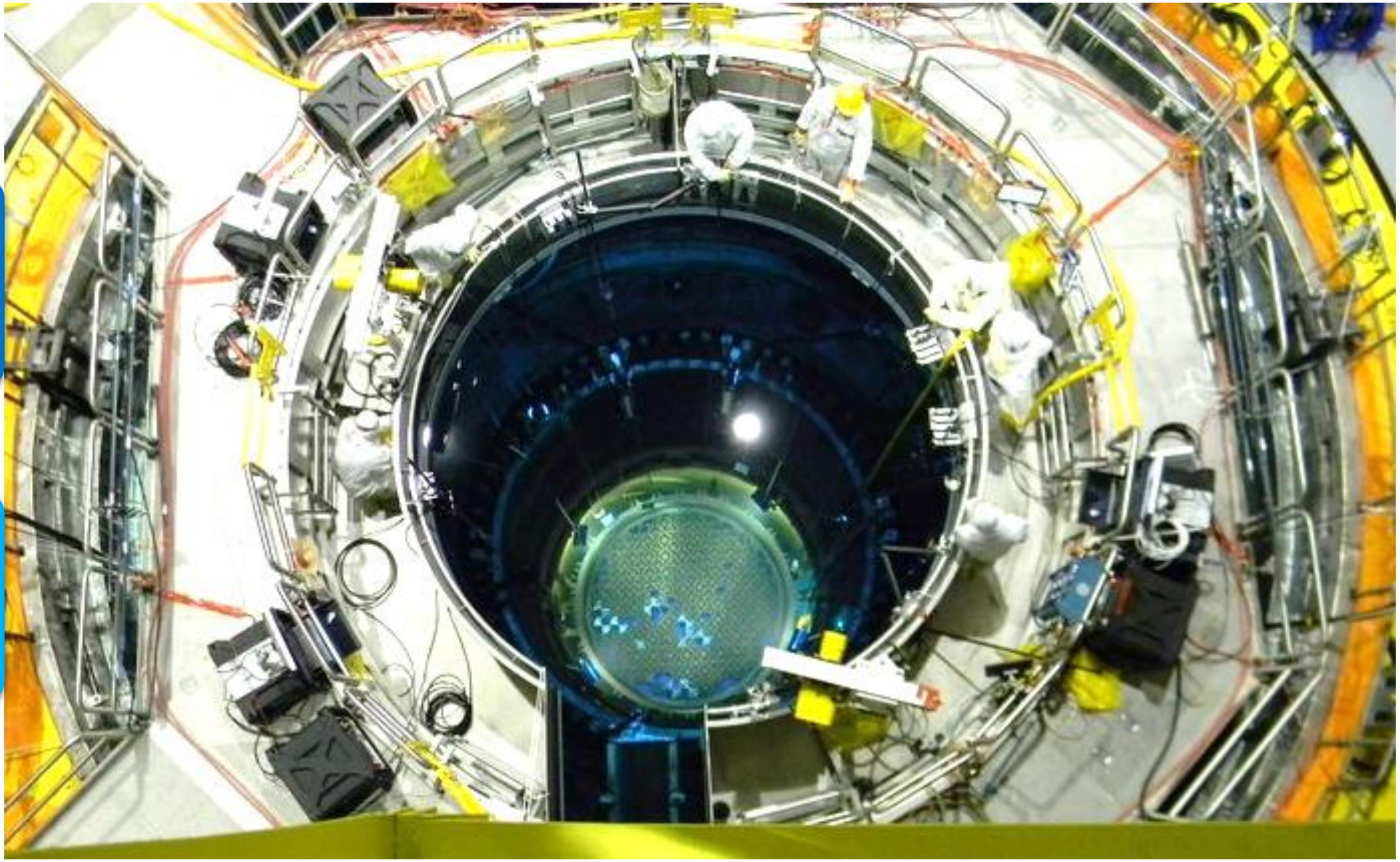
Data collection

Preliminary analysis

Real time

Data review

Often done at a later time



Fatigue

Missed flaws

Distraction

Goal: Develop a screening tool that can assist examiners

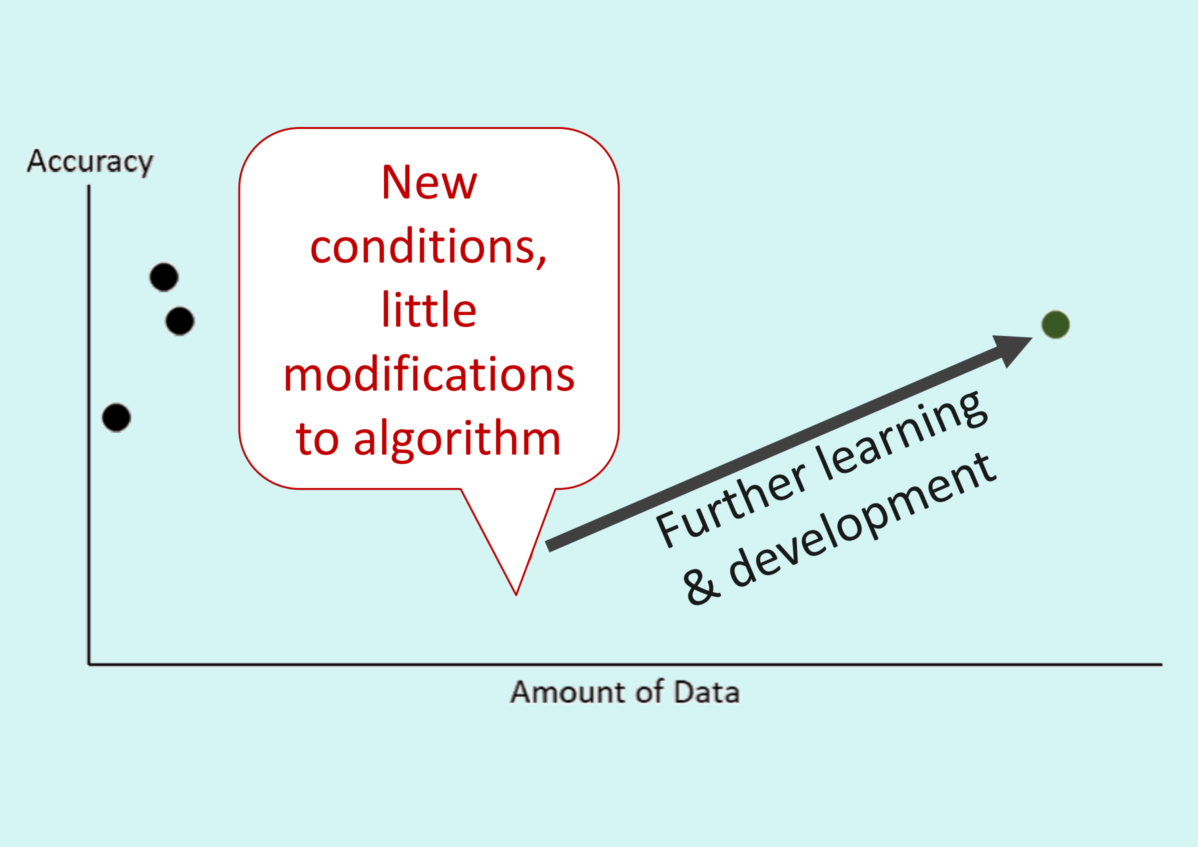
RVT Automated Analysis – Feasibility Study

- Standard definition videos with
  - Consistent raster scan
  - Constant field of view - no zooming
  - Small changes in lighting
  - Truth Data

Proof of concept → Successful

RVT Automated Analysis – More Realistic Conditions

- High Definition videos with
  - Random scanning patterns
  - Use of zooming
  - Use of auxiliary lighting
  - Some image shaking
  - No truth data – Blind Testing



Automated Analysis – Field Data

- Incorporate lessons learned from previous tests
- Further development of training algorithms based on plant data
- Test specimens cannot account for:
  - Surface conditions and crud
  - Discoloration/staining
  - Radiation
  - Thermals

Plant data is key to the success of this initiative

Current work scope

- Labelling data
- Redefining metrics to include missed-calls
- Optimize algorithms to new metrics
- Start looking at field data
- Developing GUI and test version of software

Automated inspection of fuel assemblies

Automated Analysis for Fuel Assembly Visuals

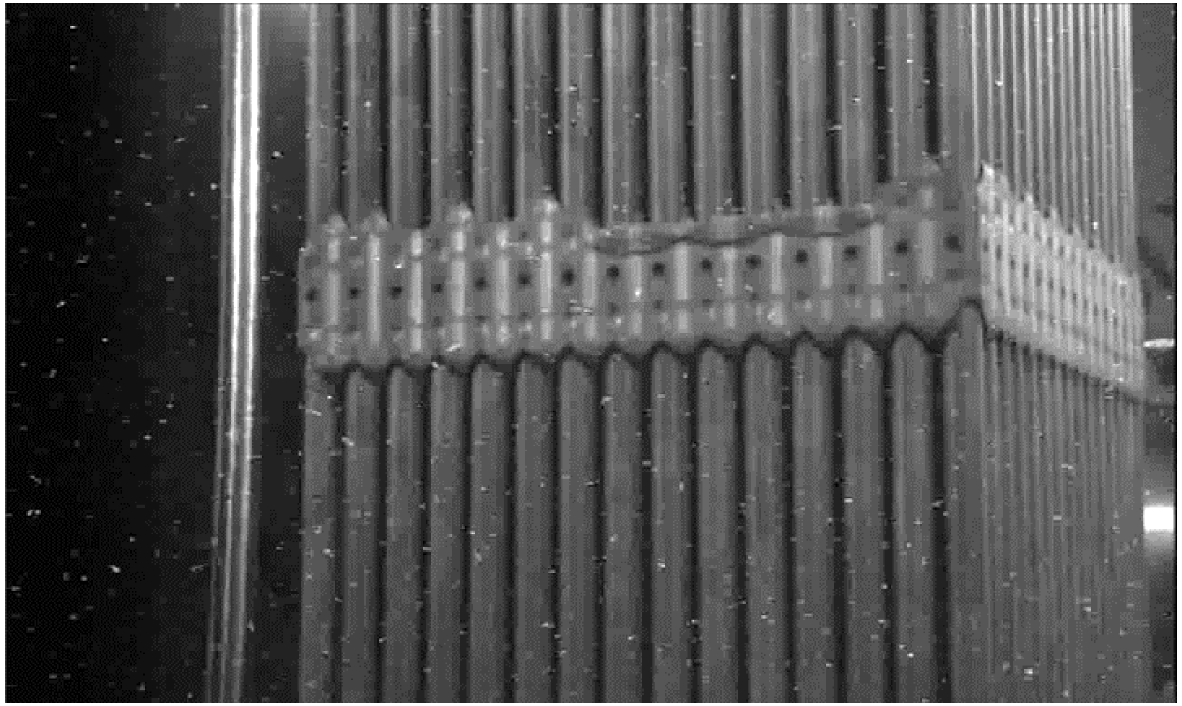
Objective: Develop an automated computational framework for assessing 4-face fuel assembly visual inspection video in real time to identify anomalies

- **Benefits:**
  - Automated computational framework for assessing 4-face fuel assembly visual inspection video in real time to identify anomalies
  - Improved accuracy in identifying anomalies
  - Reduced human factor burden
  - Potential cost savings if visual inspections are on critical path

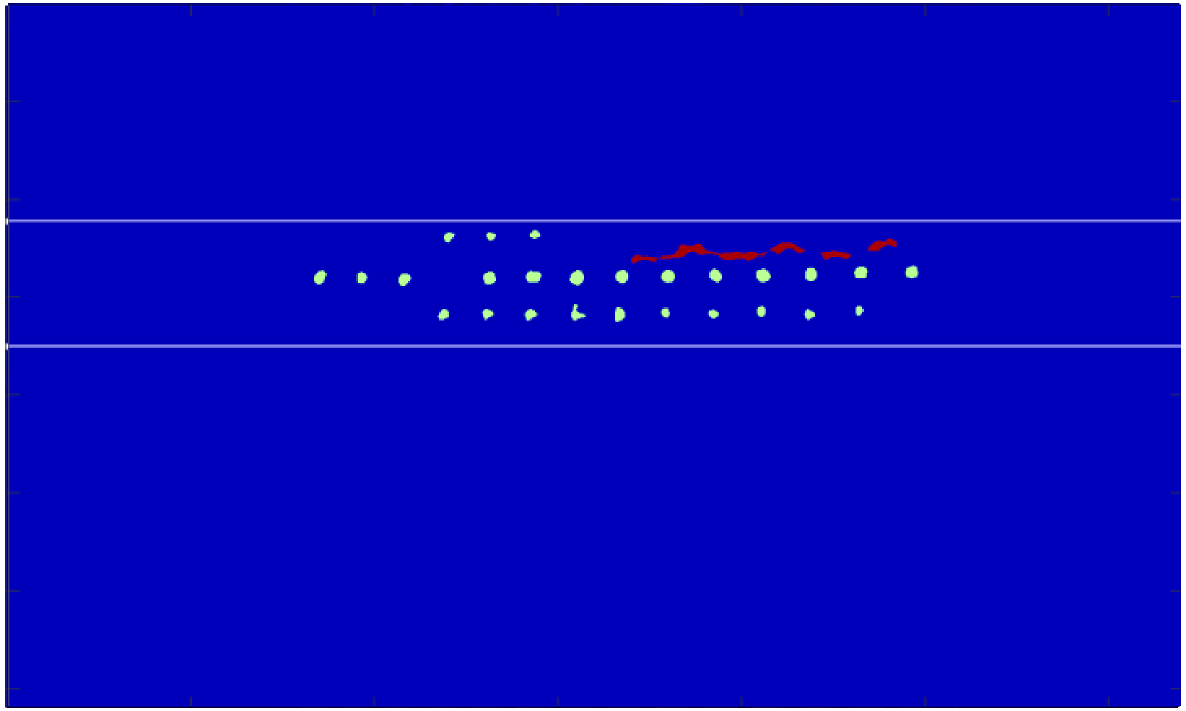
Image Processing in Action

- Remove noise due to radiation
- Isolate primary face
- Rotate and isolate grid
- Mask non-grid region
- Apply shape filters
- Classify results

Before

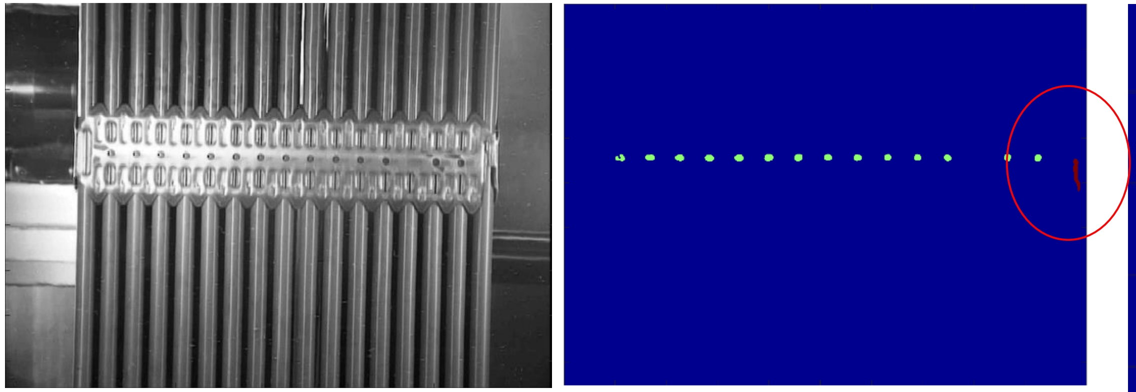


After

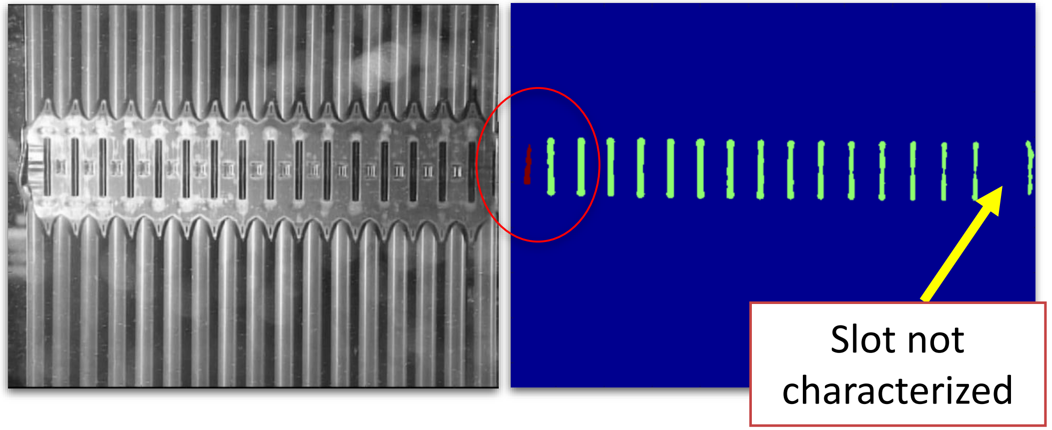


Other Examples from Feasibility Study

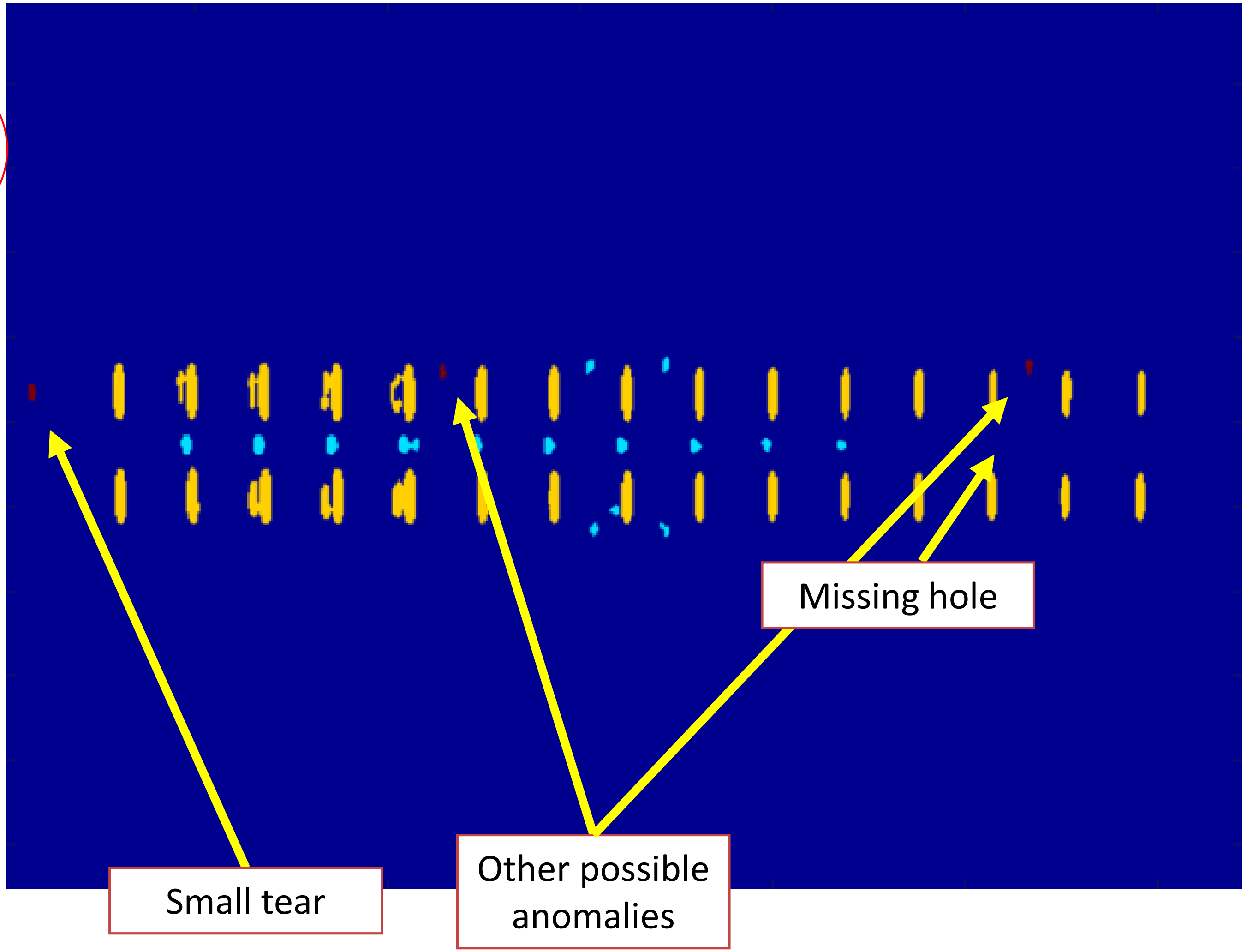
Large Tear



Displaced Material



Small Tear



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Current work scope

- Adding machine learning algorithms to identify grid-wear and to classify the level of severity
- Developing a prototype software package for pilot testing on site. Pilot testing tentatively planned for Fall 2020.

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PNNL-SA-150349

Assessment of Eddy Current Testing for PWSCC Susceptible Materials

JOHN P. (JACK) LAREAU, MICHAEL R. LARCHE, AARON A. DIAZ

Pacific Northwest National Laboratory

NRC-Industry NDE Technical Information Exchange Meetings - Rockville, MD
January 14-16, 2020

Work sponsored by the US NRC – Office of Research
Carol Nove, NRC COR

Presentation Outline

- NRC Expectations
- Purpose and Objectives
- ET Surface Exam Acceptable Flaw Length and Depth
- ET Probes, Mockups and Data Acquisition Configuration used in the Study
- Results
- Observations
- Unresolved Issues

NRC Expectations

In 2015, the NRC communicated their expectations to industry for ET inspections of peened, inlayed, and onlayed DMWs.* The focus was to ensure a better understanding of detection performance and sensitivity of ET techniques to support the development of:

- "Eddy current acceptance standards that have a technical basis given the sizes and depths of flaws that can challenge a peened surface and/or an Alloy 52 inlay or onlay"
- "Eddy current qualification requirements that provide confidence that the procedure can reliably detect shallow and near-surface flaws and be able to discriminate between shallow flaws and scratches and weld passes"
- "Alternate inspection methods or programs to determine if the mitigation process is functioning as intended."
- "Include or refer to these standards in N-770-X."

* Cumblidge SE. 2015. "NRC Expectations for Eddy Current Inspections of Peened, Inlayed, and Onlayed Dissimilar Metal Welds." Presented at *Industry/NRC NDE Technical Information, Exchange Public Meeting*, January 13-15, 2015, Bethesda, MD. ADAMS Accession ML15013A279.

Purpose and Objectives

Goal of this Research: To inform NRC regarding detection performance and sensitivity of ET for surface examinations in the context of recommended NRC criteria for ET inspections of peened, inlayed, and onlayed dissimilar metal welds (DMWs)

This presentation summarizes the ET research to develop a better understanding of detection performance and sensitivity of ET techniques to support the development of:

- A technical foundation regarding detection and sizing limits
- Effective ET qualification requirements
- The focus is on the inspection of weld metal. Base metal ET is not discussed.
- Effective alternate inspections or programs for evaluating PWSCC mitigation processes
- ET acceptance standards that can be referenced in the appropriate ASME B&PV Section XI Code Case (N-770-X).

PNNL Report on ET Assessments

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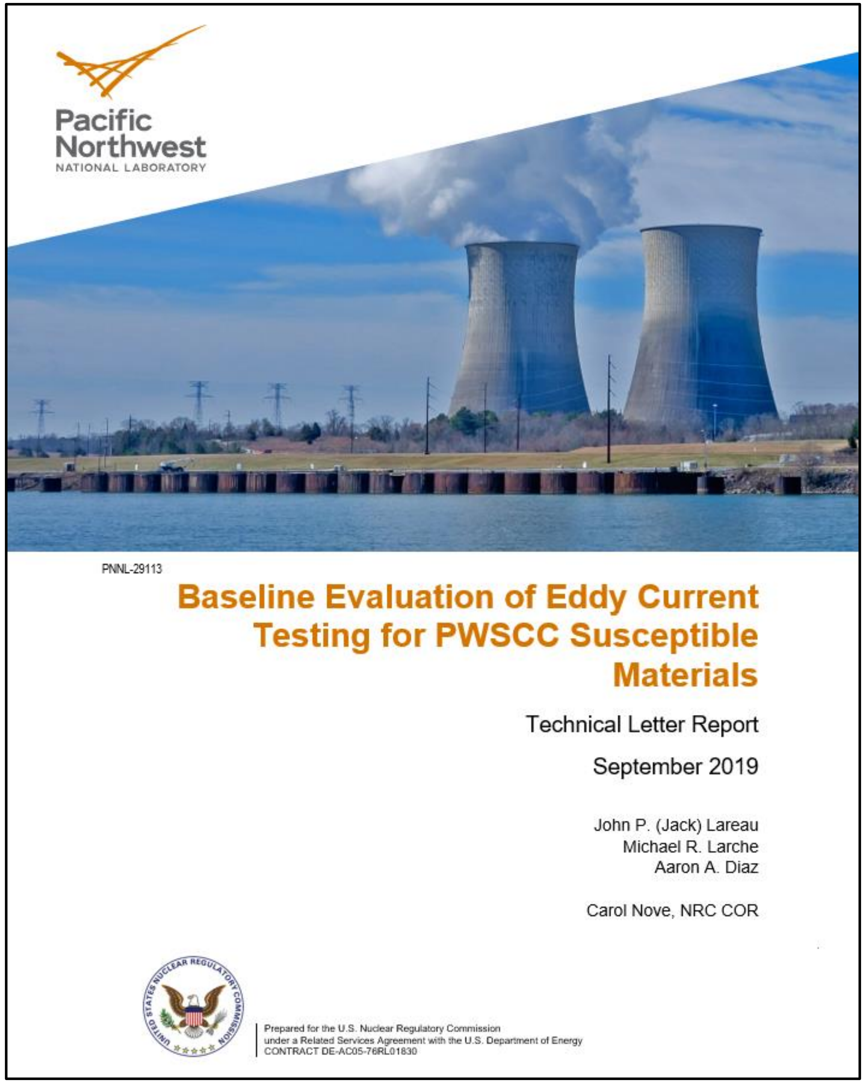
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PNNL-29113

Baseline Evaluation of Eddy Current Testing for PWSCC Susceptible Materials

Technical Letter Report

September 2019

John P. (Jack) Lareau
Michael R. Larche
Aaron A. Diaz

Carol Nove, NRC COR

Prepared for the U.S. Nuclear Regulatory Commission
under a Related Services Agreement with the U.S. Department of Energy
CONTRACT DE-AC05-76RL01830

ML19267A240

ET Surface Exam Acceptable Flaw Length

ET surface exams are described in Section XI, Appendix IV, with qualification requirements for piping and vessel exams being found in Supplement 2.

- Supplement 2 specifies a cal notch (EDM) of 0.5 mm (0.02 in.) deep and < 0.25 mm (0.01 in.) wide; or a compressed notch 1.02 mm (0.04 in.) deep.
- IWB-3514.1 does allow wetted surface planar flaws detected by preservice volumetric inspection and specifically includes PWSCC susceptible materials.
- Table IWB-3514-2 specifies allowable flaw lengths, allowing surface connected flaws < 6.35 mm (0.25 in.) for wall thicknesses ≥ 50.8 mm (2.0 in.).

- One could argue that 6.35 mm (0.25 in.) is the de facto allowable flaw length using surface ET

ET Surface Exam Acceptable Flaw Depth

ET surface exam preservice acceptance standards - solely based on length and do not address depth.

- Depth can be addressed indirectly (as a detection threshold) but cannot be evaluated quantitatively
- Section XI, Appendix IV, Supplement 2 specifies a cal notch (EDM) of 0.5 mm (0.02 in.) deep and < 0.25 mm (0.01 in.) wide; or a compressed notch 1.02 mm (0.04 in.) deep.
- While an EDM notch is a non-conservative representation of PWSCC, ET detection sensitivity associated with this notch has been shown to be suitable for detecting actual PWSCC that has been confirmed by DT.*
- There is a large body of SG tube data that supports a detection threshold of 0.25 mm (0.01 in.) depth based on 20% of a typical tube wall thickness. Detecting defects less than this depth would be questionable in weld material.

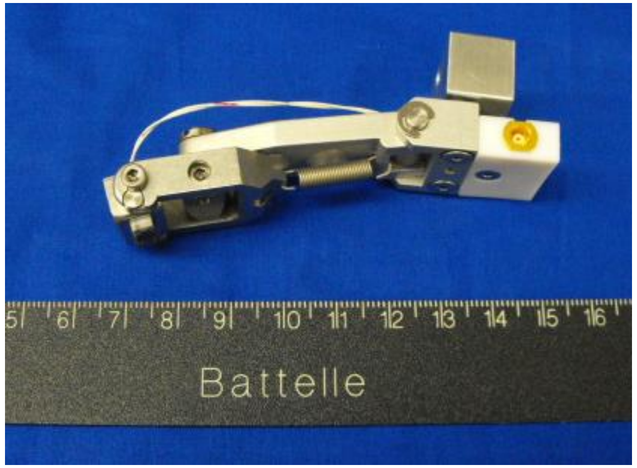
- More work is required for establishing flaw depth acceptance standards for ET surface exams in PWSCC susceptible materials.

* References provided in PNNL report 29113; ADAMS Accession #: ML19267A240

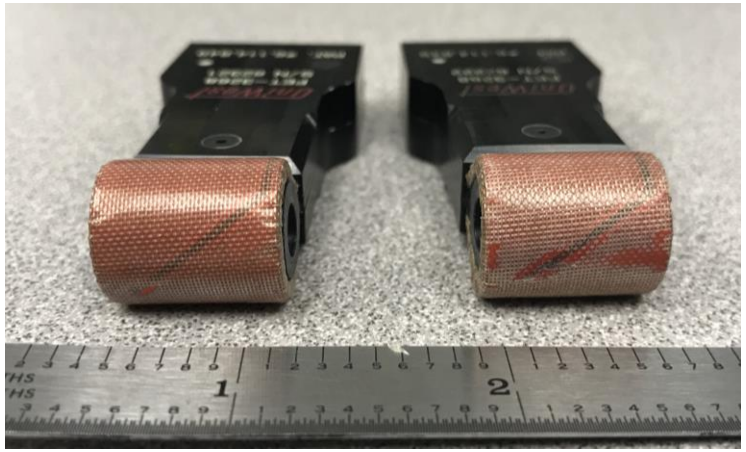
ET Probes

Probe	Model	Type	Excitation Frequency Range (MHz)
UniWest Flex Coil	FET-3427	Cross-wound coil in circumferential direction on flexible probe body for improved surface compliance near J-groove weld	0.2–2.0
UniWest Flex Coil	FET-3268	Cross-wound coil in helical direction on flexible probe body for improved surface compliance near J-groove weld	0.2–2.0
WesDyne “Grooveman”		+ Point probe on articulating body for improved compliance with examination surface	0.2–0.4

Flex Probe with Coils Wound in the Circumferential Direction



WesDyne Grooveman Probe with Articulating Body



Flex Probes with Coils Wound in Helical Direction

ET Mockups (CRDM Mockups)

Head Assembly of Unused WNP-1 RPV

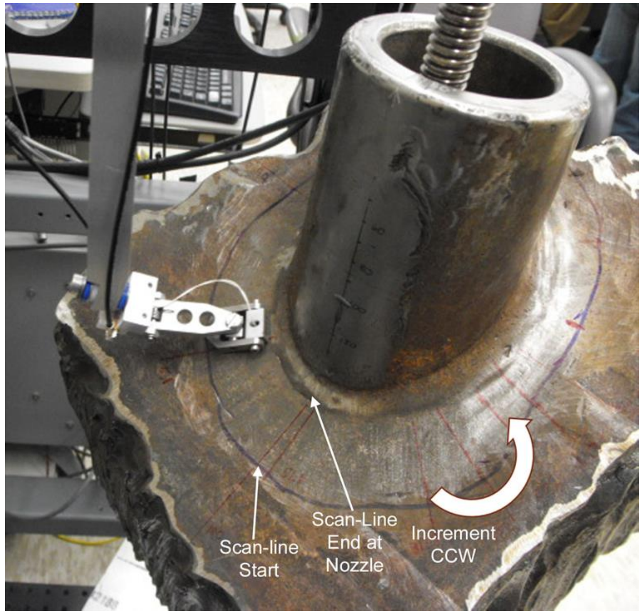
Photograph Capturing an Iron Worker Cutting Segments Containing CRDM Penetration Nozzle Assemblies from the Actual WNP-1 RPV Head

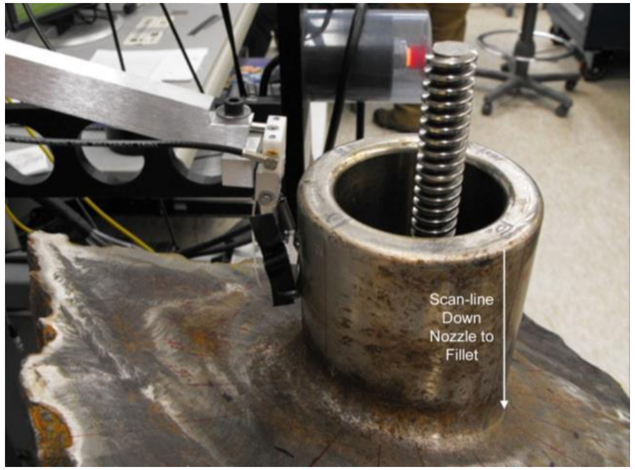
ET Mockups (CRDM Mockups)

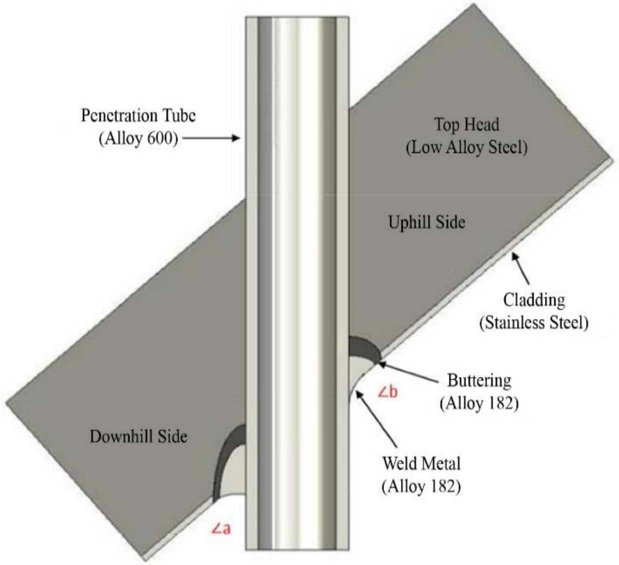
Photograph Showing Partitioning and Locations for Cutting and Extraction of CRDM Penetration Nozzle Assemblies from the WNP-1 Segment of the RPV Head

Photograph Showing WNP-1 Segment of the RPV Head Containing 16 CRDM Penetration Nozzle Assemblies

ET Mockups (CRDM Mockups)







	CRDM Penetration-Nozzle Assembly Measurements															RPV Head Cut-Out Measurements			Total Specimen
	Inside Surface of RPV Head “Wetted Side”								Outside Surface of RPV Head										
Mockup Number	Top Angle ∠b	Bottom Angle ∠a	90° - ∠a	Top Length (mm)	Bottom Length (mm)	ID (mm)	OD (mm)	Wall Thickness (mm)	Top Angle	Bottom Angle	Top Length (mm)	Bottom Length (mm)	ID (mm)	OD (mm)	Wall Thickness (mm)	X-Axis (mm)	Y-Axis (mm)	Z-Axis (mm)	Weight (kg)
CRDM #3	131.1°	43.8°	46.2°	157	38	69	102	16.5	51.8°	128.2°	258	340	69	105	18	300	313	198	181.3
CRDM #4	120.6°	59.4°	30.6°	163	66	69	102	16.5	56.7°	123.3°	265	337	69	105	18	356	318	203	140.6
CRDM #6	121.3°	58.7°	31.3°	157	69	69	102	16.5	56.2°	123.8°	277	335	69	105	18	284	269	203	136.1
CRDM #7	131.1°	48.9°	41.1°	157	71	69	102	16.5	55.4°	124.6°	366	305	69	105	18	320	305	198	174.6
CRDM #9	109.3°	70.7°	19.3°	140	107	69	102	16.5	73.0°	107.0°	277	244	69	105	18	290	328	198	154.2
CRDM #12	99.2°	80.8°	9.2°	72	58	69	102	16.5	86.4°	93.6°	295	283	69	105	18	271	285	195	127

ET Mockups (Calibration Plate Mockups)

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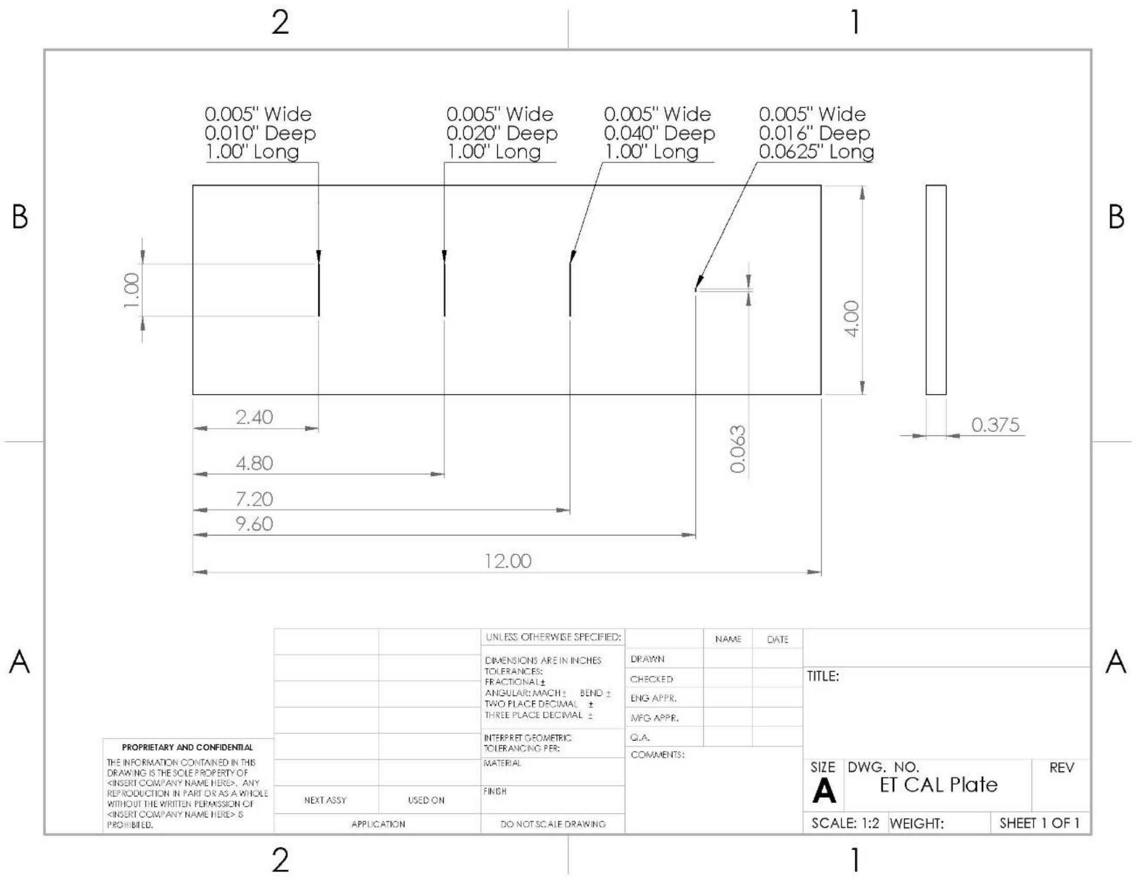


Design Drawing of EDM Notches Fabricated in SS and Inconel 600 Calibration Plates

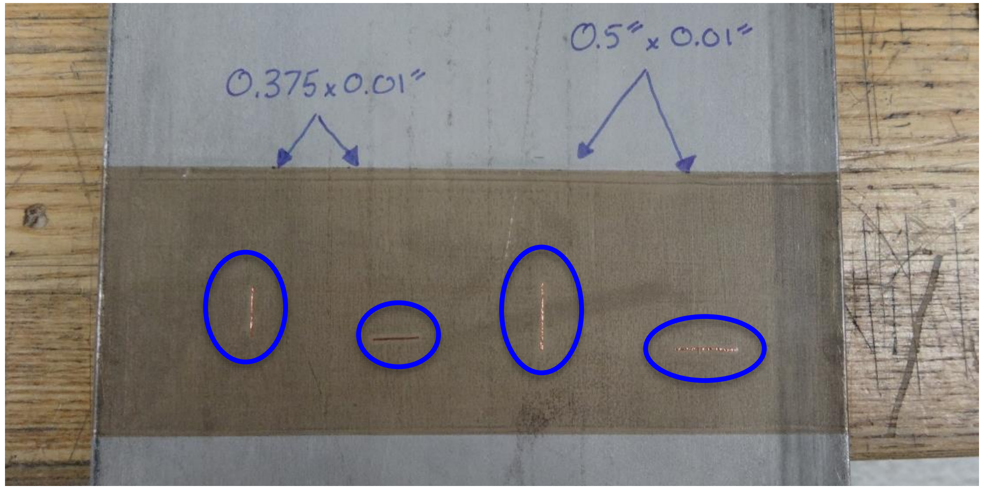
Material	Notch Dimensions in inches (Length × Width × Depth), mm (in.)	Measured Length,[a] mm (in.)	Measured Width,[b] mm (in.)	Measured Depth,[c] mm (in.)
SS	25.4 × 0.13 × 0.25 (1.00 × 0.005 × 0.010)	25±0.13 (0.985±0.005)	0.15 (0.006)	0.20 (0.008)
SS	25.4 ×0.13 × 0.5 (1.00 × 0.005 × 0.020)	25.3±0.18 (0.996±0.007)	0.18 (0.007)	0.43 (0.017)
SS	25.4 × 0.13 × 1.02 (1.00 × 0.005 × 0.040)	25.43±0.23 (1.001±0.009)	0.18 (0.007)	0.94 (0.037)
SS	1.6 × 0.13 × 0.4 (0.0625 × 0.005 × 0.016)	1.70±0.13 (0.067±0.005)	0.23 (0.009)	0.36[d] (0.014)
Inconel	25.4 × 0.13 × 0.25 (1.00 × 0.005 × 0.010)	25.45±0.15 (1.002±0.006)	0.15 (0.006)	0.15 (0.006)
Inconel	25.4 × 0.13 × 0.5 (1.00 × 0.005 × 0.020)	25.65±0.23 (1.010±0.009)	0.18 (0.007)	0.04 (0.0017)
Inconel	25.4 × 0.13 × 1.02 (1.00 × 0.005 × 0.040)	25.35±0.13 (0.998±0.005)	0.2 (0.008)	0.91 (0.036)
Inconel	1.6 × 0.13 × 0.4 (0.0625 × 0.005 × 0.016)	1.68±0.08 (0.066±0.003)	0.25 (0.010)	0.36[d] (0.014)

(a) Length was measured using the average of five manual caliper measurements.
(b) Notch width was determined using the average of ten feeler gauge measurements.
(c) Depth measurements were acquired using the optical technique reported earlier. The measured depth represents the average of five depth measurements spread over the length of the notch.
(d) Only three measurements were used for the average due to the short length of the notch.

Summary of True-state Measurements for SS and Inconel Calibration Plates

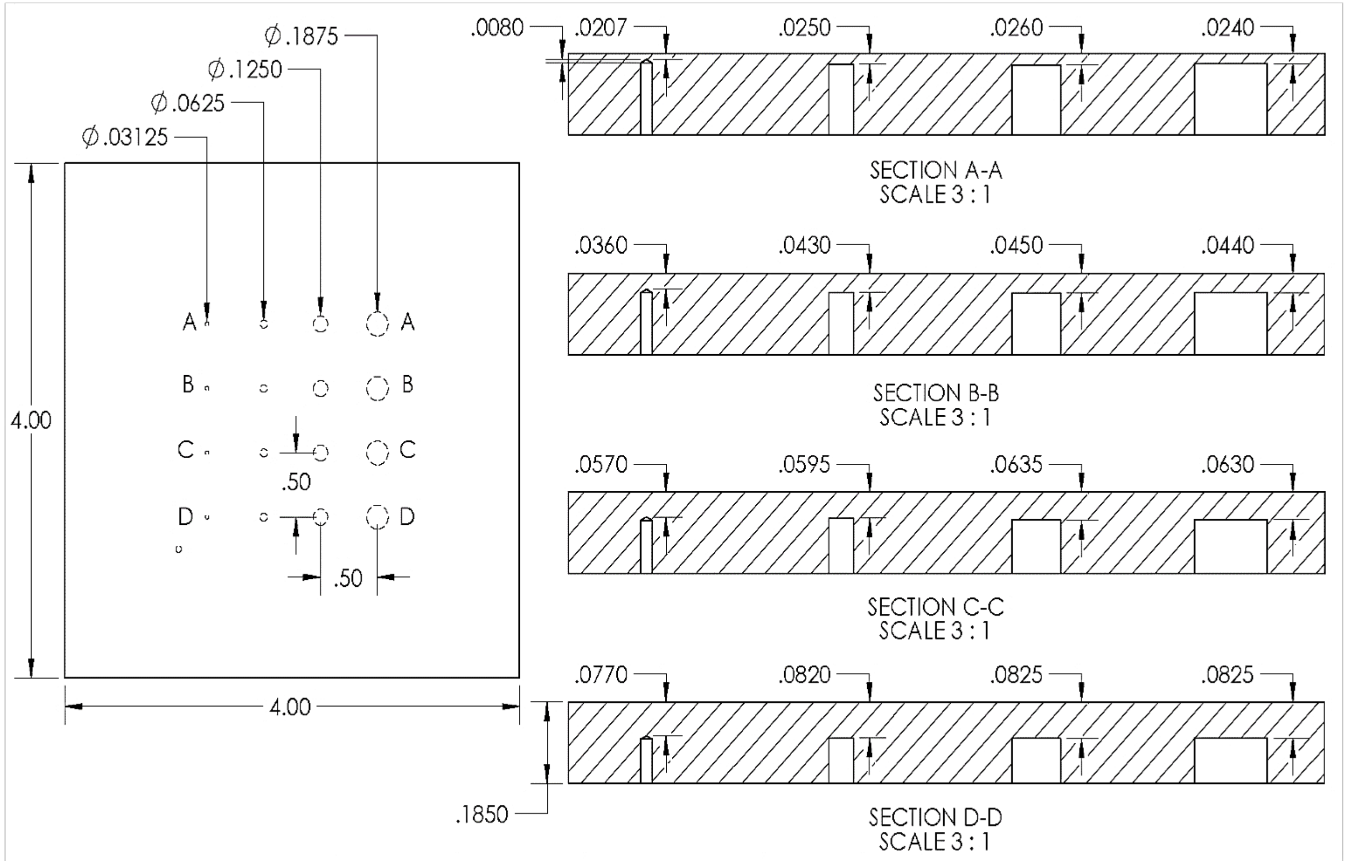
ET Mockups (Other Plate Mockups)

Stainless Steel Plates with Copper Reflector Strips



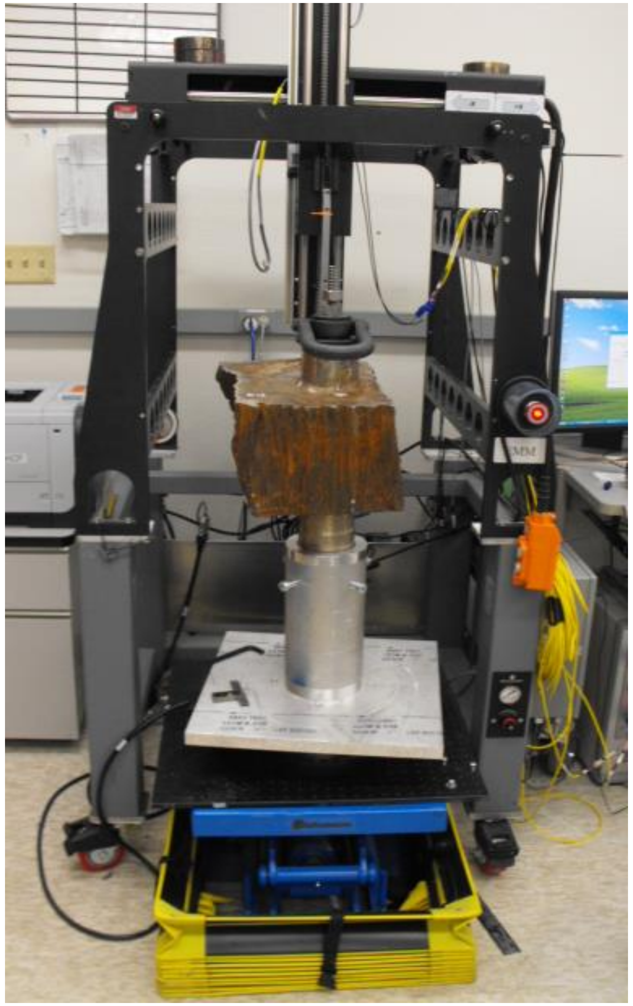
Simulate reference notches in an Inconel 600 calibration plate using narrow copper strips with an adhesion backing for placement on an examination surface

Bottom-Drilled Hole Standard

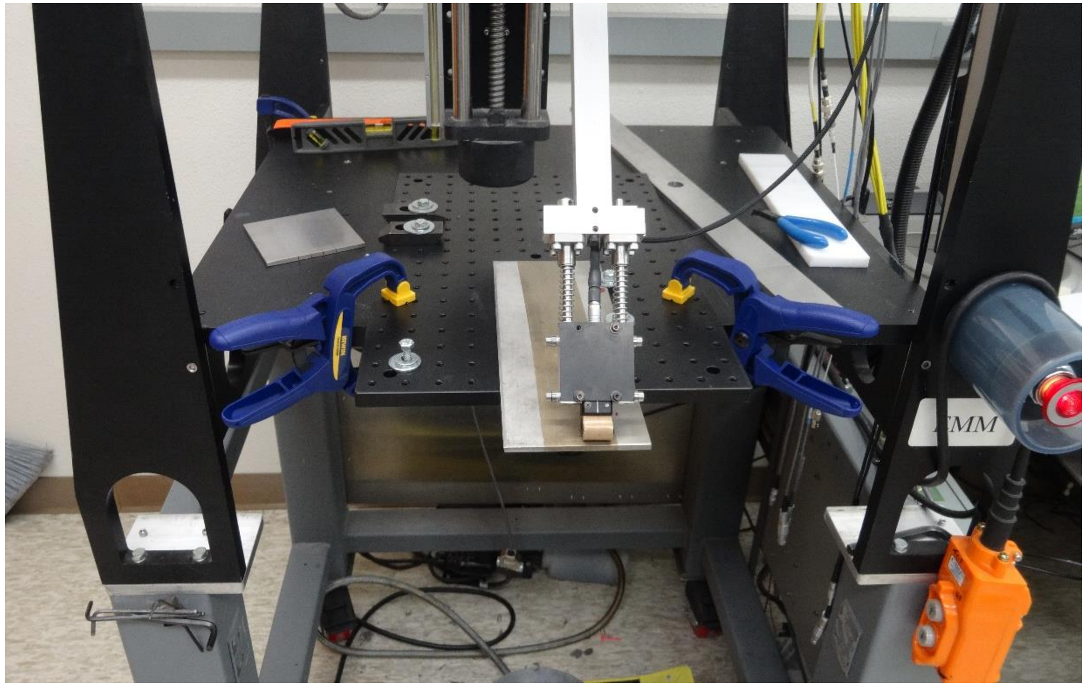


Design Drawing of the Bottom-Drilled Hole Plate with As-built Dimensions Showing Remaining Ligament

Data Acquisition Setup



Translation Stage Capable of Motion in Four Axes (X, Y, Z, rotation) Used for ET Exams

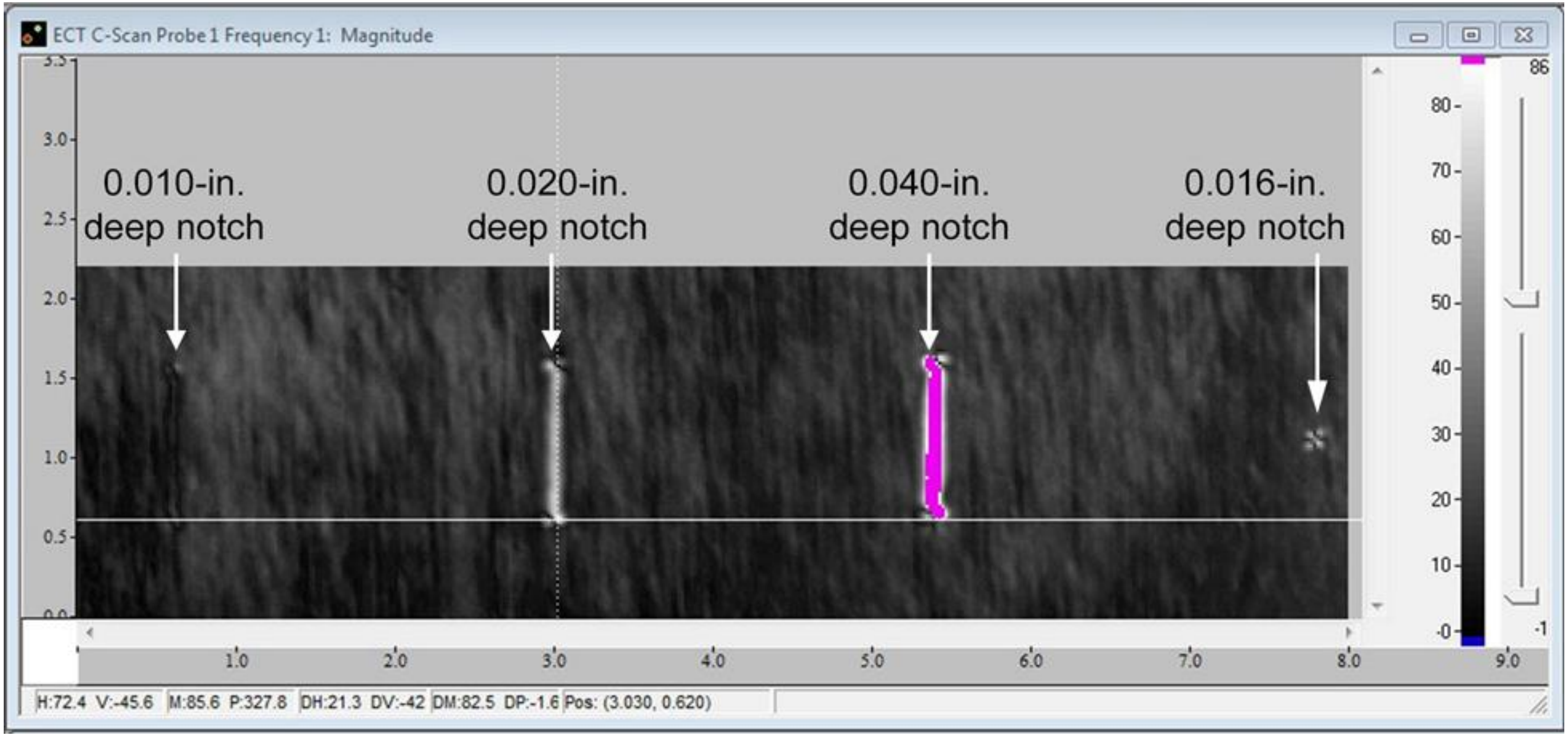


Translation Stage with Table Insert for Acquiring Data on Flat Specimens

WesDyne IntraSpect Eddy Current Examination System

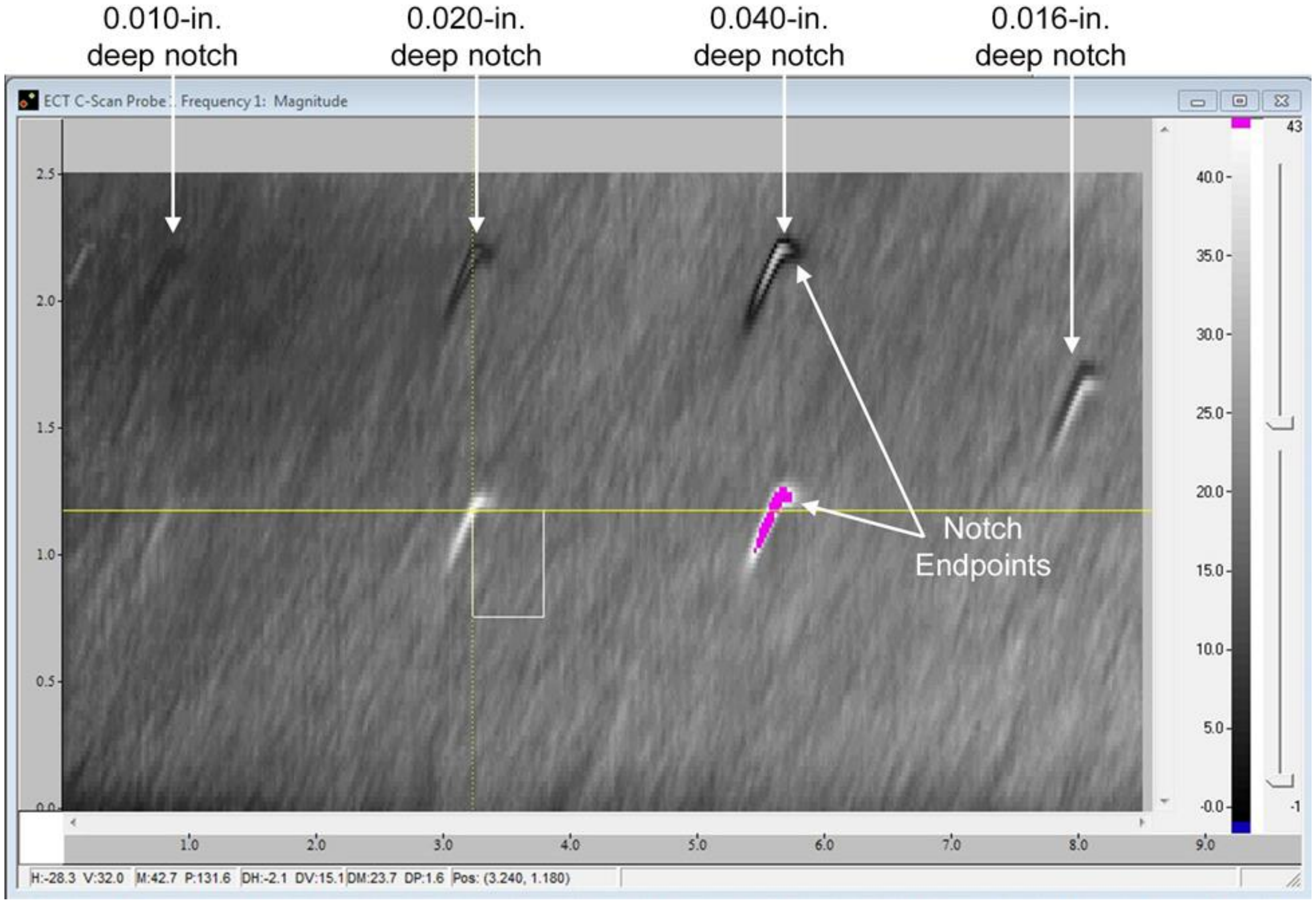
Results (Calibration Plate)

Magnitude ET Response of the Inconel 600 Calibration Plate Collected at 400 kHz with the Grooveman ET probe.



Results (Calibration Plate)

Magnitude ET Response of the Inconel 600 Calibration Plate Collected at 700 kHz with the UniWest FET-3268 Flex Probe, with a helical coil.



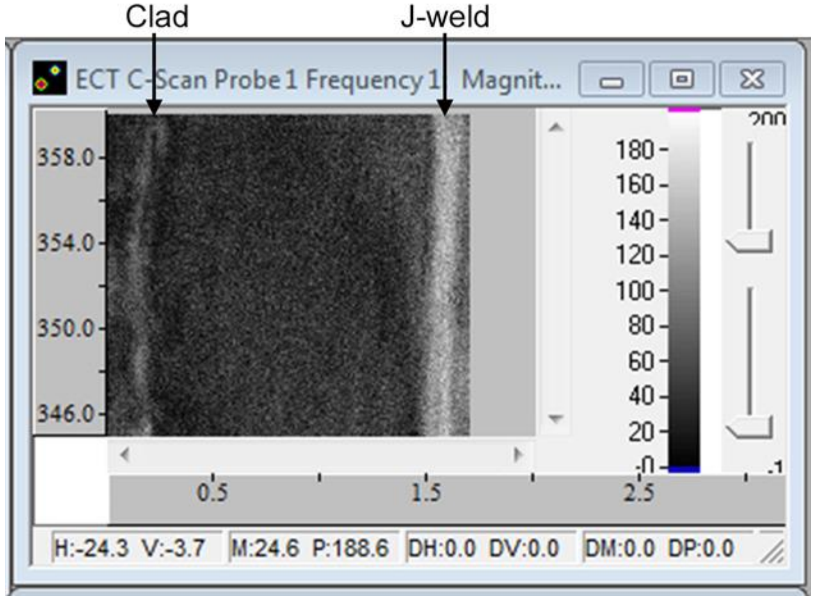
The edges of the notches are the only features that appear in the ET data. This is caused by the orientation of the coils in the ET probe relative to the notch orientation. The responses from the notch endpoints are tilted at 45° because of the helical orientation of the probe coils.

The circumferentially wound flex probe was next to be scanned before the project was ended.

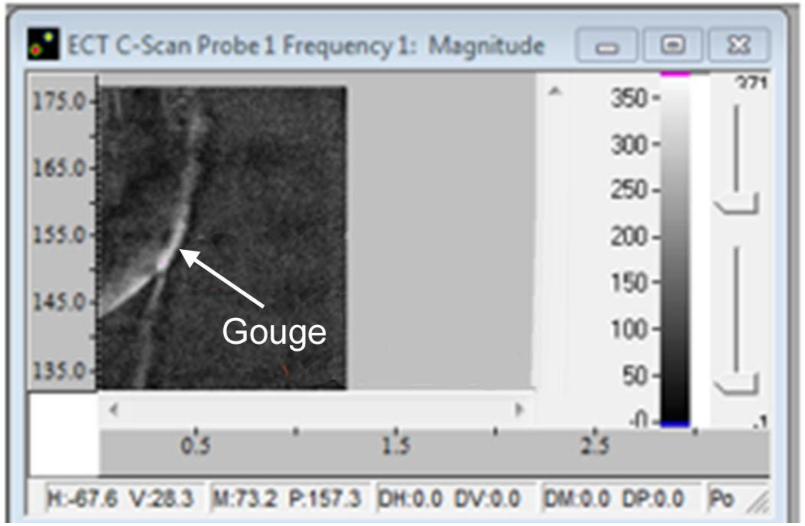
Results (CRDM Mockups)

Degrees of Exam Coverage of Each CRDM Sample with Grooveman Probe

Sample 3	Sample 6	Sample 9	Sample 12
150–180	90–100	2–23	6–9
180–210	94–115	21–42	5–22
210–225	100–115	40–55	20–35
225–240	113–134	53–74	33–48
237–250	114–142	72–93	46–61
	132–177	91–106	59–74
	135–180	104–125	72–87
	175–220	123–144	85–100
	218–233	142–163	98–113
	231–246	161–182	111–126
	244–259	180–201	124–139
	257–272	199–220	137–152
	270–291	215–230	150–165
		228–243	163–178
		241–256	177–192
		254–269	190–205
		267–282	203–218
		280–295	241–256
		293–309	254–269
		306–321	267–282
		319–334	280–295
		332–347	293–308
		345–360	306–321
			319–334
			332–347
			345–360



Grooveman probe ET data from #9 at 345°–360° using 400 kHz showing Magnitude C-scan. Cladding response shown at scan start on left and J-groove weld is shown at end of each scan line on right.



Grooveman probe ET data from #6 at 132°–177° using 400 kHz showing Magnitude C-scan. Cladding response shown at scan start on left and J-groove weld is shown at end of each scan line on right.

Results (Bottom-Drilled Hole Plate Mockup)

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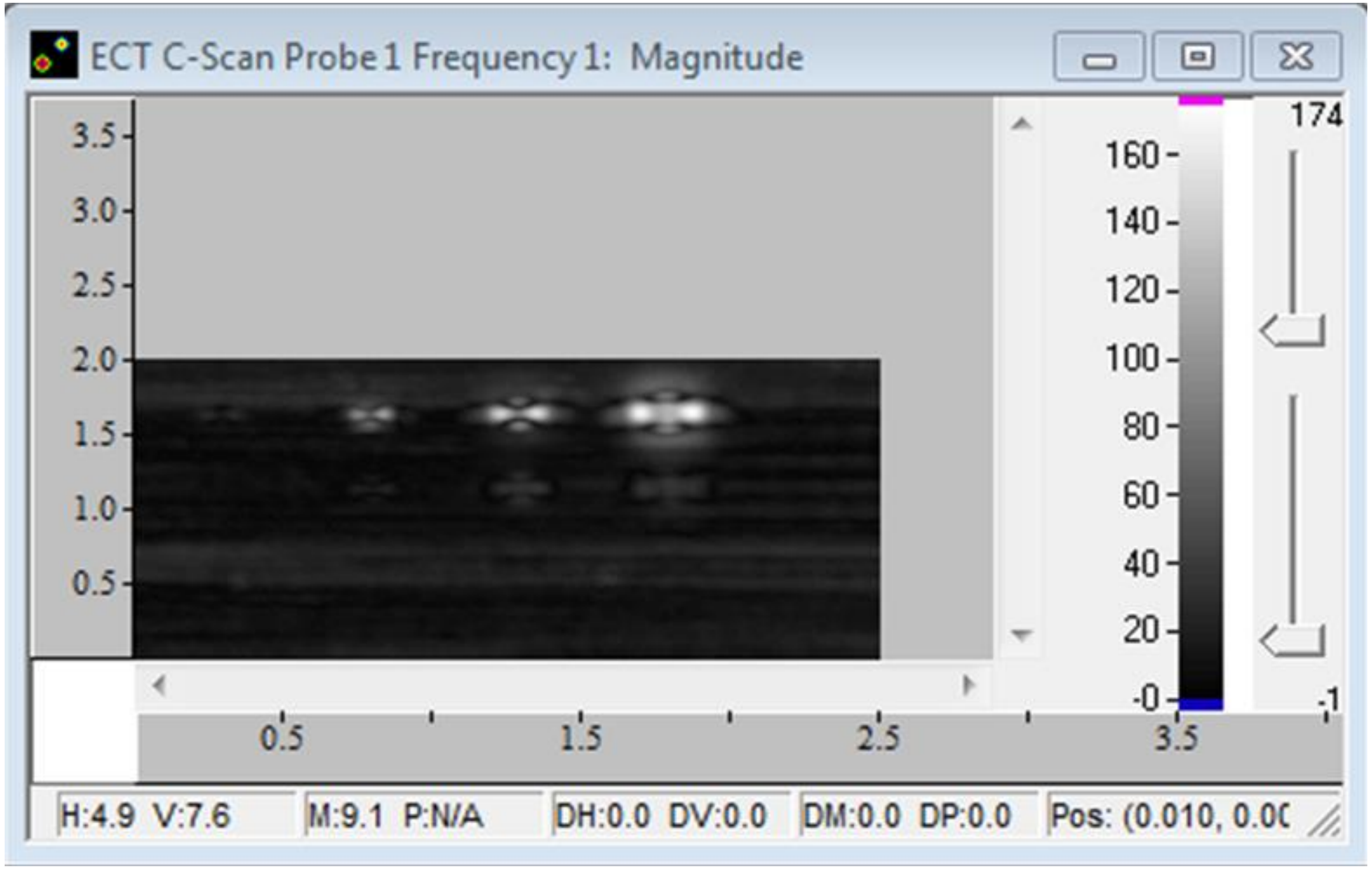
Row	Hole Diameter, mm (in.)	Remaining Ligament, mm (in.)	Grooveman Probe, 400 kHz
A	0.79 (0.03125)	0.51 (0.02027)	Detected
A	1.6 (0.0625)	0.64 (0.0250)	Detected
A	3.18 (0.125)	0.66 (0.0260)	Detected
A	4.76 (0.1875)	0.61 (0.0240)	Detected
B	0.79 (0.03125)	0.91 (0.036)	Not Detected
B	1.6 (0.0625)	1.09 (0.043)	Detected
B	3.18 (0.125)	1.14 (0.045)	Detected
B	4.76 (0.1875)	1.12 (0.044)	Detected
C	0.79 (0.03125)	1.45 (0.057)	Not Detected
C	1.6 (0.0625)	1.51 (0.0595)	Not Detected
C	3.18 (0.125)	1.61 (0.0635)	Not Detected
C	4.76 (0.1875)	1.60 (0.063)	Not Detected
D	0.79 (0.03125)	1.96 (0.077)	Not Detected
D	1.6 (0.0625)	2.08 (0.082)	Not Detected
D	3.18 (0.125)	2.10 (0.0825)	Not Detected
D	4.76 (0.1875)	2.10 (0.0825)	Not Detected

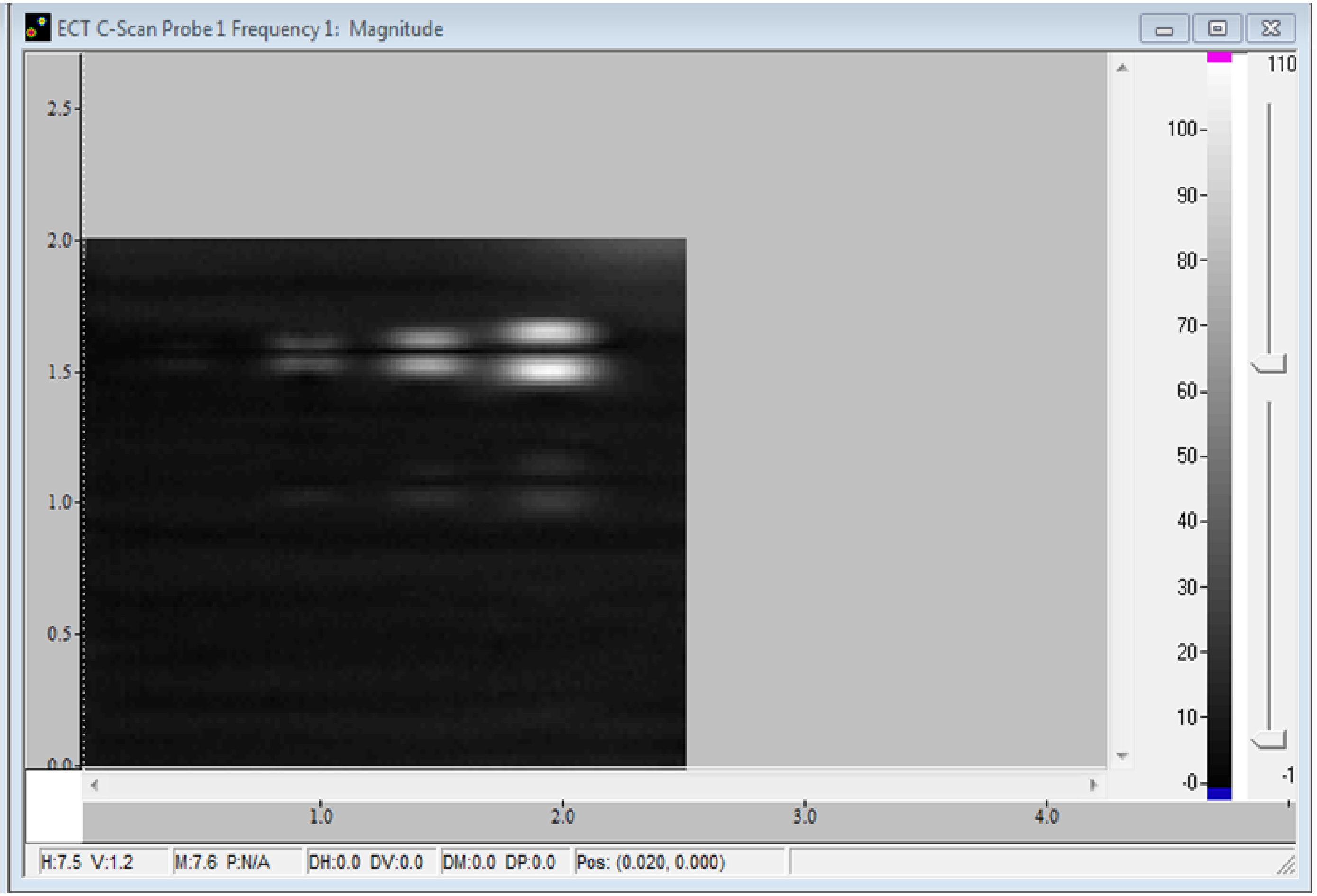
400 kHz C-Scan Magnitude ET responses for Row A – Grooveman Probe



Results (Bottom-Drilled Hole Plate Mockup)

Row	Hole Diameter, mm (in.)	Remaining Ligament, mm (in.)	FET 3427 (400 kHz) SN 65966	FET 3427 (400 kHz) SN 65967
A	0.79 (0.03125)	0.51 (0.02027)	Detected	Detected
A	1.6 (0.0625)	0.64 (0.0250)	Detected	Detected
A	3.18 (0.125)	0.66 (0.0260)	Detected	Detected
A	4.76 (0.1875)	0.61 (0.0240)	Detected	Detected
B	0.79 (0.03125)	0.91 (0.036)	Not Detected	Not Detected
B	1.6 (0.0625)	1.09 (0.043)	Detected	Detected
B	3.18 (0.125)	1.14 (0.045)	Detected	Detected
B	4.76 (0.1875)	1.12 (0.044)	Detected	Detected
C	0.79 (0.03125)	1.45 (0.057)	Not Detected	Not Detected
C	1.6 (0.0625)	1.51 (0.0595)	Not Detected	Not Detected
C	3.18 (0.125)	1.61 (0.0635)	Not Detected	Not Detected
C	4.76 (0.1875)	1.60 (0.063)	Not Detected	Not Detected
D	0.79 (0.03125)	1.96 (0.077)	Not Detected	Not Detected
D	1.6 (0.0625)	2.08 (0.082)	Not Detected	Not Detected
D	3.18 (0.125)	2.10 (0.0825)	Not Detected	Not Detected
D	4.76 (0.1875)	2.10 (0.0825)	Not Detected	Not Detected

400 kHz C-Scan Magnitude ET responses for Row A – UniWest Flex Probe



Observations

Based on ET data from domestic and international field results, as well as laboratory studies, including a removed CRDM weld from North Anna Unit 2, PINC and PARENT Programs, the following observations are made:

- The ASME Code does not have an acceptance standard for ET surface examinations of high nickel-alloy welds. However, there are numerous documented field results where ET has been demonstrated through confirmatory testing as a reliable detection technique for both service-induced PWSCC and hot tears.

- Laboratory studies at PNNL demonstrated detection of flaws 1.5 mm (0.06 in.) long by 0.4 mm (0.015 in.) deep in plate material.* However, there were no welded surfaces with flaws available for evaluation. ASME Code Section XI, Appendix IV guidelines require flaws in the base metal, HAZ, weld edge, and weld surface for demonstration.

* References provided in PNNL report 29113; ADAMS Accession #: ML19267A240

Observations (continued)

- ET probes were demonstrated capable of detecting near-subsurface voids/inclusions comparable to those identified as the root cause of failure in J-groove welds at the South Texas and Palo Verde plants. Subsurface voids were simulated using holes drilled from the back side of plates with various diameters and ligaments.
  - Conventional probe designs were not capable of coupling adequately at the toe of the weld, especially on the downhill side, due to geometric obstructions. However, a special UniWest flexible design bobbin probe detected these subsurface conditions and was able to couple onto the toe of the J-groove weld on the downhill side with very little lift-off noise.
  - These results show promise for a detection method in this region.
- PNNL laboratory work on removed nozzles from North Anna Unit 2 showed that DT confirmed ET calls that were not detected by PT. Given the small sample size, it is difficult to draw any firm conclusions.

Unresolved Issues

- Study is needed to assess performance capabilities of ET versus PT on surface breaking flaws in PWSCC susceptible materials/welds that include a variety of flaw characteristics, dimensions and locations.
  - As a subset of this, an evaluation of ET detection performance on PWSCC susceptible welds with near-subsurface flaws should shed light on the current state-of-the-art for ET capabilities.
- Assess advanced ET probe designs and quantify their impact on detection sensitivity and performance for J-groove welds.

Thank you

- Questions?

PNNL-SA-150350

Evaluating Flaw Detectability Under Limited Coverage Conditions

Joel Harrison, Matthew Prowant, Aimee Holmes, Chris Hutchinson, Richard Jacob, and Aaron Diaz

Technical Information Exchange
Carol Nove, NRC COR

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Introduction: Limited Inspection Coverage

- Incomplete examination coverage of welds is a very common issue in the nuclear power industry that exists in every plant.
- In cases where welds susceptible to degradation are not inspectable or partially inspectable, the condition must be addressed in order to determine the structural integrity of the component
- Assuming a flaw existed in an uninspectable region, to what extent would it have to propagate into the inspectable region before it would be detected?

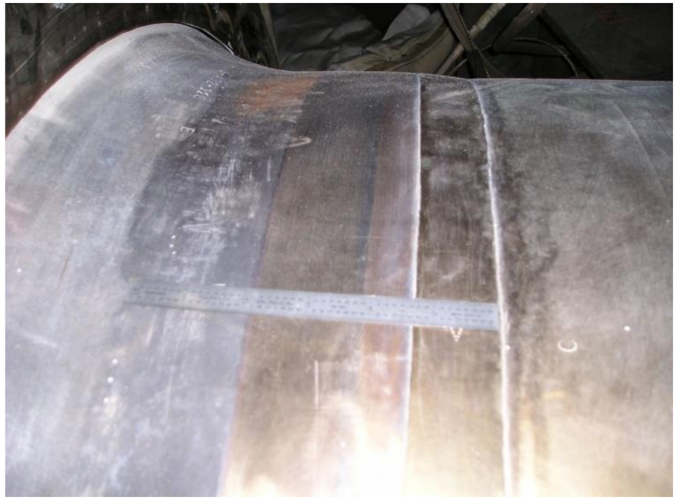
Historical Perspective of Limited Examinations

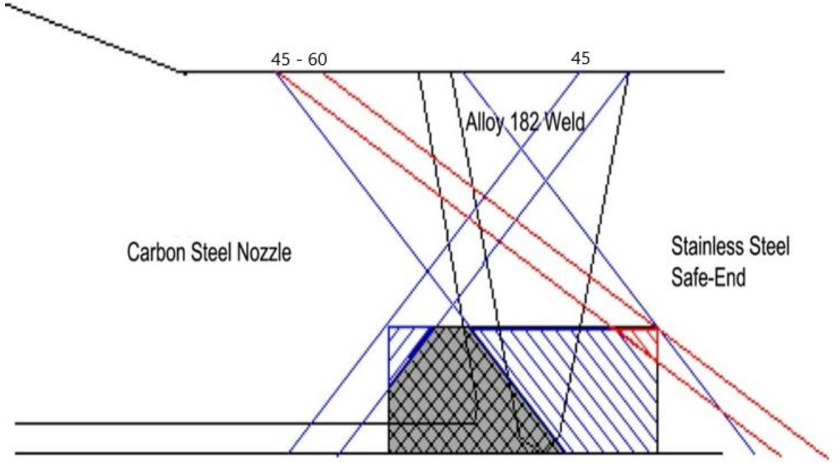
- Conventional wisdom has driven industry's position on limited examination coverage:
  - Shear Waves will not effectively propagate through austenitic material
  - Longitudinal waves produce varying flaw responses, although more effective than shear waves in propagating through austenitic material
- A variety of UT techniques have been applied to address limited coverage conditions
  - A broad assessment of these techniques has not been conducted.
  - The Performance Demonstration process only offers a Yes/No assessment
- No formal study has previously been initiated to evaluate and document the extent by which a flaw must propagate outside a limited coverage area in order to be detected

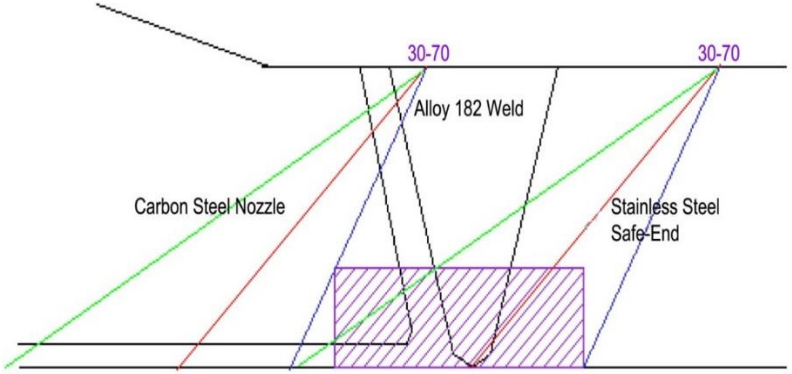
Limited Inspection Coverage

- PNNL conducted a search of NRC’s ADAMS database to locate relief requests and reports associated with limited UT examination coverage issues.
  - ML17318A120 (PNNL-26157)
- Several weld configurations that often result in limited coverage were identified and were used to prioritize PNNL’s assessment of the impact of incomplete coverage.
- Conditions that limit UT coverage of a specified examination volume restrict probe movement and include excessive weld crown width and outside surface configuration.

Examples of Limiting Conditions

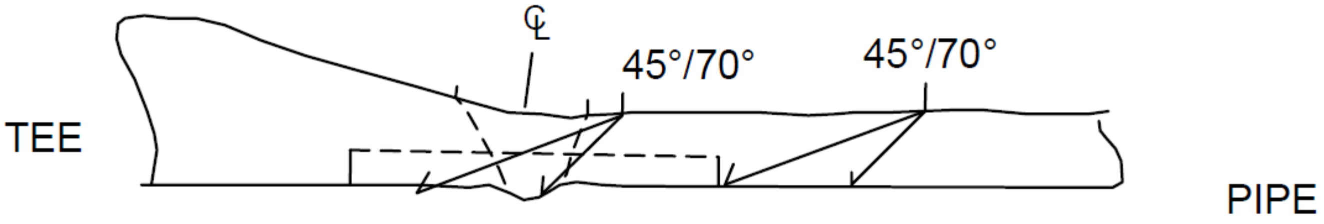


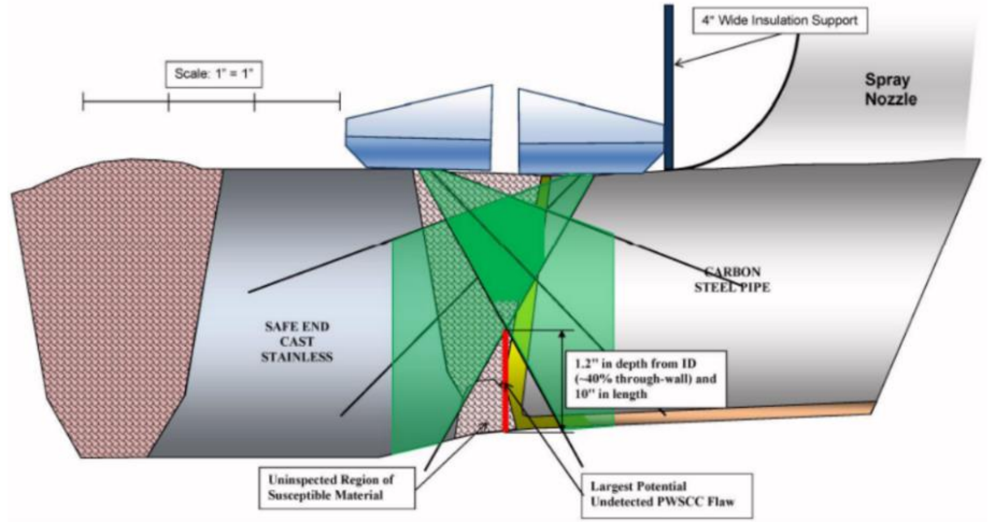




Examples of Limiting Conditions

- Configuration limited due to taper from tee and weld geometry
- Material limited due to no single sided qualification for austenitic SS welds
- Component supports block probe motion





Design of Experiments: Factors and Levels

- Factor and levels based on typical conditions in the field
- Conditions limiting coverage include taper (weld and/or component), physical access restrictions, weld geometry, and material microstructure (CASS)
- Metrics for quantifying coverage will be tabulated
- How do these factors limit Probability of Detection

Factors	Number of levels	List of levels	Notes
Materials	3	WSS – WSS CASS – CS CASS – SS	No scans to be performed from the CASS sides.
Wall Thickness	2	Thin, Thick	Thin ≤ 1.6 in.; Thick > 1.6 in.
Weld Root Condition	1	None	Assuming best case scenario of no weld root, although some specimens may have existing weld root.
Probe Aperture	2	Small, Large	
Probe Type	3	Single Element, Phased Array, Dual-Element TRL	
Refracted Angle	4	30° ,45° ,60° ,70°	PA – 30°-70° Conventional – 45°, 60°, 70° TRL – 45°, 60°
Wave Mode	2	Shear, Longitudinal	Shear is only applicable for conventional probes and near-side exams.
Probe Frequency	3	2 MHz, 2.25 MHz	Conventional – 2.25 MHz, Phased Array – 2 MHz TRL – 2 MHz
Length/Depth Ratio	3	<3 3-5 >5	Ranges have been adjusted due to lack of specimens with high aspect ratios
Flaw Parameters	Ongoing assessment with respect to size distributions, location, orientation, and tilt. Other factors may also be included as assessment progresses.		

Design of Experiments Matrix

- Data acquisition matrix resulting from the Design of Experiments analysis.
- Specimen list to include austenitic or dissimilar metal welds only.

WALL THICKNESS ≤ 1.6”				
	TW%	Length/Depth Ratio		
		< 3	3 - 5	> 5
WSS/SS	0 - 30%	✓	✓	✓
	30% - 50%	✓	✓	
	>50%	✓		

WALL THICKNESS >1.6”				
	TW%	Length/Depth Ratio		
		< 3	3 - 5	> 5
WSS/SS	0 - 30%			
	30% - 50%		✓	
	>50%			

WALL THICKNESS ≤ 1.6”				
	TW%	Length/Depth Ratio		
		< 3	3 - 5	> 5
DMW (CS/SS)	0 - 30%	✓	✓	
	30% - 50%	✓	✓	✓
	>50%	✓		

Data Partitioning

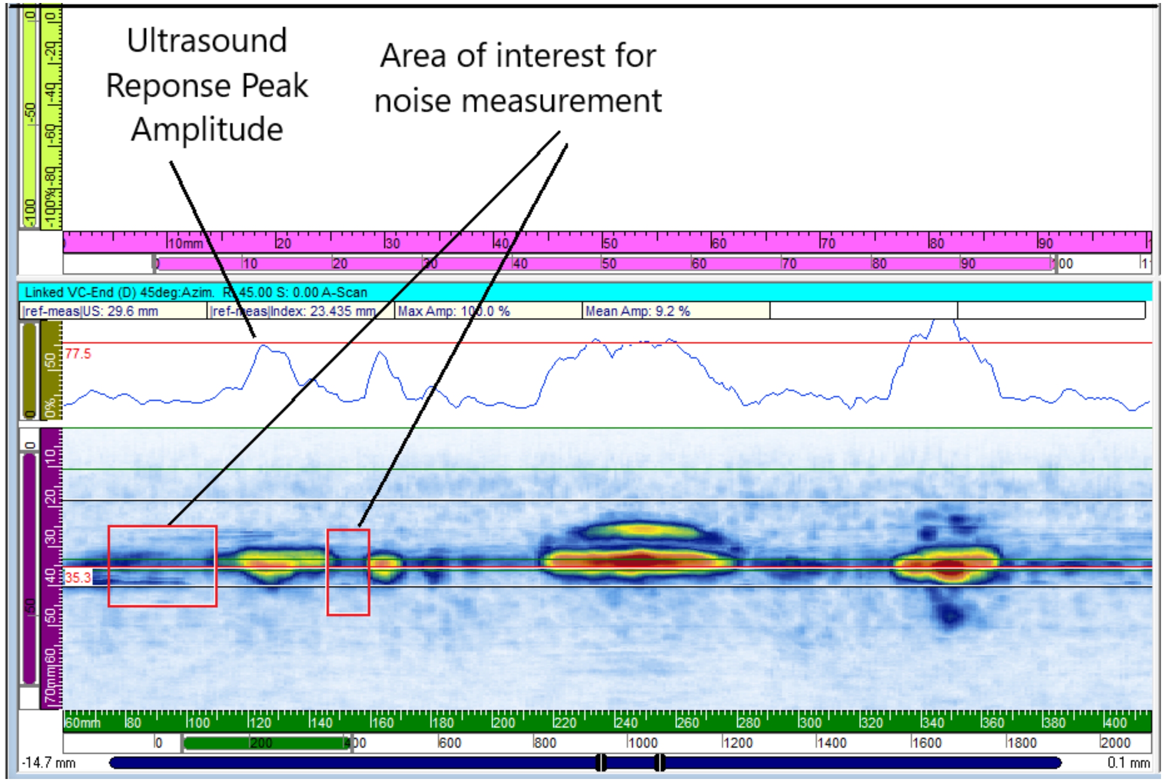
Data has been acquired and partitioned to simulate the following conditions:

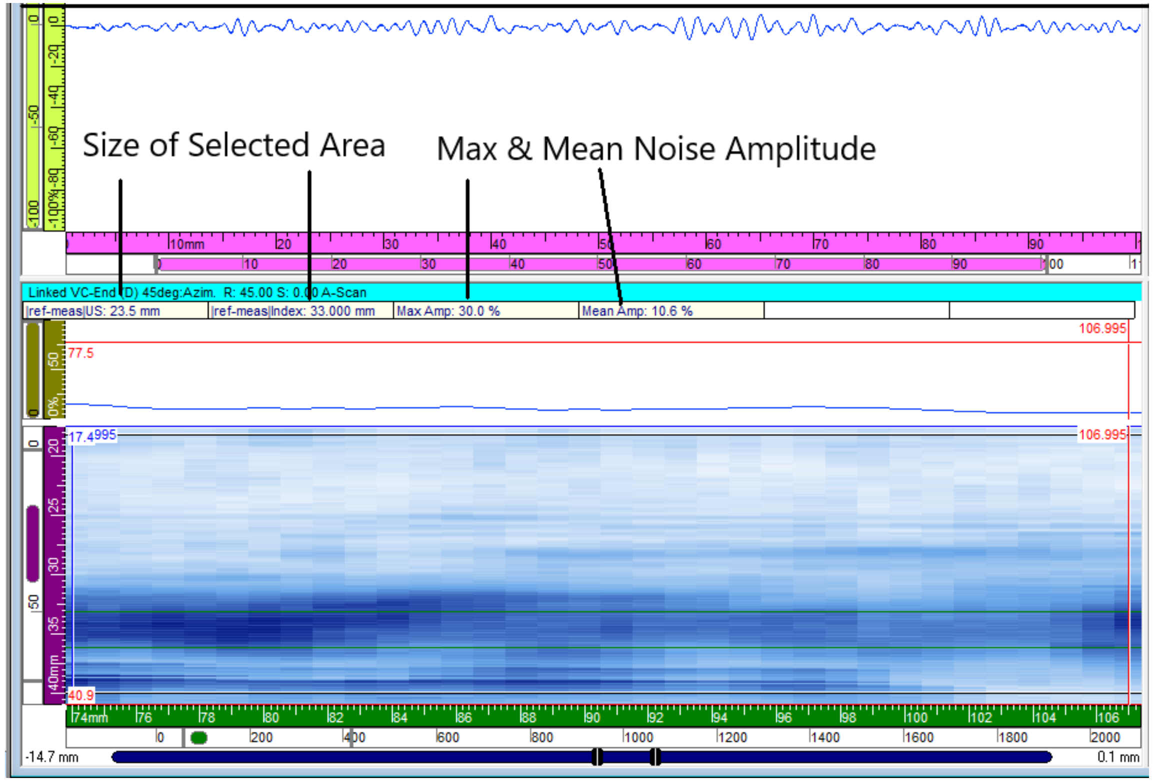
1. No obstructions
   - Unrestricted probe movement across the weld and away from the weld
2. Weld Crown Obstruction
   - Probe cannot move across the weld; however, probe movement away from the weld is unrestricted
3. Component or Support Obstruction
   - Probe can move across the weld; however, an obstruction prevents movement back away from the weld

Data Recorded for Each Flaw & Each Probe

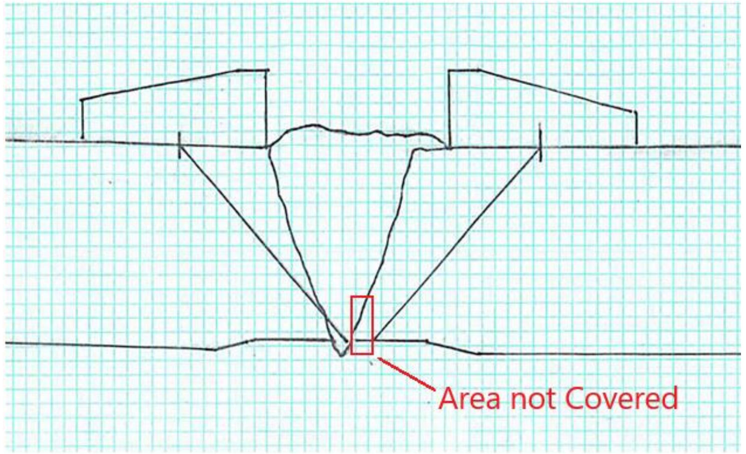
1. Flaw Detected or Not Detected
2. Presence of a Flaw Tip or Not Detected
3. Flaw Response Amplitude
4. Flaw Length at 6 dB Below Max Amplitude
5. Flaw Length at Noise Floor
6. Maximum and Mean Noise on Each Side of the Flaw
7. Signal to Noise Ratio

Determining Signal to Noise

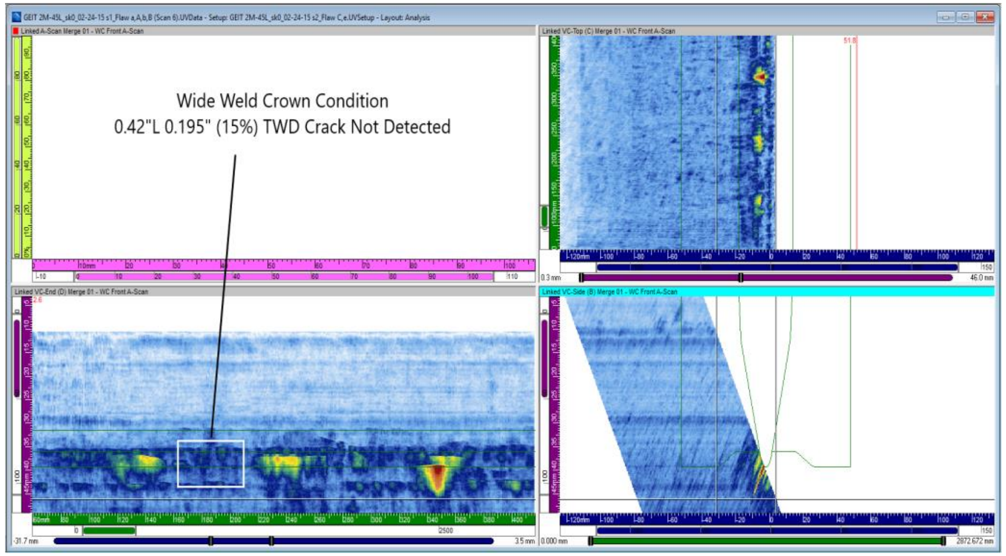




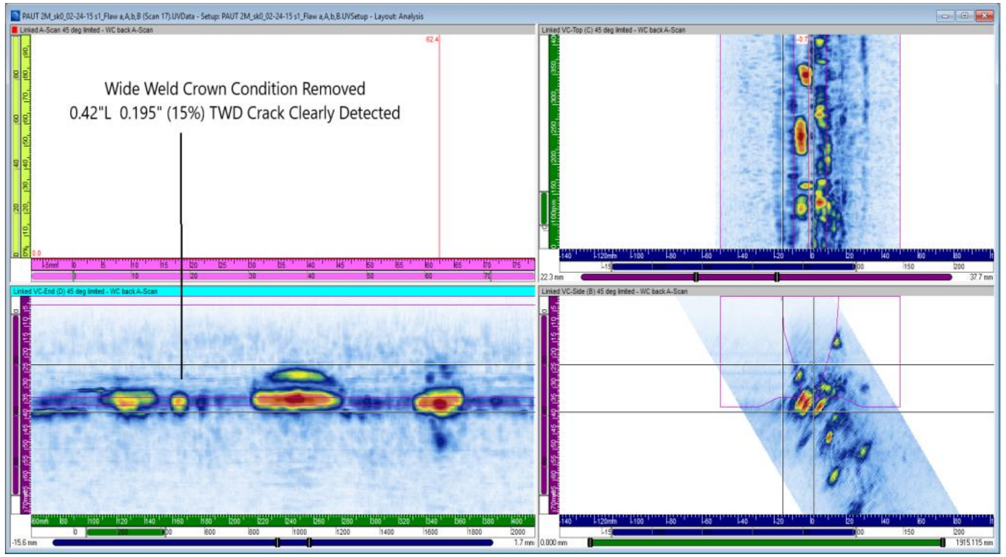
Common Limitation is WSS-WSS Piping



Weld Crown Width Prohibits Coverage of Heat Affected Zone



Missed Detection of Shallow Near Side Flaw and Determining the Full Extent of Deep Flaws

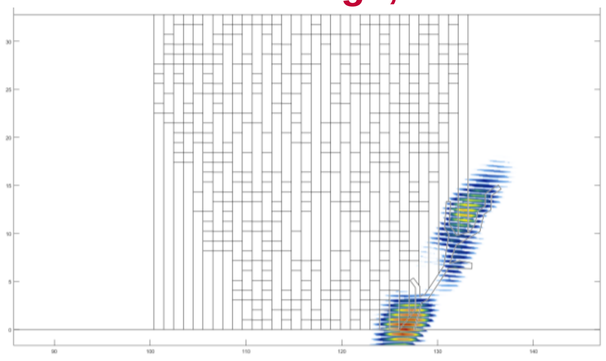


After Weld Crown Removal Shallow Flaw is Detected and Deep Flaw Tips are Identified

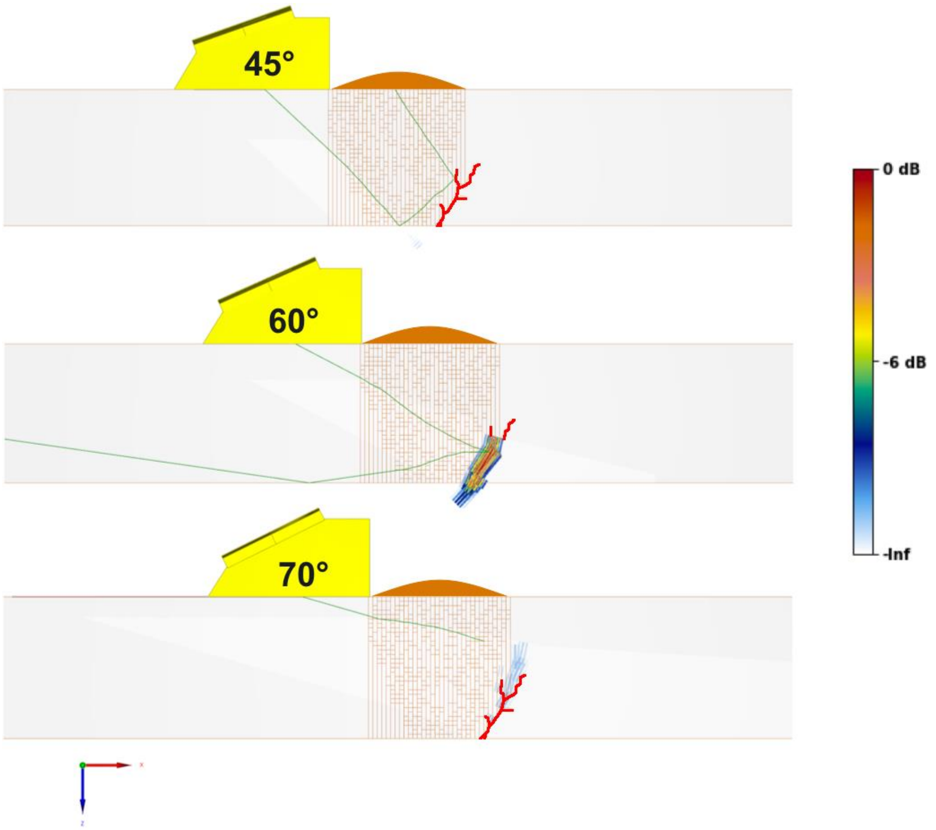
Limited Coverage Flaw Response Simulations

- Probe coverage limited by weld crown obstruction
- Coverage limitation caused:
  - Virtually no response at 45°
  - Incomplete flaw response at 60°
  - Misleading response at 70° (looks like noise or fabrication flaw)

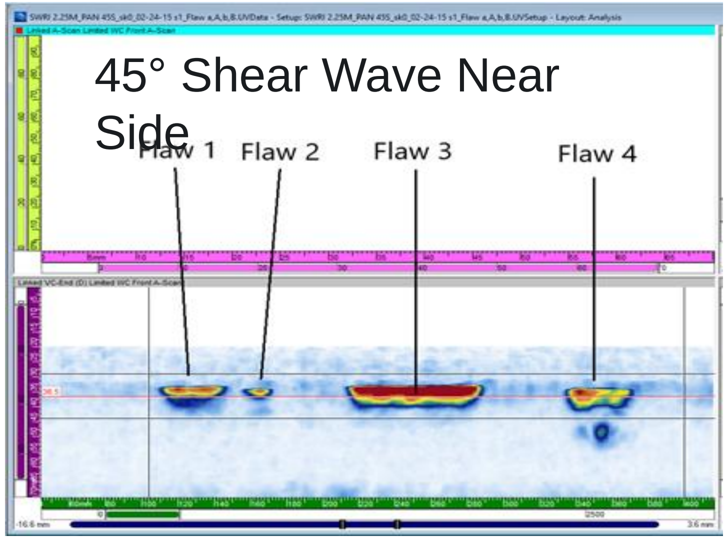
Flaw response simulation, full coverage, 45°

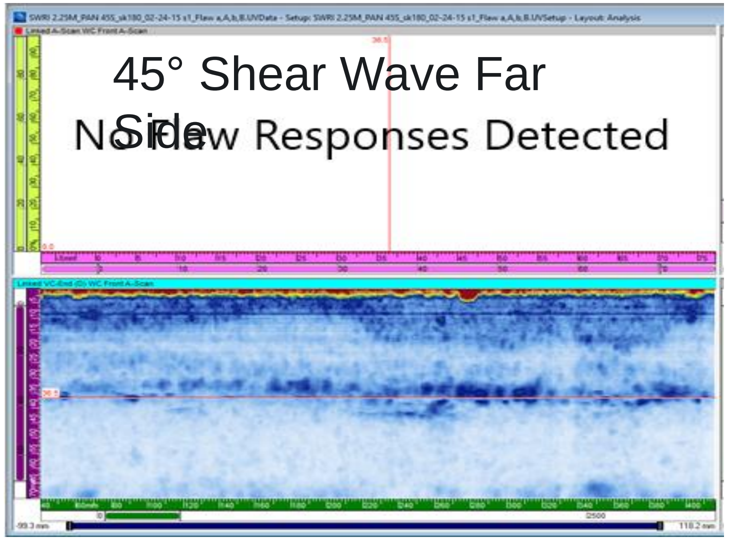


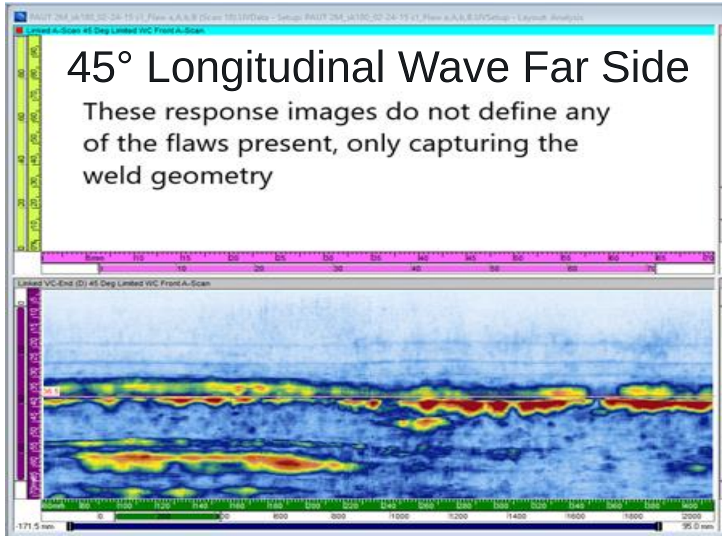
Flaw response simulations with weld crown limitations

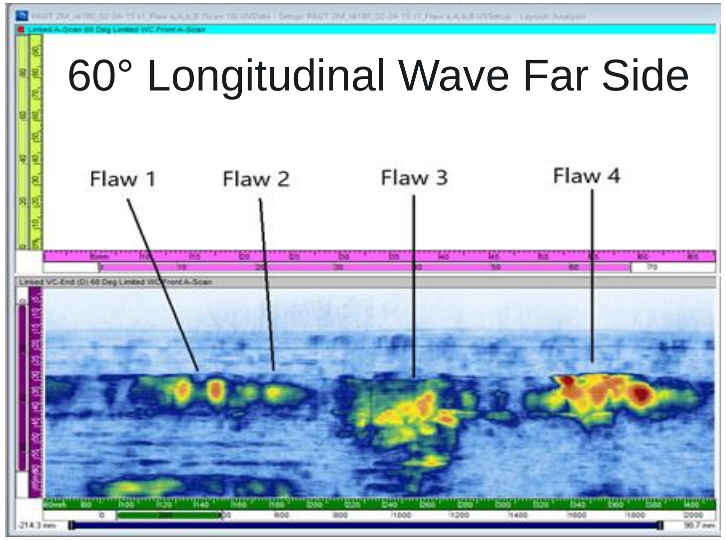


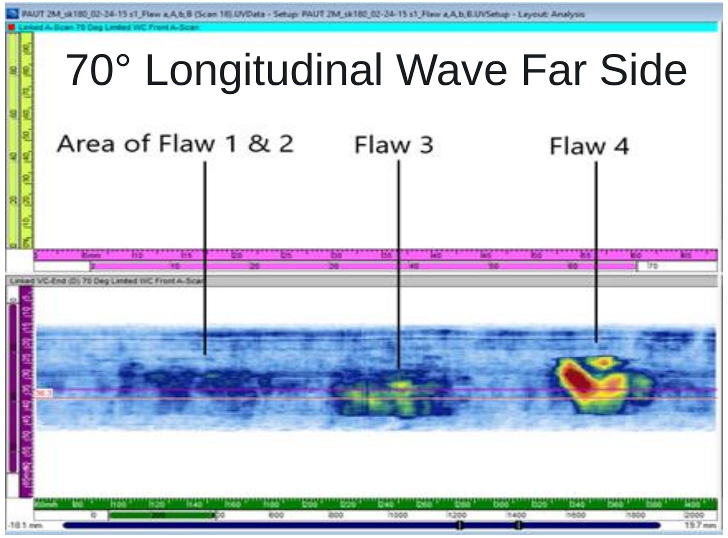
Limited Coverage Actual Flaw Responses



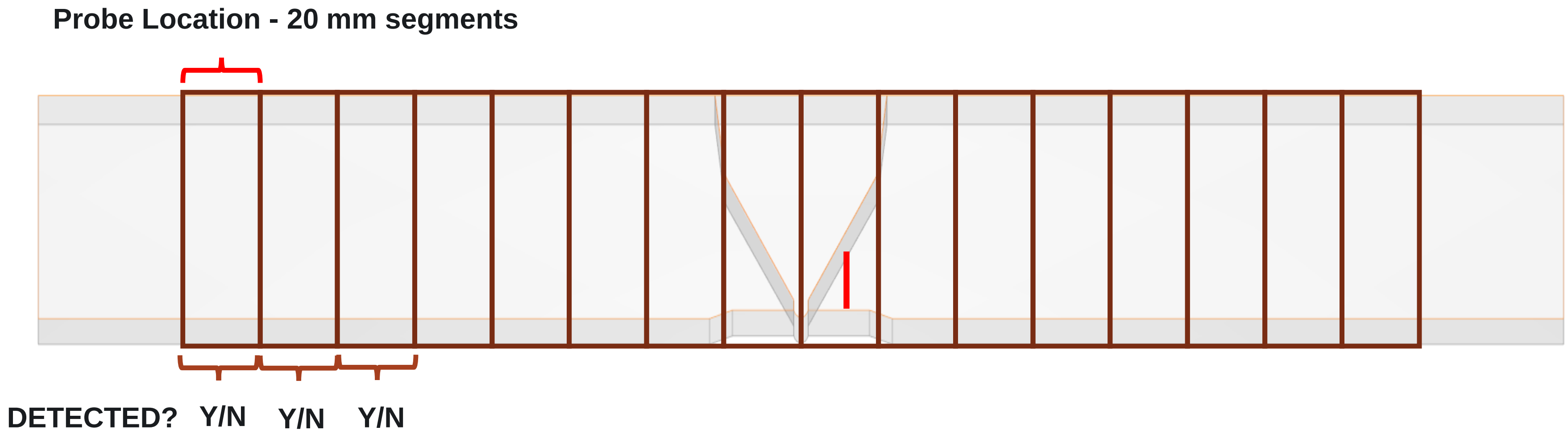








Ongoing Analysis



- Parse data into 20 mm wide sections with 10 mm overlap.
- Determine whether or not the flaw is detected (Yes/No) for each section as objectively as possible (i.e., would an analyst call a flaw from this data?)
- Calculate detectability as a function of probe position and flaw depth.

Current Activity

- Complete data collection and analysis activities for WSS-WSS welds
- Creation of Probability of Detection (POD) curves from tabulated stainless steel data
- Technical Letter Report (TLR) March 30, 2020 on Phase 1 wrought stainless to wrought stainless.
- Analysis of dissimilar metal weld data

Summary

- Conditions that limited examination coverage continues to be an industry issue
- The impact a limited examination condition has on the probability of flaw detection must be evaluated and documented.
- The ultrasound response characteristics from a portion of a flaw resulting from inadequate ensonification must be determined in order to enhance the probability of detection

Thank you

Pacific Northwest
NATIONAL LABORATORY

Human Factors in Encoded Exams: Planning for Task Analysis

January 15, 2020

Thomas F. Sanquist, Ph.D.

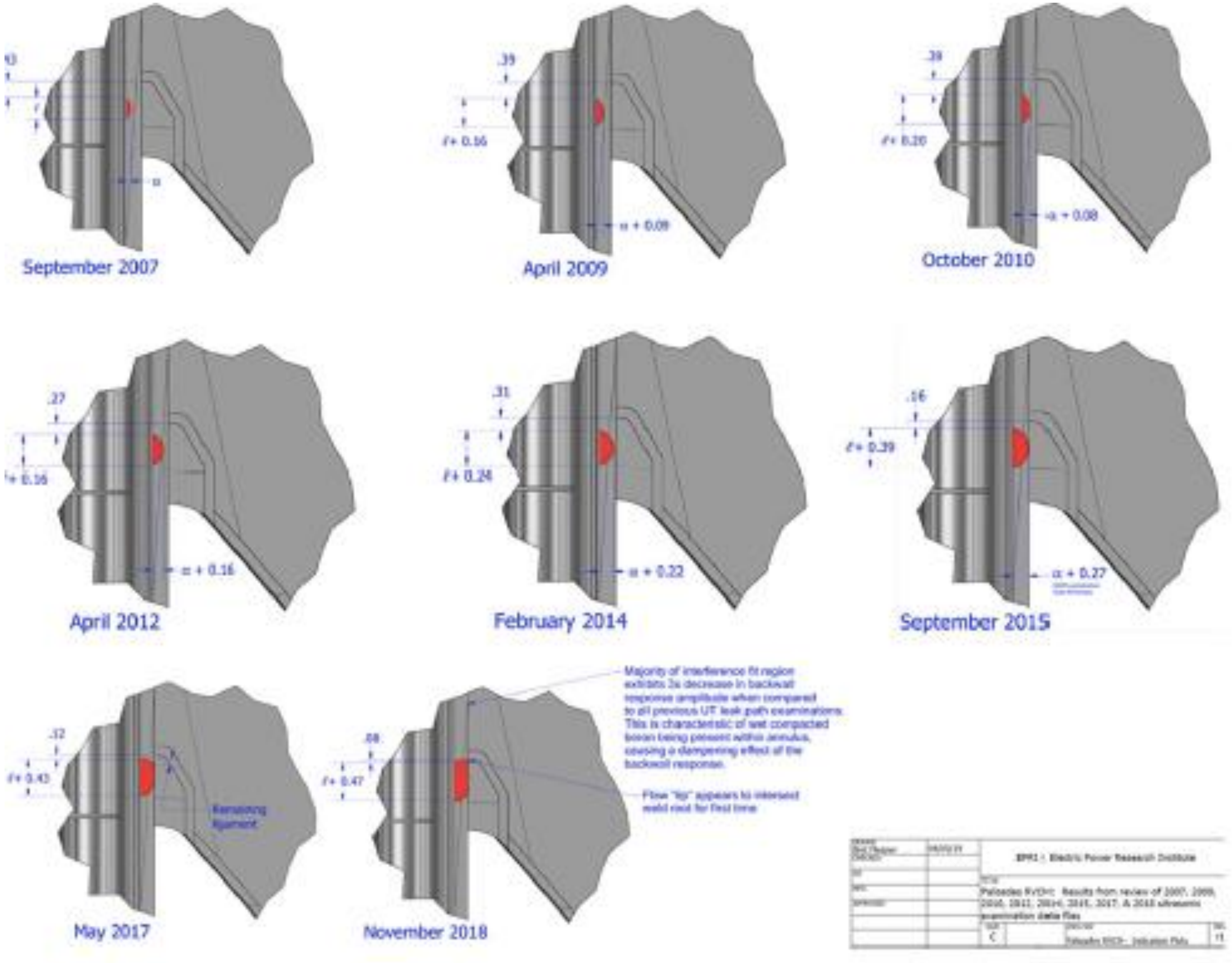
Pacific Northwest National Laboratory

Sponsored by US NRC / Office of Research

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

- Initiating Event (Palisades):
  - Missed flaw in upper head penetration for 10 years
  - Discovered via leakage
- Initially attributed to geometry, and subsequent inspections did not differ in interpretation
- Similar “miss” at Sharon Harris in 2012 (discovered by independent review)
- Encoded is more complex
  - More people, more data
- Objective: identify reliability influences and error precipitating factors
  - Extend task analysis demonstrated in manual UT to encoded exams



Ultrasonic Examination Technique Categories

Scanning technology

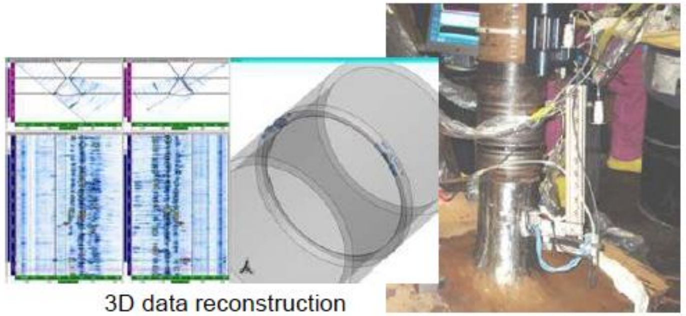
Encoded
Data is recorded for offline analysis and archiving

Non-Encoded
Data is interpreted in real time and is not recorded

UT technology

Phased array

Creates a 'fan' of sound beams



3D data reconstruction

$$$$

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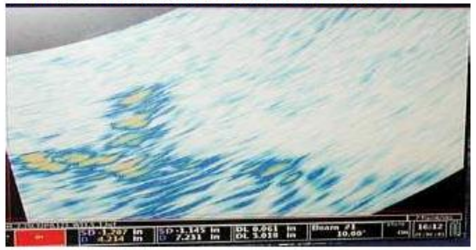
Displays a cross-section of the material; more intuitive than conventional UT



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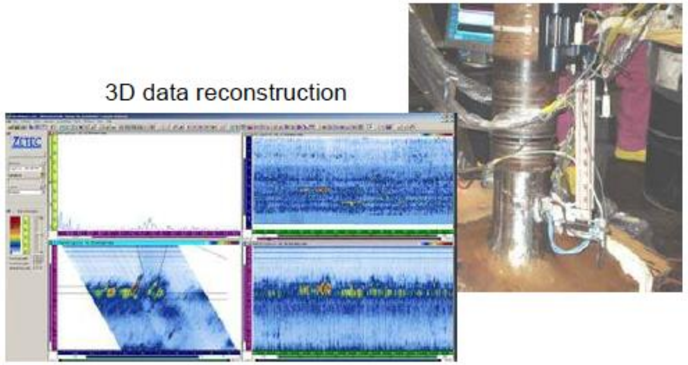
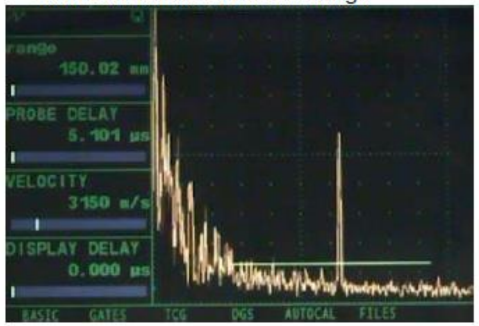
Conventional

Creates a sound beam at a single angle

3D data reconstruction



Displays a single beam angle's response; examiner builds a mental image



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Flow of Research Tasks

Plan and Prepare

- Define purpose
- Domain familiarization (observation, labs)
- Identify information sources
- Select methods (interview, functional decomposition)

Collect Data

- Task description, decomposition and verification
- Procedures
- Equipment interfaces and operation
- In-person interviews
- On-site task observation
- Structured task walkthrough

Analyze Data

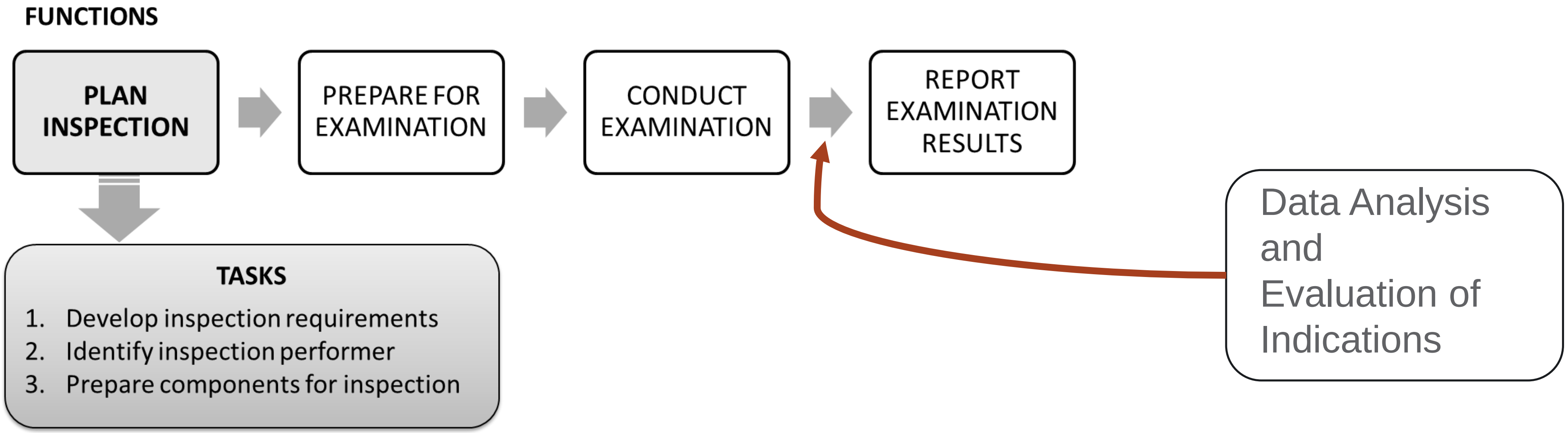
- Interview transcript content analysis
- Performance influence factors
- Error modeling
- Identify mitigations

Selection from structured interview protocol

Planning Inspection

First, let's start with what happens before you even get to a site to perform a UT exam *[Show graphic]*

[Note: This function may not apply to all interviewees – skip if needed.]



- As an examiner, what is your role in planning for the inspection?
- When planning the inspection, what tasks are most important to get right? Why?
- What factors can influence how well these tasks are performed? What kinds of problems are encountered if these tasks are not performed well?
- Task Check: Are there any tasks not on this list that you think are important?

From PNNL-27441, *Human Factors in Nondestructive Examination: Manual Ultrasonic Testing Task Analysis and Field Research,* June 2018, ML18176A055

Function	Task	Subtask
1. Plan for Examination	1.1 Develop plan based on requirements and previous data	1.1.a Review and revise procedures
	1.2 Identify qualified examiners	1.2.a Bid contract if necessary
	1.3 Ensure component prepared for examination in the field	1.3.a Walk-down areas to be examined 1.3.b Determine special equipment, personnel, and access requirements 1.3.c Measure components and access routes 1.3.d Prepare work packages
2. Prepare for Examination	2.1 Receive plant orientation and training	
	2.2 Review work package and procedure	2.2.a Obtain work package 2.2.b Review drawings, operating experience, location of component, weld history, weld profile, previous scanning technique, etc. *2.2+ Review prior exam results* *2.2+ Check system linearity and channel function (element check)* 2.2.c Develop scan plan according to procedure *Raster or line scan (circumferentially oriented flaws)* *Raster scan (axially oriented flaws)* *Select manual or fully automated drive* *Select reference system associated with technique* *Create data acquisition layout to allow operator to observe and monitor data acquisition* *Calculate focal laws for probes* *Conduct channel function check* *Create examination setup file detailing parameters of inspection* 2.2.d. Determine recording criteria for indications according to procedure
	2.3 Verify that the component is within the procedure and personnel qualification ranges	
	2.4 Assemble equipment and materials	2.4.a Select scope, transducers, cables, couplant gel, *drive mechanisms,* etc. according to procedure 2.4.b Re-familiarize self with equipment
	2.5 Calibrate equipment to procedure	2.5.a Save calibration files 2.5.b Complete calibration forms

Data Analysis Functions for Encoded PA Exams

Function	Task	Subtask
Data Analysis and Evaluation of Indications	Verify post-examination calibration	
	Verify data quality; re-examine areas as necessary	
	Flaw Detection Analysis	*Gate volume to identify benchmark information* *Gate regions within volume. Compare patterns and responses from different wave modes, angles, skews and beam directions* *Adjust sensitivity (gain or palette) to improve contrast as necessary*
	Classify indications as flaw or geometry	
	Determine size and depth per procedure	
	Record non-relevant indications in sufficient detail to assist future examinations.	

Content Analysis of Interview Data to Identify Themes

- The statement needed to convey a positive or negative influence on examination outcome. All other material was considered task description or extraneous comment.
- The block of text should be limited to only the content needed to capture the nature of the comment. This may be one or several sentences, but generally brief.

Original Order	Number	Quotation	Performance Influencing Factor	HF Category
1	1	Kind of get a feel for what exams take a little more work as far as pre calibrations etc. So when he pulls it out, he might give more lead time when he knows who is going to be doing it.	Utility Planning	Organizational Factors
2	2.1		Utility Planning	Organizational Factors
3	2.2	understanding if there is industry OE e.g. dissimilar metal welds - that you do all the pre planning actions that are associated with that type of examination they are not all equal - some require more effort	Task Complexity	Task Characteristics
4	3	if you don't do a good job of finding out the history, you can set the guy up who goes to do it, if it's in a high radiation area, he might spend more time into it. e.g. weld profiles, previous geometry that had been recorded previously	Utility Planning	Organizational Factors

Issues for Discussion

- Manual UT Task Analysis demonstrated utility of method – SME interviews and job functional decomposition
- Extension to Encoded UT will require more focus due to complexity
  - Equipment Operators
  - Data Analysts
  - Off-line analysis
- Can we use findings from project 1 to narrow our focus to areas most likely affect reliability?
  - Functions
  - Tasks and subtasks within functions
  - Performance Influence Factor definitions
- Opportunities for observation and interviewing in coming outage seasons – do plants in your utility have encoded exams in scope of Spring ISI?

Potential Areas of Focus

- Division of responsibility and communication between Equipment Operator and Data Analyst
- Task Complexity:
  - Factors such as ambiguity in assessing or executing the task, the degree of mental effort or knowledge involved, whether special sequencing or coordination is required, or whether the task requires sensitive and careful manipulations
- Knowledge/Experience
  - What the examiner knows, level of experience on the job, and certifications and qualifications
- Time Pressure
  - Temporal constraints due to specific exam performance or the overall inspection schedule
- Workload/Stress/Fatigue
  - Pace, intensity, and duration of exam, work shifts or assignments

Development of Technical Bases for Optimization of Examination Requirements

Robert Grizzi
EPRI

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Content

- Background
- Objective
- Scope
- Approach
- Generic Technical Basis Overview
- Technical Basis – Selected Sections Overview
- Anticipated Schedule for Technical Bases and Actions

Background (1/4)

- Previous Engagements and Communications
  - July 17, 2017: NRC/EPRI – Project Kick-off Meeting (Public)
  - January 2018: NRC/Industry NDE Technical Exchange – Project Status Update
  - May 2018: NRC/MRP Technical Exchange – Project Status Update
  - October 23, 2018: NRC Drop-in Meeting – Project Status Update
  - December 12, 2018: NRC Public Meeting on PFM
  - January 2019: NRC/Industry NDE Technical Exchange – Project Status Update
  - February 28, 2019: NRC Public Meeting, Pre-submittal Teleconference for Diablo Canyon Nuclear Power Plant, Units 1 and 2 Examination Category B-N-1, Item B13.10
  - May 2019: NRC/MRP Technical Exchange – Project Status Update
  - August 25, 2019: NRC Public Meeting, Pre-submittal Teleconference for Vogtle Units 1 & 2 Power Plants Steam Generator - Class 2, Category C-B, Item No. C2.21, C2.32, & C2.22
  - November 18, 2019: NRC Public Meeting, Pre-submittal for Duke Energy (fleet) Examination Category B-G-1, Item No. B6.20 (RPV Closure Studs)
  - November 19, 2019: Drop-in Meeting w/New NRC Management Org.

Background (2/4)

- There are many NDE examinations being performed that are perceived to have low value based on the history of few or no relevant indications being identified during routine inspections on prescribed intervals
- ***Where*** were these intervals established?
  - Codes and Standards of the construction era
- ***When*** were these intervals established?
  - Somewhere between 40 – 60 years ago
- ***How*** were these intervals established?
  - Technical Bases?
  - Engineering Judgment?

Background (3/4)

- Many of these examinations can have significant impact and burden
  - General health and safety of personnel
  - Radiation dose concerns (i.e. ALARA)
  - Outage schedule & preparation
    - Planning evolutions
    - Pre-job briefs
    - Radiation Worker Procedures
    - Scaffold building and tear down
    - Insulation removal and reinstallation
  - Contracting vendors to perform the examinations

Background (4/4)

- A 2016 NDE Work Plan project was initiated by EPRI, *'Identification and Assessment of Low-Value Examinations with High Outage Impacts'*
  - Surveyed utility members, ranked and prioritized results
  - 34 individual ASME Section XI Code-required examinations
- EPRI Report 3002012965: *Identification and Assessment of Low-Value NDE examinations with High Outage Impacts*

Metrics Used to Prioritize Examinations – Value

Item	Metric (unit)	Point Value Assigned		
		15	4	1
1	Perceived Value of The Exam *Considerations: probability of finding flaws, component criticality, reactor type applicability, NSSS design applicability* (Qualitative – *Subjective*)	Low	Med	Hi

Metrics Used to Prioritize Examinations-Impact

Item	Metric (unit)	Point Value Assigned		
		1	2	3
2	Impact to Critical Path (hours)	≤ 2	>2 and ≤ 12	> 12
3	Expected Accumulated Dose (mrem)	≤ 100	>100 and ≤ 1000	>1000
4	Cost to Perform Exam ($1000)	≤ 50	> 50 and ≤ 250	> 250
5	Safety Considerations *Confined Space Entry, Lifting/Rigging, Fall Hazards, Chemical Hazards, Climbing Required, Extreme Temperature Area, High Noise Area* (# of considerations)	≤ 2	>2 and ≤ 4	>4
6	Exam Frequency Multiplier (# of times per interval or period)	≤1 time/interval	>1 time/interval and <1 time/period	≥1 time/period
7	Probability of Success in Reducing Scope/Frequency or Eliminating (Chance of Success - *Subjective*)	≤ 30%	>30% and ≤ 60%	>60%

Objective (1/2)

- Using historical operating experience, fundamental engineering methods, and the application of modern day analysis tools; develop technical bases to optimize examination requirements for selected components, without adversely impacting safe and reliable operations of the nuclear facilities.

Objective (2/2)

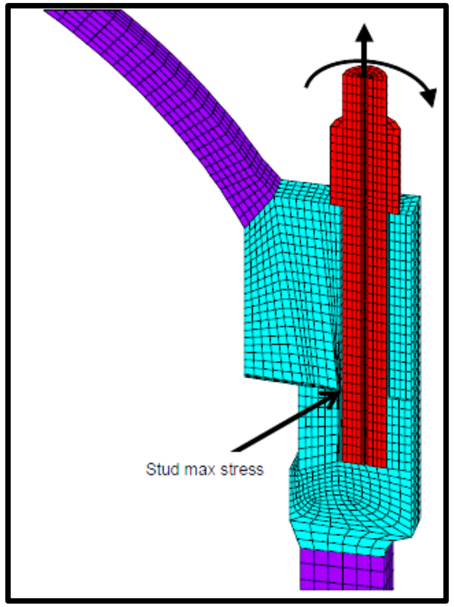
- The objectives of this project are not new
- There are several precedents for RPVs, RCPs, and HXs dating back to the early 1990s

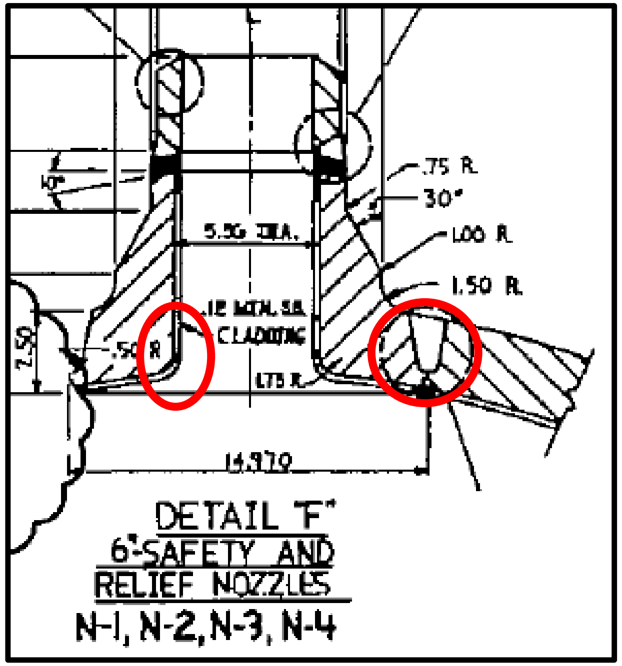
Document	Description	Approach		Result			Ref.	Revised Inspection Requirement
		D	P	SR	FR	CEM		
BWRVIP-05	BWR vessel welds		X	X			19	Elimination of circumferential weld inspections
BWRVIP-108	BWR inner radius and vessel-to shell welds	X	X	X			2	Sample size reduced from 100% to 25% of each nozzle type
WCAP-16168-NP-A	PWR vessel and nozzle-to-shell welds		X		X		8	Inspection frequency extended from 10 years to 20 years
SIR-94-080	RCP Flywheel: CE and B&W	X			X		52	Inspection frequency extended from 3.5 years to 10 years
WCAP-15666	Westinghouse RCP flywheel	X	X		X		53	Inspection frequency extended from 3.5 years to 10 years
EPRI-3002007626	RPV thread in flange	X			X		30	Inspection frequency extended from 10 years to (at least) 20 years
PVP-2001 (Bamford et al.)	RPV inner radius inspections	X	X	X			17	Elimination of these inspections
PVP2006-ICPVT-11-93892	Regen and residual heat exchangers	X	X			X	12	Inspection method changed from volumetric to visual
PVP2015-45194 supplemented by MRP-82 and NUREG/CR-6934	Appendix L flaw tolerance evaluation to manage fatigue in surge line	X			X		54	Justified maintaining the current 10-year inspection interval
MRP-375	Alloy 690 RPV head nozzle penetration nozzles	X	X	X	X		55	Inspection frequency extended from 10 years to 20 years. Scope reduced using sister head concept.

D = Deterministic Method
SR = Scope Reduction
CEM = Change in Examination
P = Probabilistic
FR = Frequency Reduction

Scope – By Examination Category (1/3)

- Current EPRI research is focused on **(5)** ASME Code Examination Categories
  1. **Reactor Vessel Interior Inspections (B-N-1 Exams)**
  2. **Class 1 & 2, Pressure Retaining Bolting Greater Than 2” in Diameter**
     - RPV Studs
     - Recirc Pumps, Manway Closures, Reactor Coolant Pumps, etc.
  3. **Class 1 & 2, Non-Reactor Vessel Nozzle Inside Radius Sections**
     - Steam Generator, Pressurizer, BWR Heat Exchangers
  4. **Class 1 & 2, Non-Reactor Vessel Nozzle-to-Vessel Welds**
     - Steam Generator - Feed Water, Main Steam, Primary Inlet/Outlet
     - Pressurizer - Surge, Safety/Relief, Spray
     - BWR Heat Exchangers
  5. **Class 1 & 2, Non-Reactor Vessel Welds**
     - BWR Heat Exchangers
     - PWR Steam Generator & Pressurizer Vessels





Scope – Realignment By Component Type (2/3)

1. **Reactor Vessel Interior Inspections (B-N-1 Exams)**
   - In conjunction with ASME Code, developed the technical basis for eliminating the B-N-1 exam. There was no realignment of components in this effort
2. **Class 1 & 2, Pressure Retaining Bolting Greater Than 2” in Diameter**
   - **RPV Studs –** PWR and BWR studs had enough similarity to group and analyze in the same technical basis
   - **Component bolting –** All other studs and bolting not associated with RPV closure (pumps, manways, valves, etc.) analyzed in same technical basis

Items in this examination category were re-grouped

Scope – Realignment By Component Type (3/3)

3. **Class 1 & 2, Non-Reactor Vessel Nozzle Inside Radius Sections**
4. **Class 1 & 2, Non-Reactor Vessel Nozzle-to-Vessel Welds**
5. **Class 1 & 2, Non-Reactor Vessel Welds**

- **Steam Generator Main Steam and Feedwater Nozzle to Shell and Inner Radius**
  - Class 2 components (steam side) analyzed in same technical basis
- **Steam Generator Primary Nozzle to Shell, Inner Radius, and Pressure Vessel Welds**
  - Class 1 components analyzed in same technical basis
- **Pressurizer Nozzle to Shell, Inner Radius, and Pressure Vessel Welds**
  - All pressurizer components are Class 1, analyzed in same technical basis
- **BWR Heat Exchanger Nozzle to Shell, Inner Radius, and Pressure Vessel Welds**
  - PWR heat exchangers covered by Code Case N-706-1, HX is the only BWR component in these examination categories, analyzed in same technical basis

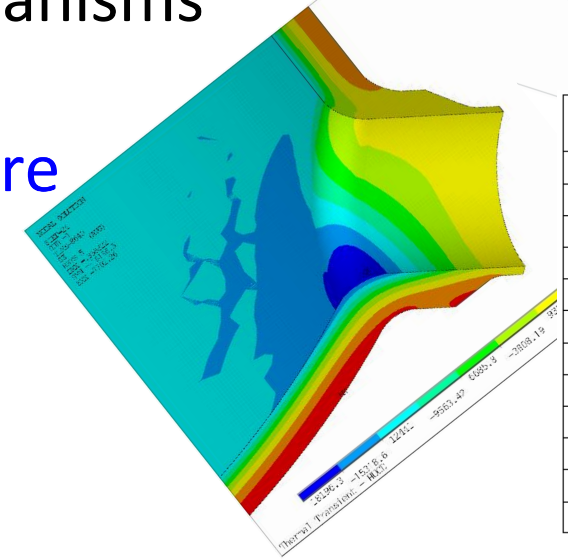
Examination categories were combined and re-grouped by component to better align with utility inspection scopes

Approach

- Identification of applicable components
- Collect the original bases for examinations (if available)
- Research all applicable degradation mechanisms
- Compile operating experience, examination data, and results (fleet survey)
- Compile existing documentation:
  - Previous relief requests and associated NRC safety evaluations
  - Applicable industry guidance documents
  - Redundancy of inspections due to other industry activities (e.g. BWRVIP, MRP)
- Compile existing Code Cases for evaluated Code items
- Perform component-specific fracture mechanics (probabilistic & deterministic) and engineering analyses

Generic Technical Basis Overview

- Introduction
- Review of Previous Related Work
- Review of Inspection History and Examination Effectiveness
- Survey of Components and Selection of Representative Components for Analysis
- Material Properties, Operating Loads and Transients
- Evaluation of Potential Degradation Mechanisms
- Component Stress Analysis
- Probabilistic* and/or Deterministic Fracture Mechanics Evaluation
- Plant Specific Applicability
- Summary and Conclusions



Sensitivity Study Variable	Importance Factor (%) for Probability of Leakage
Fatigue Crack Growth Rate Coefficient	87.82
Crack Length	9.39
Crack Depth	0.00
Fatigue Crack Growth Rate Threshold	0.01
Fracture Toughness	0.01
Crack Face Pressure	0.04
Pressure	1.82
Residual Stress	0.00
Heat-Up/Cooldown	0.01
Loss of Load	0.04
Load Increase (5%)	0.69
Load Decrease (5%)	0.16

Technical Basis – Selected Sections Overview

Technical Basis – Selected Sections Overview (1/17)

- Introduction
- Review of Previous Related Work
- Review of Inspection History and Examination Effectiveness
- Survey of Components and Selection of Representative Components for Analysis
- Material Properties, Operating Loads and Transients
- Evaluation of Potential Degradation Mechanisms
- Component Stress Analysis
- Probabilistic* and/or Deterministic Fracture Mechanics Evaluation
- Plant Specific Applicability
- Summary and Conclusions

EPRI briefed NRC on these 5 topics at the 10/23/2018 drop-in meeting

On the following slides, we will provide a review and update to these topics

This will also be covered

Technical Basis – Survey of Components and Selection of Representative Components for Analysis (2/17)

- Selection of representative components considered the following factors, e.g., for SG Main Steam & Feedwater Nozzles:
  - Component grouping applies to PWRs only
  - Establish whether a single component could represent all PWR plant designs types (e.g., 2-loop Westinghouse, 3-loop Westinghouse, 4-loop Westinghouse, B&W and CE);
  - Summarize all available component geometries;
  - Summarize all available component operating characteristics (loads and transients);
  - Summarize all available component materials;
  - Summarize all available field experience with regards to service-induced cracking; and
  - Evaluate the availability and quality of component-specific information

Technical Basis – Material Properties, Operating Loads, and Transients (3/17)

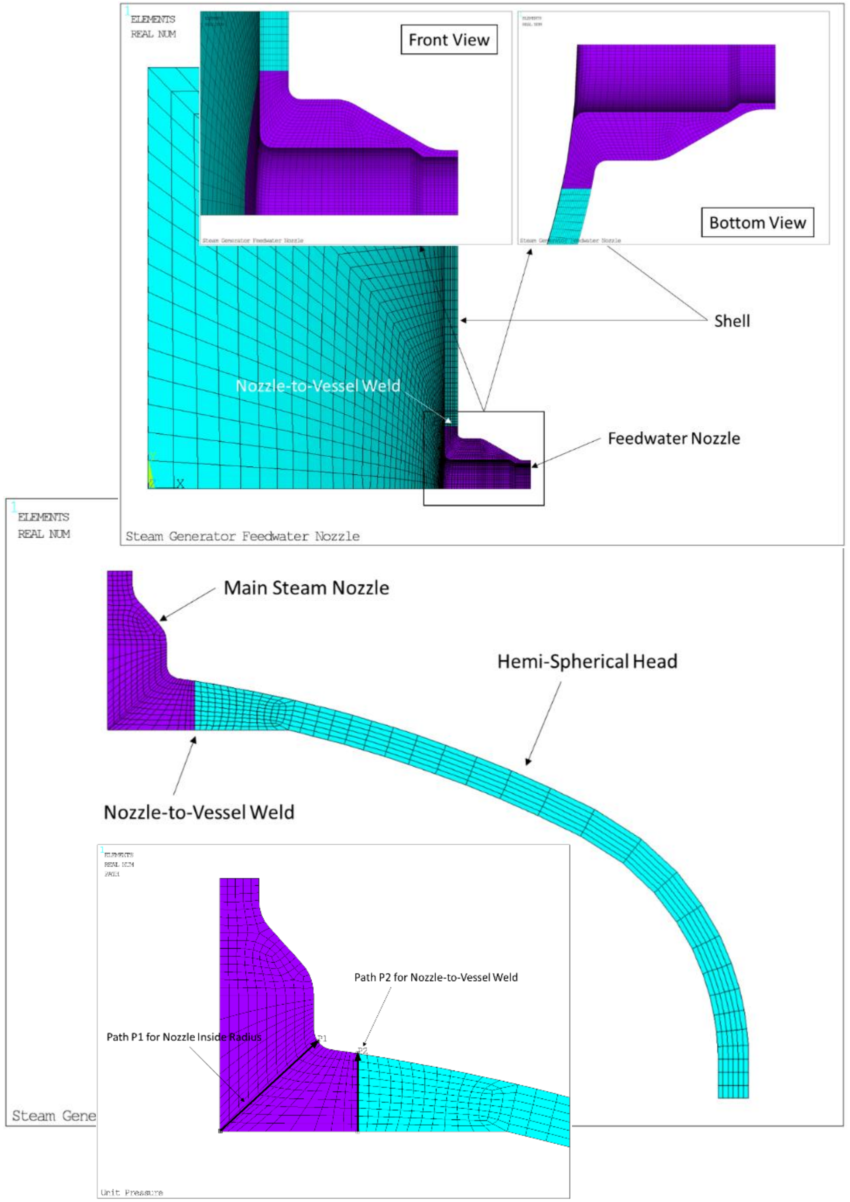
- Summarized and evaluated all available materials across components and designs
- Used temperature-dependent material properties for representative material from ASME Code, Section II, Part D
- Defined representative loads for all applicable thermal and pressure transients
  - Attempted to define bounding loads; however, plants need to check loads as part of plant specific applicability

Technical Basis – Evaluation of Potential Degradation Mechanisms (4/17)

- Environmentally-Assisted Cracking/SCC:
  - Intergranular Stress Corrosion Cracking (IGSCC)
  - Transgranular Stress Corrosion Cracking (TGSCC)
  - External Chloride Stress Corrosion Cracking (ECSCC)
  - Primary Water Stress Corrosion Cracking (PWSCC)
  - Corrosion Fatigue (EAF)
- Localized Corrosion:
  - Microbiologically Influenced Corrosion (MIC)
  - Pitting
  - Crevice Corrosion
- Flow Sensitive degradation:
  - Erosion-Cavitation
  - Erosion (i.e., abrasive wear)
  - Flow Accelerated Corrosion (FAC)
- General Corrosion:
  - Corrosion/Wastage
  - Galvanic Corrosion
- Fatigue:
  - Thermally Assisted Stratification, Cycling and Striping (TASCS)
  - Thermal Transients (i.e., low-cycle severe thermal shocks)
  - Mechanical Fatigue

Technical Basis – Component Stress Analysis (5/17)

- 3 Finite Element Models (FEMs):
  - Westinghouse MS, B&W MS, and FW Nozzles
  - Intended to be bounding models based on survey results
    - Used bounding R/t ratios, etc.
    - All plants will need to do plant-specific evaluation of stresses for application of generic results
- Pressure and Thermal Stress Analyses Finite Element Analysis (FEA):
  - Internal pressure
  - Heat-up / Cool-down transients
  - Bounding temperatures, pressures, and flow rates were used to maximize transient pressures and delta-Ts



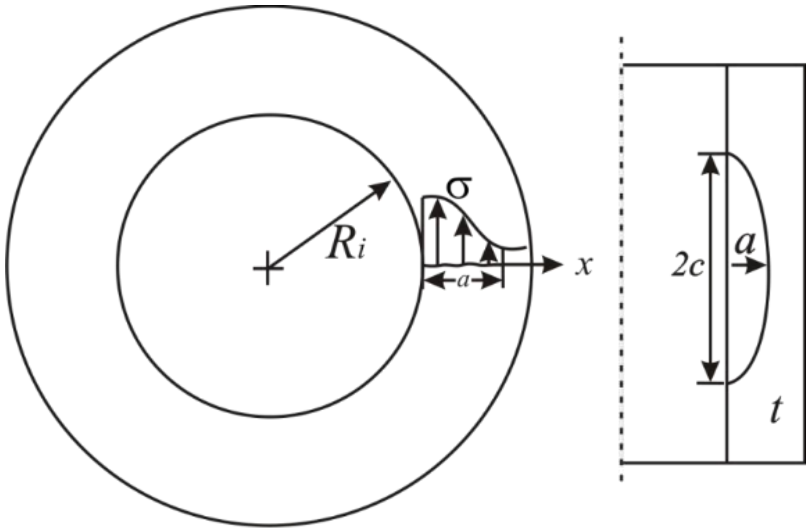
Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation (6/17)

- Probabilistic Fracture Mechanics (PFM) and Deterministic Fracture Mechanics (DFM) were performed using FEA results, consisting of:
  - PFM Software benchmarking
  - PFM evaluation of Base Case
  - PFM investigation of alternatives
  - PFM sensitivity studies for all inputs
  - DFM used to validate PFM results (i.e.= "Belt and Suspenders" approach)

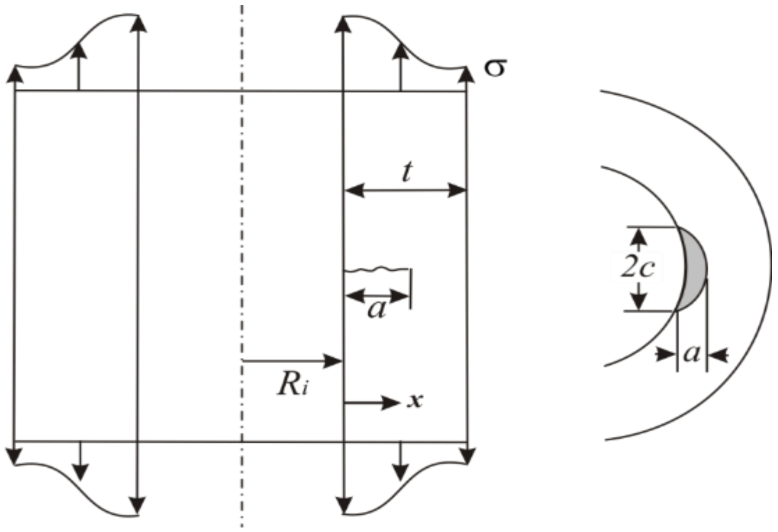
Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation – cont'd (7/17)

- PFM and DFM fracture mechanics models:

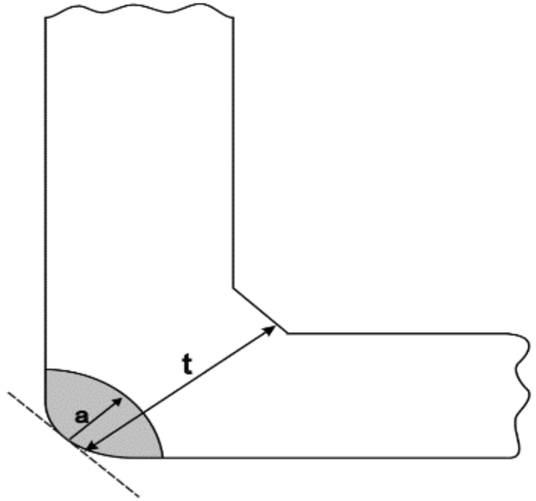
Fracture Mechanics Models



Semi-Elliptical Axial Crack
API-579/ASME-FFS-1



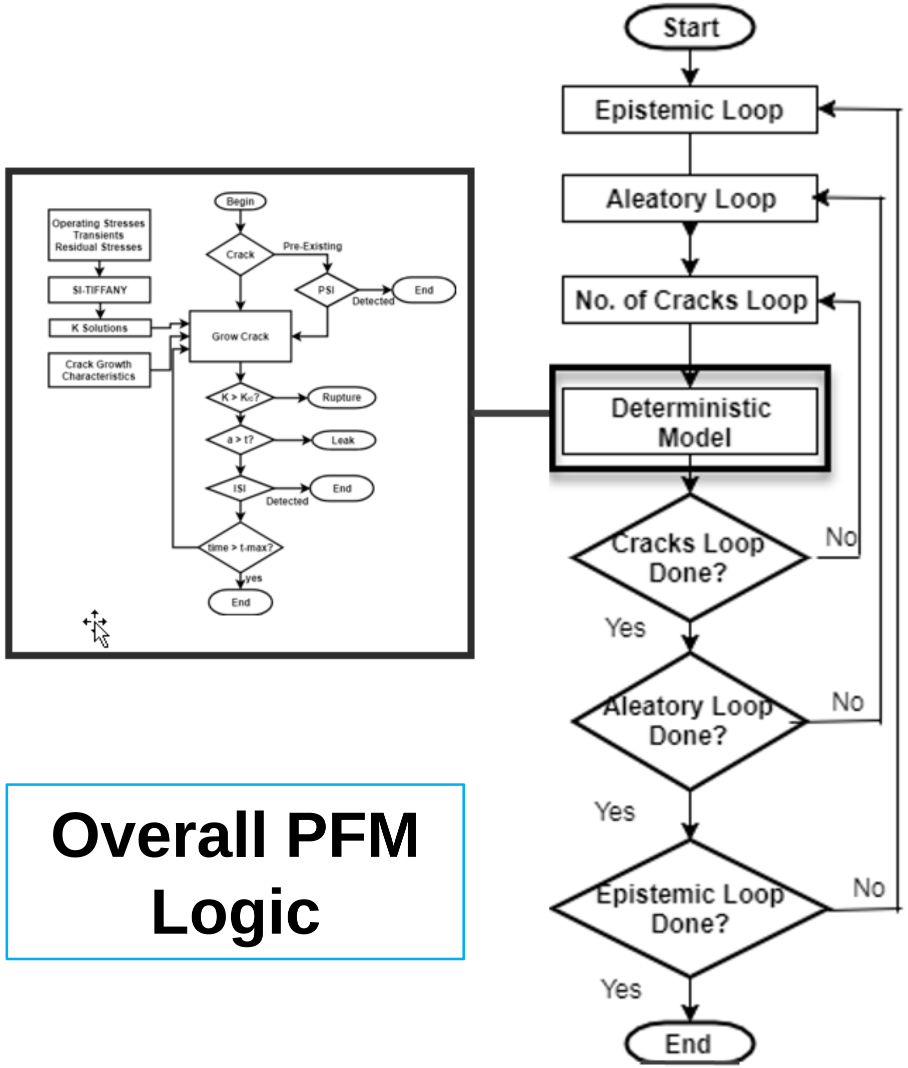
Semi-Elliptical Circumferential Crack
API-579/ASME-FFS-1



Nozzle Corner Crack Weight Function
(same as ASME XI App. G)

Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation – cont'd (8/17)

- PFM software:
  - PROMISE 1.0 (new, SIA-developed)
    - NQA Software, SIA Appendix B QA Program
    - V&V Documentation
    - Theory and Users Manual
    - Benchmarked against VIPERNOZ 1.1
      - Same software used for BWRVIP-108/BWRVIP-241 nozzle work
    - Software and documentation available for NRC review



Overall PFM Logic

Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation – cont'd (9/17)

- PFM software inputs and their treatment:

Example of Random Variable Distributions

Variable	Distribution
Crack depth	Tabular (PVRUF or NUREG-6817)
Crack length	Log-normal
Transient stresses	Normal
Fracture toughness	Normal
Fatigue crack growth rate	Log-normal
Fatigue crack growth threshold	Log-normal
Crack detection	Tabular (POD curve)
No. of cracks per weld or nozzle	Poisson
Residual stresses	Constant
OD, thickness	Constant

Benchmark Case Inputs for Comparison to VIPERNOZ 1.1 Work

Input	Value
No. of cracks per inner radius section	1, constant
Crack depth distribution	PVRUF
Fracture toughness (ksi√in)	Normal (200,5)
PSI	None
ISI	None
POD Curve	Not applicable
Fatigue crack growth law and threshold	BWRVIP-108
Uncertainties on transients	None
Residual stresses (ksi)	None

Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation – cont'd (10/17)

- PFM Base Case inputs:
  - Represents a case of "what plants do now"
  - The Degree of Separation Method was used to rank the effect of the input variables on the output probabilities
    - Used to help define the sensitivity studies

No. of realizations	Epistemic = 1, Aleatory = 10 million
No. of cracks per nozzle-to-shell weld	1, constant
No. of cracks per nozzle inside radius section	0.001, constant
Crack depth distribution	PVRUF
Crack length distribution	NUREG/CR-6817-R1
Fracture toughness (ksi√in.)	Normal (200, 5)
Inspection coverage	100%
PSI	Yes
ISI	20, 40, 60 (20-year interval)
POD curve	BWRVIP-108, Figure 8-2
Fatigue crack growth law and threshold	A-4300, log-normal, Second Par. = 0.467
Uncertainties on transients	None
Weld residual stresses (ksi)	Cosine curve (8, 8), constant (not random)

Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation – cont'd (11/17)

- PFM sensitivity studies:
  - The most limiting case, in terms of probability of leakage, from the base case was investigated
  - The purpose was to identify the random variables that have the most impact on the calculated probabilities (rupture or leakage)

Variable	Importance Factor (%)	
	Probability of Leakage	Probability of Rupture
Fatigue Crack Growth Rate Coefficient	79.16	23.69
Crack Depth	0.02	0.10
Crack Length	8.89	8.43
Fatigue Crack Growth Rate Threshold	0.01	0.00
Fracture Toughness	11.92	67.86

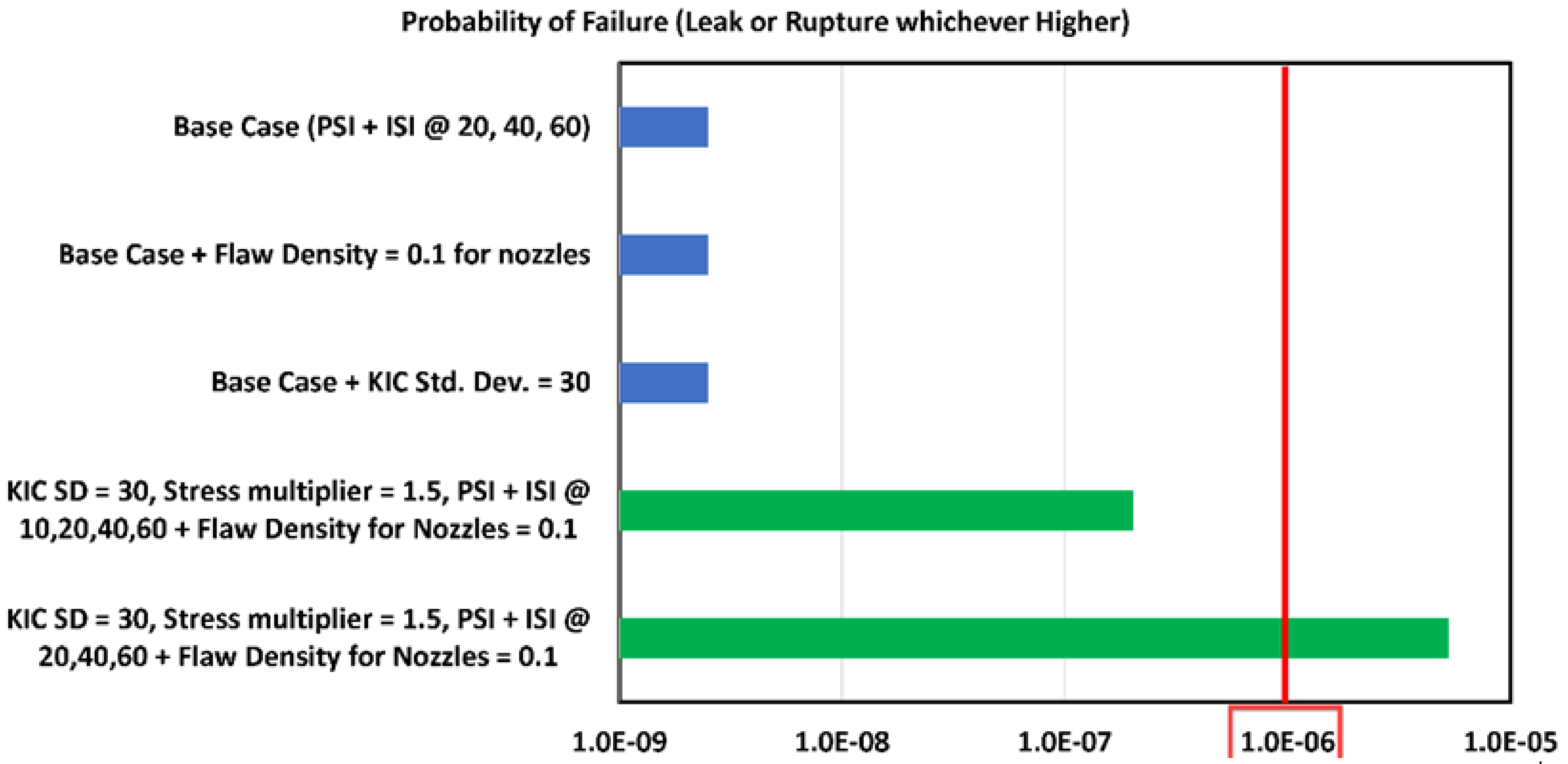
  - These results defined sensitivity studies that were performed
  - 11 variables were investigated

Results of Sensitivity Studies with Random Multipliers were tabulated with Importance Factors

Variable	Importance Factor (%) for Probability of Leakage
Fatigue Crack Growth Rate Coefficient	87.82
Crack Length	9.39
Crack Depth	0.00
Fatigue Crack Growth Rate Threshold	0.01
Fracture Toughness	0.01
Crack Face Pressure	0.04
Pressure	1.82
Residual Stress	0.00
Heat-Up/Cooldown	0.01
Loss of Load	0.04
Load Increase (5%)	0.69
Load Decrease (5%)	0.16

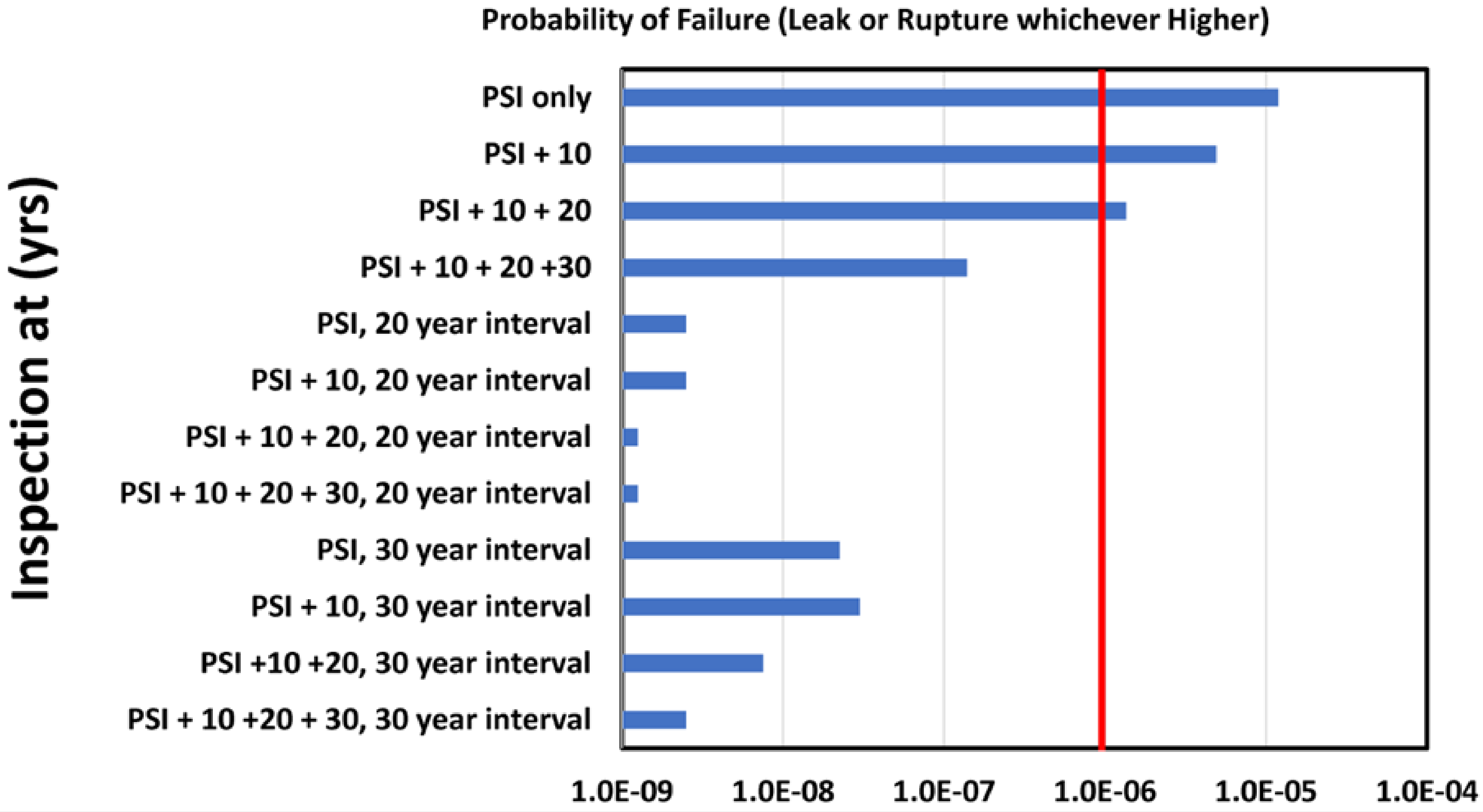
Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation – cont'd (12/17)

- Summary of key sensitivity analysis results:



Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation – cont'd (13/17)

- PFM results for various inspection scenarios



Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation (14/17)

- DFM was performed using the FEA results, consisting of:
  - Postulate an initial flaw size consistent with ASME XI acceptance standards
  - Calculate the allowable flaw size
  - Perform a crack growth evaluation
  - Determine the length of time until the allowable flaw size is reached
  - DFM Inputs:

Geometry	Same as used in the PFM
Initial crack size	5.2% of the thickness, c/a = 1
Fracture toughness	200 ksi$\sqrt{in.}$
Fatigue crack growth law	ASME Code, Section XI Appendix A, A-4300
Operating transient stresses	Same as used in the PFM
Residual stresses	Cosine curve (8, 8)

Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation (15/17)

- DFM Results

- DFM results align with PFM results (supports increased examination intervals)

Component	Case Identification	Years to Leak	Max. K at 80 Years (ksi√in.)
Westinghouse Main Steam Nozzle (SGW)	SGW-P1N	795	38
	SGW-P2C	950,000	8
	SGW-P2A	8221	18
B&W Main Steam Nozzle (SGB)	SGB-P1N	716	40
	SGB-P2N	4660	16
	SGB-P3C	32,640	14
	SGB-P3A	1086	36
	SGB-P4A	36,190	12
	SGB-P4C	5529	20
Westinghouse Feedwater Nozzle (FEW)	FEW-P1N	**147**	**101**
	FEW-P2N	1890	13
	FEW-P3C	4612	15
	FEW-P3A	396	27
	FEW-P4A	3468	15
	FEW-P4C	7998	13

Note: Limiting value is displayed in **red bold** text.

Technical Basis – Probabilistic and Deterministic Fracture Mechanics Evaluation (16/17)

- Conclusions:
  - Revised inspection intervals are not explicitly defined
  - Plant specific situations may dictate plant specific inspection intervals
    - For example, current plant age and the need for inspections in license renewal periods
    - There may be other plant specific issues
  - The plant-specific alternative inspection interval will be defined in the pilot plant NRC submittal
  - Generic inspection interval for future Code actions are still under consideration

Technical Basis – Plant Applicability (17/17)

- Plant specific applicability criteria must be satisfied; for example, for MS and FW nozzles
  - *The nozzle-to-shell weld must be one of the configurations shown in Figure 1-1 or Figure 1-2*
  - *The materials of the SG shell, feedwater nozzle, and main steam nozzle must be low-alloy ferritic steels that conform to the requirements of ASME Code, Section XI, Appendix G, Paragraph G-2110*
  - *The SG must not experience more than the number of all transients shown in Table 5-5 over a 60-year operating life*
  - *The piping attached to the feedwater nozzle must be 14-in. to 18-in. NPS.*
  - *The feedwater nozzle design must have an integrally attached thermal sleeve*
  - *Auxiliary feedwater nozzles connected directly to the SG are not covered in this evaluation*
  - *For Westinghouse and CE SGs, the piping attached to the main steam nozzle must be 28-in. to 36-in. NPS*
  - *For B&W SGs, the piping attached to the main steam nozzle must be 22-in. to 26-in. NPS*
  - *The SG must have one main steam nozzle that exits the top dome of the SG. For B&W plants, there may be more than one main steam nozzle; it will exit the side of the SG*
  - *The main steam nozzle shall not significantly protrude into the SG (for example, see Figure 4-7) or have a unique nozzle weld configuration (for example, see Figure 4-6)*

Anticipated Schedule for Technical Bases and Actions

Anticipated Schedule for Technical Bases and Actions (1/4)

1. Reactor Vessel Interior Inspections

- **B-N-1 Examinations**
  - ✓ EPRI Report 3002012966, *Evaluation of Basis for Periodic Visual Examination of Accessible Areas of Reactor Vessel Interior per Examination Category B-N-1 of ASME Section XI, Div. 1* – Published 04/10/2018
  - ✓ Technical Basis supports Code Case N-885 that was published in July 2019

Anticipated Schedule for Technical Bases and Actions (2/4)

2. Class 1 & 2, Pressure Retaining Bolting Greater Than 2" in Diameter

- **RPV Studs**
  - ✓ EPRI Report 3002014589, *Technical Basis for Optimization of the Volumetric Examination Frequency for Reactor Vessel Studs* – Published 12/03/2018
  - ✓ Lead Plants for NRC Submittal – Duke Energy (potential multi-site submittal) – **1Q 2020**
  - ✓ Code Case Action after NRC submittal – ~**05/2020**
- **Component Bolting (pumps, manways, valves, etc.)**
  - ✓ EPRI Report 3002015907, *Technical Basis for Optimization of the Volumetric Examination Frequency for Non-Reactor Vessel Closure Classes 1 and 2, Pressure-Retaining Bolting Greater than 2 Inches (51 mm) in Diameter* – Published 09/30/2019
  - ✓ No lead plant submittal planned
  - ✓ Code Case Action Initiated - **10/2019**

Anticipated Schedule for Technical Bases and Actions (3/4)

3 - 5 Class 1 & 2, Non-Reactor Vessel Nozzle to Shell, Inner Radius, and Pressure Vessel Welds

- **Steam Generator Main Steam and Feedwater Nozzle to Shell and Inner Radius**
  - ✓ EPRI Report 3002014590, *Technical Bases for Inspection Requirements for PWR Steam Generator Feedwater and Main Steam Nozzle-to-Shell Welds and Nozzle Inside Radius Sections* – Published 04/17/2019; (Posted on ADAMS 12/2019 - ML19347B107)
  - ✓ Lead Plants for NRC Submittal – Southern Nuclear Company (Vogtle 1&2) – Submitted on 12/11/2019; (ML19347B105)
  - ✓ Code Case Action after NRC submittal – ~**05/2020**
- **Steam Generator Primary Nozzle to Shell, Inner Radius, and Pressure Vessel Welds**
  - ✓ EPRI Report 3002015906, *Technical Bases for Inspection Requirements of PWR Steam Generator Primary Nozzle-to-Shell, Inner Radius, and Pressure Vessel Welds* – Published 10/10/2019
  - ✓ Lead Plants for NRC Submittal – Dominion (Millstone 2) – **2Q 2020**
  - ✓ Code Case Action after NRC submittal – ~**11/2020**

Anticipated Schedule for Technical Bases and Actions (4/4)

3 - 5 Class 1 & 2, Non-Reactor Vessel Nozzle to Shell, Inner Radius, and Pressure Vessel Welds

- **Pressurizer Nozzle to Shell, Inner Radius, and Pressure Vessel Welds**
  - ✓ EPRI Report 3002015905, *Technical Bases for Inspection Requirements of PWR Pressurizer Nozzle-to-Shell, Inner Radius, and Pressure Vessel Welds* – Published 12/20/2019
  - ✓ Lead Plants for NRC Submittal – PSG&E (Salem 1&2) **2Q 2020**
  - ✓ Code Case Action after NRC submittal – ~**11/2020**
- **BWR Heat Exchanger Nozzle to Shell, Inner Radius, and Pressure Vessel Welds**
  - ✓ EPRI Report in process - **03/2020**
  - ✓ Lead Plants for NRC Submittal – Exelon (Limerick 1&2), Iberdrola (Cofrentes) – **2Q 2020**
  - ✓ Code Case Action after NRC submittal – ~**11/2020**

DISCUSSION/QUESTIONS?

Together…Shaping the Future of Electricity

ELECTRIC POWER RESEARCH INSTITUTE

Update on reactor vessel upper head volumetric exam OE

Kevin Hacker
Dominion Energy

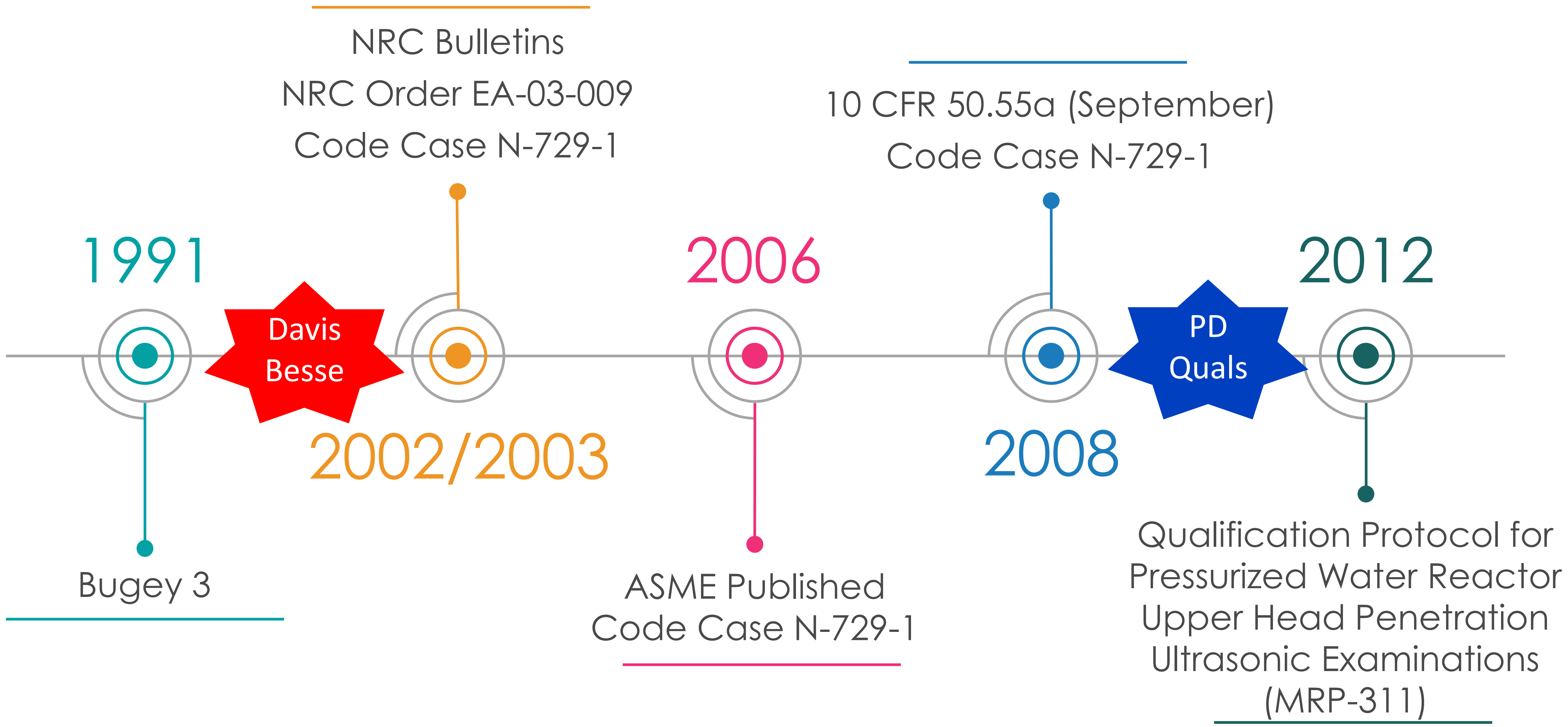
Robert Grizzi
EPRI

January 2020
Industry/NRC NDE Technical Information Exchange Meeting

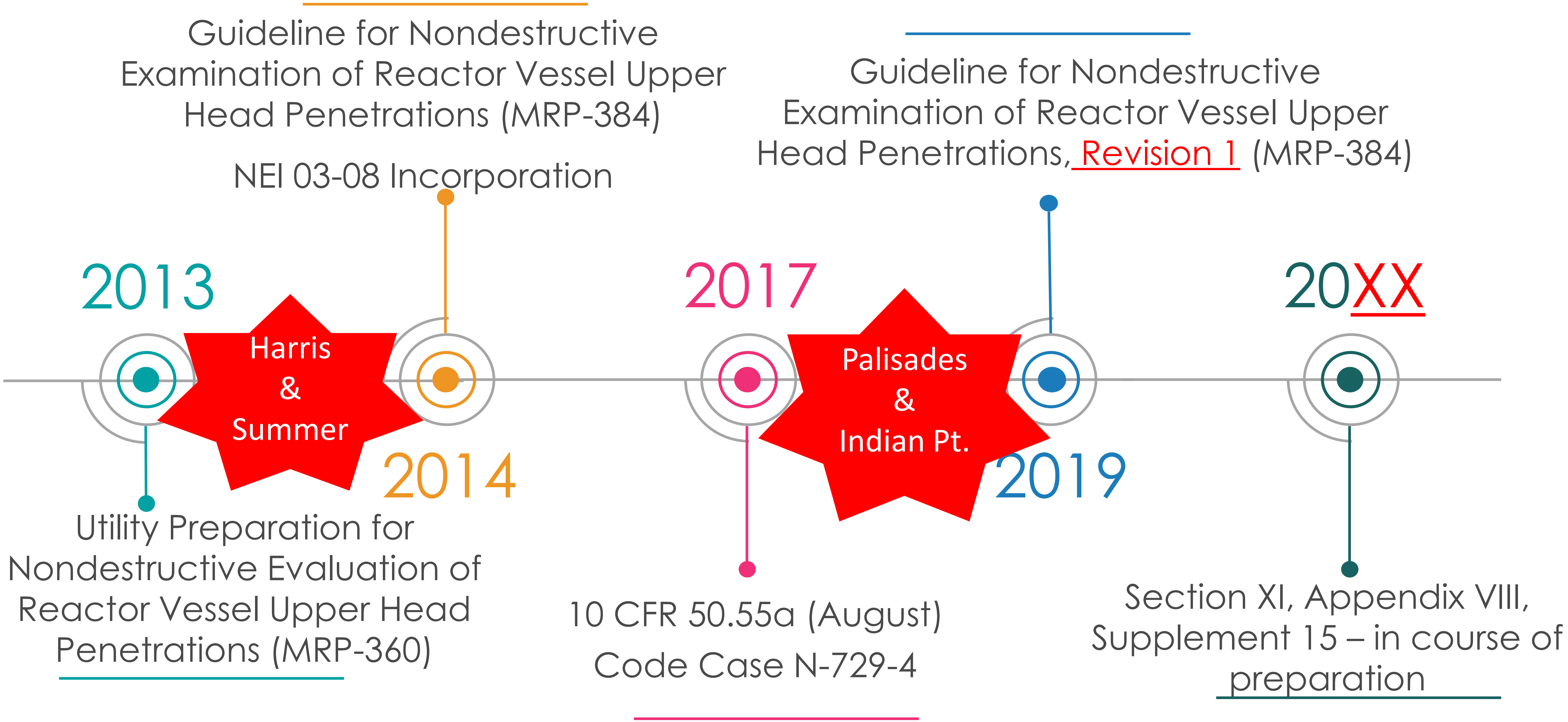
Outline

- RVUH Penetration Examination – Timeline
- Background Information on Recent OE
- Focus Group Findings
- Industry Guidance
- Summary

RVUH Penetration Examination – Timeline (1/2)



RVUH Penetration Examination – Timeline (2/2)



Background Information on Recent OE

- RVUH volumetric examinations performed in 2018 have identified several areas of the NDE process to be improved upon
  - Missed detection of cracks
  - Misidentification of several leak path indications
- The NDE vendor performed a root cause analysis (RCA) of the missed cracks and a misinterpretation of a leak path indication
- Industry formed a focus group to perform an assessment of these issues and determine appropriate actions to improve the NDE reliability for RVUH volumetric examination

Focus Group Findings (1/2)

- Vendor RCA report identified the penetration configuration (thickness and amount of surface distortion in the weld region) as unique to this specific head and not generic to the industry
- EPRI identified unintended changes to the qualified examination procedure essential variables as potentially impacting the capabilities of the procedure
  - Changes were made to address lessons learned from performing examinations
  - Redemonstrations of the procedures, with the changes, indicated that the procedures still met the qualification requirements
- Determined that the existing qualification program and mockups are acceptable

Focus Group Findings (2/2)

- Identified several areas for improvement and provided guidance to strengthen the examination process
  - Control of qualified examination procedures
  - Procedure enhancements for data analysis process
    - Proper focus on areas of less than optimal surface contact between the UT probe and examination surface (recognizing and dispositioning)
    - Proper interrogation of the entire examination volume for potential cracking (ID and OD surfaces)
    - Leak path assessment for newly formed leaks
  - Oversight process
  - Use of site specific mockups
  - Pre-job briefing process
  - Site training of the data analysts
  - Comparison of examination data to previous examination results
  - Independent review of the examination data

Industry Guidance

- Guidance was developed to address the identified areas for improvement to the examination process
  - Guideline for Nondestructive Examination of Reactor Vessel Upper Head Penetrations, MRP-384 Revision 1 (3002017288)
  - Issued December 2019; publicly available report

- Includes five NEI 03-08 elements
  - Four "Needed" and one "Good Practice"
    - Needed – to be implemented wherever possible, but alternative approaches are acceptable
    - Good Practice – implementation is expected to provide significant operational and reliability benefits, but the extent of use is at the discretion of the individual utility
  - 60 day implementation of the guidance

NEI 03-08 Elements

Table from the report

Detailed in following slides

Item	Implementation Category	NEI 03-08 Requirement
1	Needed	The utility shall develop and implement an RVUH examination oversight process in accordance with the requirements in Section 4.
2	Needed	Oversight personnel and examination vendor data analysts shall receive training in accordance with the requirements of Sections 5.1 and 5.2.
3	Good Practice	The utility should develop a process that provides a work environment that minimizes distractions for the data acquisition and analysis personnel in accordance with Section 6.2.1.
4	Needed	The utility shall require independent analysis of the NDE data by at least two data analysts working separately and independently in accordance with the requirements of Section 6.2.2.
5	Needed	RVUH examination data shall be evaluated by comparing the current outage examination data to past examination data in accordance with the requirements of Section 6.2.3.

Item #1 – Needed

The utility shall develop and implement an RVUH examination oversight process in accordance with the requirements in Section 4

1. Review and acceptance of vendor examination procedures, procedure qualifications, and limitations as they apply to the site's configuration(s), technical justifications (TJ), NDE written practices, and personnel qualifications (Section 4.4)
2. Verification of the need and use of site-specific mockups (unique configurations, demonstrations, training, etc.), as required (Section 4.2)
3. Verification that access to previous examination data is available (Section 4.3)
4. Verification that the training for oversight and vendor data analyst personnel is performed (Section 5)
5. Performance of pre- and post-job briefings (Sections 6.1 and 6.4)
6. Verification that the independent analysis process has been implemented (Section 6.2.2)
7. Review of the data comparison process for current and previous data (Section 6.2.3)
8. Review of equipment calibrations for procedure compliance
9. Review of examination data for quality and procedure compliance
10. Review of examination reports for procedure compliance
11. Review of any recorded relevant indication and coverage limitations for concurrence and needed actions

Item #2 – Needed (1/2)

Oversight personnel and examination vendor data analysts shall receive training in accordance with the requirements of Sections 5.1 and 5.2

Section 5.1 Oversight Personnel (minimum of 8 hours)

1. Examination procedure scope, limitations, and requirements
2. Examination techniques
3. Data analysis software
4. Data analysis process
5. Fabrication and geometrical indications, repair indications, and flaw indications
6. Signal response characteristics
7. Techniques for resolving and sizing flaws
8. Documentation of the examination results (e.g. calibration, indications, lack of coverage, etc.)

Item #2 – Needed (2/2)

Oversight personnel and examination vendor data analysts shall receive training in accordance with the requirements of Sections 5.1 and 5.2

Section 5.2 Site Specific – (at least 6 hours)

1. Site examination scope of work
2. Procedure requirements and applicable technical justifications
3. Plant-specific review of component and examination history
4. Lessons learned from previous examinations
5. Repair history, geometry, previous indications
6. Coverage, access restriction issues, or other factors that could impact the examination
7. Industry and site-specific operational experience
8. PWSCC flaw signal responses from field data
9. Fabrication reflector signal responses from field data
10. Leak path responses from field data
11. Plant-specific mockup data, where applicable
12. Data quality expectations

Item #3 – Good Practice

The utility should develop a process that provides a work environment that minimizes distractions for the data acquisition and analysis personnel in accordance with Section 6.2.1

- Utilities should provide an area free of distractions by limiting access to the area, limiting office phones, minimizing interruptions, and minimizing other inappropriate interventions. Room temperature, background noise, music, conversation, ventilation, table heights, chairs, and lighting can all affect performance to some degree.

Item #4 – Needed (1/3)

The utility shall require independent analysis of the NDE data by at least two data analysts working separately and independently in accordance with the requirements of Section 6.2.2

- Analysts evaluate data for many penetration tubes over a short period of time
- Each data file requires the analyst to process many decisions and assessments such as:
  - Data quality
  - Examination parameters used for data collection
  - Examination coverage
  - Indication evaluation
  - Comparison with previous data
  - Recording of examination results
- Analysts have a high potential for cognitive overload based on:
  - Number of examination angles
  - Amount of surface distortion or other surface anomalies
  - Number of fabrication indications
  - Number of rescans
  - Number of previous examination files being compared
  - Number of indications being recorded
  - Working long hours

Item #4 – Needed (2/3)

The utility shall require independent analysis of the NDE data by at least two data analysts working separately and independently in accordance with the requirements of Section 6.2.2

- The utility shall require independent analysis of the electronic UT data by at least two qualified data analysts, consisting of a primary and a secondary review
- An independent analysis is defined as an analysis performed separately, without the knowledge of the other analysis results, and not as a joint effort
- Communication between primary and secondary analysts should be prohibited prior to completion of analysis of a penetration tube
- Consideration should be given to ensuring that data analysts are working in an environment conducive to independent analysis, such as physically separate areas

Item #4 – Needed (3/3)

The utility shall require independent analysis of the NDE data by at least two data analysts working separately and independently in accordance with the requirements of Section 6.2.2

- The secondary analysis is intended to focus on the verification of data quality, examination coverage, and the detection of PWSCC
- Each analyst's results for each RVUH penetration tube examination are to be documented independently
- Discrepancies between the primary and secondary analysis shall be reviewed and resolved
- All the results of the analyses and any discrepancy resolutions shall be documented and included in the final report

Item #5 – Needed

RVUH examination data shall be evaluated by comparing the current outage examination data to past examination data in accordance with the requirements of Section 6.2.3

- Comparison of examination data to past data is an integral part of the data analysis process
  - When past electronic examination data is available, current examination data shall be compared to previous data
- Select comparative data set consisting of an examination technique that is similar with the current technique
- Comparison of non-sequential outage UT data is recommended
- Comparison of data focuses on:
  - Changes in UT responses from previous data
  - New indications that have not been recorded previously
  - Changes in existing indication size and/or signal amplitude
  - Coverage changes

Summary

- Recent RVUH UT OE issues were determined to be site specific and not generic to all heads
- The existing UT qualification program and mockups have been evaluated as effective and acceptable
- A critical evaluation of the recent OE was performed and identified opportunities for improvements to the examination process
- Guidance addresses important steps in the examination process in order to provide a reliable examination, regardless of penetration material or examination interval
- Guidance provides sufficient level of detail to ensure new program owners and less experienced examiners can understand the key steps in performing a reliable RVUH volumetric examination
- This OE has no impact on proceeding with the Supplement 15 Code actions
- Code actions should be pursued to better define the procedure essential variables in Appendix VIII, allowing procedure changes to reflect ongoing OE without forcing unnecessary procedure requalifications

Together…Shaping the Future of Electricity

Update on MRP-60

ELECTRIC POWER
RESEARCH INSTITUTE

Visual Examination for Leakage of PWR Reactor Vessel Upper Head Nozzles

Kevin Hacker
Dominion Energy

Robert Grizzi
EPRI

NRC/Industry NDE Technical Information
Exchange Meeting
January 2020

Outline

- Background
- Code Case N-729-4 visual examination (VE) Requirements
- Recent RVUH Penetration VE OE
- MRP-60 Update
- MRP-60 Evaluation Process Guidance
- Summary

Background

- MRP report on VE for leakage of PWR reactor vessel upper head (RVUH) penetrations was initially developed in the early 2000's
- Objectives:
  - Capture OE of leakage identified on top of the RVUH
  - Provide guidance for utilities and examiners for performing VE
  - Increase examiner awareness of the appearance of penetration leakage
- Contained:
  - Lessons learned for evaluating penetration leakage – light cleaning such as vacuuming or controlled compressed air (40-60 psi) to determine if deposit is tightly adhering
  - Images of penetration leakage
- Head leakage from the highly susceptible heads was easy to identify
- Report periodically updated to capture ongoing OE and leakage images

Images of Highly Susceptible Head Leakage (Early 2000's)

Code Case N-729-4 VE Requirements

- -3141 (c) defines VE relevant conditions as evidence of reactor coolant leakage, such as corrosion, boric acid deposits, and discoloration
- -3142.1 (b)(1) requires relevant conditions to be further evaluated to determine the source of the leakage and correction of the source of leakage
- -3142.1 (b)(2) requires:
  - relevant conditions to be evaluated to determine the extent, if any, of degradation
  - boric acid crystals and residue to be removed to the extent necessary to allow adequate examinations and evaluation of degradation
  - a subsequent VE of the previously obscured surfaces prior to return to service
  - a VE of the previously obscured surfaces in the subsequent refueling outage
- -3142.1(c) A nozzle whose VE indicates relevant conditions indicative of possible nozzle leakage shall be unacceptable for continued service unless it meets the requirements of -3142.2 or -3142.

Recent RVUH Penetration VE OE

- Most highly susceptible heads have been replaced
- Recent RVUH visual examinations have resulted in relevant conditions being identified that are not related to head penetration leakage due to cracking
- These conditions need to be properly evaluated to avoid unnecessary repair or supplemental actions

Examples of Recent Relevant Conditions not Associated with Penetration Leakage

White debris masking the penetration annulus

Surface staining

MRP- 60 Update

- The MRP report for the VE for Leakage of PWR reactor RVUH penetrations has been revised in 2018
  - Contains a section that focuses on recent visual examinations (2014 – 2018)
    - Includes images and examination results of recent relevant conditions of penetration leakage and non-penetration leakage
  - Contains sections that includes images and examination results of examinations performed prior to 2014
  - Captures lessons learned on the characteristics of boric acid deposits resulting from head penetration leaks and methods for determining the source of the leakage
  - Provides an evaluation process for guidance to assist in the evaluation of the relevant conditions being identified
- MRP-60 Rev 5, "Visual Examination for Leakage of PWR Reactor Vessel Upper Head Nozzles", 3002013268
  - Does not contain an NEI 03-08 implementation element

MRP-60 Evaluation Process Guidance

- Guidance is provided to assist utilities with the evaluation of VE results
- Perform initial bare metal visual (BMV) examination
  - Review history of spillage and leaks from maintenance and refueling activities
  - View down into annulus around each penetration
  - When relevant conditions are identified in or around the penetration annulus, view the penetration above the annulus to identify any potential source of leakage from above
  - Review previous examination results
  - Record relevant conditions

MRP-60 Evaluation Process Guidance (continued)

- Use VE data to distinguish between relevant and non-relevant conditions
  - Relevant conditions
    - Evidence of reactor coolant leakage such as corrosion, boric acid deposits, and discoloration
      - Tightly adhering boric acid, glossy appearance, spaghetti shaped, ball shaped
      - Evidence of possible reactor coolant leakage such as streaking, spray patterns, light residue over an area
  - Non-relevant conditions such as debris, insulation, foreign materials

MRP-60 Evaluation Process Guidance (continued)

- Relevant Condition Evaluation
  - Obtain chemical and radiological samples if sufficient material is present (MRP-372 Appendix A, "Sampling and Analysis Guidance for Deposits Found on Reactor Pressure Vessels at Various Locations" is a useful reference)
  - Perform light cleaning such as vacuuming or controlled compressed air (40-60 psi) to determine if deposit is tightly adhering
  - Review previous examination results for comparison to current examination results
  - Perform volumetric or surface examinations, if needed
  - Evaluate the relevant condition to determine the source of leakage and correct the source of leakage
    - Conditions not indicative of possible nozzle leakage are acceptable if corrected by repair/replacement activity or by corrective measures necessary to preclude degradation

MRP-60 Evaluation Process Guidance (continued)

- Documentation
  - It is recommended to document the examination results via photos of the nozzle in the as-left condition, particularly when conditions are evaluated for comparison to subsequent examinations

Summary

- Many of the recently identified relevant conditions identified with the VE are not related to penetration leakage and need to be properly evaluated
- MRP-60, Revision 5 provides a good source of VE OE to prepare examiners for examinations by increasing their awareness of relevant conditions and images of relevant conditions
- Relevant conditions need to be properly evaluated to avoid unnecessary repair or supplemental actions
- MRP-60, Revision 5 provides guidance to assist utilities with the evaluation of VE results
  - Does not contain an NEI 03-08 implementation element
- 2019 RVUH VE OE will be evaluated to determine whether MRP-60 should be updated to address it

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Update on RV UT procedure change OE

Carl Latiolais
Senior Program Manager
NDE Reliability

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Overview

- Issues Related to Reactor Upper Head Penetration Procedures
- Issues Related to Reactor Pressure Vessel Procedure

Issues Related to Reactor Upper Head Penetration Procedures

Issues Related to Reactor Upper Head Penetration Procedures

- Issue 1
  - In 2018 a vendor was in the process of expanding diameter ranges and it was noted that the procedures had been revised several times since the last PDQS was issued
    - Open Housing Procedure
      - Last PDQS Revision 5
      - Current Revision 20
    - Blade Probe Procedure
      - Last PDQS Revision 3
      - Current Revision 15

Direction/ Type	Data Interval	Maximum Velocity
Axial Scan /Comb/Raster	0.04” (1 mm)	2.5 inches/sec
Circumferential Interval	2° (Comb) or 1° (Raster)	40 °/sec

Direction/ Type	Data Interval	Maximum Velocity
Axial Scan /Comb/Raster	0.04” (1 mm)	2.5 inches/sec
Circumferential Interval (Calibration/Inspection)	2° Raster or Comb	40°/sec
Circumferential Interval (Inspection)	1° Raster (analyzing odd or even sweeps) or 2° Comb	40°/sec

Issues Related to Reactor Upper Head Penetration Procedures

- Issue 1 (continued)
  - EPRI performed a reconciliation between the various revisions to determine if changes to essential variables were made
  - During review it was noted that a change to the demonstrated scan pattern was made to the open housing procedure
    - Unidirectional to bi-directional (comb and raster)
  - VIII -2100 (d)(4) considers scan pattern to be a essential variable
- Attempts to qualify change were unsuccessful
  - Vendor was notified and they performed a detailed evaluation and it was determined that the unqualified scan pattern was never used to perform and examinations

Issues Related to Reactor Upper Head Penetration Procedures (continued)

- Issue 2
  - While evaluating data from previous examinations EPRI noted that the procedures had been revised several times since the last issuance of a PDQS
    - Open Housing Procedure
      - Last PDQS Revision 11
      - Current Revision 13
    - Blade Probe Procedure
      - Last PDQS Revision 5
      - Current Revision 10
  - EPRI performed a reconciliation between the various revisions to determine if changes to essential variables were made
  - As a result of the procedure reviews, it was determined that three (3) changes of potential significance on essential variables would require demonstration for the open housing procedure and eight (8) changes of potential significance on essential variables would require demonstration for the blade probe procedure

Issues Related to Reactor Upper Head Penetration Procedures (continued)

- Issue 2 (continued)
  - All changes were related to the processes used for data analysis
    - VIII-2100 (d)(9) considers the method and criteria for the discrimination of indications (e.g., geometric versus flaw indications and for length and depth sizing of flaws) to be an essential variable
  - Additionally, it was determined that the calibration verification sections of these procedures had undergone significant changes
    - It was not possible to fully demonstrate the calibration verification processes defined within the procedures during the qualification; however, ASME Section XI, Appendix VIII, 2100(c) [1] states:
      - *"Any calibration method may be used provided is it described and complies with VIII-2100(d)(5)".* VIII-2100(d)(5) states, "*methods of calibration for detection and sizing (e.g., actions required to ensure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeated from examination to examination).*"

Issues Related to Reactor Upper Head Penetration Procedures (continued)

- Actions
  - A detailed test plan was developed and additional qualifications were performed using the modified criteria and the vendor successfully demonstrated that the changes had no effect on the results of the examination
  - The vendor has developed a technical basis to show that the changes in the calibration verification processes defined in the procedures did not have an effect on the examination
    - This technical basis has not been reviewed by EPRI
  - EPRI is awaiting revised procedures and once approved will issue new PDQS documents

Issues Related to Reactor Pressure Vessel Procedure

Issues Related to Reactor Pressure Vessel Procedure

- A vendor's procedure was qualified in February 2001 and satisfied the requirements of Appendix VIII, Supplements 4 and 6
  - Supplement 4 - Qualification Requirements for the Clad/Base Metal Interface (Inner 15%)
  - Supplement 6 – Qualification Requirements for Reactor Pressure Vessel Welds Other than the Clad Base Metal Interface (Outer 85%)
- Procedure was designed for the examination of reactor pressure vessel welds from the inside surface

Issues Related to Reactor Pressure Vessel Procedure (continued)

- Supplement 6 requires that the specimen set contain at least one sample that is at least 90% of the maximum thickness to be examined and have a distribution of flaws sizes at varying depths as denoted in table VIII-S6-1
- There is no requirement to demonstrate the minimum thickness

Supplement 6 APPENDIX VIII — MANDATORY Supplement 7

* TABLE VIII-S6-1
DETECTION AND SIZING TEST FLAWS AND LOCATIONS

Flaw Location	Flaw Through-Wall Dimension, in. (mm)				
	0.075–0.200 (1.91–5.08)	0.201–0.350 (5.09–8.89)	0.351–0.550 (8.90–13.97)	0.551–0.750 (13.98–19.05)	0.751–2.00 (19.06–50.8)
Inner 10% [Note (1)]	X	X	S	S	...
Outer 10%	X	X	S	S	...
11–30% *T*	...	...	X	X	S
31–60% *T*	...	...	X	X	S
61–89% *T*	...	...	X	X	S

NOTE:
(1) Does not apply to clad vessels (see Supplement 4).

LEGEND:
X applies to detection and sizing flaws.
S applies only to sizing flaws.
T, thickness of the thickest specimen in the specimen set.

*American Society of Mechanical Engineers (ASME) Section XI, Appendix VIII, Supplement 6 (2001 Edition)

Issues Related to Reactor Pressure Vessel Procedure (continued)

- The procedure was demonstrated on a mock-up that was 11.07” thick
  - Techniques were designed for this thickness and absolute values were used to define the depth of holes used for establishing sensitivity
    - Probe A – Designated for inside surface up to 2.5”
      - Hole used for sensitivity 1/16” diameter side drilled hole (SDH) at a depth of 0.50” from inside surface
    - Probe B – Designated for depths of 2.5” to 0.6t (6.6”)
      - Hole used for sensitivity 3/16” diameter side drilled hole (SDH) at a depth of 6.0” from inside surface
    - Probe C – Designated for depths of 0.6t (6.6”) to t (11.07”)
      - Hole used for sensitivity 3/16” diameter side drilled hole (SDH) at a depth of 10.0” from inside surface

Issues Related to Reactor Pressure Vessel Procedure (continued)

- Issue Identified
  - After qualification, the vendor has examined a number of vessels, including BWR shell plate and PWR lower heads, having wall thicknesses in the range of 5.0” to 8.0”
  - As qualified, the procedure calibration method for Probe C (3/16”SDH hole at 10.0”depth) resulted in an overly sensitive examination of the thinner shell sections
    - Saturated Data - Not possible to satisfy the image quality requirements defined in the procedure

Issues Related to Reactor Pressure Vessel Procedure (continued)

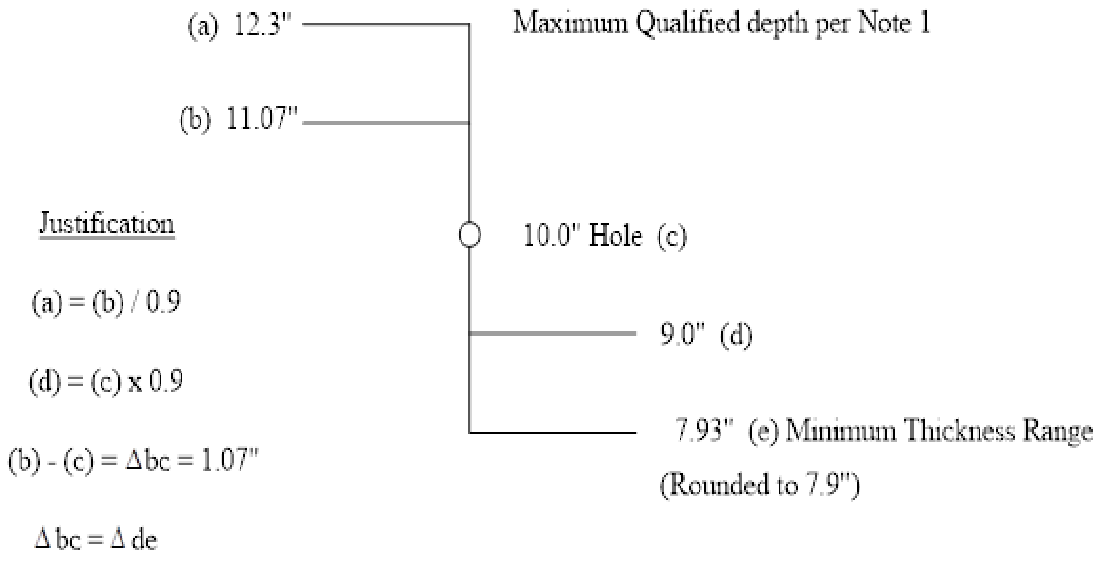
- Vendor Actions
  - The vendor initiated a field change/revision that allowed the use of a 6.0"deep 3/16" diameter SDH in lieu of the 10.0" deep SDH for examinations performed on shell segments less than 7.9" in thickness when using Probe C
  - *The vendor developed a technical basis document that included the following;
    - A general position that the changes did not represent a compromise in the qualified essential parameters
    - An explanation of the rationale for the examination depth ranges applicable to the 6.0 "deep reference reflector and the 10.0 "deep reference reflector

*Vendor document titled " Vendor Technical Basis for Revision 7 of Procedure PDI-ISI-254" dated February 14, 2005

Issues Related to Reactor Pressure Vessel Procedure (continued)

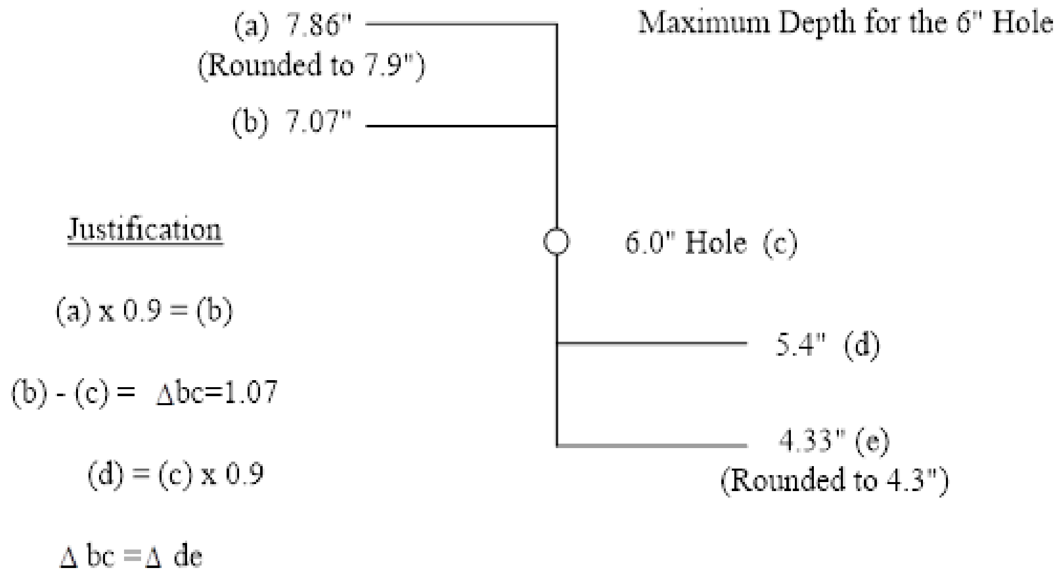
- Rationale for Change*

Examination Range of the 10.0" Deep Calibration Reflector



Note 1: Reference Section XI, Appendix VIII, Supplement 6 par 1.1(b)

Examination Range of the 6.0" Deep Calibration Reflector



Note 1: Reference Section XI, Appendix VIII, Supplement 6 par 1.1(b)

*Vendor document titled " Vendor Technical Basis for Revision 7 of Procedure PDI-ISI-254" dated February 14,2005

Issues Related to Reactor Pressure Vessel Procedure (continued)

- Vendor Conclusion*
  - The minimum and maximum test ranges are calculated by taking into account the Code maximum qualification thickness, qualification specimen thickness and the position of the reference reflectors related to those values
  - The changes represent a logical interpolation of qualified values and not an extension or expansion of previously qualified values

*Vendor document titled “ Vendor Technical Basis for Revision 7 of Procedure PDI-ISI-254” dated February 14,2005

Issues Related to Reactor Pressure Vessel Procedure (continued)

- EPRI Review
  - In February of 2005 the vendor submitted a the technical basis to EPRI for review
  - The EPRI review concluded that, while not specifically identified at the time of qualification the sensitivity process defined in the new revision (Revision 7) of the procedure was actually demonstrated during the original Revision 4 qualification EPRI issued a letter documenting this review and the revised procedure has been used since then, with no questions asked

Basis for Conclusion

Randy T. Linden
Committee Chairman
PPL, Susquehanna, LLC

Gary Lofthus
Committee Vice-Chairman
Southern Nuclear Co.

Dave Anthony
Quality Assurance
AmerGen

PDI
PERFORMANCE DEMONSTRATION INITIATIVE

Bill Jens
Fina
Nuclear Management Company (NM

Frank Leon
Program Operations — R
Tennessee Valley Autho

Richard Ful
Program Operations — Piping/Bolt
Dominion Nuclear Connecti

February 14, 2005

Subject: Review of Ultrasonic Examination Procedure PDI-ISI-254 Rev. 7

To Whom It May Concern:

The subject procedure was reviewed to determine if the process described in Revision 7 to determine shear wave examination sensitivity changed the essential variable originally qualified with Revision 4.

In revision 4, sensitivity was defined by an absolute value; i.e., a side-drilled hole at a depth (D) of 10 inches. In revision 7, sensitivity is redefined based on a process that takes into consideration the component thickness; i.e., (D + 1.07")/0.9 for the upper limit and (D - 1.07")(0.9) for the lower limit.

Though not specifically identified at the time, the sensitivity process defined in revision 7 was demonstrated during the original revision 4 qualification. Therefore, the changes made to the procedure do not affect any of the essential variables which have been demonstrated. The procedures are considered equivalent and the comments noted on the revision 4 PDQS still apply.

Issues Related to Reactor Pressure Vessel Procedure (continued)

- NRC Concern
  - During a recent inspection an NRC inspector reviewed the changes made to procedure since the last issuance of a Performance Demonstration Qualification Summary (PDQS)
  - He noted the change in the calibration section of the procedure and interpreted this change to be an alternative to what was originally demonstrated and that the rules defined in Appendix VIII-4300 should have been applied
  - If this interpretation is correct, the changes made to the procedure in 2005 would not be able to satisfy these requirements (-2 dB) and the procedure would require requalification

- *** VIII-4300 CALIBRATION METHODS**
- Alternative calibration **methods** may be demonstrated equivalent to those described in the qualified procedure without requalification. This demonstration of equivalence shall be conducted for each beam angle and mode of propagation to which it applies, as follows.
- *(a)* Calibrate the examination system in accordance with the alternative methods.
- *(b)* Compare the sensitivity of the alternative calibration method to that of the qualified calibration method.
- ***(c)* The alternative calibration method is acceptable when the system sensitivity is no more than 2 dB below that obtained by the qualified method.**

*Reference: American Society of Mechanical Engineers (ASME) Section XI, Appendix VIII, Supplement 6 2001 Edition

Issues Related to Reactor Pressure Vessel Procedure (continued)

- Potential Impact
  - Since 2005 the vendor has performed numerous examinations in both PWR and BWR units
    - Compliance Issue
  - Preliminary technical review of the changes indicated that there should be little to no impact on the procedures capability, thus no impact on safety, but it was decided to continue with a formal demonstration process to confirm this evaluation and to document compliance

Issues Related to Reactor Pressure Vessel Procedure (continued)

- Vendor Actions
  - Initiated a CAR
  - The vendor successfully performed a Supplement 6 qualification on the EPRI 161 series samples (6.88” thick, with an Appendix VIII field applicable thickness of 7.64”) and the EPRI 162 series sample (7.89" thick with an Appendix VIII field applicable thickness of 8.77”) with the probe sensitivity established utilizing the modified process that requires use of the 6.0” SDH
  - New PDQS has been issued

- EPRI Actions
  - Initiated a CAR
  - Provided technical support to licensee to the extent possible
  - Exercised the common “Operating Experience and Emergent Issues Protocol”
    - Informed NDE, MRP and BWRVIP RIC’s
    - Informed MAPC
  - Issuing letter to all owners of procedures (NDE 20191126-002)
    - Share OE
    - Provide recommendations
    - Request status of current procedures

Summary

- In the past year and a half there have been three instances noted where revisions to previously qualified procedures resulted in the change of essential variables and these changes were not requalified. The changes including the following:
  - The required scan pattern was inadvertently changed
  - Changes were made to the criteria used for discrimination of indications
  - Methods of calibration for detection and sizing (e.g., actions required to ensure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system are repeated from examination to examination)
- The changes above were not discovered until several examinations had been performed with the revised procedures
- In Case 1 it was determined that the unqualified scan pattern was not used to perform examinations, but in Cases 2 and 3 additional qualifications (post examination) were required to assure that the changes did not have an effect on the examinations performed
- In all cases significant resources were expended to address these issues and there was a potential, if requalification was not possible, that the examinations would have had to be repeated at significant cost and (potentially) dose
- In all cases these changes placed the affected utilities in a non-compliant position, until such time the issues were resolved

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NDE for Advanced Manufacturing

Discussion notes

Background slides – industry roadmap

-

Closing the day

Public comment period

End-of-day announcements

- Thursday session begins 8:00

Wednesday

Announcements

Update on virtual mockups and eFlaws

J. Leif Esp
Principal Project Manager

NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Helpful Definitions

- What is a Virtual Mockup?
  - A mockup that is made up of components and flaws sourced from real mockups or created in a computer model – simply put it's a mockup that only exists in a data file on a computer – it is not real.
- 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 for a Virtual Mockup.
- What is a Synthetic Flaw?
  - It is a flaw that is sourced from a computer model or other modeling source – this is a flaw that has never existed in a real mockup and it gets placed into a Virtual Mockup.

Past Work

- Project work performed in the past
  - *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
    - Report detailing results of last 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 dissimilar metal weld 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.* EPRI, Palo Alto, CA: 2017. 3002010539

TOFD CRDM Data Work

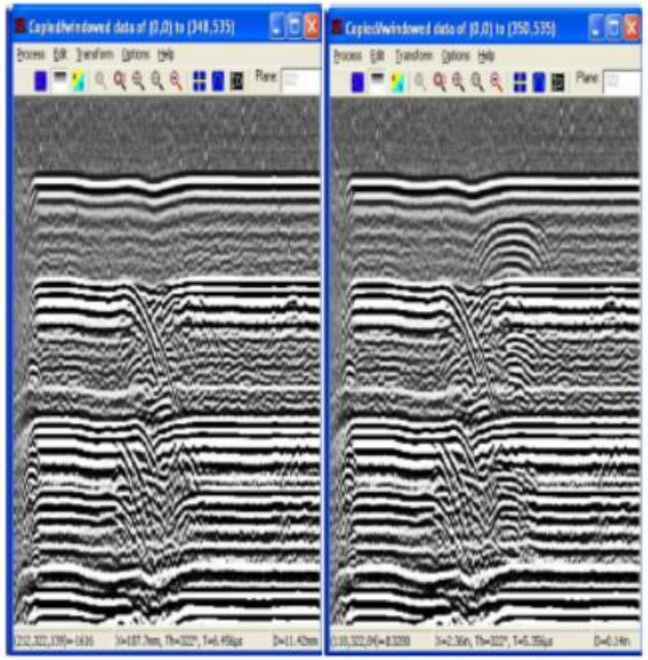


Figure 3-12
Flaw 4 Before and After Insertion (B-scan view)

Conventional UT Data Austenitic Piping Welds

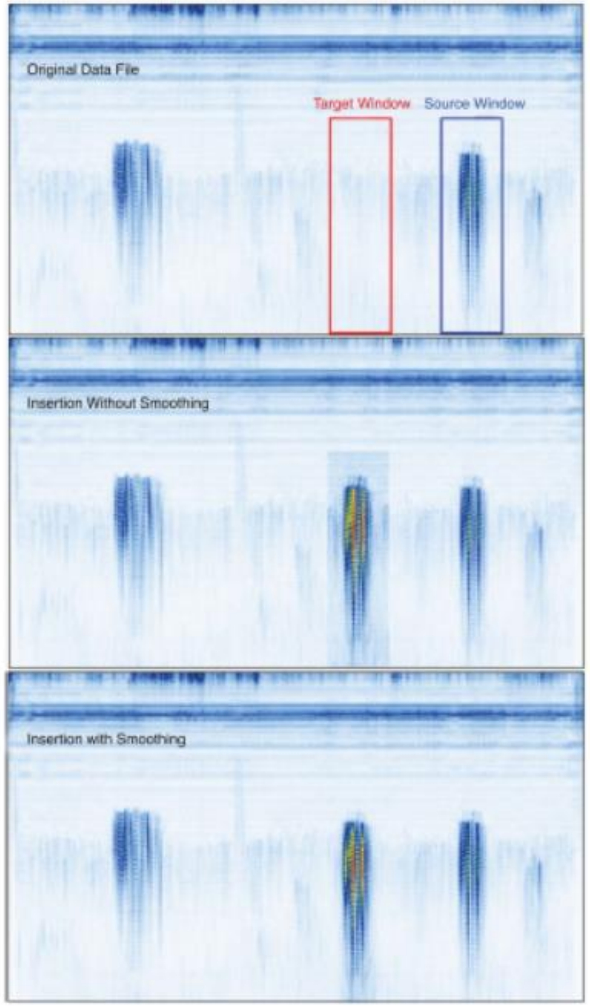


Figure 2-6
Effect of Smoothing

Phased Array UT Data Dissimilar Metal Welds

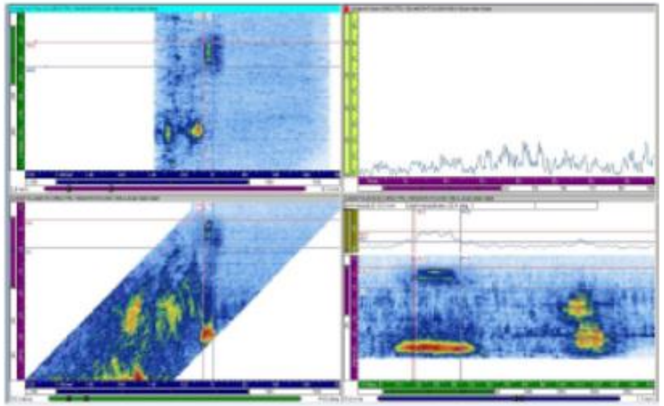


Figure 5-6
70° Longitudinal Wave Ultrasonic Data Images from Sample 705-8VF for Lack of Fusion Flaw 705-8-03VF(A)

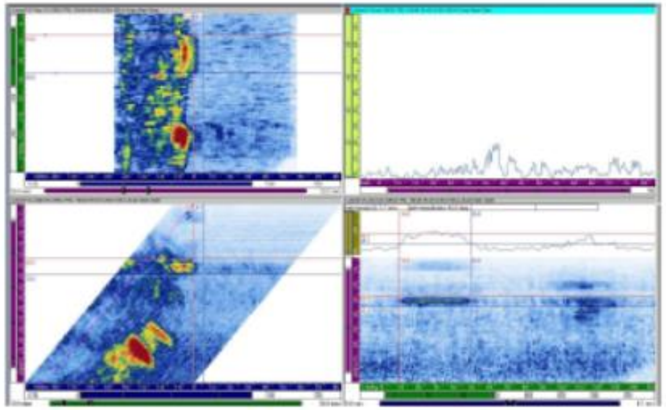


Figure 5-7
45° Longitudinal Wave Ultrasonic Data Images from Sample 705-8VF for Incomplete Penetration Defect 705-8-03VF(B)

Past Virtual Flaw Activity in the Domestic Industry

- Two virtual samples have been created that could be provided to vendors for review and comment.
  - Mockups were provided by Dominion; one pipe to pipe, one pipe to elbow
  - Requested output was two pipe to pipe mockups with a variety of flaws from the current inventory
    - Pipe to pipe mockup
      - Creation of the mockup was straight forward
    - Pipe to elbow mockup
      - Flaws on the elbow side proved to be challenging when importing them into a pipe to pipe configuration, depending on geometry and on flaw location within the mockup
  - Data analysts were unable to distinguish the virtual mockups from other physical mockups
  - Take away – creating virtual samples using flaws from similar mockups is straight forward, changes in geometry between the source mockup and the final mockup can cause challenges but is possible (may not be cost effective)

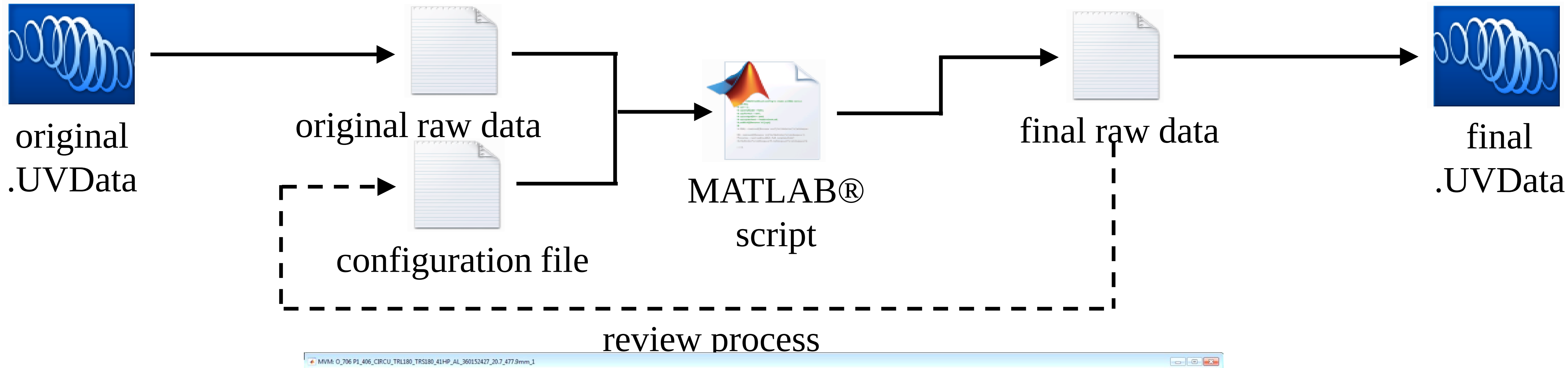
Recent Advancements in the Virtual Flaw Creation Process

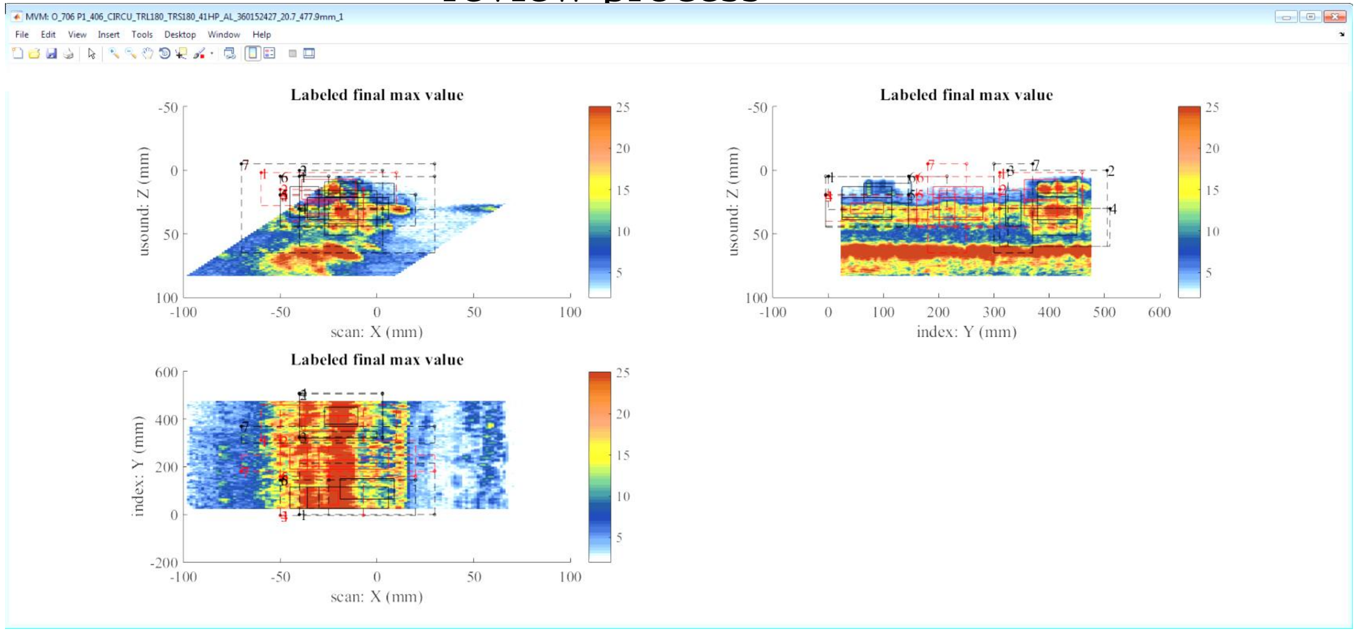
- Limitations previously existed around the metadata located in the data files. Once the files were modified much of the metadata was removed through the process (e.g. Ultrasound Settings, Mechanical Settings, Specimen Settings, and Advanced PA Calculator settings would lack data or contain default data unrelated to how the data was actually collected). This has now been fixed in the process and all relevant metadata now fully transfers to the new files when a virtual data set is developed.
- The source and target windows have been updated to allow for shapes with slanted edges or other irregular shapes.
  - The new allowance for shapes with slanted edges allows for the orienting of the source and target windows along given beam directions instead of the previously defined regular shapes in Cartesian axes.
- Transformations can now be adjusted on a beam-by-beam basis.
  - This allows the virtual mockup creation process to take into account the different wave modes and/or inspection angles interacting with defects differently.

Recent Advancements in the Virtual Flaw Creation Process

- Development work in the area of providing an adequate stretching operation, desired to more easily elongate or shrink flaw signals, is in-process and many improvement have been made.
  - It is becoming easier to obtain exactly the desired flaw length and height dimensions through the improved process.
  - The next step for this process is to provide these altered flaws to subject matter experts to determine if any unintentional secondary effects are identifiable during the data analysis process.
- Proof of principle studies around flaw creation have been completed.
  - This allows us to source flaws from ultrasonic flaw response simulations instead of relying exclusively on data sources from existing data files / mockups.
  - Next logical step for this effort will be to provide these simulated flaws to subject matter experts to determine if any unintentional secondary defects are identifiable during the data analysis process.

How are virtual flaw samples sourced from existing data made?





Where are we and where are we going?

- Current Capabilities
  - Mockup creation – manufacture mockup with a set of flaws
    - Limitless new mockups can be created using the data from one or two 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 all flaws required for testing are represented in flawed mockups
      - Utilizing these 2 or 3 mockups, as many mockups as needed could potentially be built (virtually)
      - Downside – must create new set of virtual mockups for each procedure / technique

Where are we and where are we going?

- Stretch Goal
  - Mockup creation – manufacture blank mockup (no flaws)
    - Consistent weld properties / geometry / materials
  - Create flaws in modeling software and import into data from blank mockup
    - Proof of concept points to plausibility and cost effectiveness – see following slides
- Ultimate Goal
  - Mockup creation from nothing
  - Does not seem plausible nor cost effective at this time

Creation of synthetic flaws for virtual mockups

- Note:
  - A synthetic flaw is constructed analytically
  - A virtual flaw is appropriated from an existing flaw

- The idea:
  - Import a synthetic flaw from NDE simulation software (e.g. CIVA™) into a UT data file
  - Demonstrate that it can be blended with an existing UT data file being used as a template

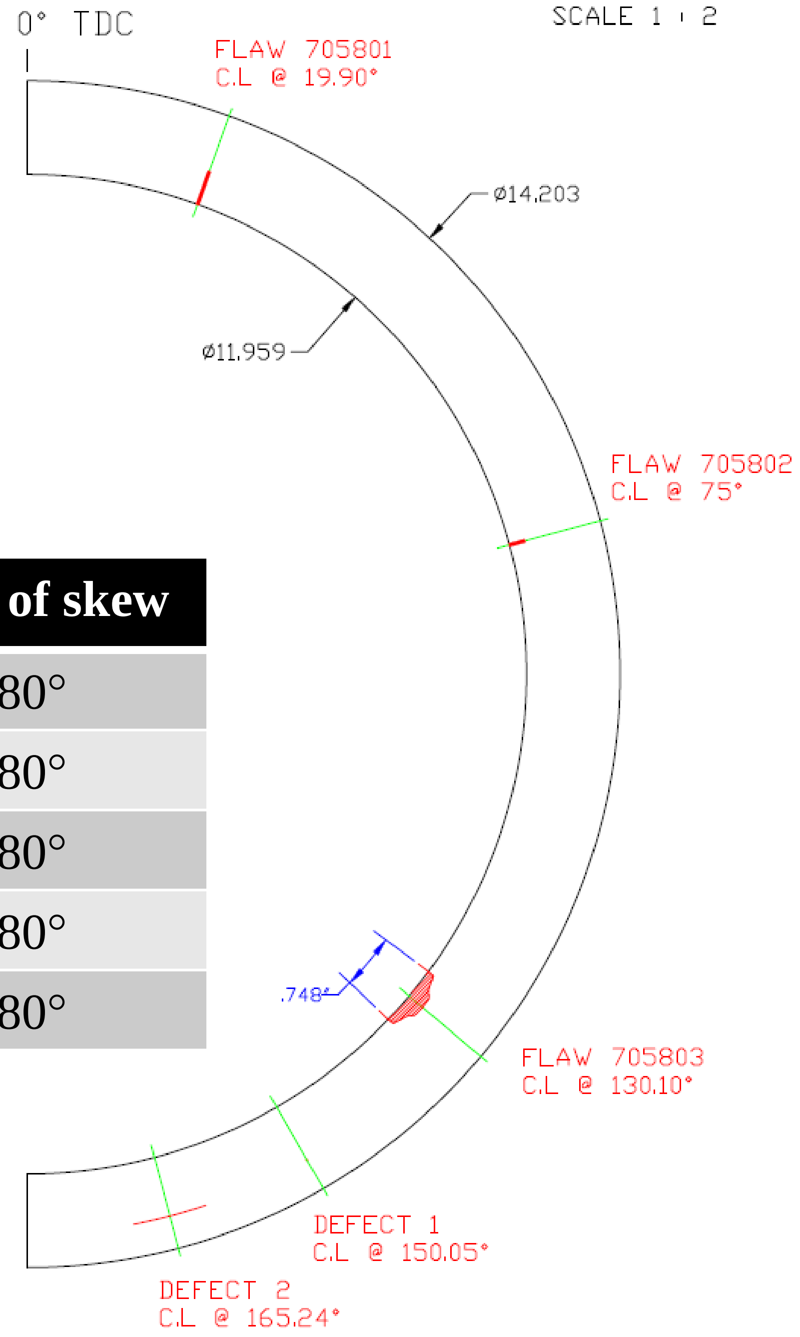
- Motivation:
  - NDE Modeling Software currently in use (CIVA™) is familiar to many, and simple to use
  - The modeler has complete control over the number, type and orientation of simulated defects
  - It is quicker and cheaper to use a simulation software to generate a desired type of flaw than to build a physical mockup

Synthetic Flaw Test (1/5)

- Identify the UltraVision template file and build the CIVA™ model to match the template structure
  - In this example, UltraVision template file is a circumferential scan of OP705
  - One circumferential flaw at 130°: 705803
- File structure:

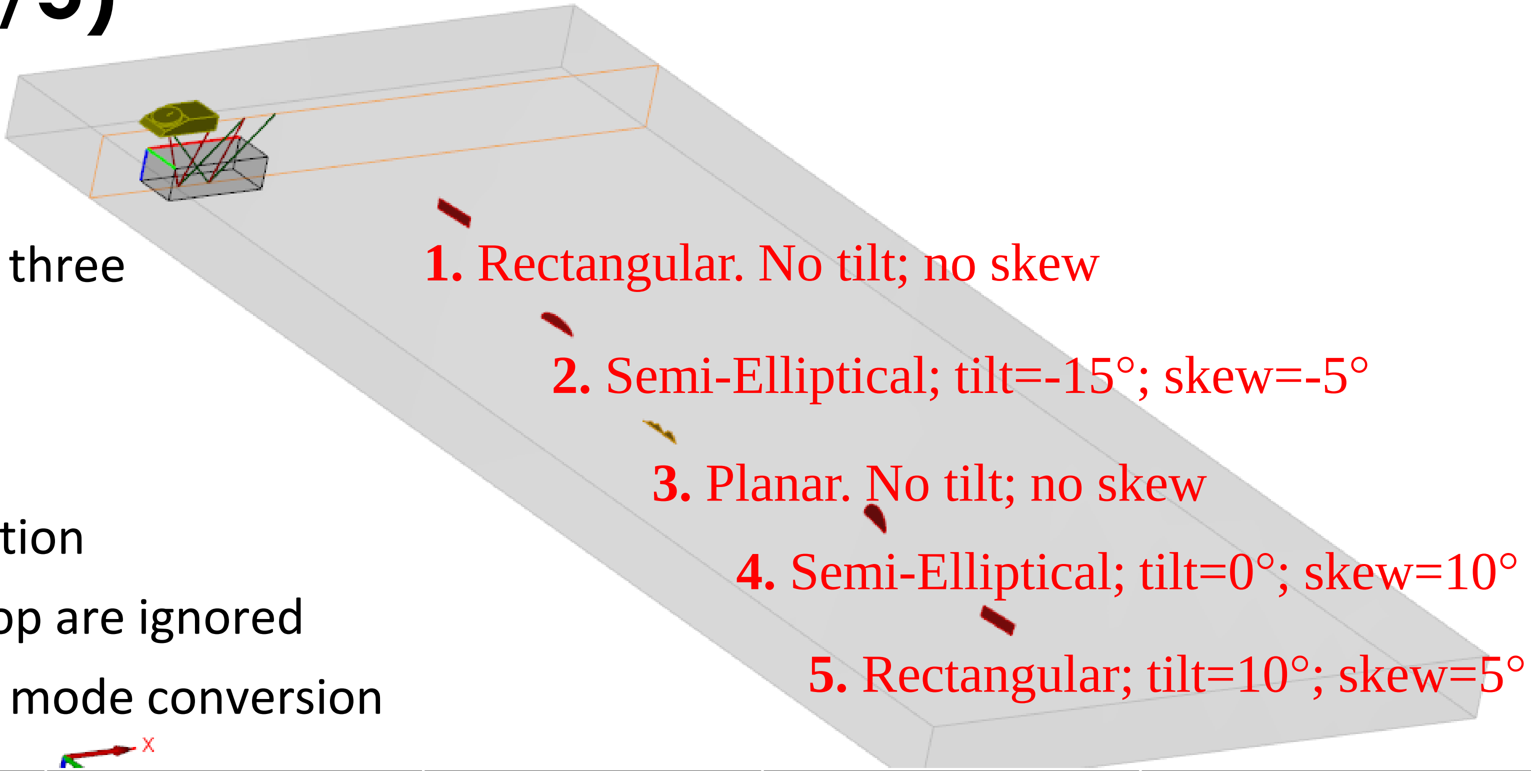
Channel	Mode	Angle of refraction	Angle of skew
1	L	45°	180°
2	L	60°	180°
3	L	70°	180°
4	T	45°	180°
5	T	60°	180°

- Scan structure: Raster scan with:
  - 91 steps along scan axis in 1.05mm increments
  - 137 steps along index axis in 3.821mm increments
  - **62,335 A-Scans per scan direction (all angles)**



Synthetic Flaw Test (2/5)

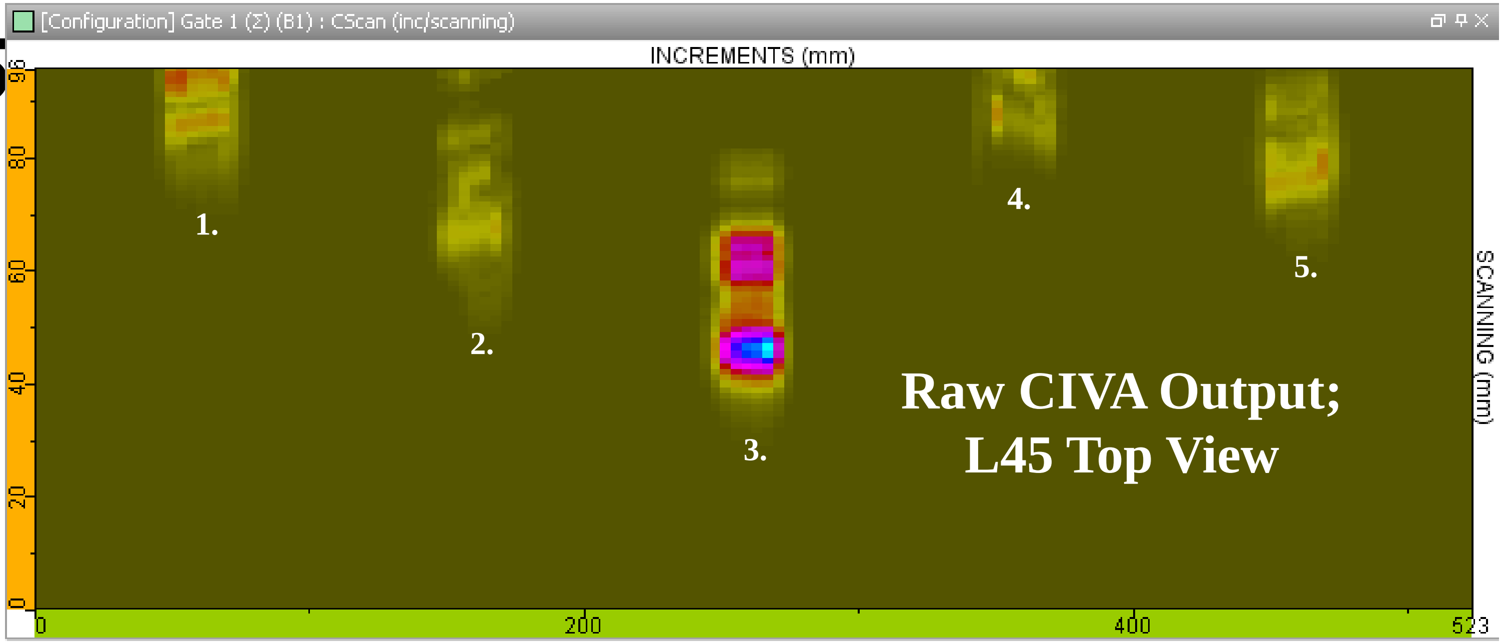
- In CIVA™ a series of five simulations is built with new defects
  - Defects are evenly-spaced and are of three different types at varying angles of tilt and skew
  - Simulation block is flat as opposed to a pipe to increase rate of computation
  - Reflections from sides, corners and top are ignored
  - Each simulation accounts for L, T and mode conversion

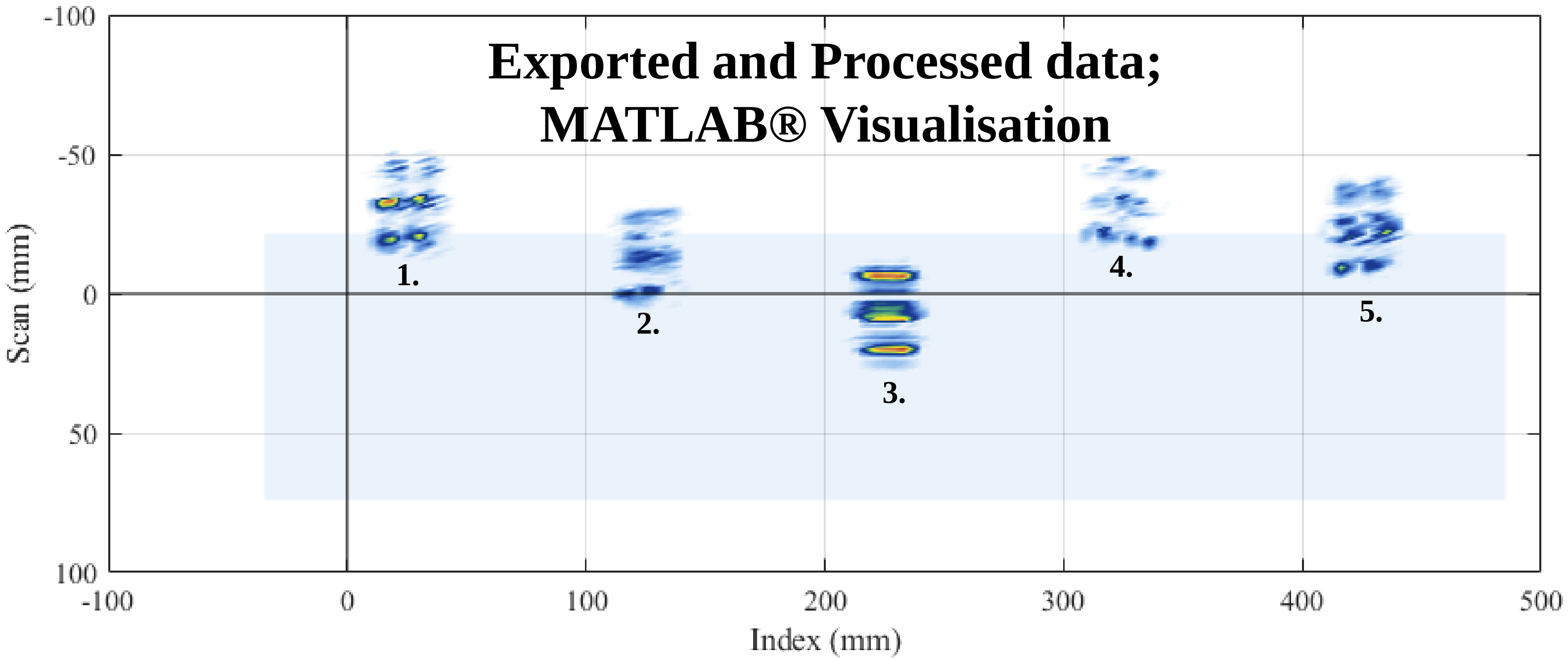


Index	Type	Side	Length (mm)	Height (mm)	Position (mm)	Ligament (mm)
1	Rectangular	Upstream	20.0	5.0	120	2.0; Embedded
2	Semi-Elliptical	Downstream	20.0	5.5	220	Touching ID
3	Planar	Downstream	23.9	2.7	320	Touching ID
4	Semi-Elliptical	Upstream	20.0	7.5	420	Touching ID
5	Rectangular	Upstream	20.0	5.0	520	Touching ID

Synthetic Flaw Test (3/5)

- The C-scans are exported from each CIVA simulation in turn; composited into a .txt file of the same type as a .UVData export
- They are down-sampled to match data resolution of the .UVData file
- Compositing, interpolation and output of .txt file carried out in Python 3.6
- Graphical visualization carried out in MATLAB®





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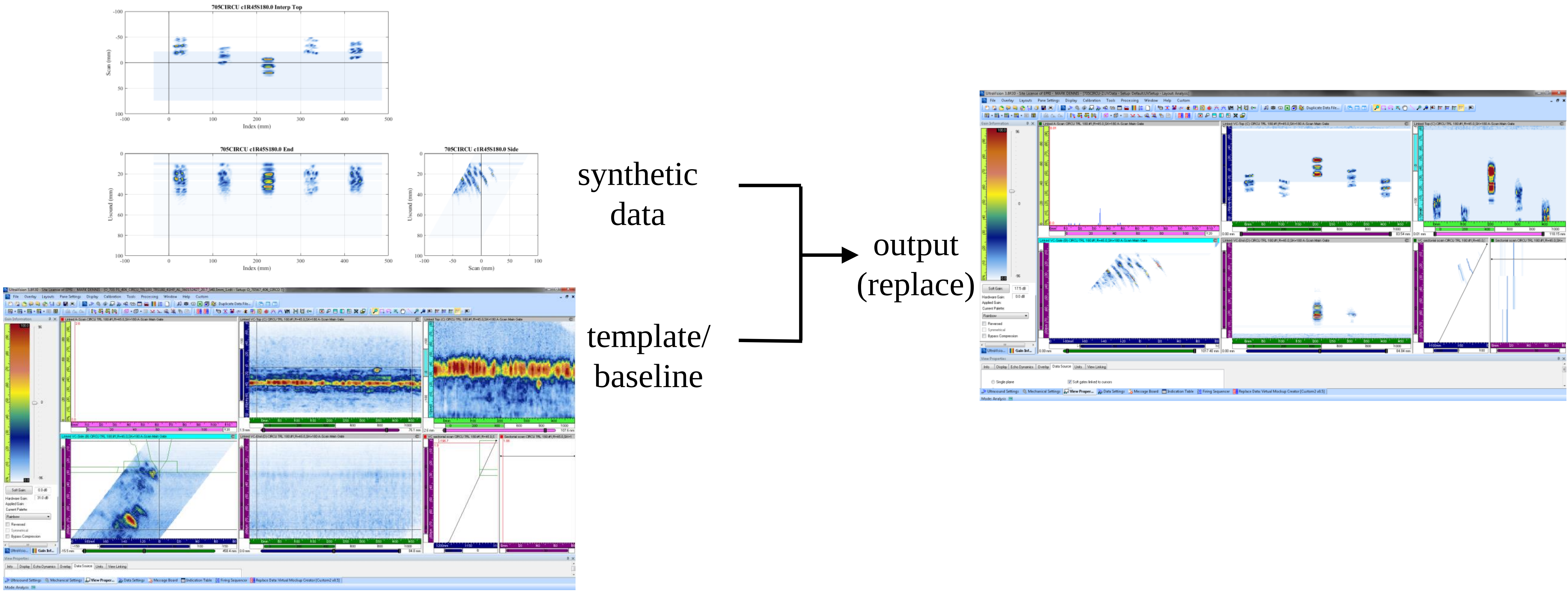
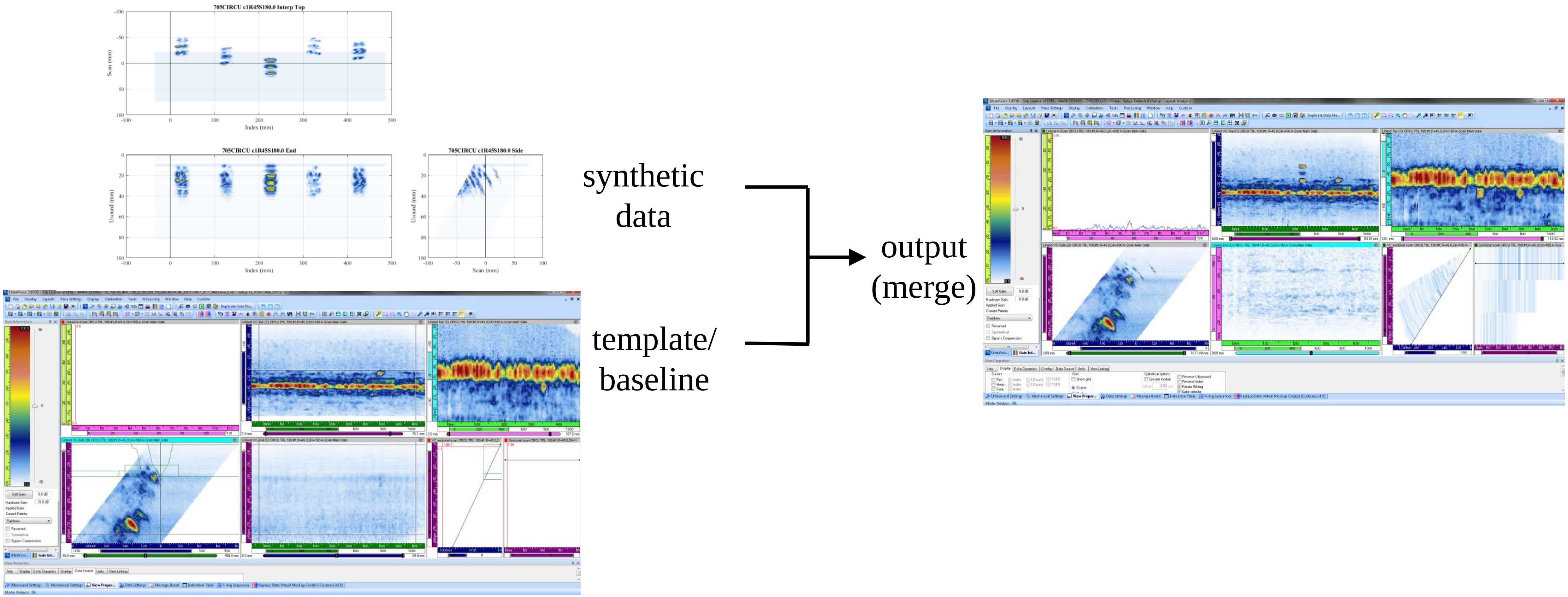
Synthetic Flaw Test (4/5)

- A tool already developed in-house in Zetec UltraVision is used to replace the data in the original template; original data completely obscured



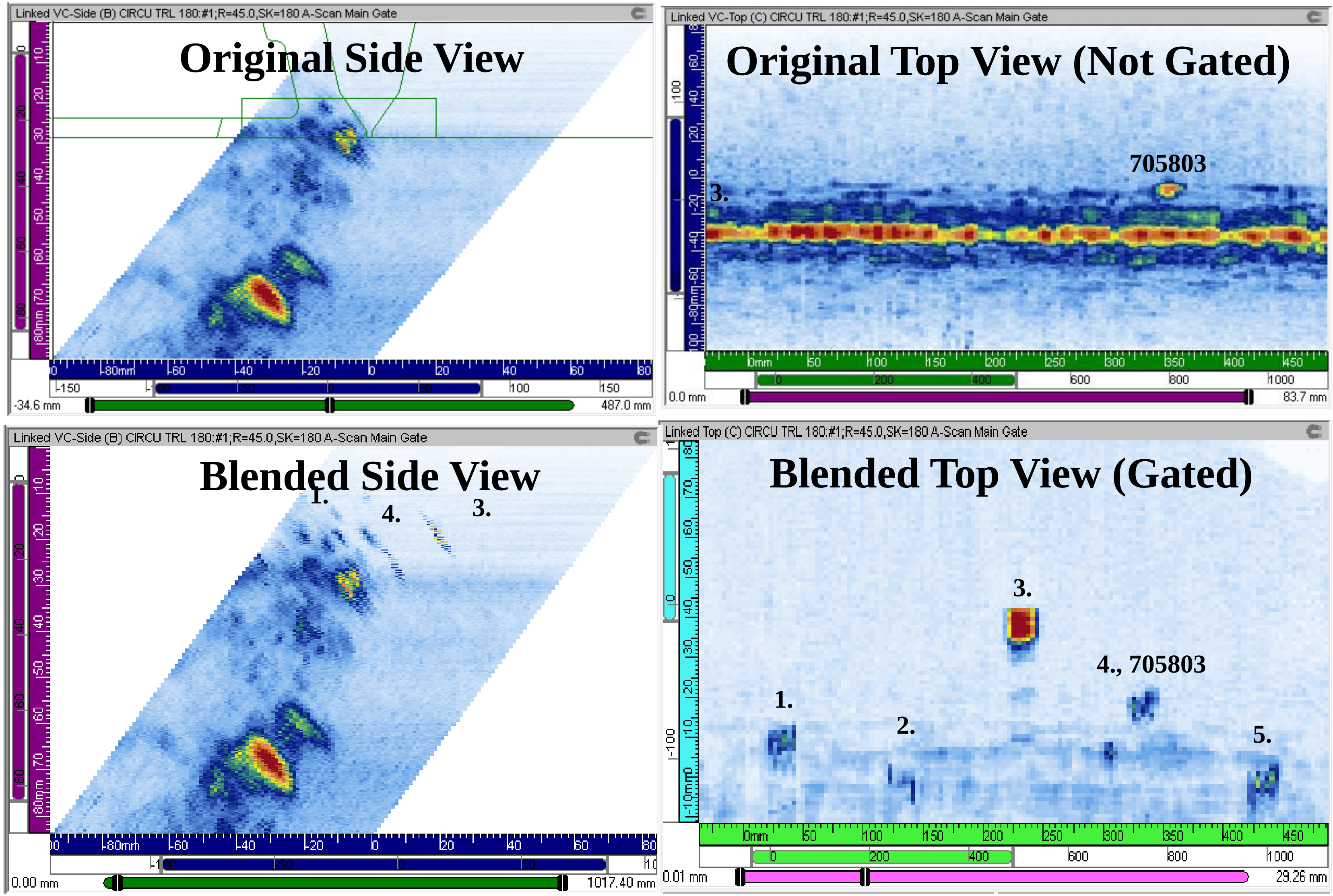
Synthetic Flaw Test (5/5)

- The same tool can be used to blend with instead of replacing the original data
  - Blending zone measures (mm): -50 ≤ Scan ≤ 20; 10 ≤ Index ≤ 450; 10 ≤ Usound ≤ 40



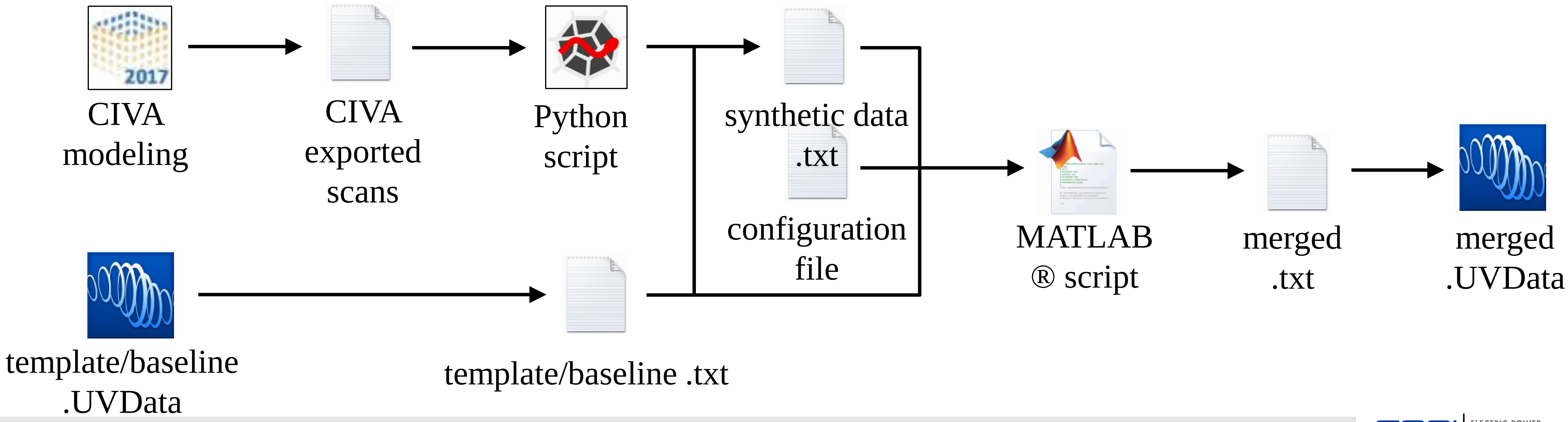
Results

- A process for merging and blending of synthetic data into an existing UltraVision data file is demonstrated
- With appropriate windowing of blended results, the responses from all five CIVA flaws can be identified



Summary

- A comprehensive workflow of the merging process:
  - Select template/baseline .UVData file and construct CIVA model to match scan plan and setup
  - Export CIVA data and generate synthetic data. txt to match the exported template/baseline .txt
  - A script merges the synthetic data .txt and the exported template/baseline .txt according to the configuration file
  - Import the merged .txt into a new .UVData file



 www.epri.com

Lessons Learned on Simulated Defect Insertion into Virtual Mockups To Date

- Several outstanding items still need to be addressed:
  - Q1 / Q2 2020 a full review of the new data files is planned to be performed by ultrasonic practitioners to gather feedback and comments
  - Some work is still needed on the interpolation process, we are still experiencing flaws that look a bit grainy and blocky at times
  - CIVA output is of a large size (many gigabytes) and we looking at potential ways to downsize or compress the resultant CIVA data while maintaining data integrity to make the process more efficient
  - Matching CIVA simulation space to the real structure from which the UltraVision original data were collected is difficult and must be done with great care

2020+ Scope

- Field Trials
  - Utilizing a mix of the standard virtual flaw approach (taking existing flaws and moving them into new mockups) and the potential synthetic flaw (modeling new flaws and placing into mockups) processes
  - Work with an international collaboration on a targeted application for virtual flaws that will involve regulatory bodies
    - We already have interest from a couple of volunteers to perform this (non-US)
  - Build a demonstration or qualification program around the use of virtual mockups to enable the process to be tested and help the organization create a program without creating a ton of new physical mockups (costly)
    - This proof of concept would allow us to expose this process to members and regulators while also allowing for collection of lessons learned to help the process in the future

2020+ Scope

- Ongoing development of a virtual mockup library
  - No additional physical mockups are needed at this time
  - Direct benefit to applications of the UT Simulator

- Participation in PIONIC
  - Planned participation as part of the ongoing development work
  - Will work to identify any lessons learned and help steer the development work

Together…Shaping the Future of Electricity

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Modeling and Simulation Update

Mark Dennis
Myles Dunlap
EPRI

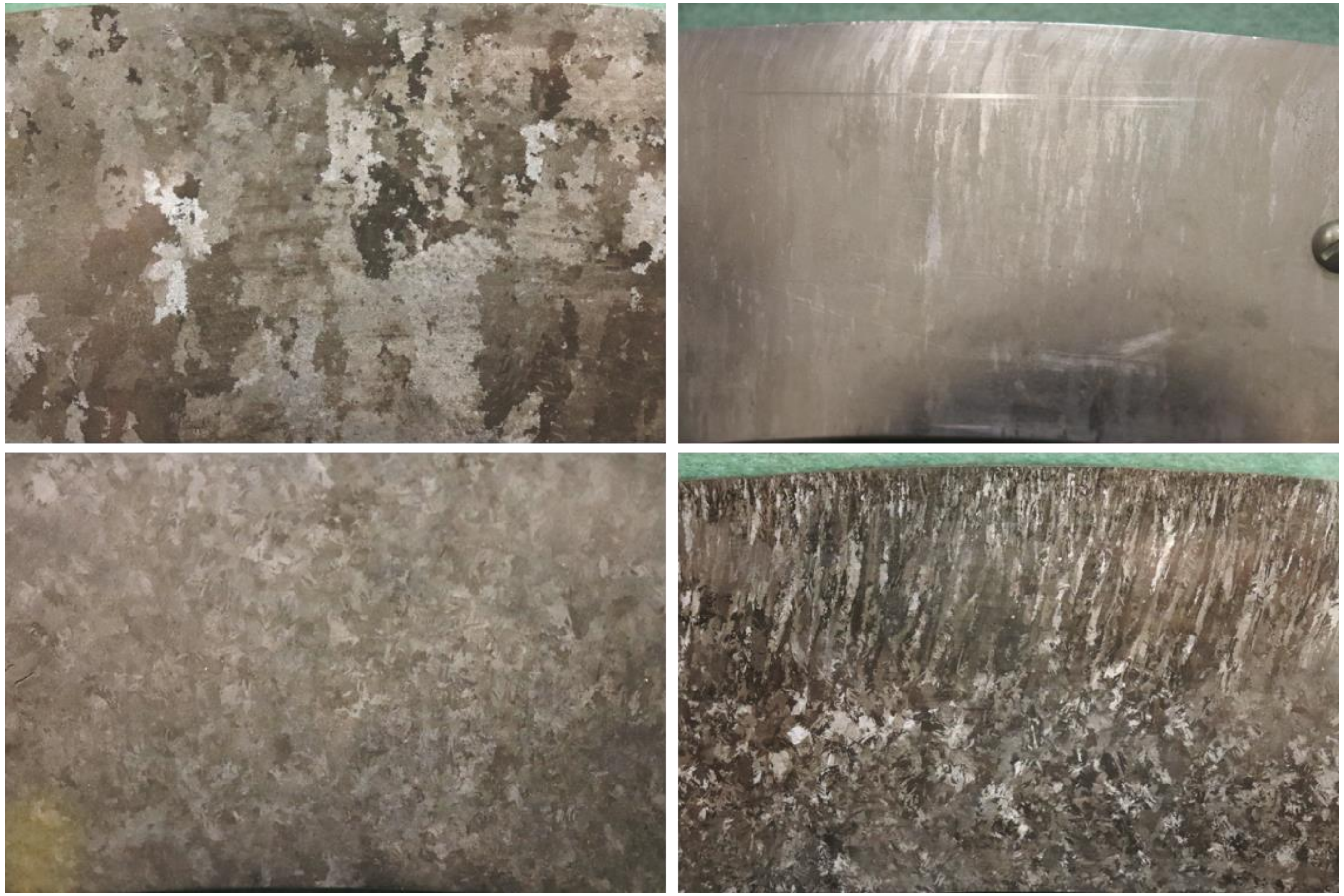
NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Presentation Outline

- Background
- Research Objective
- Results
- Conclusions

Background

- Ultrasonic testing (UT) of Cast Austenitic Stainless Steel (CASS) is challenging due to the coarse-grained anisotropic and inhomogeneous nature of the material.
- Ultrasonic wave interaction within the material structure is subject to scattering and attenuation.
- Results in reduced signal-to-noise ratios (SNR) and challenging analysis and interpretation of results.



Research Objective

- This research proposes an experimental based strategy to setup ultrasonic models and simulations aiming at accurately simulating Ultrasonic Testing (UT) in challenging materials such as CASS.
- UT simulations of coarse grained materials can be used to further investigate techniques and approaches for the reliable inspection of CASS materials.
- A previous EPRI study [1] determined a need for the incorporation of noise into ultrasonic simulations as well as a need to decrease simulation run time.
  - For these reasons we have been investigating the software OnScale for ultrasonic modeling and simulation.
- This study uses CASS as the study case; however it can be expanded to other materials such as DMW and SS.

[1] *Ultrasonic Modeling and Simulation of Cast Austenitic Stainless Steel.* EPRI, Palo Alto, CA: 2018. 3002013160.

OnScale

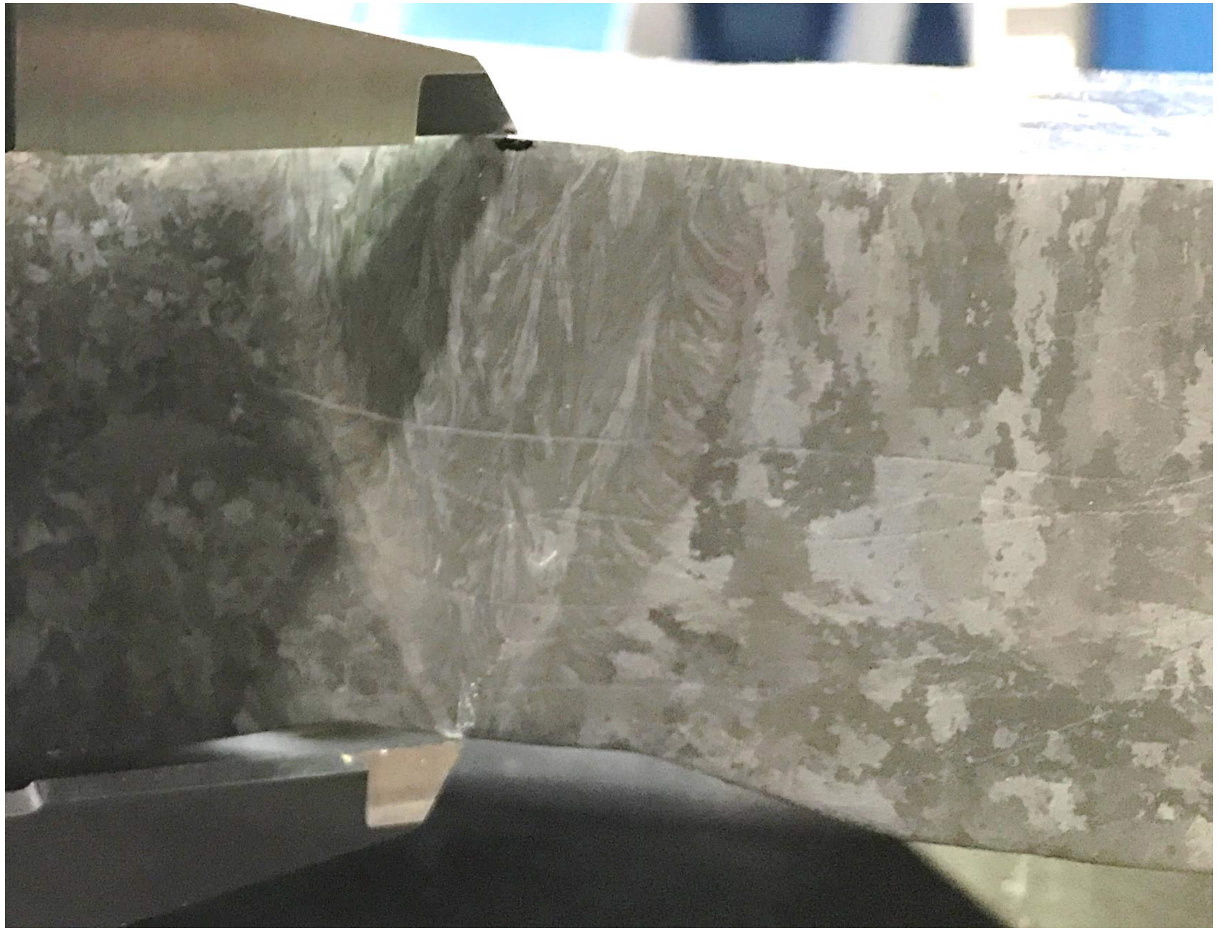
- OnScale is a multiphysics solver that can be used to model and simulation ultrasonic testing in NDE.

- OnScale is a Cloud Engineering Simulation Platform
  - Allows users to run massive number of ultrasonic testing simulations in parallel

Experimental Setup

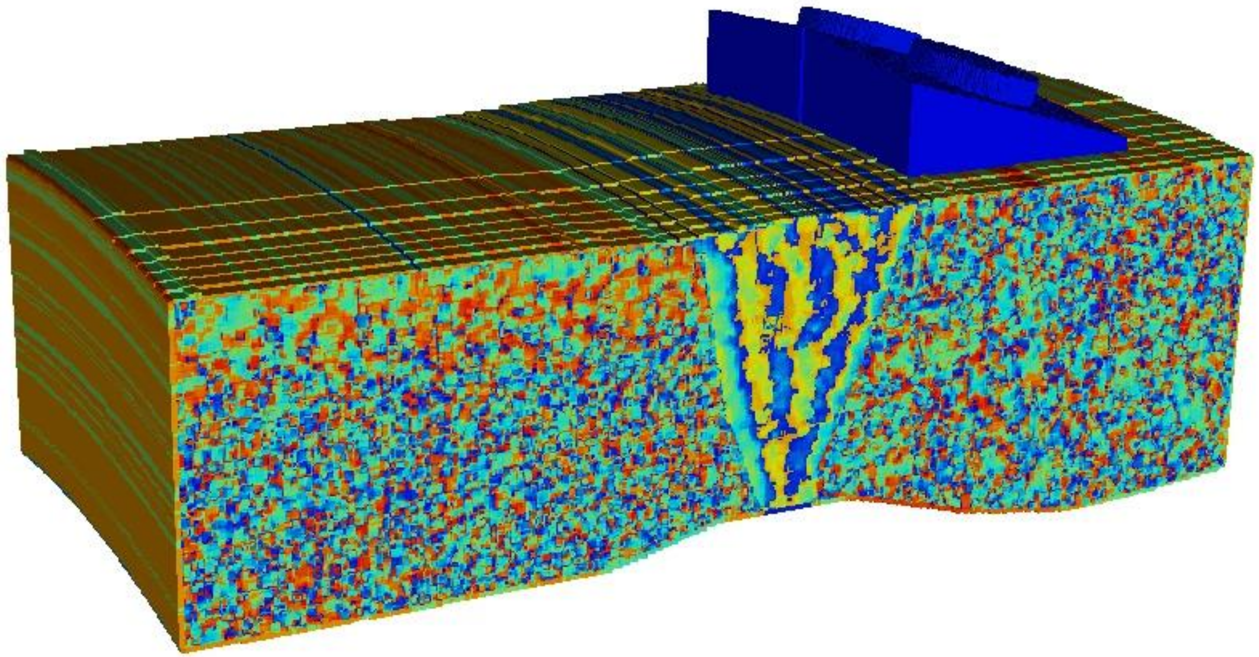
CASS Sample

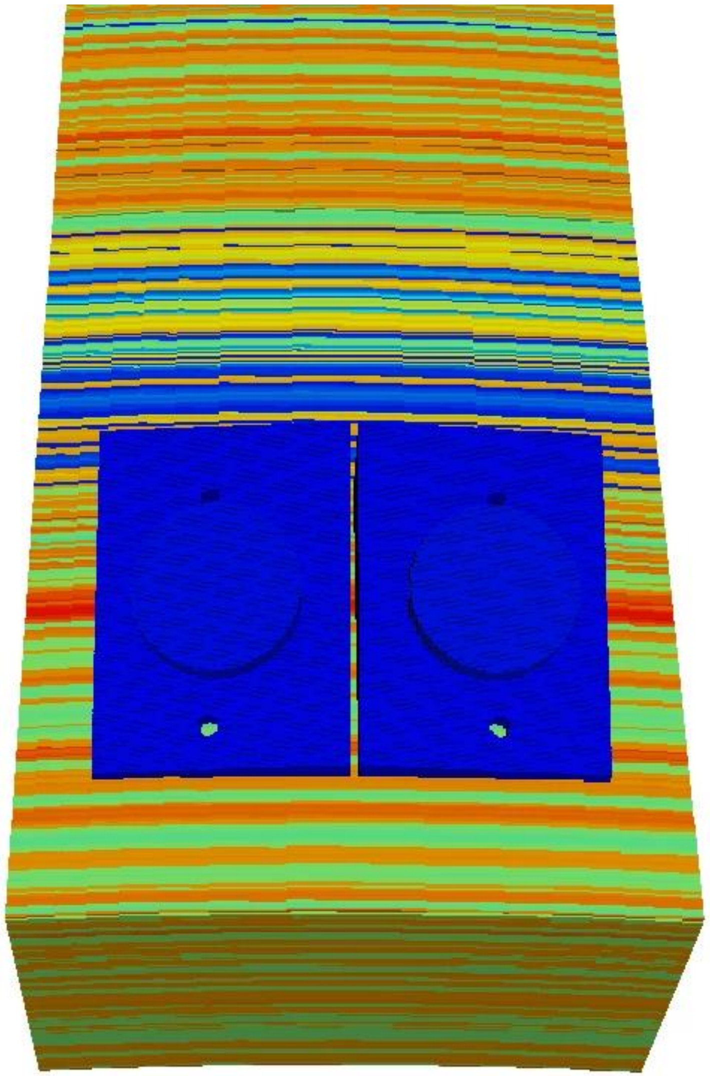
- WOG sample OPE-2
  - Statically cast elbow to centrifugally cast pipe
  - One crack located on the elbow side of the weld centerline
- Flaw information:
  - Mechanical Fatigue
  - Length of 1.65 inches
  - Depth of 0.5 inches
- 45° TRL probe
- Two scans simulated
  - Flaw response
  - Control – No flaw



CASS Modelling

Model Geometry





Model Metrics

Model	500 kHz	1 MHz
Simulation size (Degrees of Freedom)	228 Million	1.8 Billion
Number of Timesteps	2170	4350
Memory	14 GB	120 GB
Simulation Time (Core Hours)	4.8	150

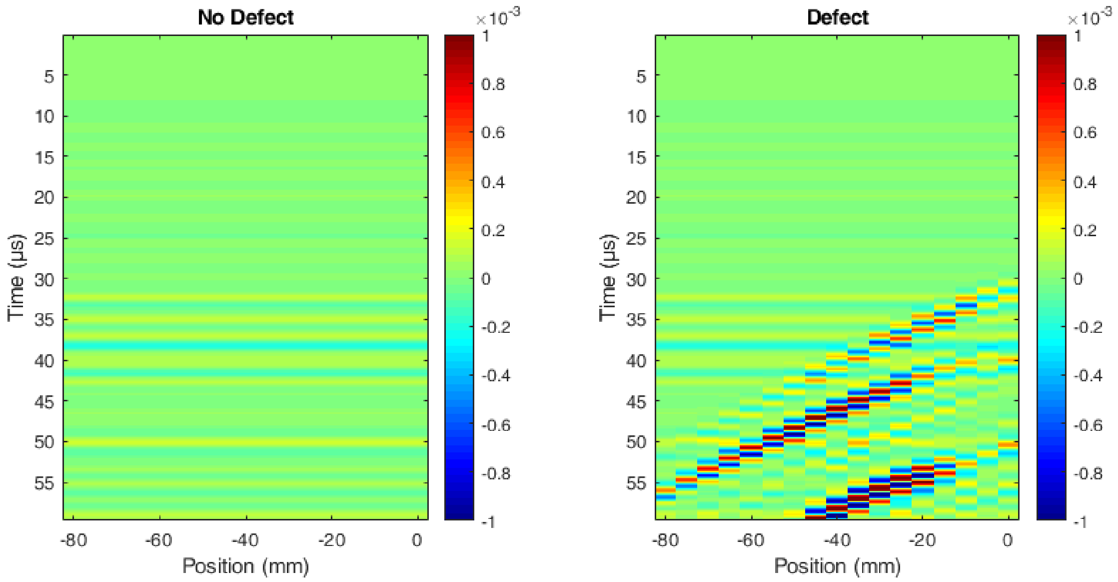
- These are large models and would take days to solve without multiple cores.
- Simulation time was 9.5 hours and could be reduced further my using more cores.

500 kHz Simulations

0.5 MHz Isotropic Block Simulation

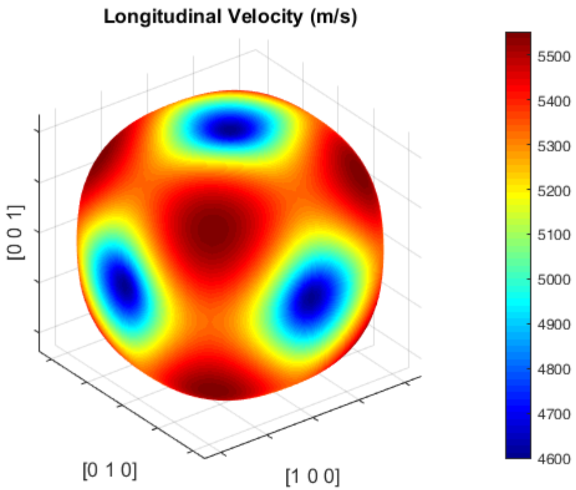
- Simple model to investigate detection capability of probe
  - Pipe geometry replaced with simple isotropic block
  - Same crack parameters

- Clear defect detection



Simulation B-Scans for isotropic block without/with crack defect

Material Property Velocity Profiles



Anisotropic material properties: velocity map

Isotropic material properties determined using Hooke's law in stiffness form, see:

https://www.efunda.com/formulae/solid_mechanics/mat_mechanics/hooke_isotropic.cfm

(All values in GPa or m/s)	Original Anisotropic c11 = 167.1, c12 = 120.0, c44 = 80.9	Original Isotropic c11 = 274, c12 = 112, c44 = 81	Adjusted Isotropic* c11 = 203.5, c12 = 95, c44 = 54.25
Longitudinal			
Max	5552	5889	5075
Min	4598	5889	5075
Average	5075	5889	5075
Range	954	0	0
Shear Horizontal			
Max	3200	3202	2621
Min	1725	3202	2621
Average	2462	3202	2621
Range	1475	0	0
Shear Vertical			
Max	3200	3202	2621
Min	2342	3202	2621
Average	2771	3202	2621
Range	858	0	0

*Adjusted Isotropic material properties:

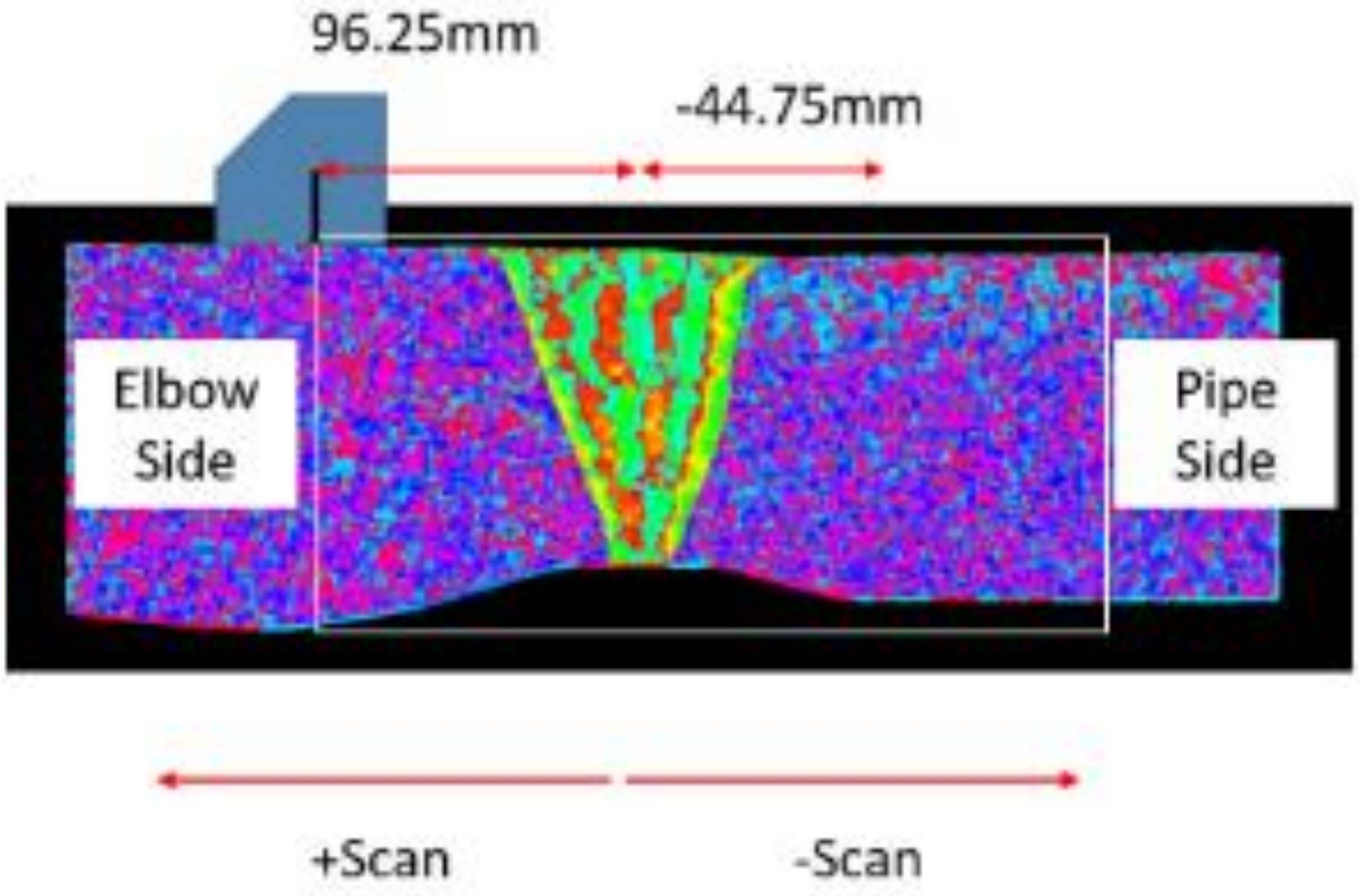
- c11 adjusted to give longitudinal velocity = average of anisotropic longitudinal velocity
- c12 adjusted to give shear velocity = average of anisotropic shear velocities
- c44 = (c11 - c12)/ 2

Material Property Generation

(All values in GPa or m/s)	Material Property 1 c11 = 203.5 c12 = 95.0 c44 = 54.25	Material Property 2 c11 = 194.4 c12 = 101.25 c44 = 60.91	Material Property 3 c11 = 185.3 c12 = 107.5 c44 = 67.58	Material Property 4 c11 = 176.2 c12 = 113.75 c44 = 74.24	Material Property 5 c11 = 167.1 c12 = 120.0 c44 = 80.9
Longitudinal					
Max	5075	5199	5319	5437	5552
Min	5075	4961	4843	4723	4598
Average	5075	5080	5081	5080	5075
Range	0	238	476	714	954
Shear Horizontal					
Max	2621	2777	2925	3066	3200
Min	2621	2428	2219	1988	1725
Average	2621	2602	2572	2527	2462
Range	0	349	706	1077	1475
Shear Vertical					
Max	2621	2777	2925	3066	3200
Min	2621	2554	2486	2415	2342
Average	2621	2665	2705	2740	2771
Range	0	223	439	650	858

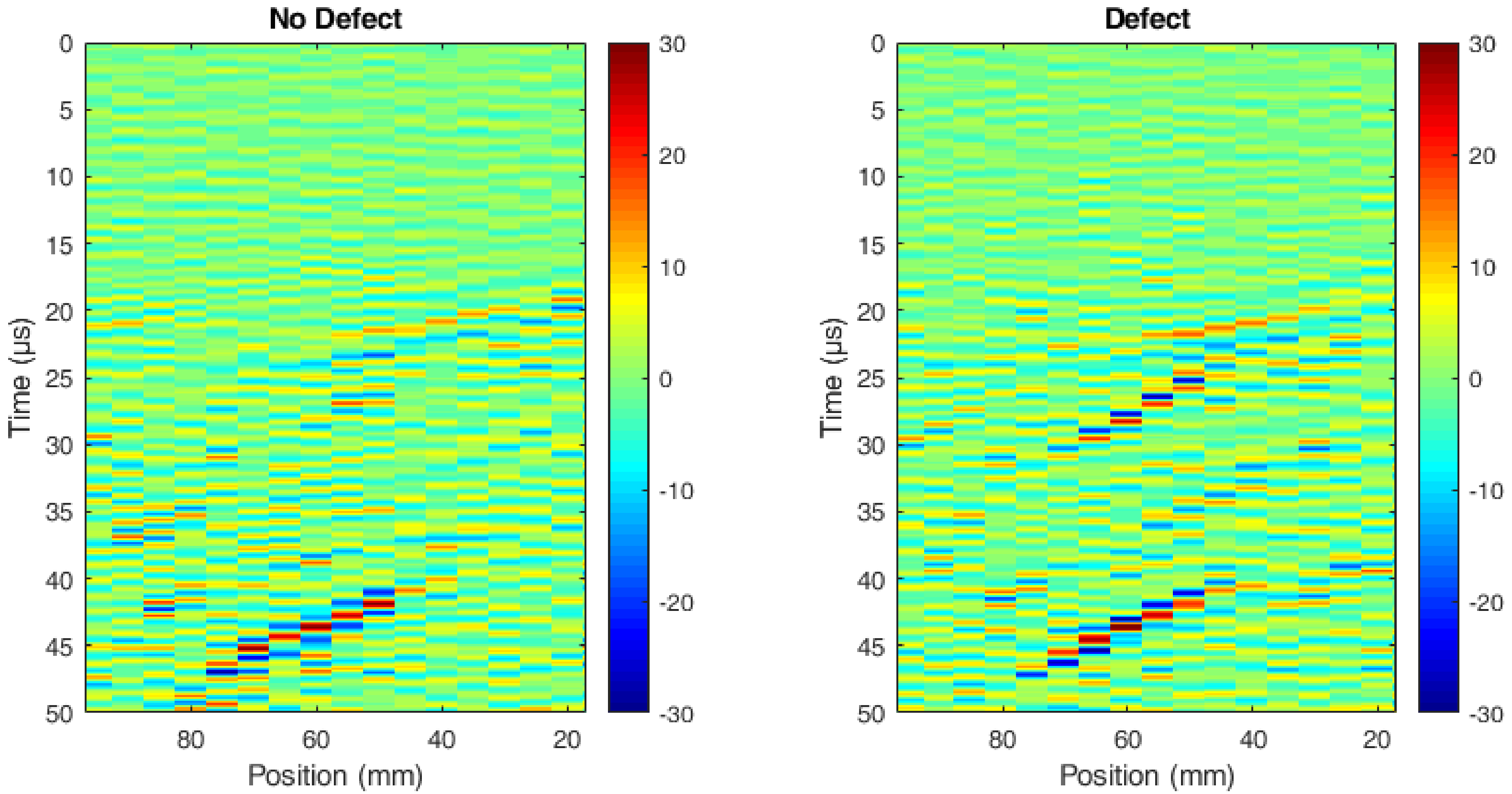
B-Scan Simulations

- B-Scan simulations performed using each of the generated material properties
- Probe frequency set to 0.5 MHz
  - Reduces model size to make faster and less expensive
- Simulated B-Scan details:
  - Start: 96 mm
  - End: 17 mm
  - Pitch: 5 mm
  - Repeated with and without defect
- Experimental data plotted using same scan details



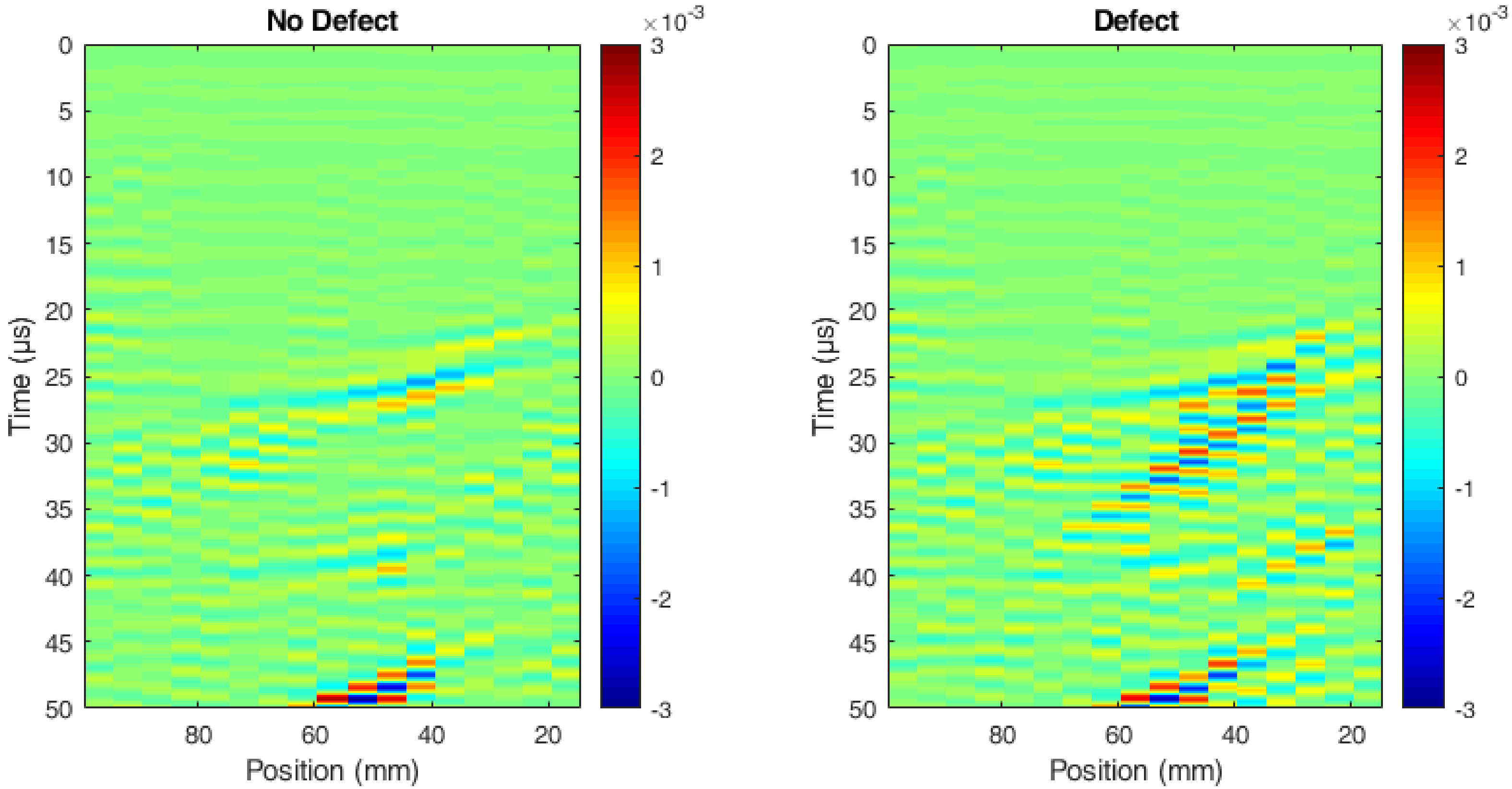
Experiment

- Experimental data adjusted to allow for plotting same region and scan pitch as simulation



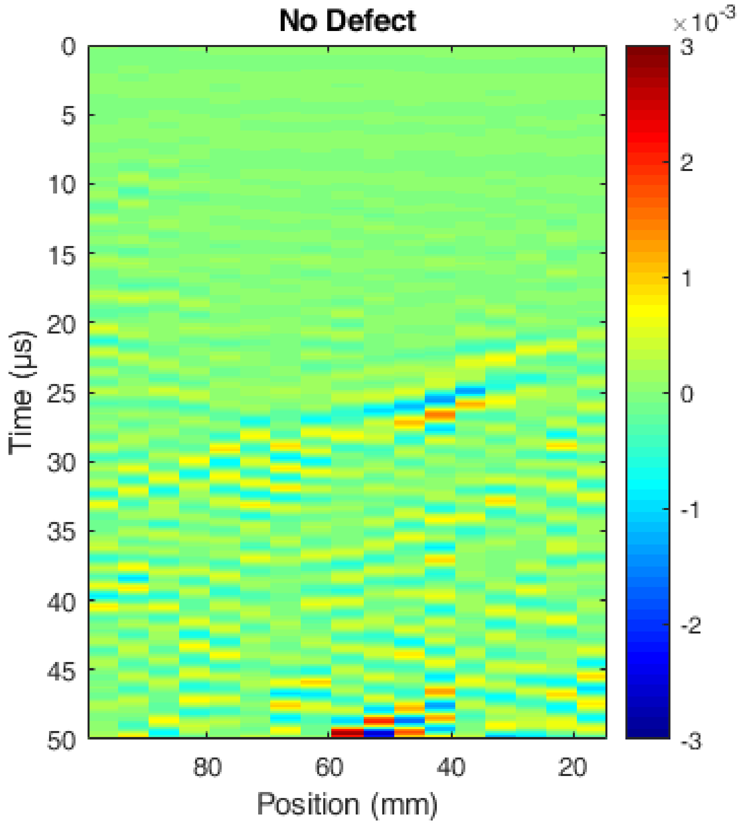
Material Property 1

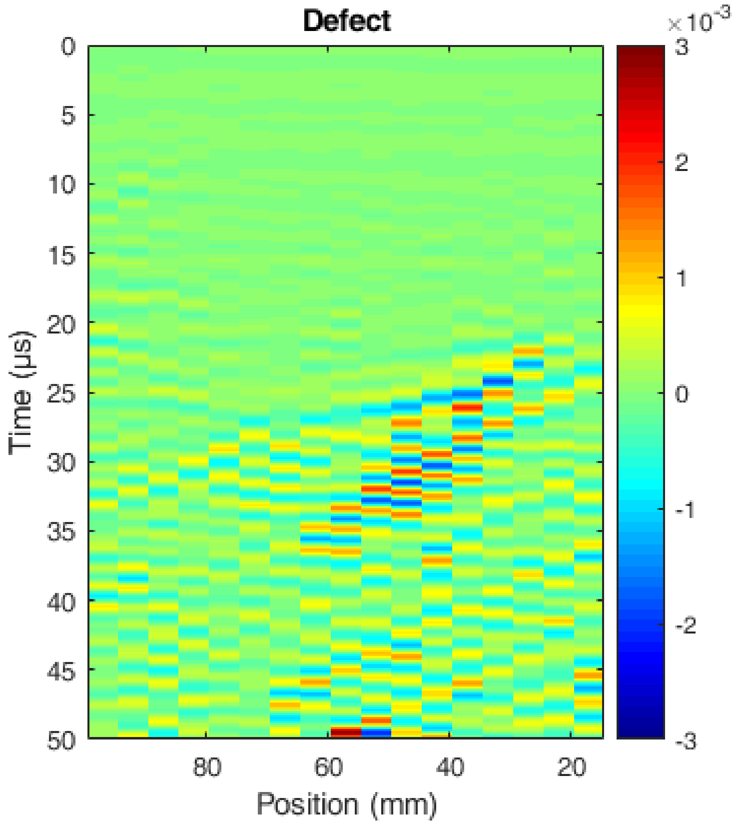
Longitudinal Velocity (m/s)	
Max	5075
Min	5075
Average	5075
Range	0



Material Property 2

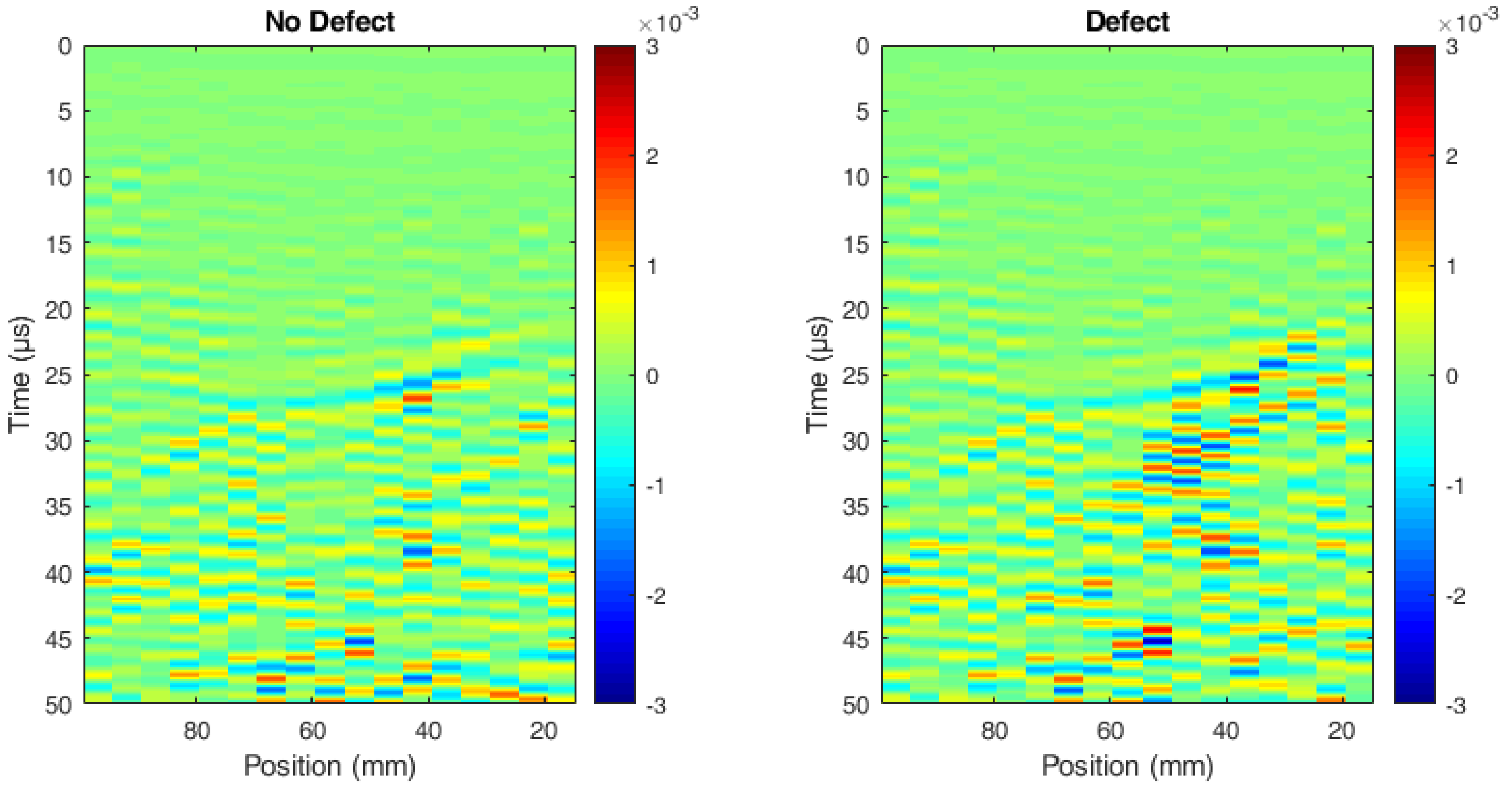
Longitudinal Velocity (m/s)	
Max	5199
Min	4961
Average	5080
Range	238





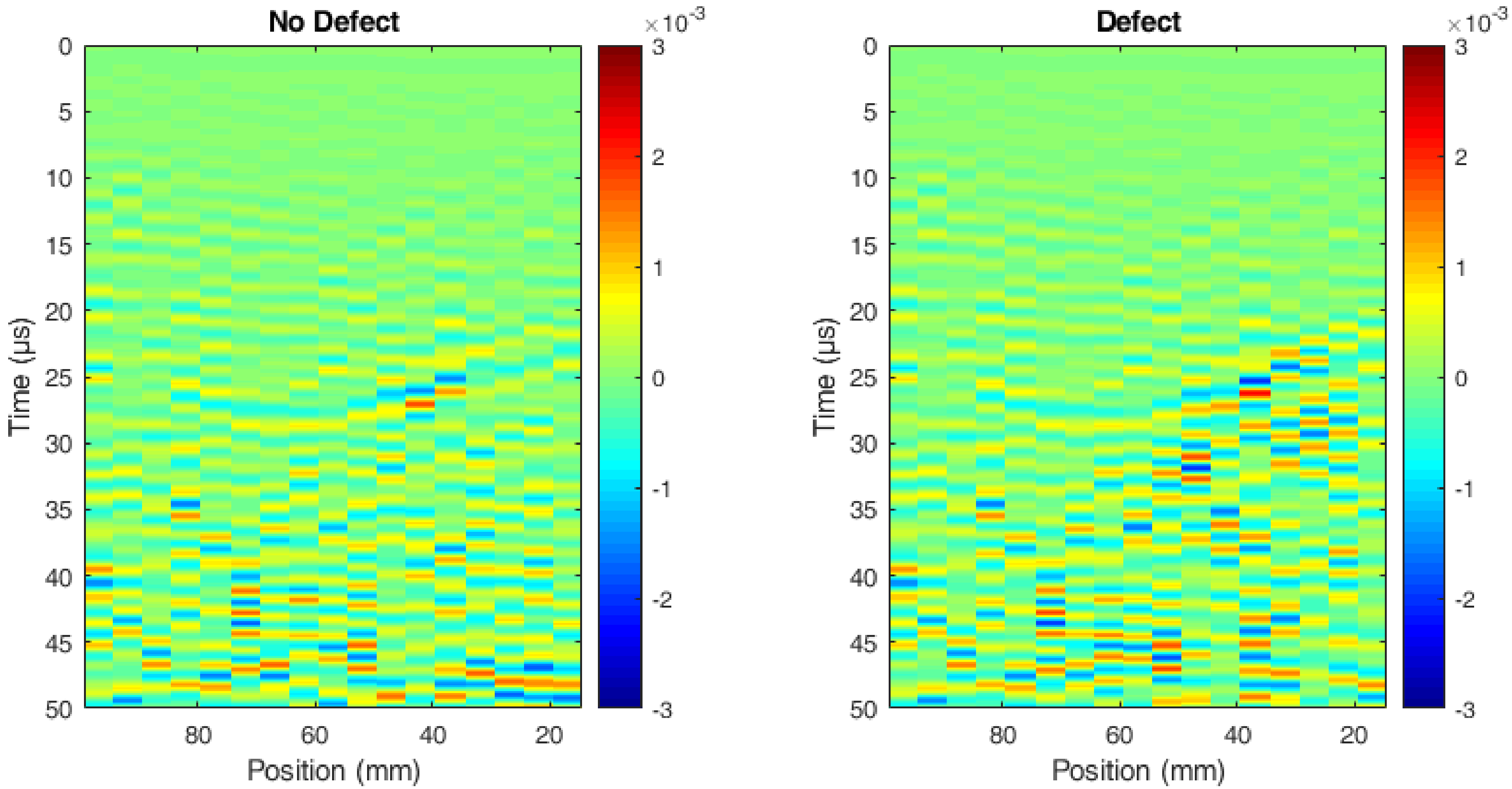
Material Property 3

Longitudinal Velocity (m/s)	
Max	5319
Min	4843
Average	5081
Range	476



Material Property 4

Longitudinal Velocity (m/s)	
Max	5437
Min	4723
Average	5080
Range	714



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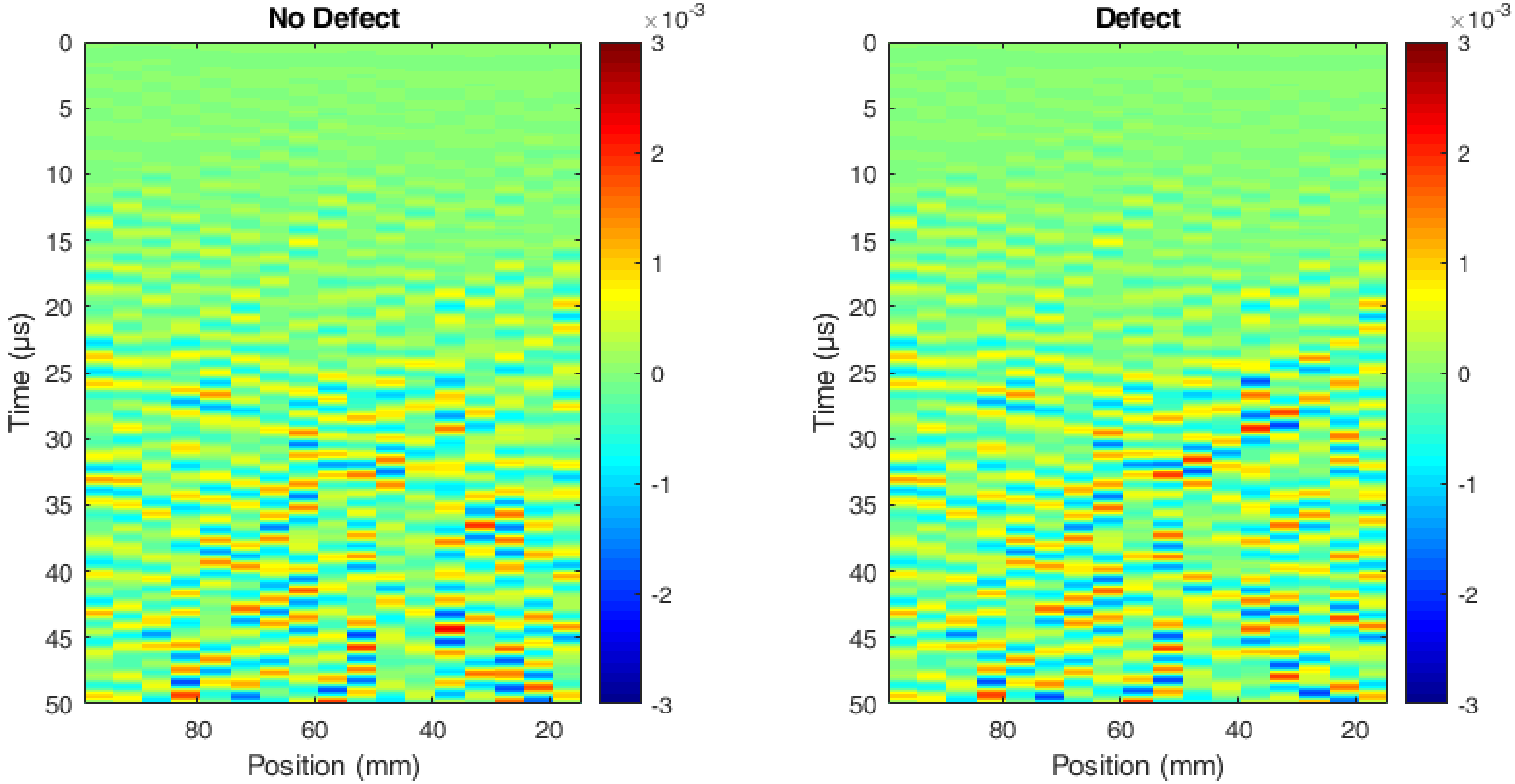
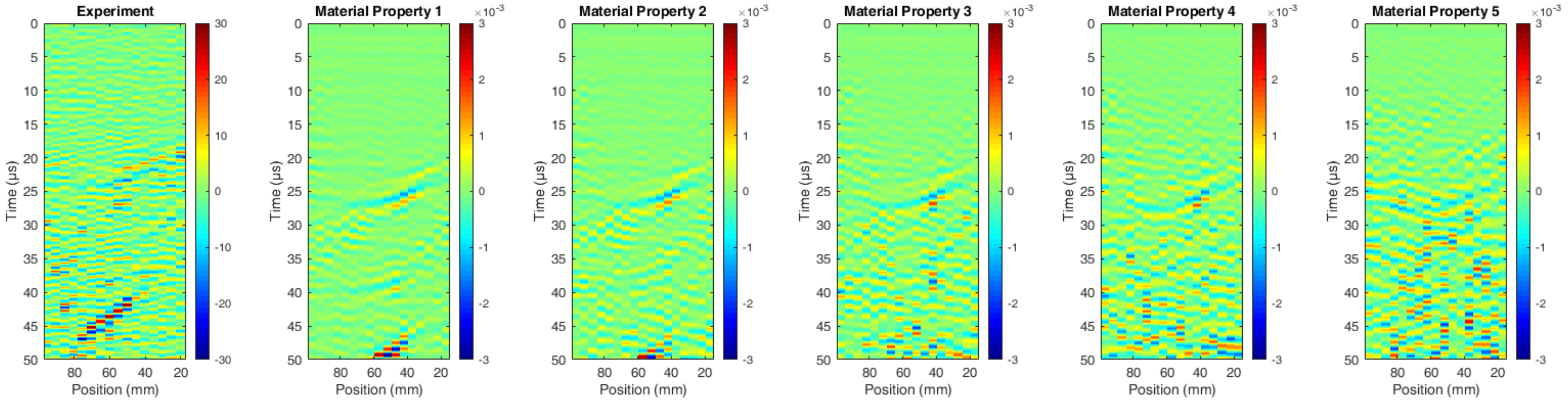
Material Property 5

Longitudinal Velocity (m/s)	
Max	5552
Min	4598
Average	5075
Range	954

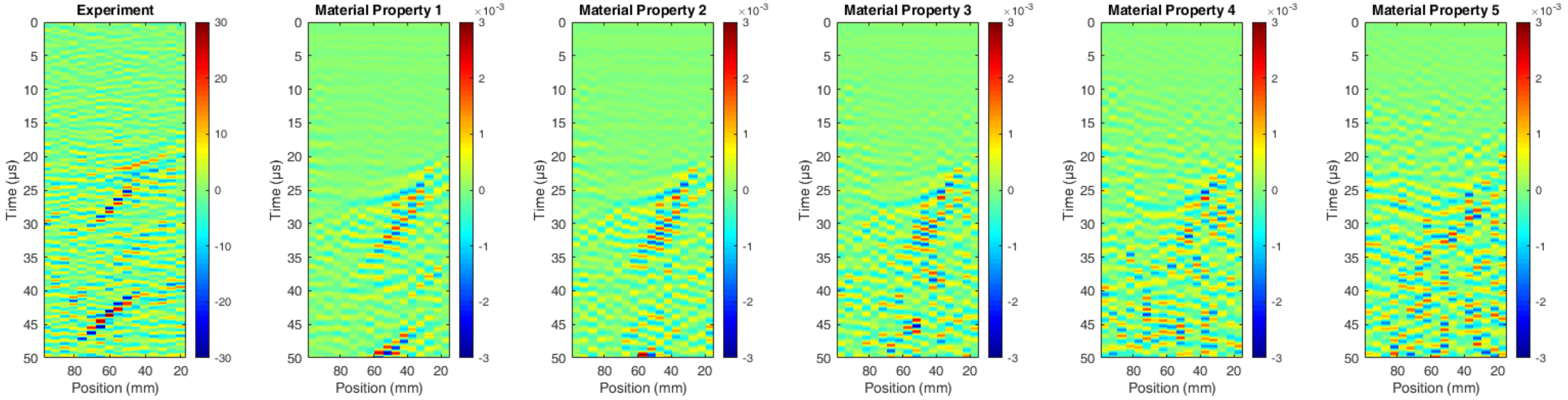


All Scans

No Defect

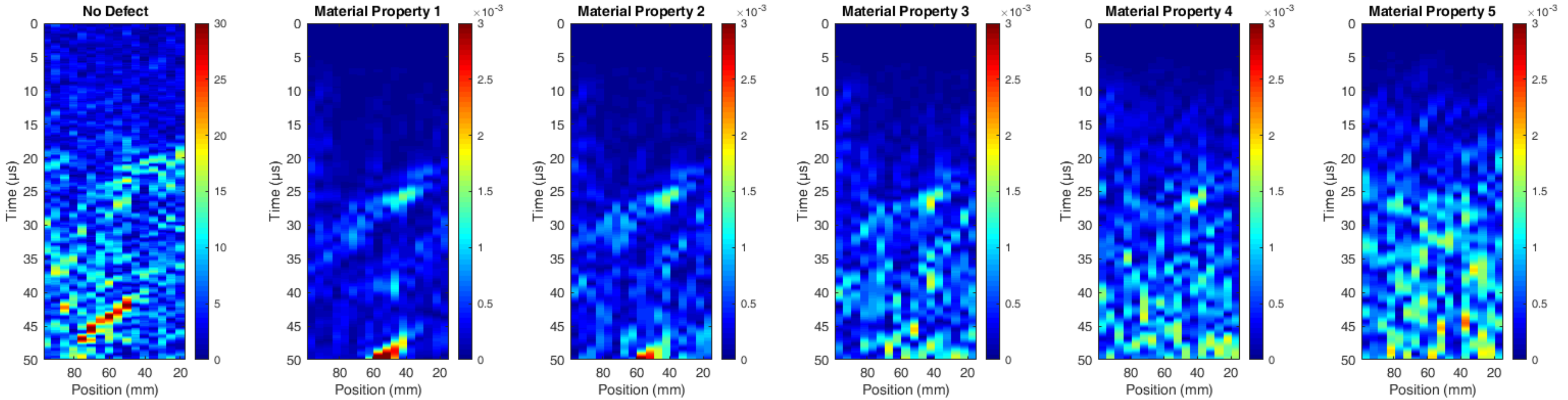


Defect

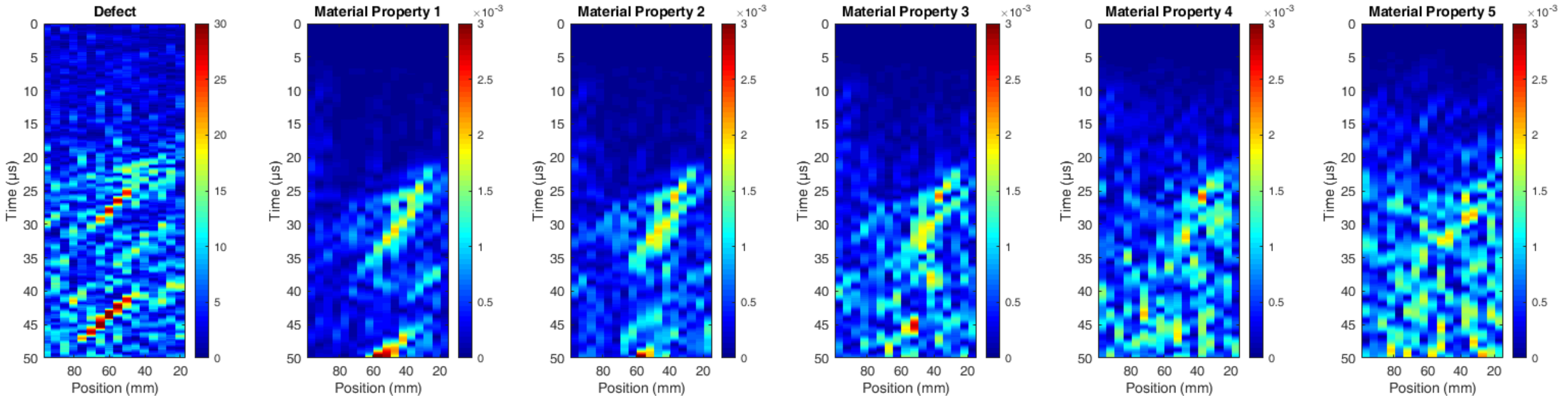


All Scans with Hilbert function

No Defect



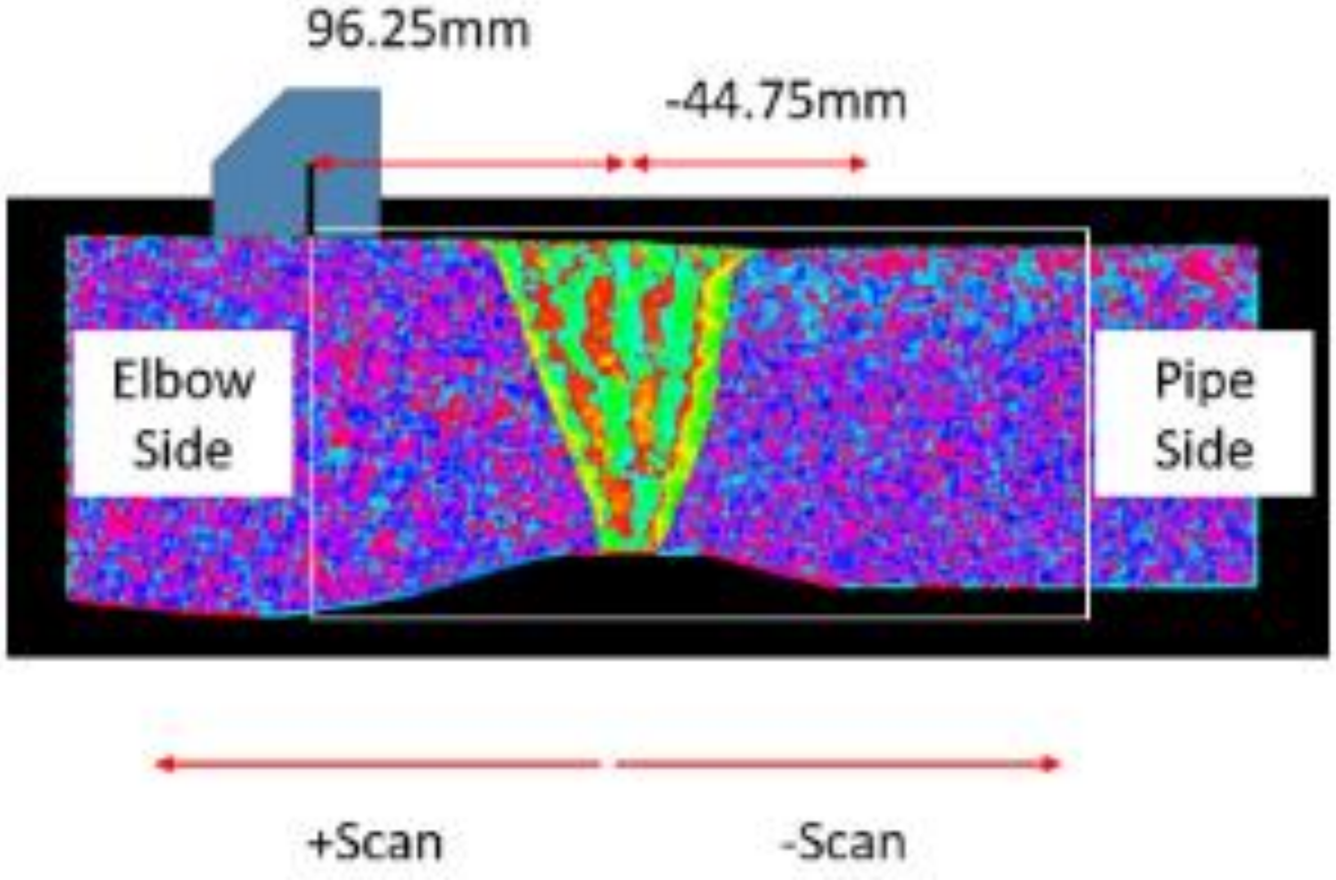
Defect



1 MHz Simulations

B-Scan Simulations

- B-Scan simulations performed using each of the generated material properties
- Simulated B-Scan details:
  - Start: 96 mm
  - End: 17 mm
  - Pitch: 5 mm
  - Repeated with and without defect
- Experimental data plotted using same scan details

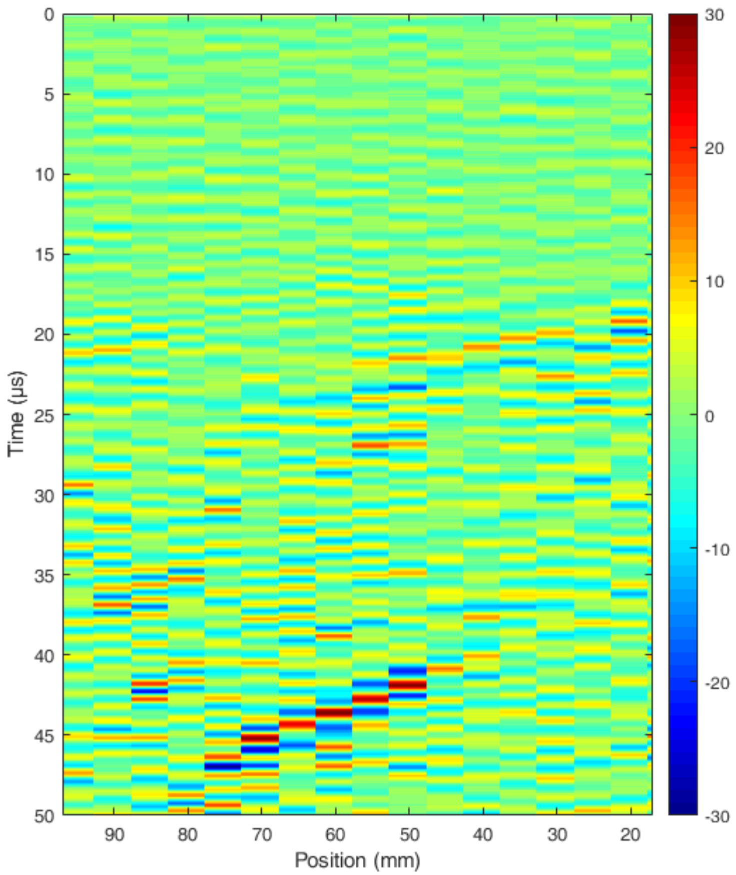


Simulation Material Properties

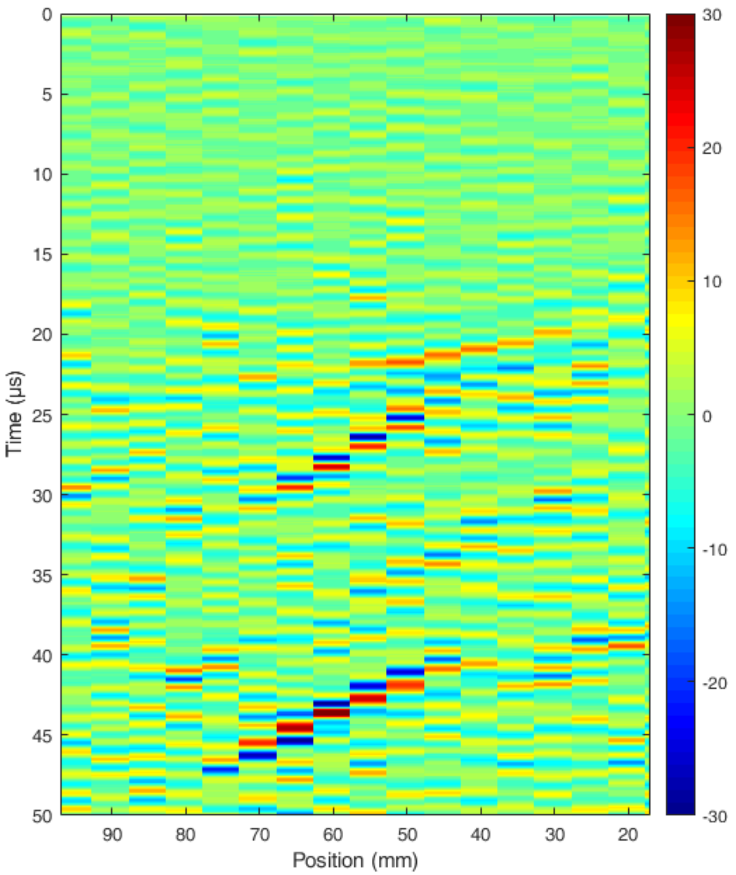
(All values in GPa or m/s)	Material Property 1 c11 = 275 c12 = 113 c44 = 81	Material Property 2 c11 = 270 c12 = 118 c44 = 86	Material Property 3 c11 = 265 c12 = 123 c44 = 91
Longitudinal			
Max	5900	5989	6076
Min	5900	5846	5792
Average	5900	5917	5934
Range	0	143	284
Shear Horizontal			
Max	3202	3299	3394
Min	3202	3102	2998
Average	3202	3201	3196
Range	0	198	396
Shear Vertical			
Max	3202	3299	3394
Min	3202	3171	3140
Average	3202	3235	3267
Range	0	128	254

Experiment

- Experimental data adjusted to allow for plotting same region and scan pitch as simulation



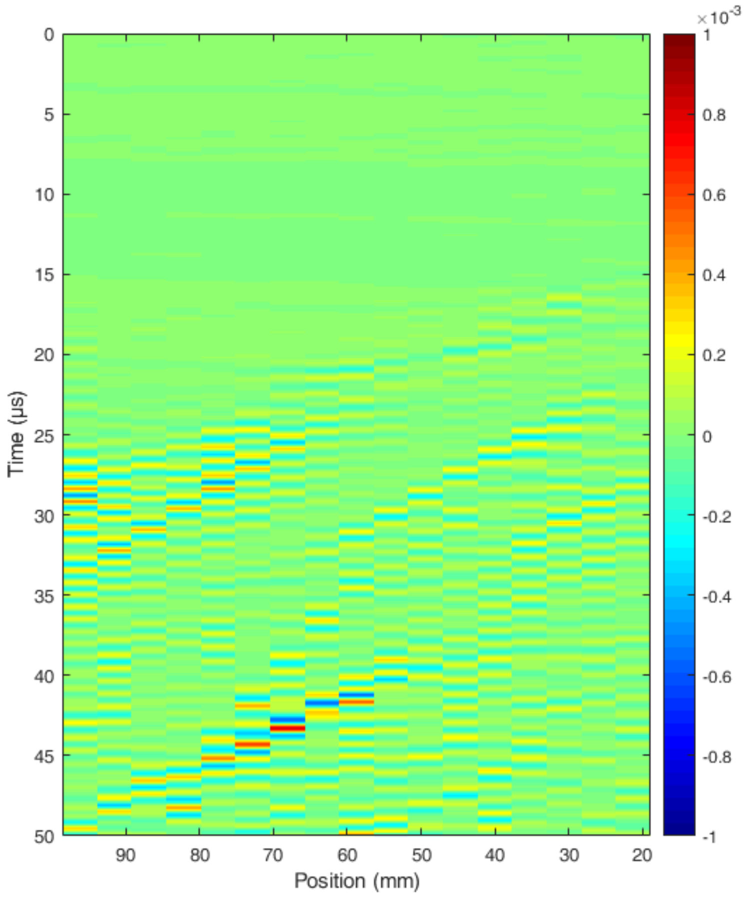
No Defect



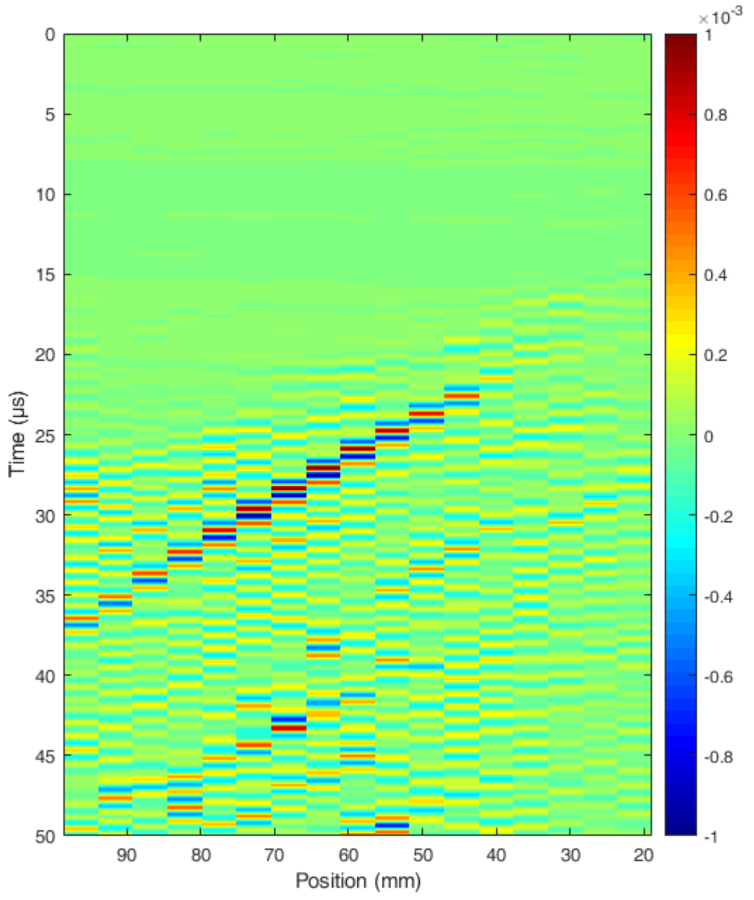
Defect

Material Property 1

Longitudinal Velocity (m/s)	
Max	5900
Min	5900
Average	5900
Range	0



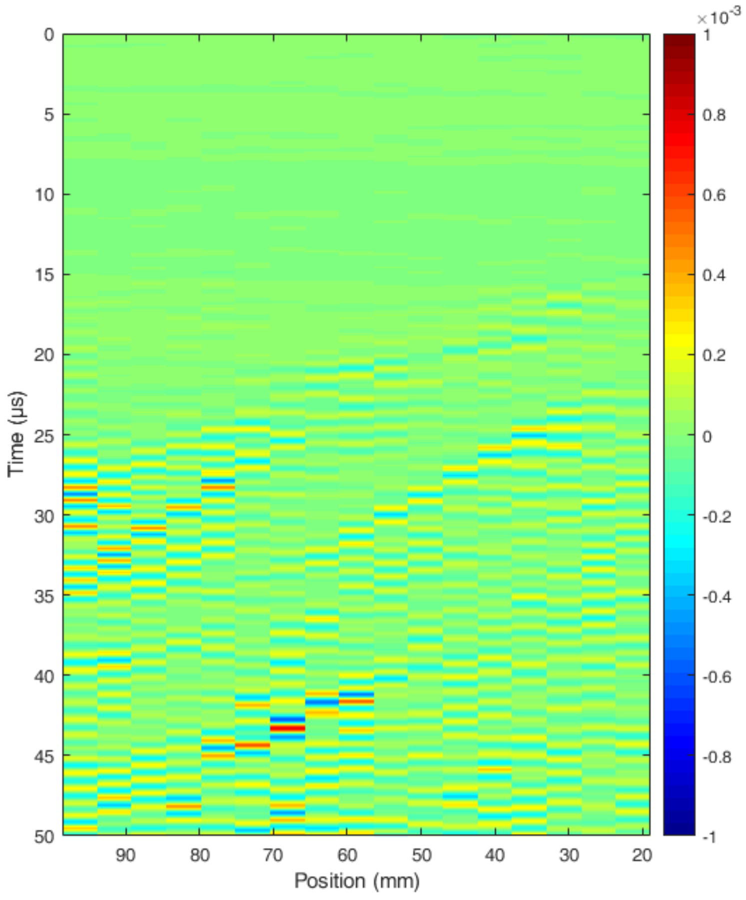
No Defect



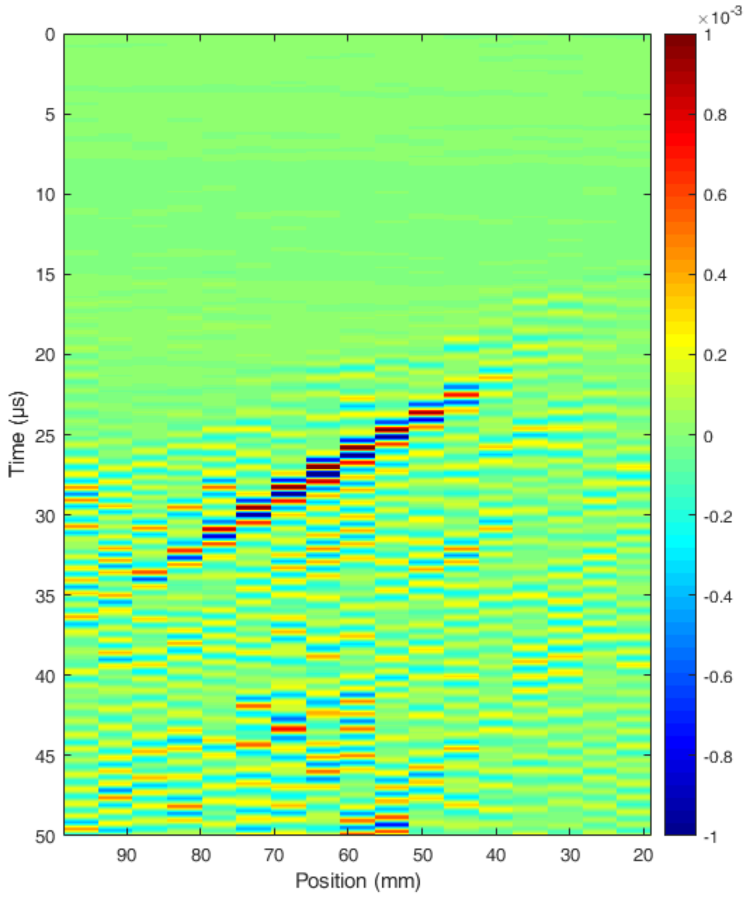
Defect

Material Property 2

Longitudinal Velocity (m/s)	
Max	5989
Min	5846
Average	5917
Range	143



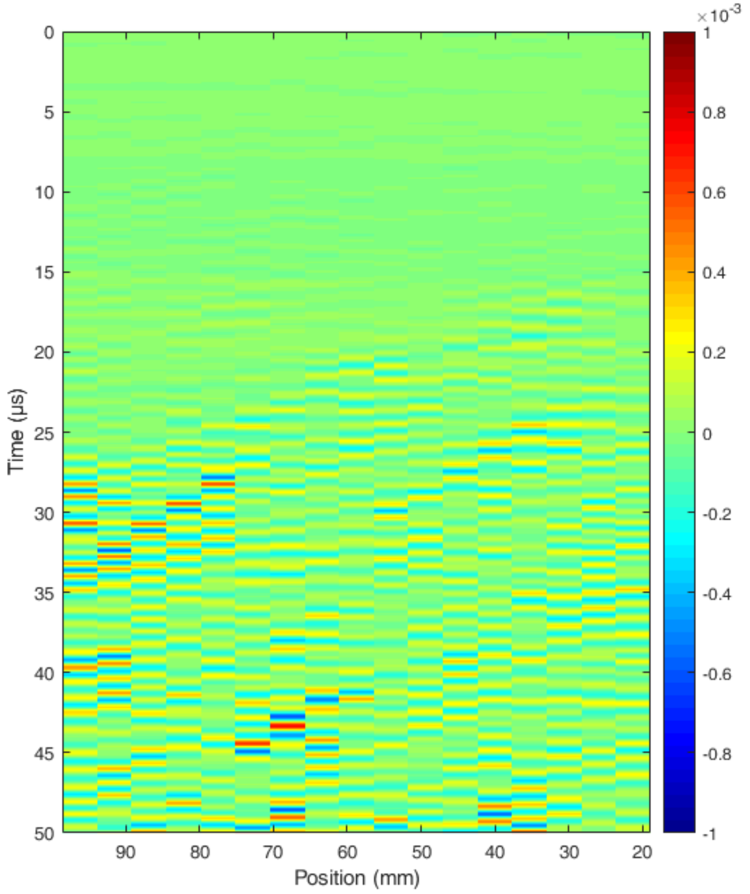
No Defect



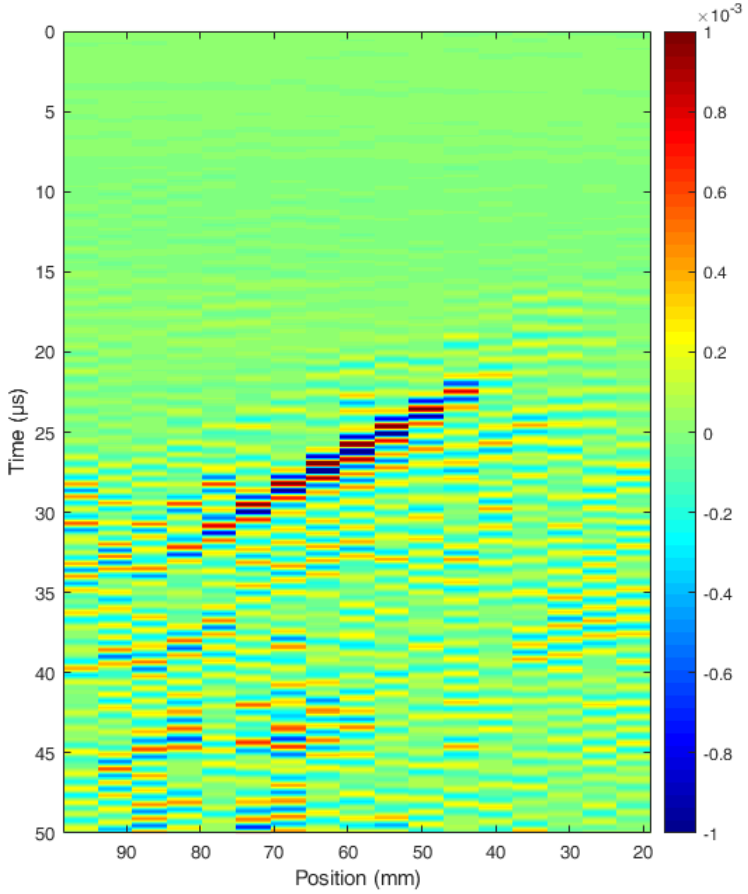
Defect

Material Property 3

Longitudinal Velocity (m/s)	
Max	6076
Min	5792
Average	5934
Range	284

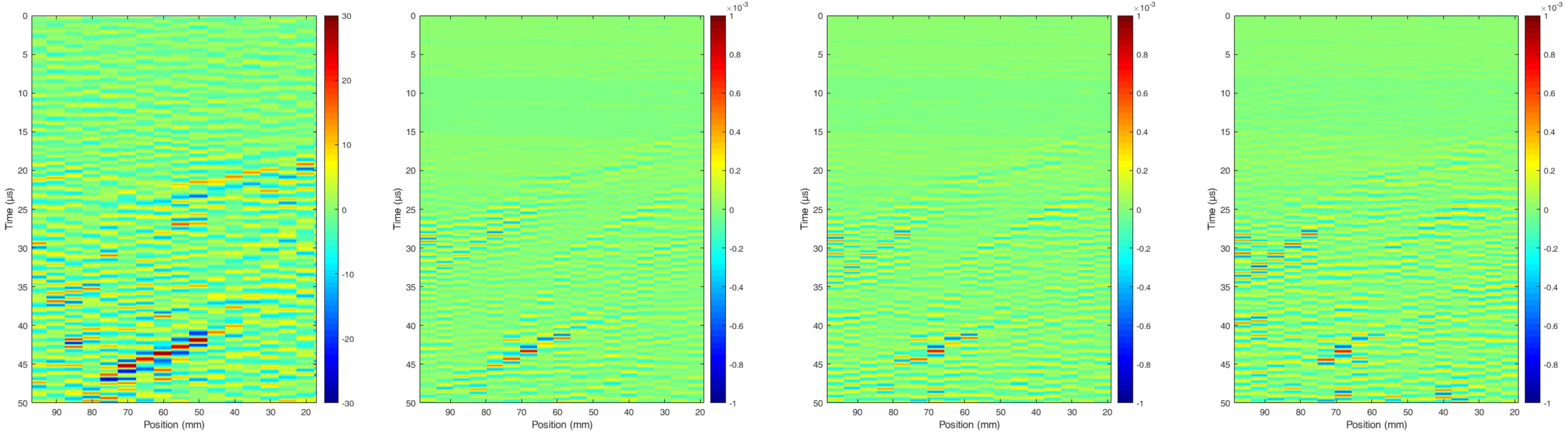


No Defect



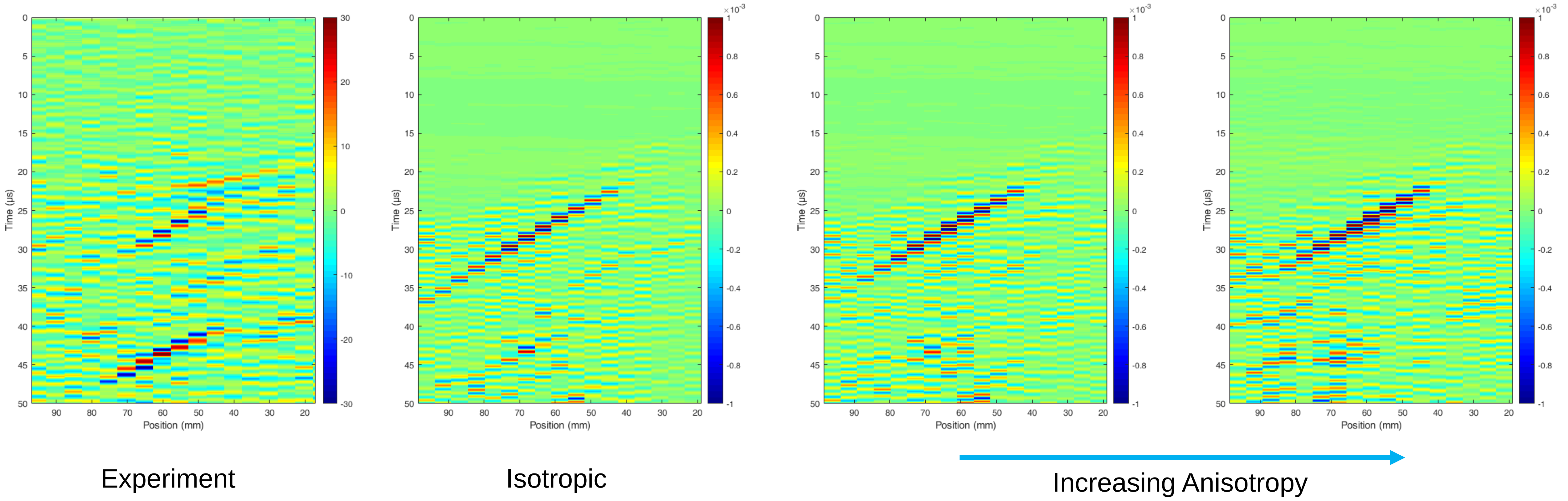
Defect

All – No Defect



Experiment | Isotropic | Increasing Anisotropy

All - Defect



Time (µs)
Position (mm)
×10^-3
Experiment
Isotropic
Increasing Anisotropy

Conclusions

- The results have shown a qualitative agreement between the experimental and simulated data for a challenging CASS sample.
- The results shown now incorporate inherent material noise due to the heterogenous and anisotropic properties.
- Simulation run times can be conducted on the time scale of a few hours.
- More research is currently underway and will continue to focus on:
  - Quantitatively assessing signal responses
  - Documenting the best practices for conducting ultrasonic testing of welding model
  - Comparison with other ultrasonic modeling software such as CIVA
- This study used CASS as the study case; however it can be expanded to other materials such as DMW and SS.

PNNL-SA-150337

Pacific Northwest
NATIONAL LABORATORY

Modeling and Simulation for Ultrasonic NDE

Richard E. Jacob, Matthew Prowant, and Aaron A. Diaz

Technical Information Exchange
January 2020

Sponsored by US NRC / Office of Research

Carol Nove, NRC COR

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Purpose

Goal of this Research: Provide a solid technical basis for conducting, interpreting, and applying ultrasonic modeling to assess the effectiveness of inspections of NPP components.

This presentation will focus on PNNL’s work to:

- Evaluate the usability of CIVA for predicting beam coverage in granular structures.
- Evaluate the effectiveness of models for predicting volumetric coverage and detecting flaws through austenitic welds.

Approach

- Thoroughly evaluate simulation tools (CIVA and UltraVision) and determine their potential usefulness for nuclear NDE.
  - Beam simulations
  - Flaw response simulations
  - Metamodels
  - Comparison with experimental data
- Create image similarity metrics for quantitatively comparing simulation results.
- Generate realistic models of austenitic welds and coarse-grain materials, including crystalline orientations.
- Evaluate the accuracy and usefulness of CIVA beam simulations and flaw response simulations through complex grain structures, such as:
  - Austenitic welds
  - Dissimilar metal welds
  - Coarse-grain CASS

Recent PNNL Reports on Modeling and Simulation

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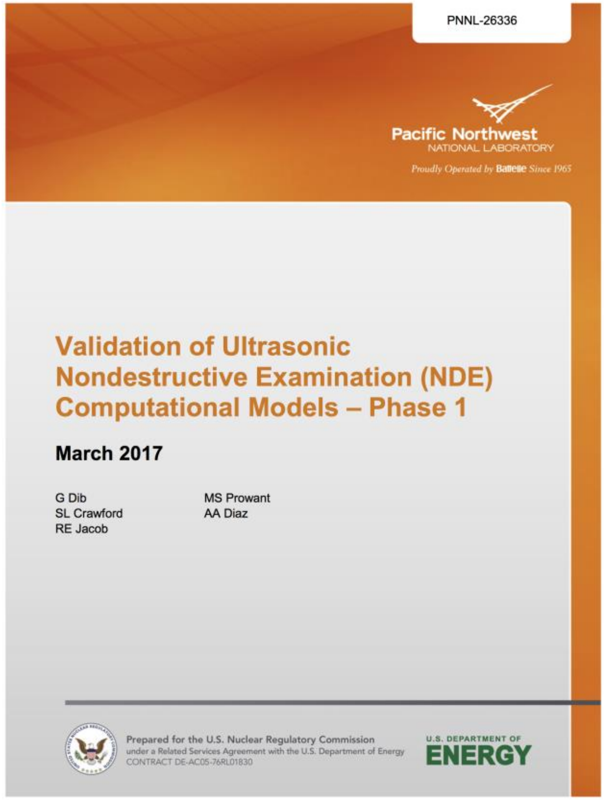
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Validation of Ultrasonic Nondestructive Examination (NDE) Computational Models – Phase 1

March 2017

G Dib
SL Crawford
RE Jacob
MS Prowant
AA Diaz

Prepared for the U.S. Nuclear Regulatory Commission
under a Related Services Agreement with the U.S. Department of Energy
CONTRACT DE-AC05-76RL01830

U.S. DEPARTMENT OF ENERGY

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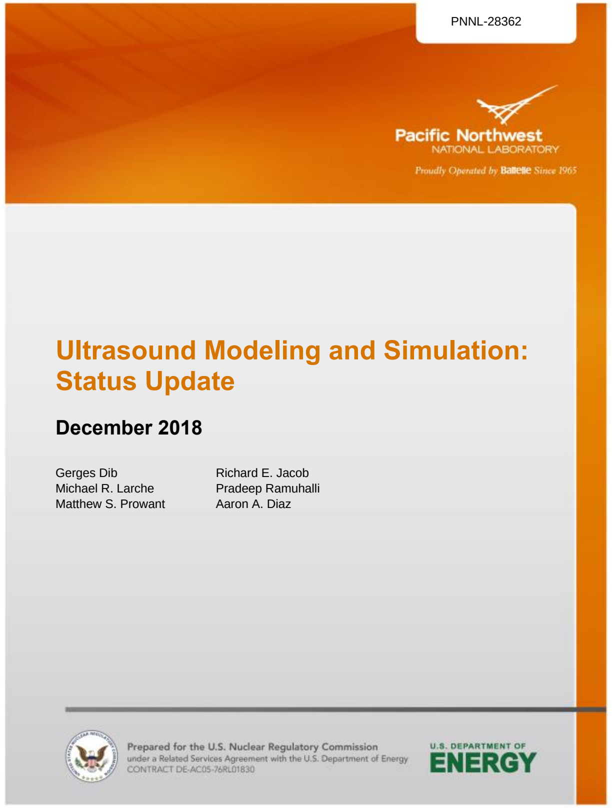
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Ultrasound Modeling and Simulation: Status Update

December 2018

Gerges Dib
Michael R. Larche
Matthew S. Prowant
Richard E. Jacob
Pradeep Ramuhalli
Aaron A. Diaz

Prepared for the U.S. Nuclear Regulatory Commission
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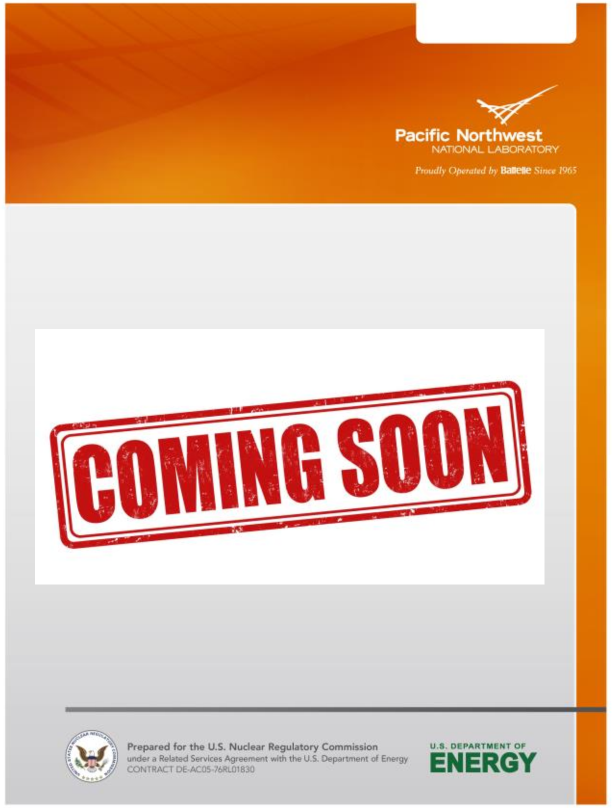
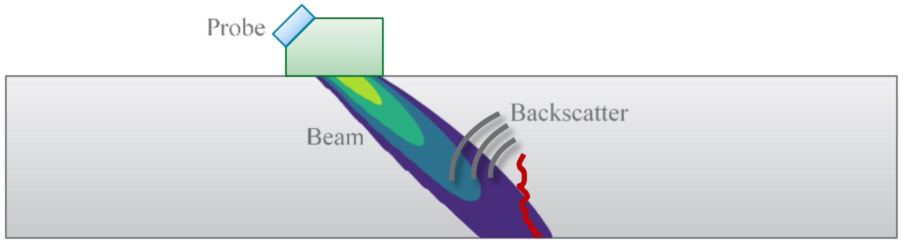


A new report is due to be published in spring of 2020

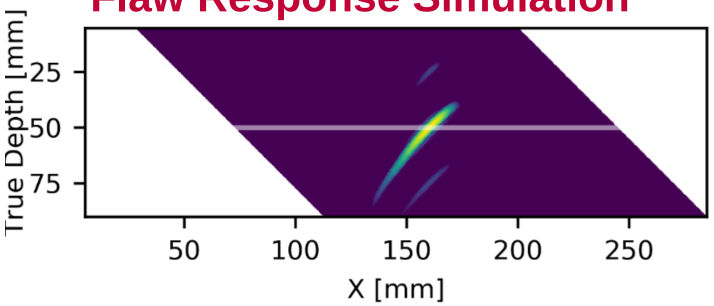
Key Concept Definitions

- Models are simplified approaches to approximating real-world outcomes.
- Models provide the framework for performing simulations.
- “Beam models” are used to simulate ultrasonic beam characteristics.
- “Flaw response models” are used to simulate the response from an insonified flaw.
- CIVA is a UT software package with both beam and flaw response models.
- UltraVision is a data acquisition and analysis tool that includes a beam model application.

Beam Simulation



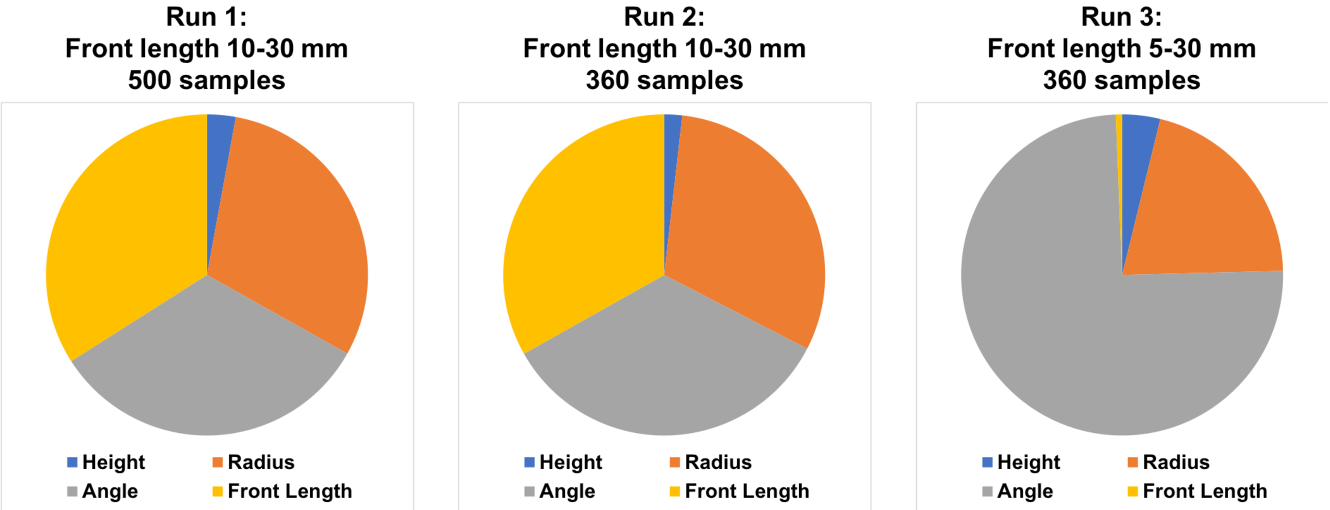
Flaw Response Simulation

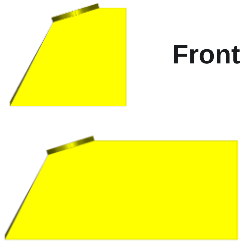


CIVA Metamodels

- CIVA provides a “metamodels” tool for rapid parametric studies and POD predictions.
- Small changes in input ranges can have a strong effect on resulting variable sensitivities.
- For example:
  - Wedge variables of height, angle, radius, and front length were variation parameters.
  - A small change in the front length range caused a huge change in results
- Metamodels should be used with caution. Use realistic input ranges and understand the effects of changing or adjusting parameters.

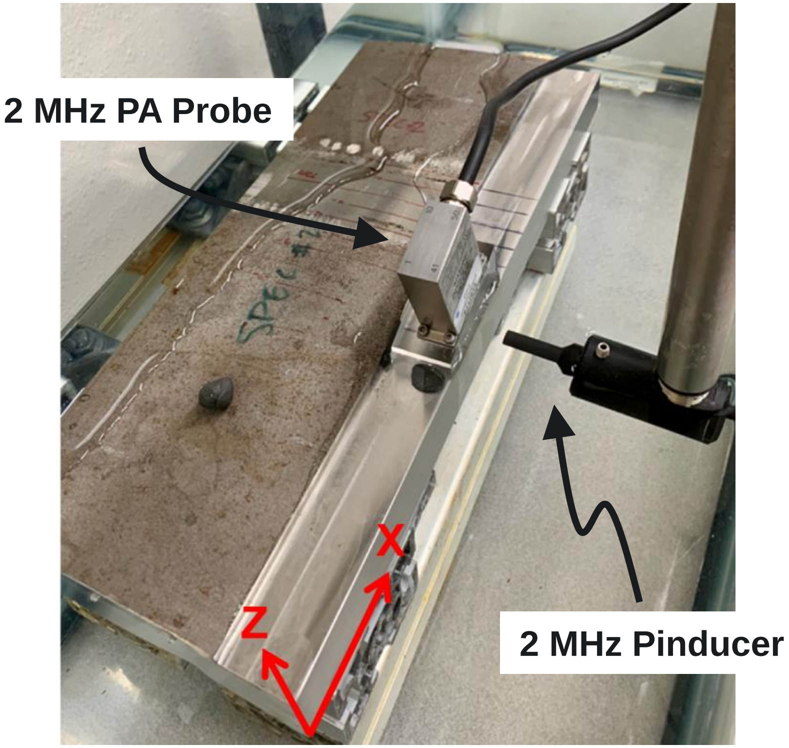
CIVA pie charts show the relative sensitivity of flaw response to each parameter

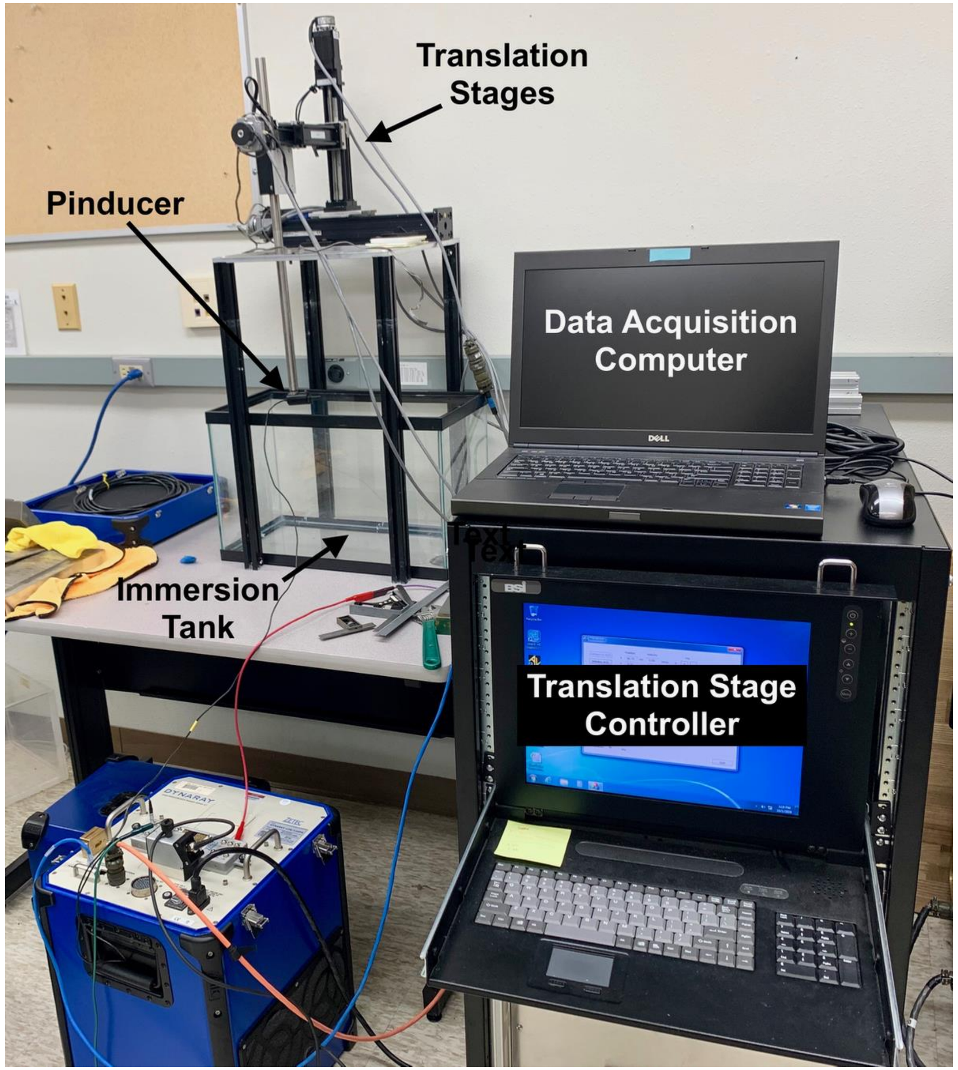




Effects of Weld Microstructure on Beam Simulations: Experimental Validation

- Measurements were taken on three weld specimens.
- A pencil probe, or pinducer, was used with water coupling to measure the side profile longitudinal sound fields from a 2 MHz 10x5 matrix phased array probe (transmit only).

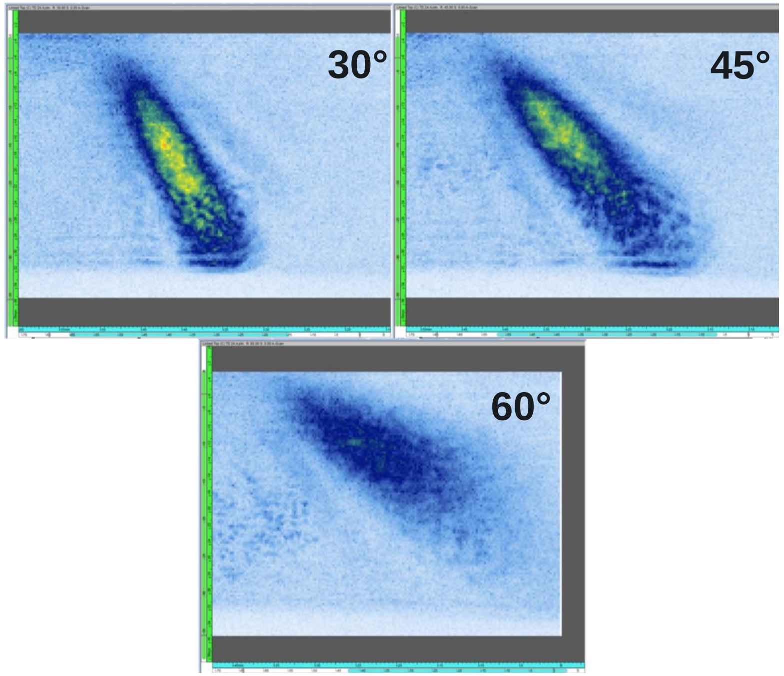


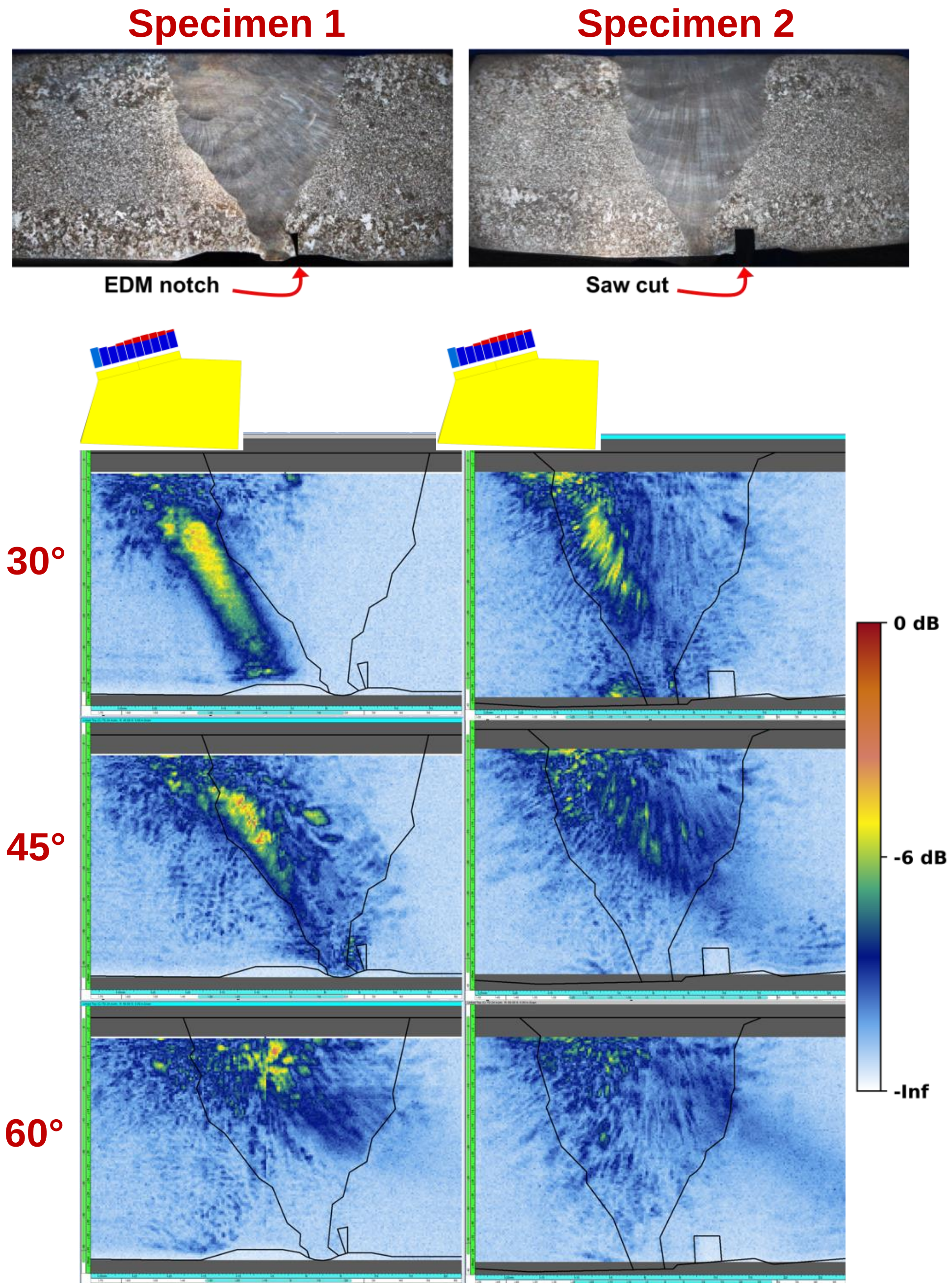


WSS-WSS Beam Maps

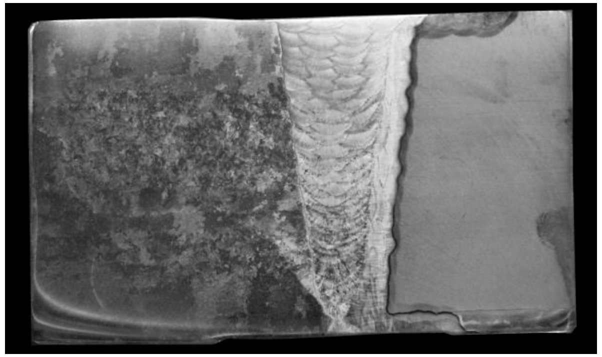
- WSS-WSS specimens, 36 mm thick
- 2 MHz PA probe with 24 mm true-depth focus
- 30°, 45°, and 60° focal laws

Parent Material Beam Maps

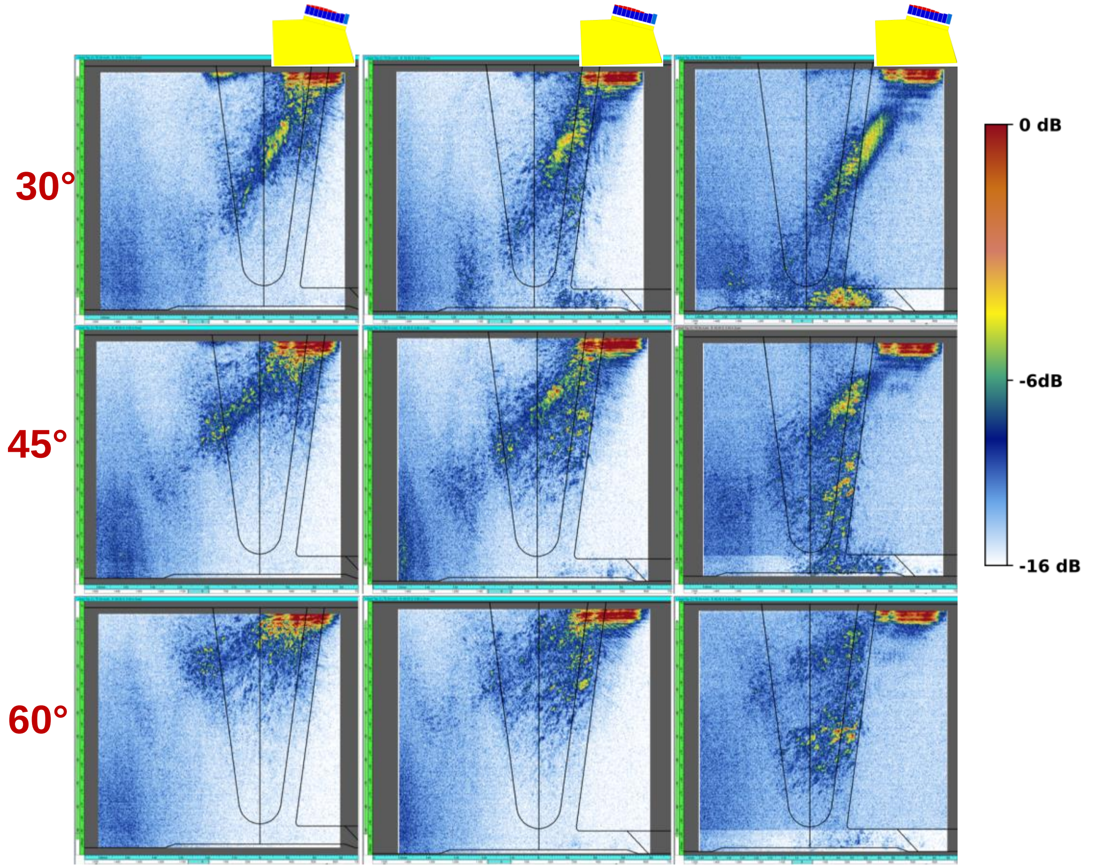




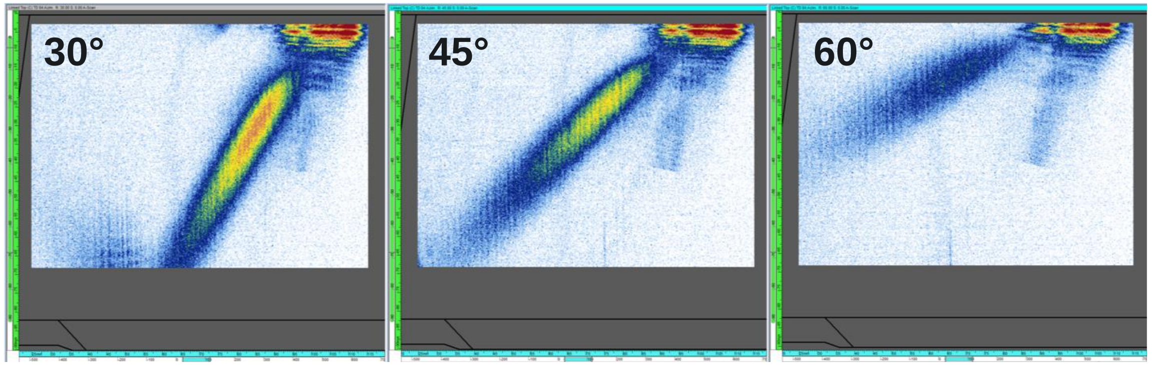
DMW Beam Maps



- CASS-CS specimens, 84 mm thick
- 2 MHz PA probe with 84 mm true-depth focus
- Probe placed on the CS side
- 30°, 45°, and 60° focal laws

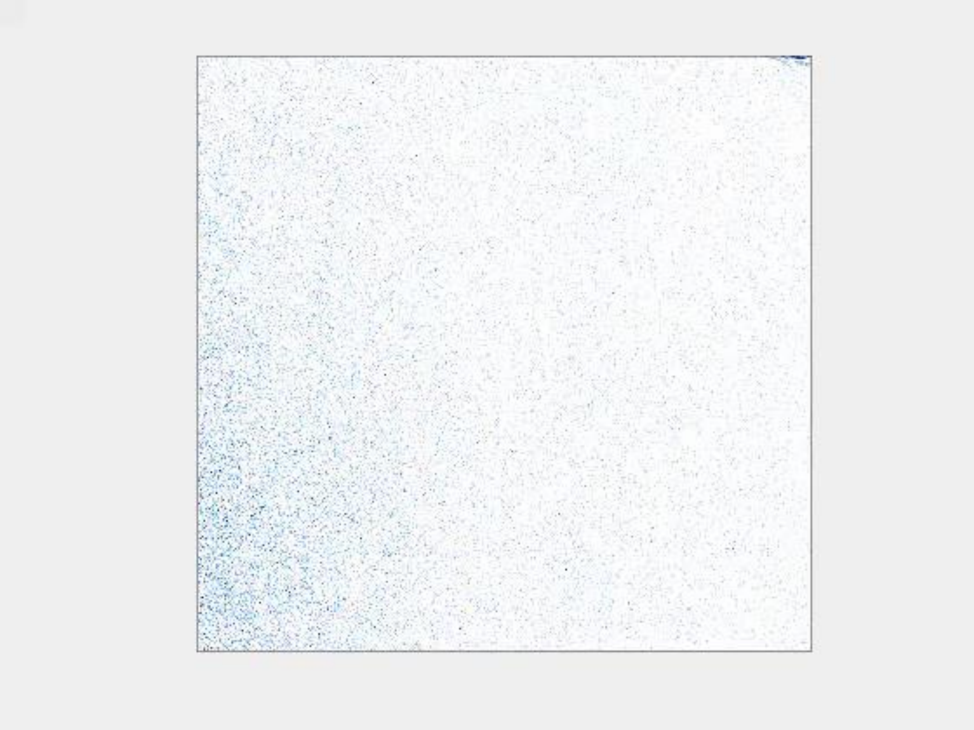


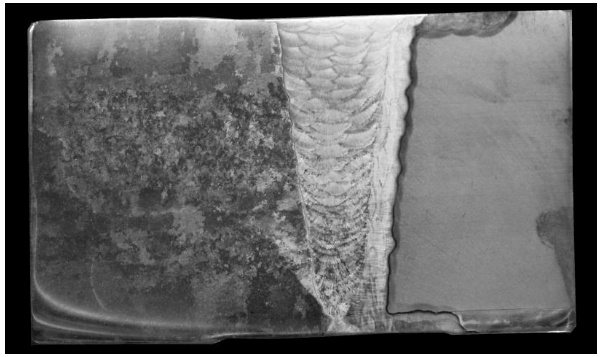
CS Parent Material Beam Maps

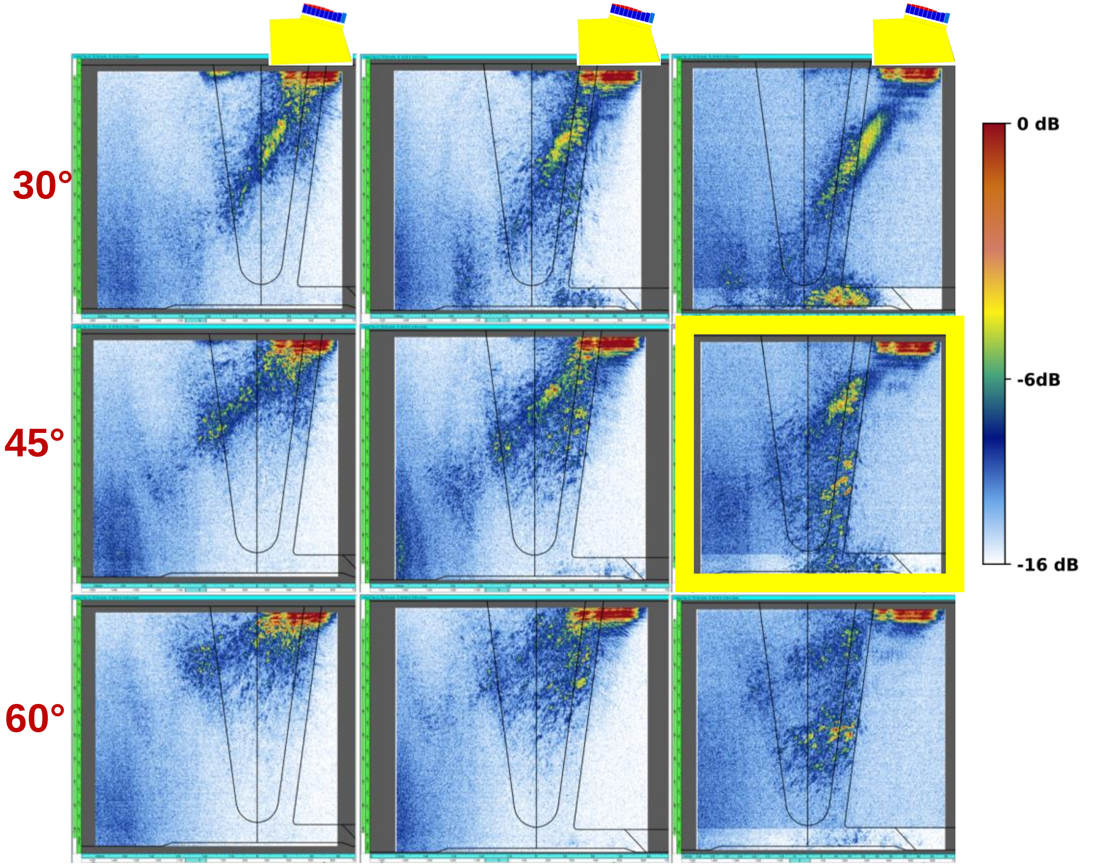


DMW Beam Maps

- Video shows the 45° focal law at the farthest probe position.

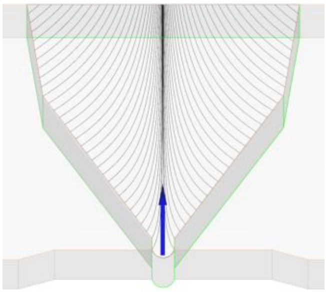






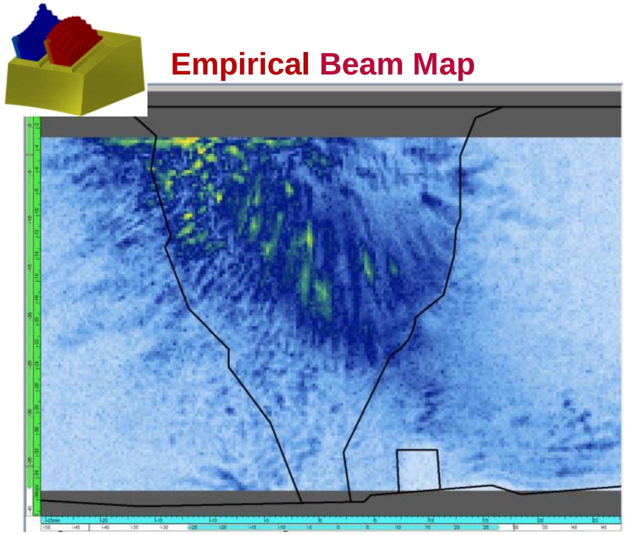
The Ogilvy Weld Model for Austenitic Beam Simulations

- The Ogilvy model is commonly used to approximate grain structures in austenitic welds because it is easy to implement and simulates some beam redirection.
- However, the Ogilvy model generates grains with continuously varying crystalline orientations.
- Seven simulations were run with the same Ogilvy model but using different stiffness matrix values from the literature.
- The Ogilvy model does not result in beam scatter and still allows for beam focusing – attributes not observed experimentally.

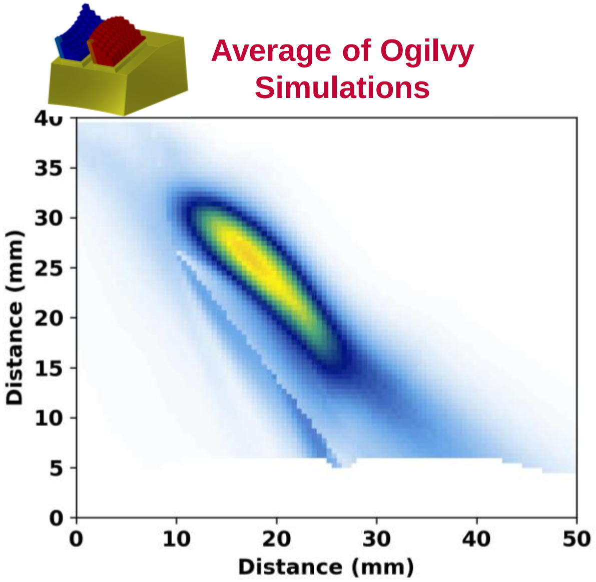


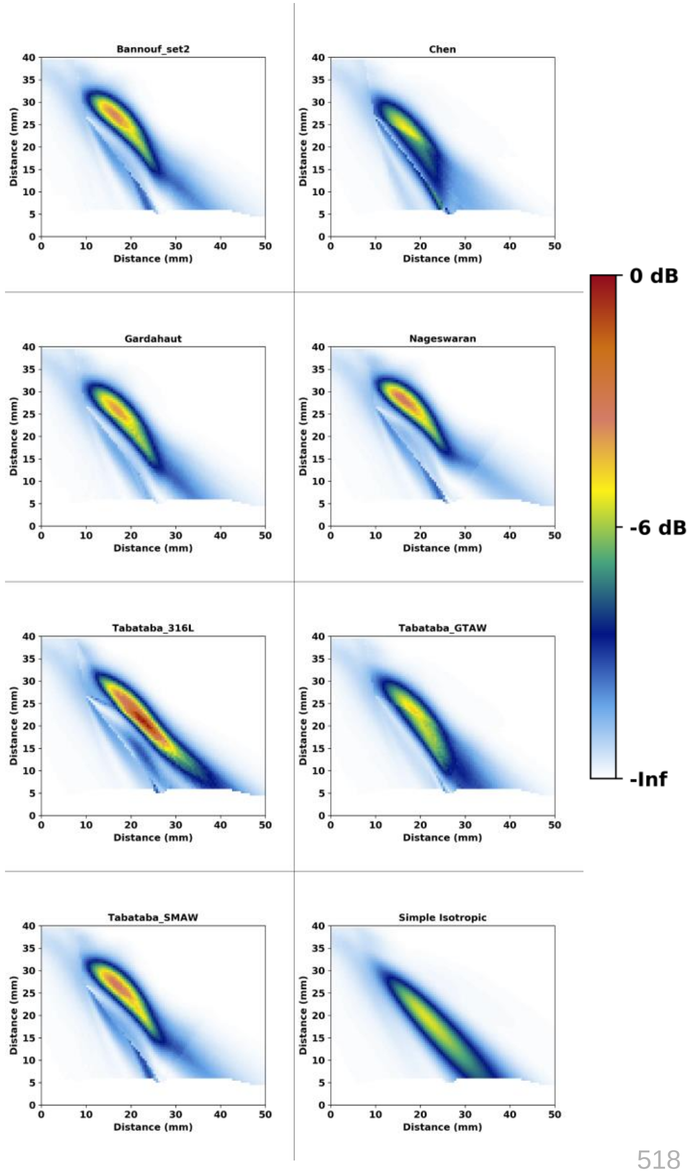
The Ogilvy model used for simulations

Empirical Beam Map



Average of Ogilvy Simulations

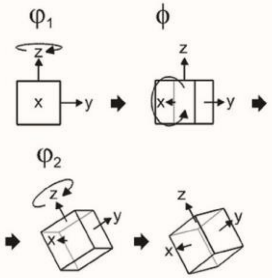




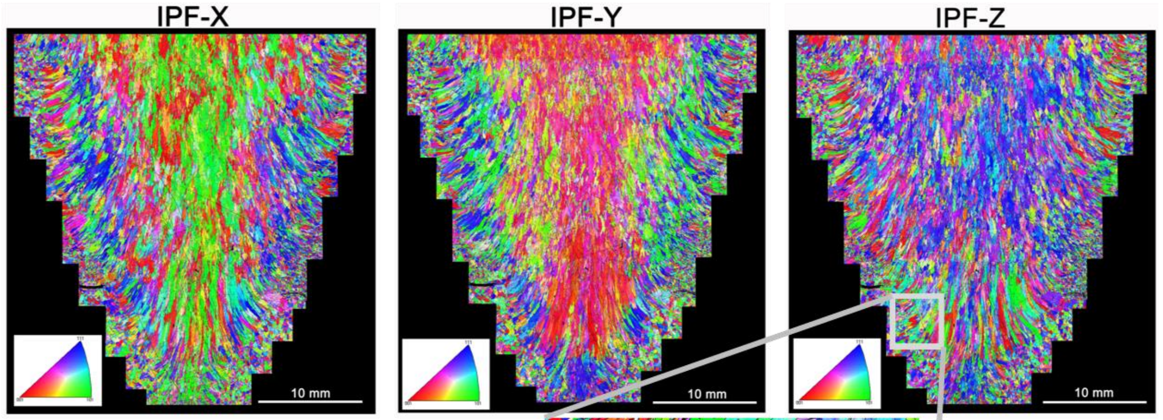
Weld Microstructure Characterization

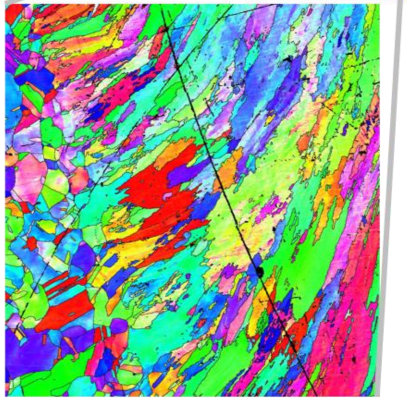
- A more realistic representation of weld microstructure was needed to provide a basis, or true-state, for modeling inputs.
- An austenitic weld sample was polished and etched to characterize the weld microstructure.
- Electron backscatter diffraction (EBSD) was employed to measure grain size and orientation.
  - The grain sizes were measured to 4 μm (0.00016 in.) resolution.
  - Grain crystal orientations (Euler angles) were also measured.

Euler angles are used to define grain orientations



Electron Backscatter Diffraction Results



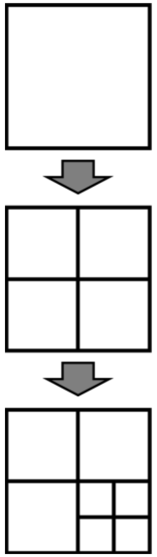


Each color represents a different grain orientation

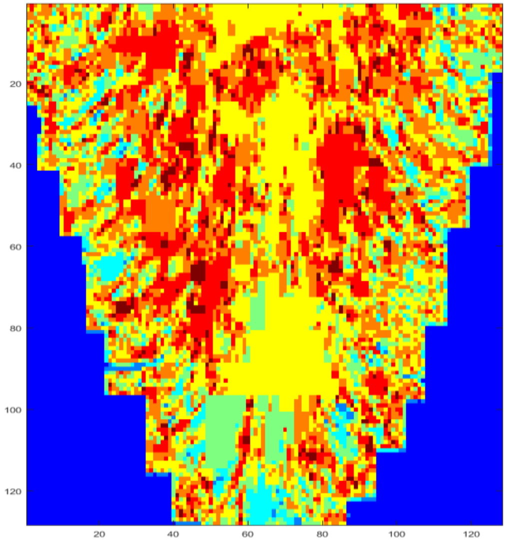
Weld Photograph

Weld Microstructure Downsampling

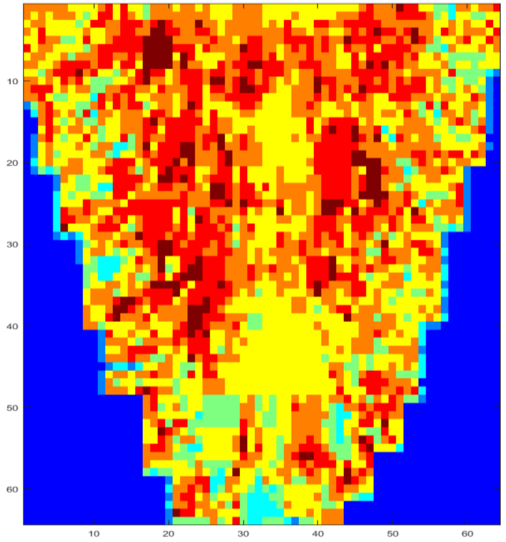
- What grain resolution is required to simulate the weld microstructure with sufficient accuracy while balancing simulation runtime?
- To test this, a quadtree decomposition was implemented to downsample the microstructure to varying levels of resolution: 256 pixels (≈ 40% λ at 2 MHz), 128 pixels (≈ 20% λ), and 64 pixels (64 pixels ≈ 10% λ).
- To further reduce complexity, Euler angles were grouped into discrete bins.
- Several weld cartograms of varying resolution were generated to test simulation sensitivity to weld microstructure parameters.



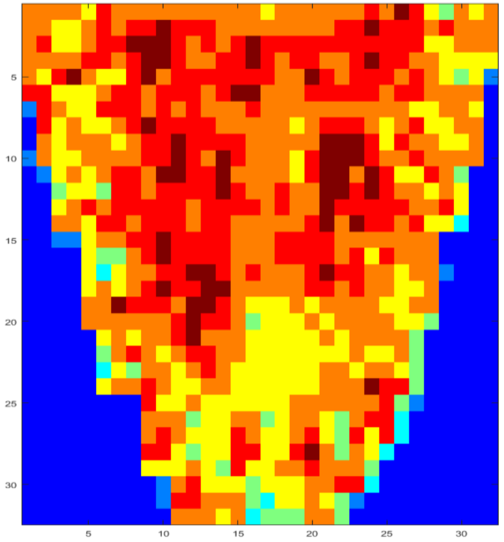
64 pixels



128 pixels

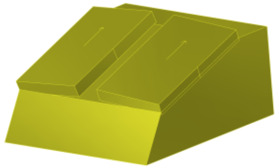


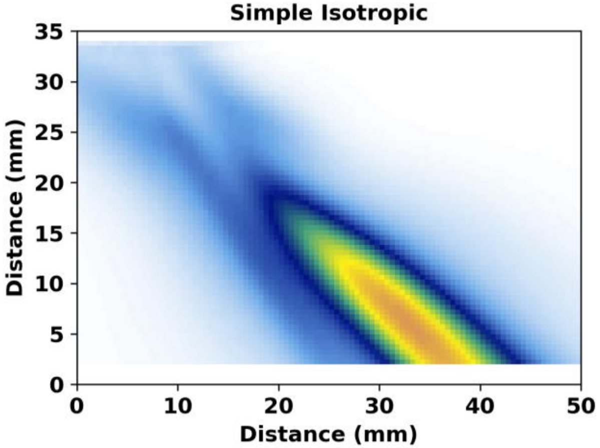
256 pixels

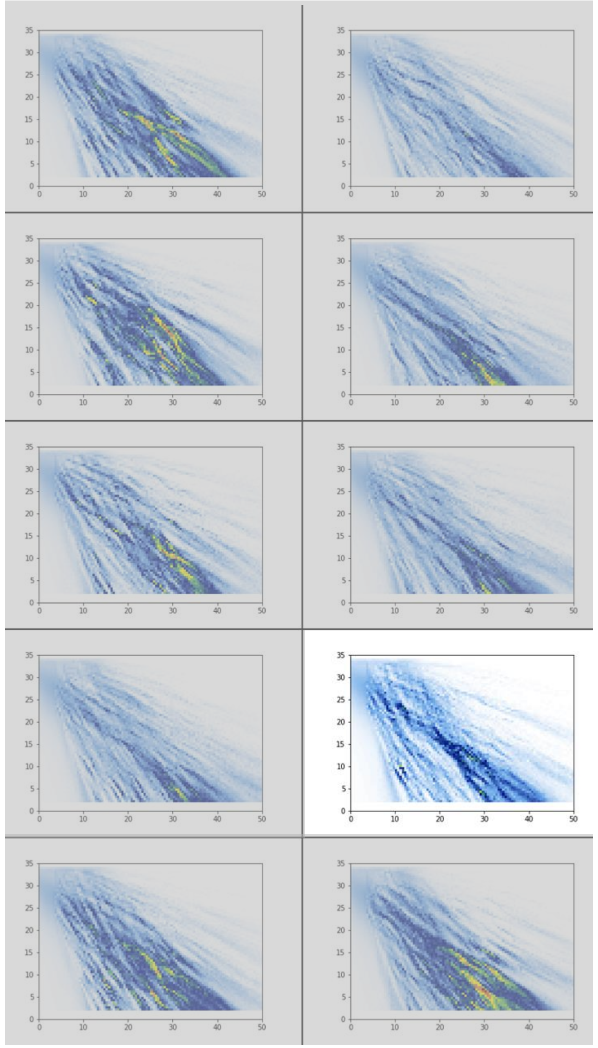


Through-weld Beam Simulations – TRL Probe

- Dual-element, 2 MHz TRL probe at 45°, 36 mm focal depth.
- To test beam variability with different grain orientations, 10 simulations were run with the same geometry but different Euler angles.
- Results were compared to the overall average by using image similarity metrics to determine the “most typical” case.
- The most typical case was then used in future simulations to represent a “typical” austenitic weld.







Average of 10 Simulations

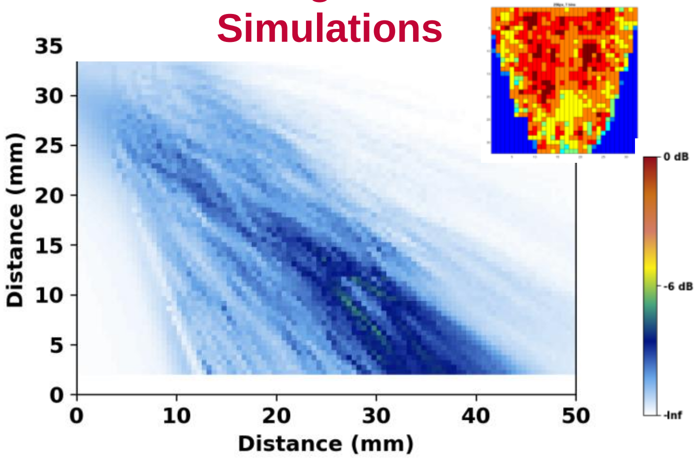
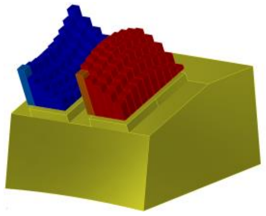


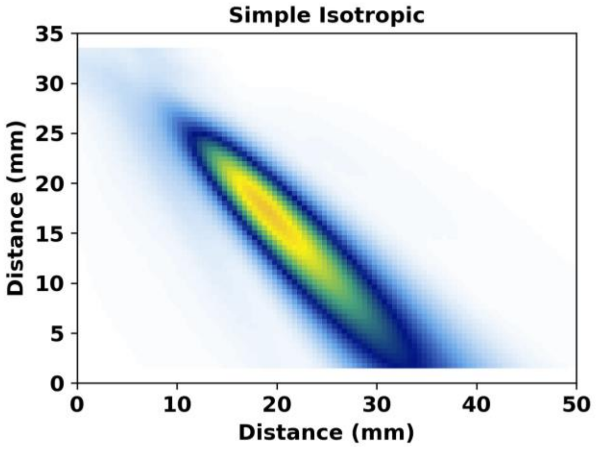
Image Similarity Metrics Compared to Average

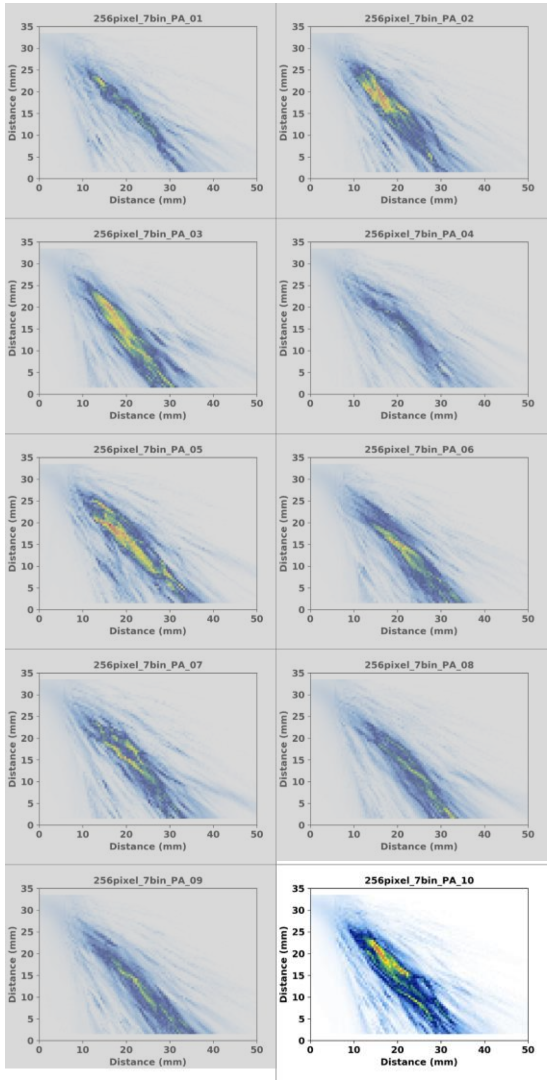
Case	ssim	mse	corrcoef
Average	1.000	0.000	1.000
isotropic	0.488	38.25	0.907
01	0.446	12.35	0.829
02	0.499	14.25	0.897
03	0.505	20.87	0.921
04	0.445	11.52	0.854
05	0.430	26.27	0.846
06	0.463	11.55	0.843
07	0.429	14.76	0.836
08	0.511	7.61	0.888
09	0.510	9.12	0.870
10	0.505	19.65	0.883

Through-weld Beam Simulations – PA Probe

- Dual-element, 2 MHz PA probe at 45°, 24 mm focal depth.
- 10 simulations, each with a set of 7 Euler angles.
- Results were quantitatively compared to the overall average to determine a nominal case.







Average of 10 Simulations

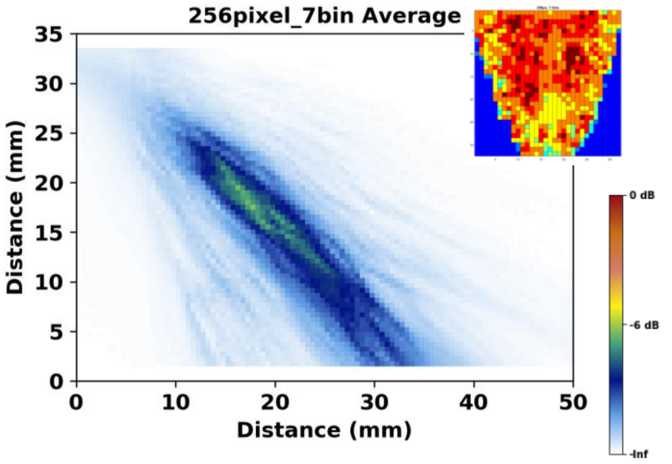
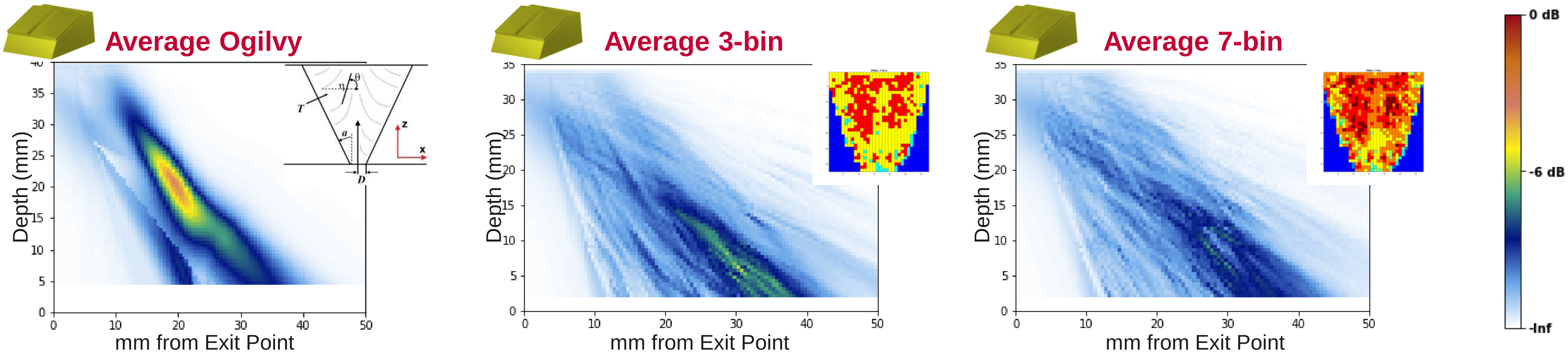


Image Similarity Metrics Compared to Average

Case	ssim	mse	corrcoef
Average	1.000	0.00	1.000
isotropic	0.648	3.24	0.967
01	0.588	1.93	0.871
02	0.639	2.35	0.920
03	0.592	3.54	0.890
04	0.613	1.90	0.892
05	0.543	3.37	0.919
06	0.618	1.34	0.932
07	0.606	1.53	0.917
08	0.642	1.20	0.923
09	0.638	1.02	0.934
10	0.658	1.62	0.943

Comparing Beam Simulation Results

- Ogilvy models show little beam scatter and good beam formation.
- Overall, the 3-bin and 7-bin results showed significant beam scatter and poor beam formation.
- The 7-bin results show less simulation-to-simulation variation in the beam pattern, which means the beam is being scattered more across the scan region.
- The 3-bin results show better beam formation, which means less scatter and more beam redirection.



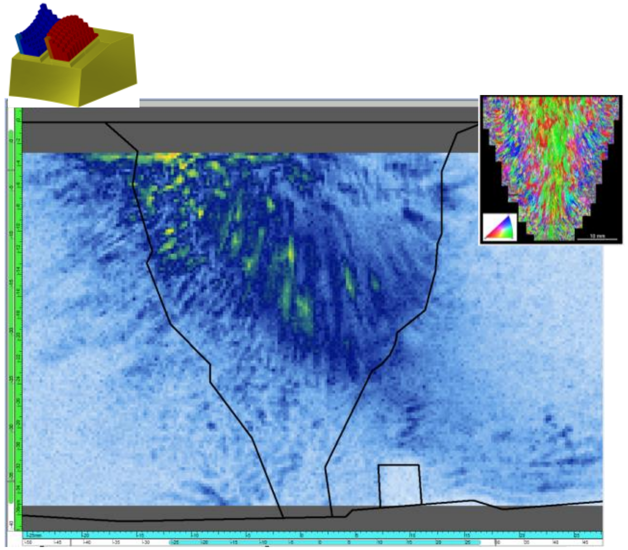
Average of 8 Simulations

Average of 10 Simulations

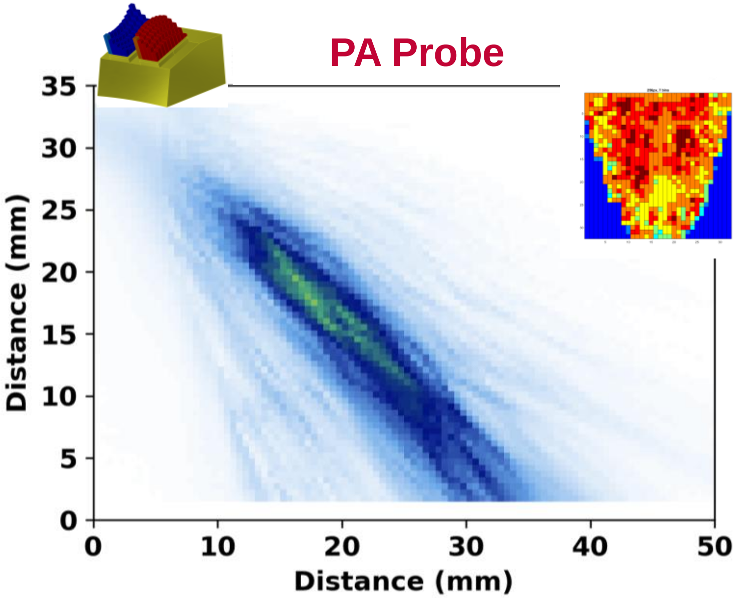
Average of 10 Simulations

Comparing Beam Simulation Results

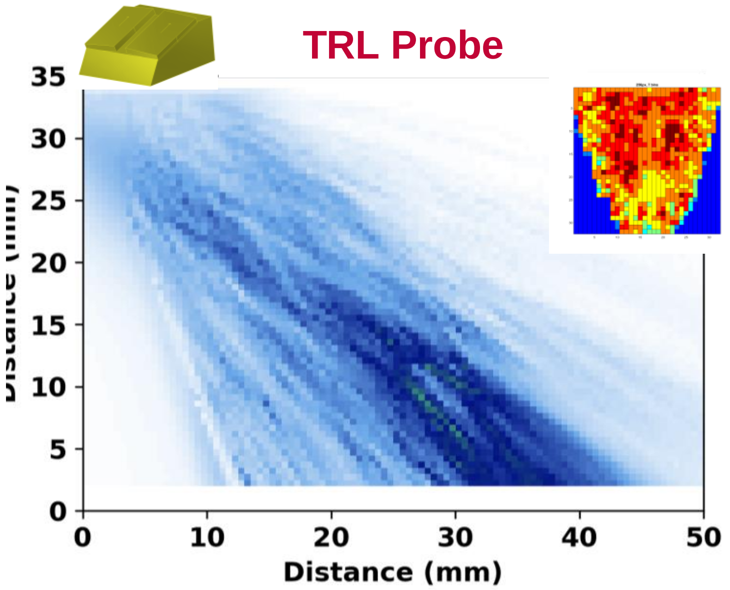
- The simulations show unrealistically high levels of beam formation and sound penetration through the weld.
- The empirical beam shows almost no far-side backwall insonification, little insonification of the inner 1/3 volume, and much more near-OD scatter.
- Model shortcomings include:
  - Lack of attenuation
  - Grain sizes too large
  - Limited number of Euler angles
  - No mode conversions or interface interactions



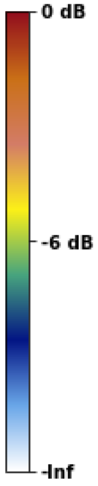
Empirical
Sscan, 45°



Average of 10 Simulations

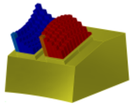


Average of 10 Simulations



Attenuation

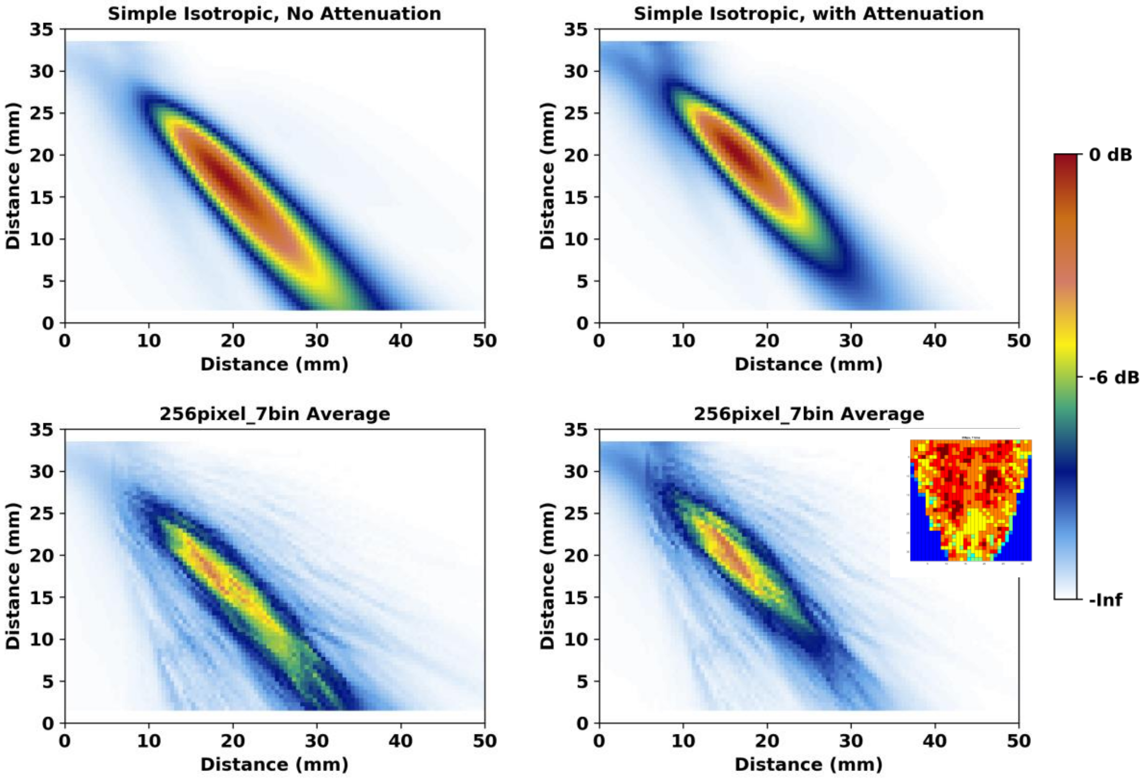
- Adding attenuation to the models helps bring results more in line with empirical data
- 2 MHz PA probe, WSS-WSS Specimen.

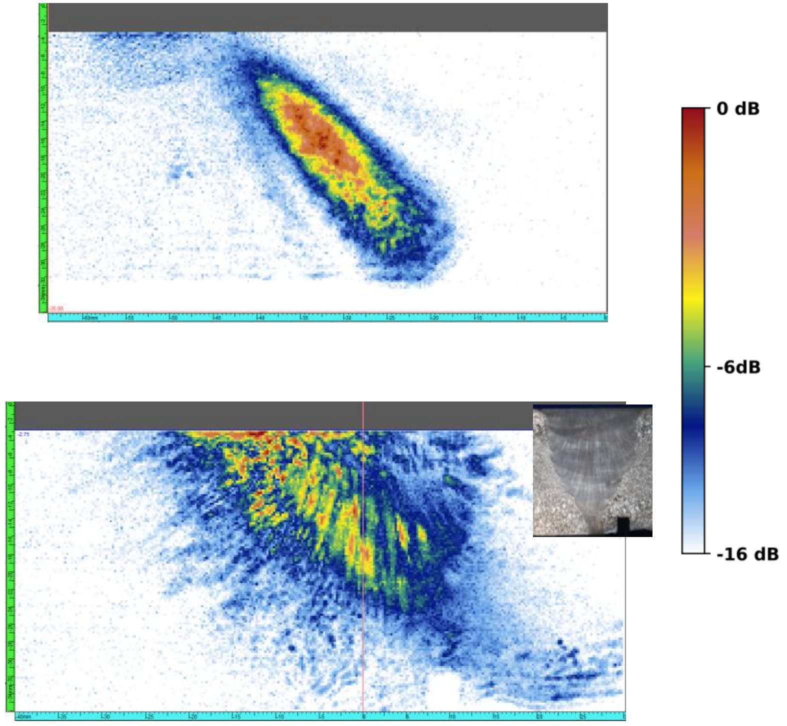


No Attenuation | **0.2 dB/mm Attenuation** | **Beam Maps**

Isotropic

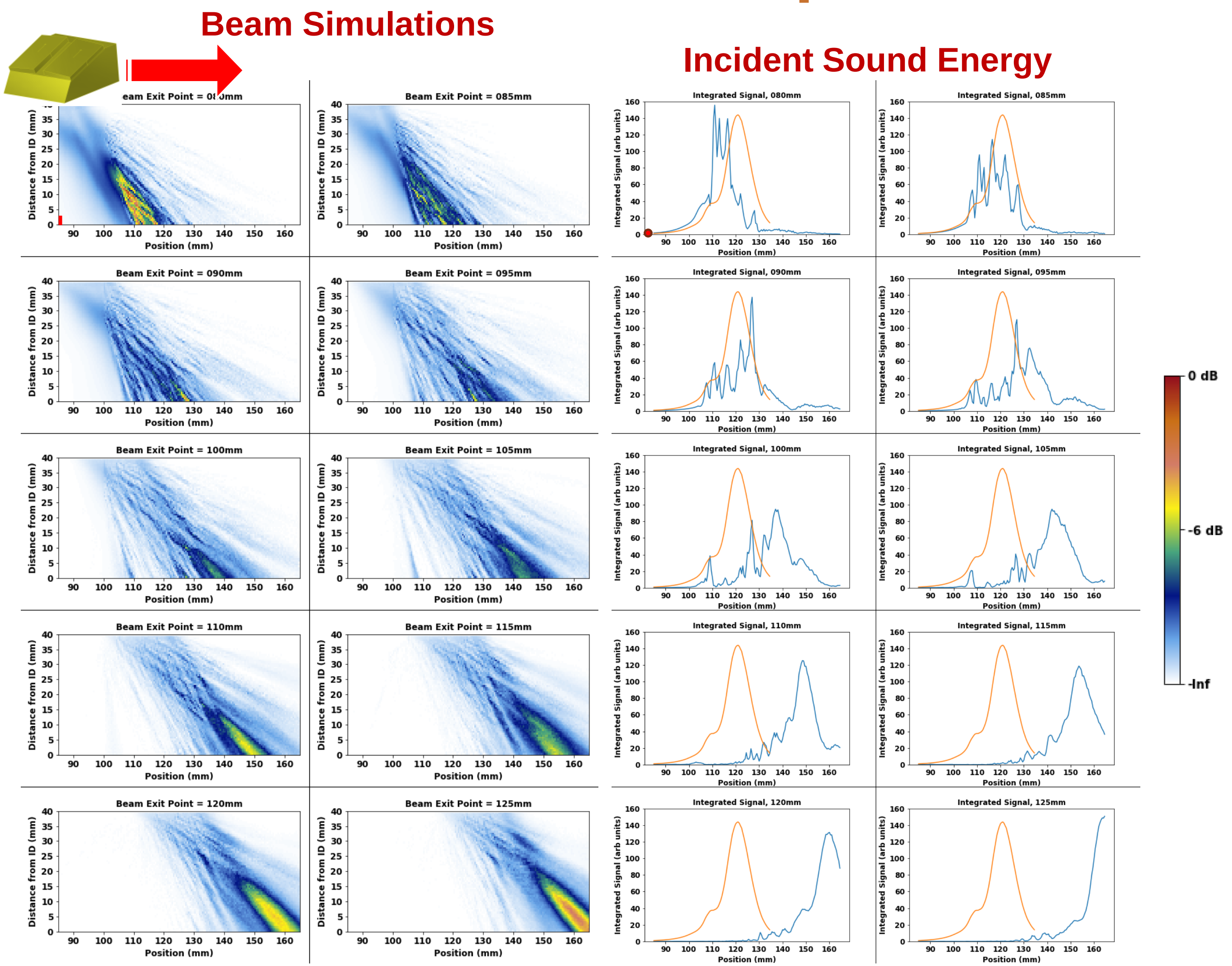
Through-weld





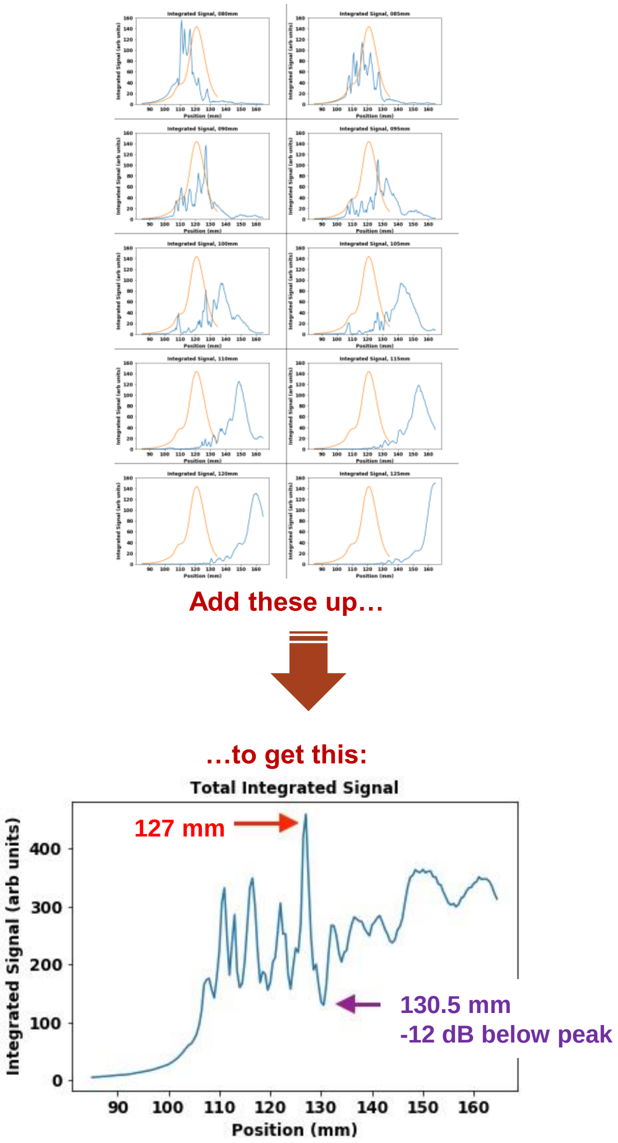
Beam Simulations to Predict Flaw Response

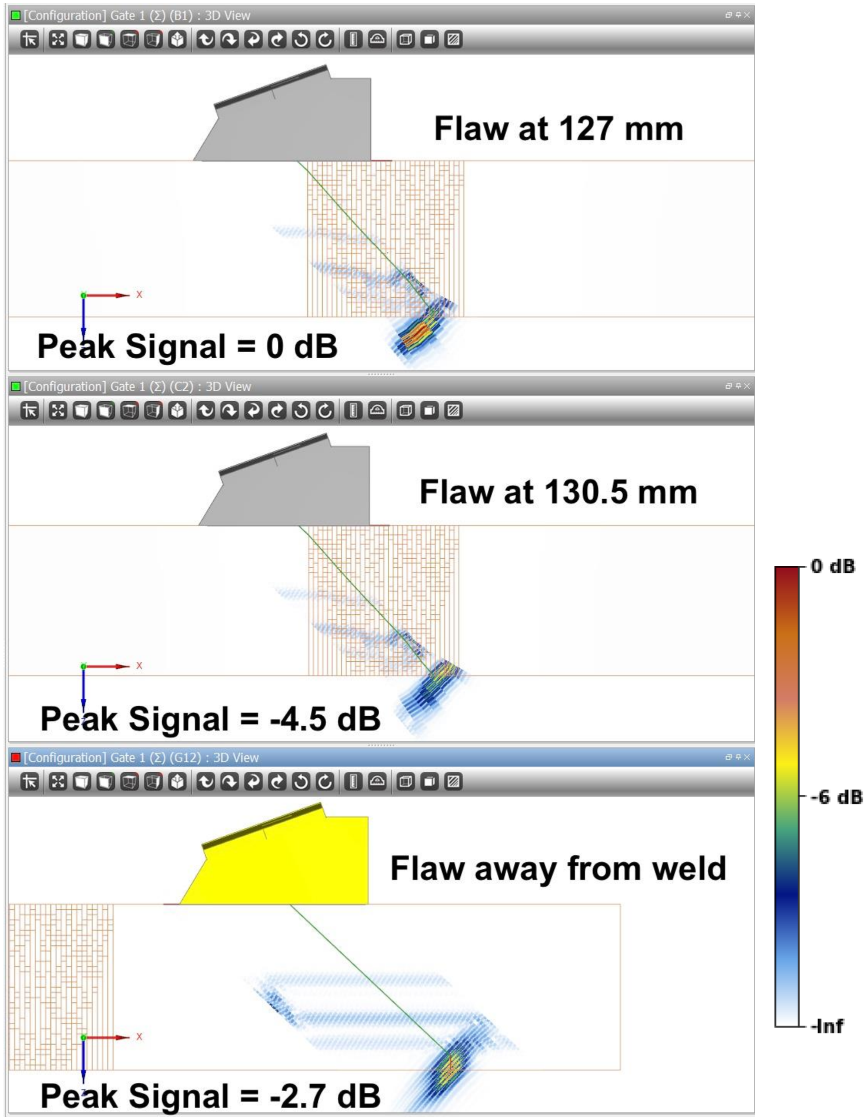
- Beam simulations of a 2 MHz TRL probe scanning across the weld with 5 mm steps
- Sound energy hitting a 3 mm flaw across the entire ID was measured to simulate a corner response
- Graphs of sound energy hitting the flaw were made for each probe position
- Blue lines show the weld simulations, orange lines show the isotropic case
- Local peaks in sound energy indicate localized beam focusing



Beam Simulations vs Flaw Response Simulations

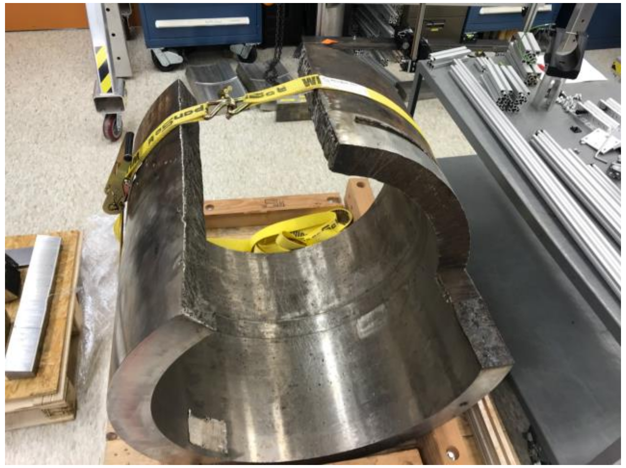
- All the blue lines were added to get a total sound incident on the ”flaw”.
- A local peak and trough were identified 3.5 mm from one another.
- Flaw response simulations were run with a 3 mm “flaw” at the two locations.
- Results show a higher flaw response at the peak position than at either the trough position or the control (isotropic) position.
- The flaw position can make a big difference in signal response based only on what the weld region is doing to the sound beam.



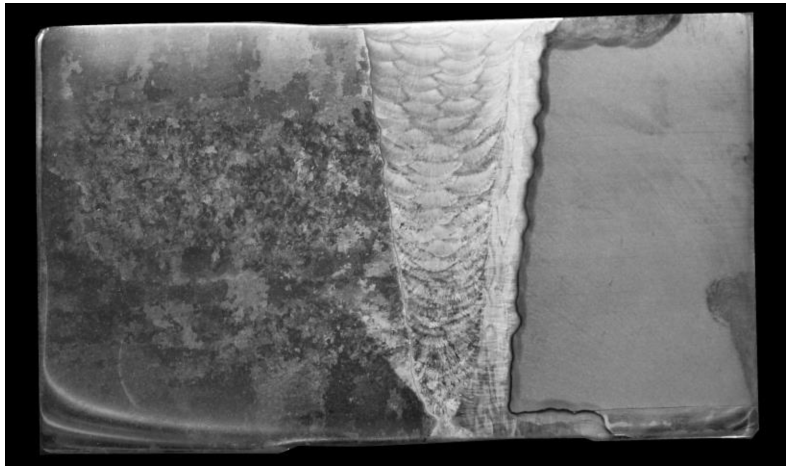


DMW Model

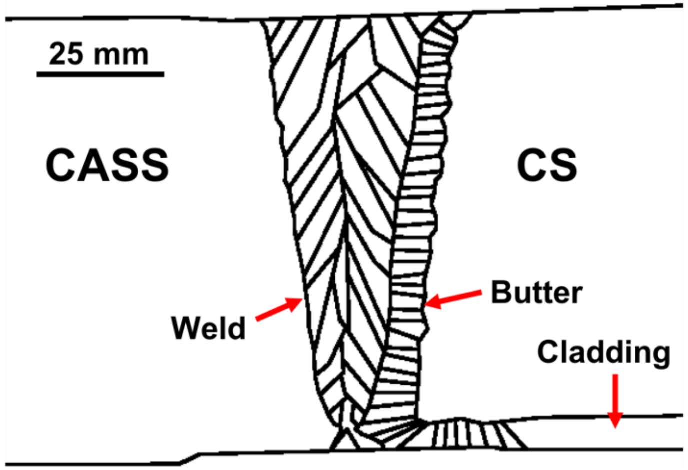
- Thick-wall CASS-CS DMW mockup
- A coarse-grain weld model was developed for initial simulations using a polished section.
- Substituted WSS for CASS to work around a limitation in CIVA for defining grains in the CASS side.
- 10 sets of Euler angles were randomly assigned to the different grains.



Thick-wall DMW mockup
See ML19255J814



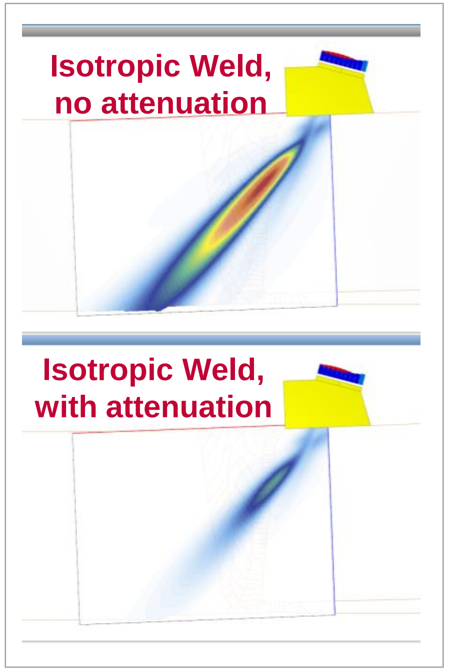
Polished and etched weld region

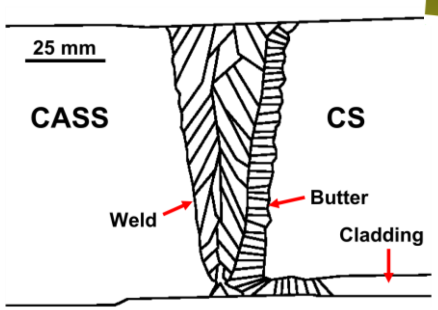


Sketch of weld region to define grain boundaries

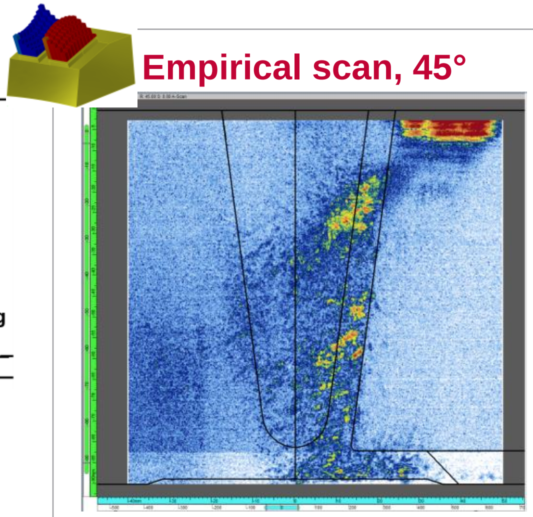
DMW Simulation Results

- 2 MHz PA probe with 84 mm focal depth and 0.1 dB/mm attenuation.
- Simulated scatter does not reflect beam maps.
- Stochastic and geometric scattering predominated in simulation results.
- The model grains are too large to provide realistic beam scatter.

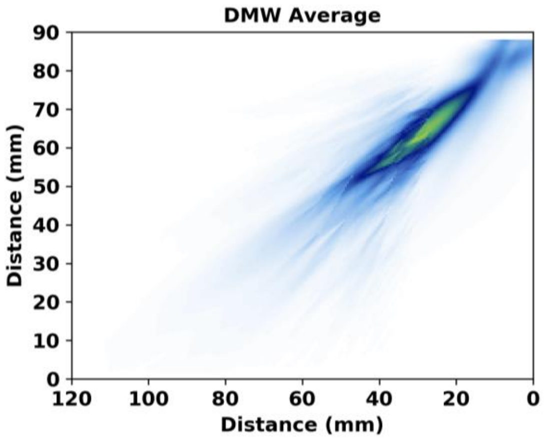


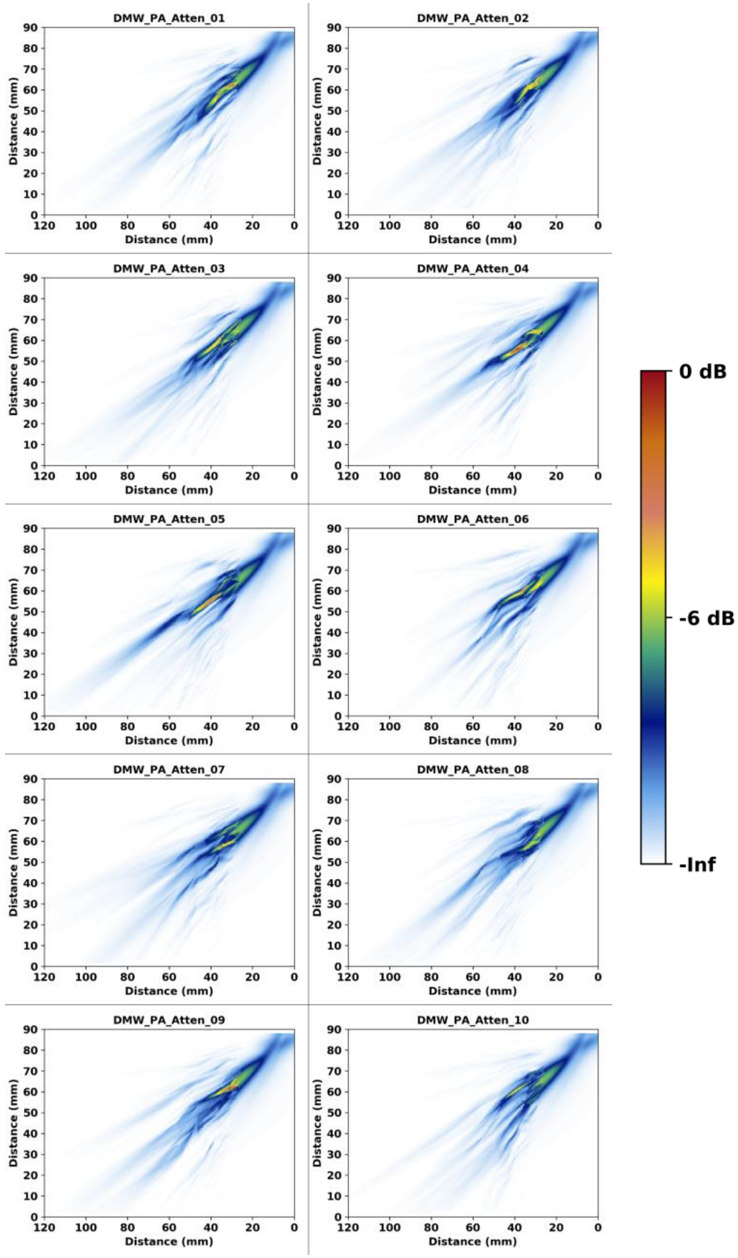


Empirical scan, 45°



Average of 10 Simulations

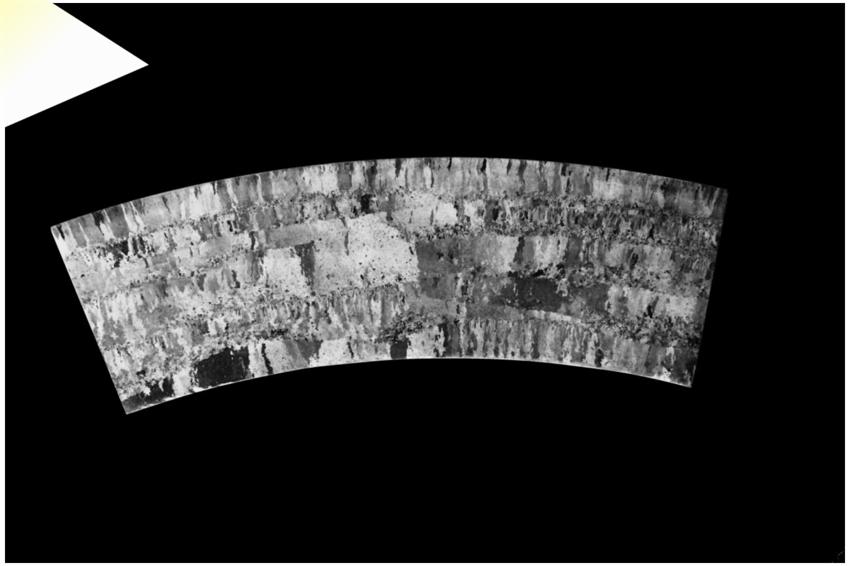


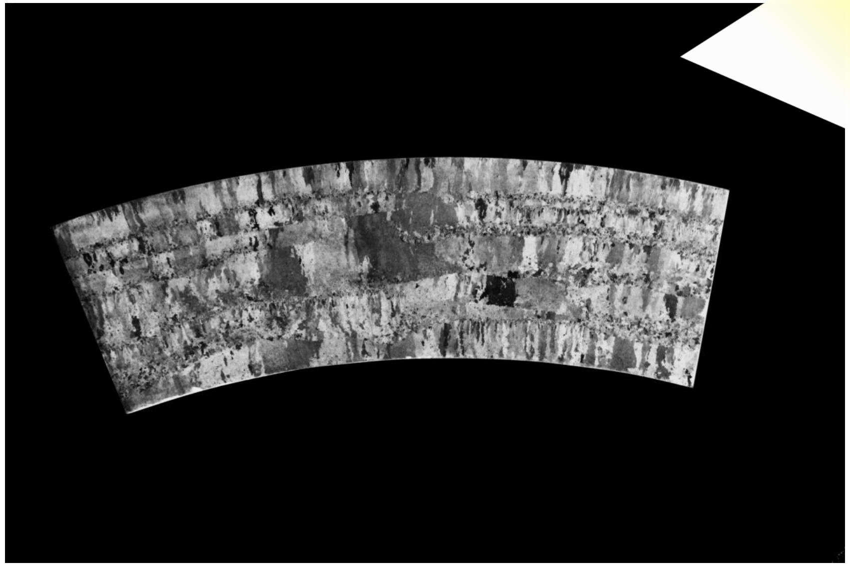


Simulations with Realistic Grain Boundaries

- Simulations in coarse-grained CASS materials require grain boundary definitions
- Photographs from multiple illumination angles capture the grain boundaries of polished and etched sections
- Appearance of grain reflections depends on incident light angle

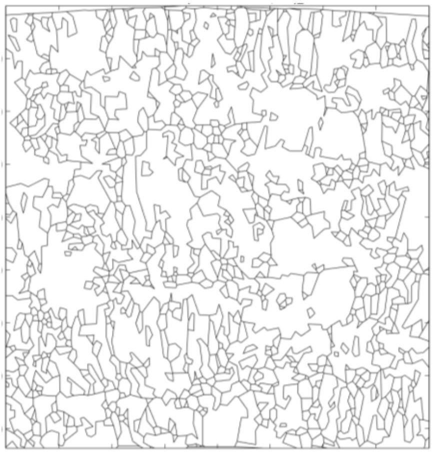
Same specimen in both photos



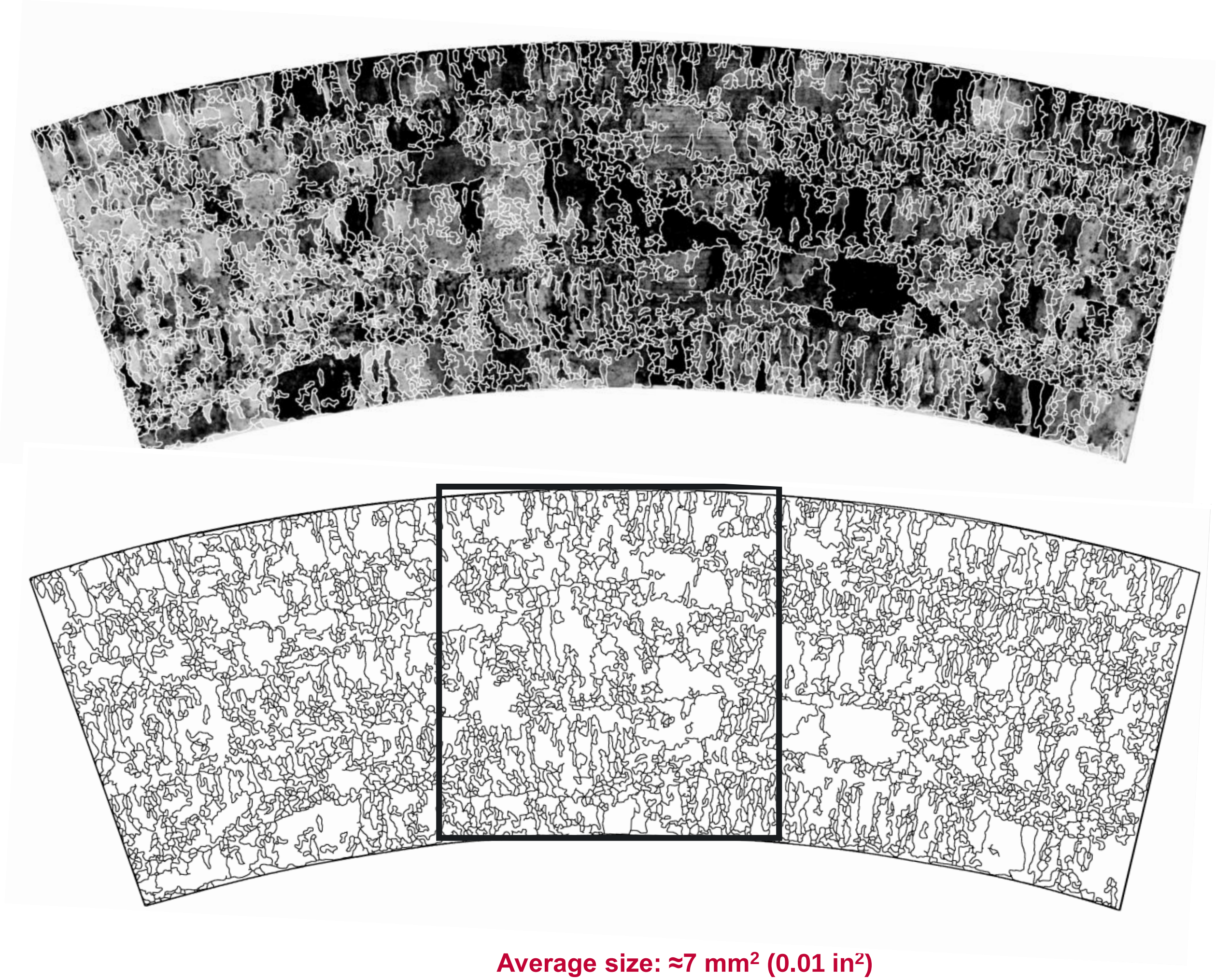


Identify and Outline the Grain Boundaries

- Photos were processed and filtered to highlight and outline grain boundaries.
- Grains smaller than ~1/10 the sound wavelength at 1 MHz were removed.
- Curved grain boundary outlines were made into straight line segments to generate a CAD file.
- The CAD file can be imported into CIVA.



Subsection of specimen with straight line segments used in simulations

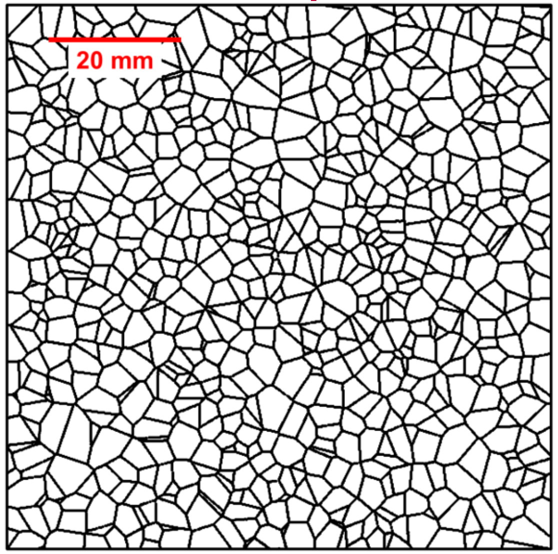


Average size: ≈7 mm^2 (0.01 in^2)
Median size: ≈2 mm^2 (0.003 in^2)

Realistic Geometries vs CIVA-generated Models

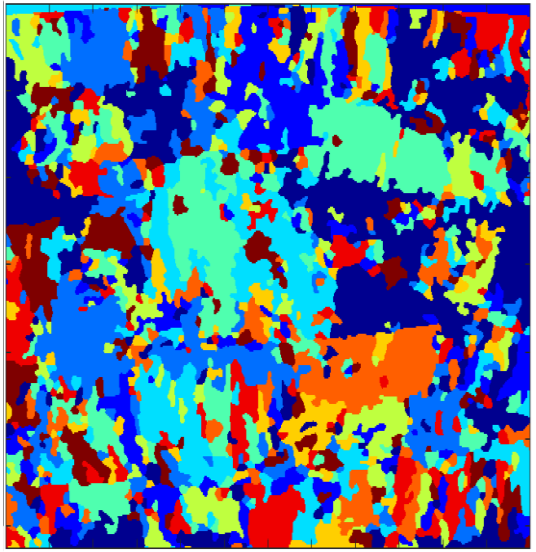
- CIVA can automatically generate random Voronoi regions to imitate coarse-grained geometries. To compare simulation results, the number of Voronoi regions and course-grained regions was the same.
- For the coarse-grained model, 10 Euler angles were assigned at random, and stiffness matrix values were taken from the literature.
- CIVA does not assign Euler angles to the Voronoi regions; instead it assigns different propagation velocities.

Voronoi, Equiaxed



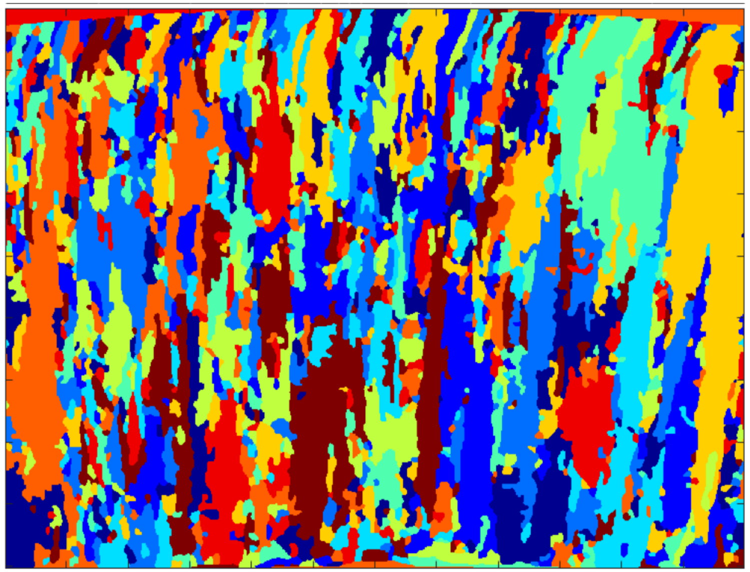
Voronoi:
- **810 regions**
- **7 mm^2 avg.**
- **26 mm^2 max.**

Coarse-grain Equiaxed



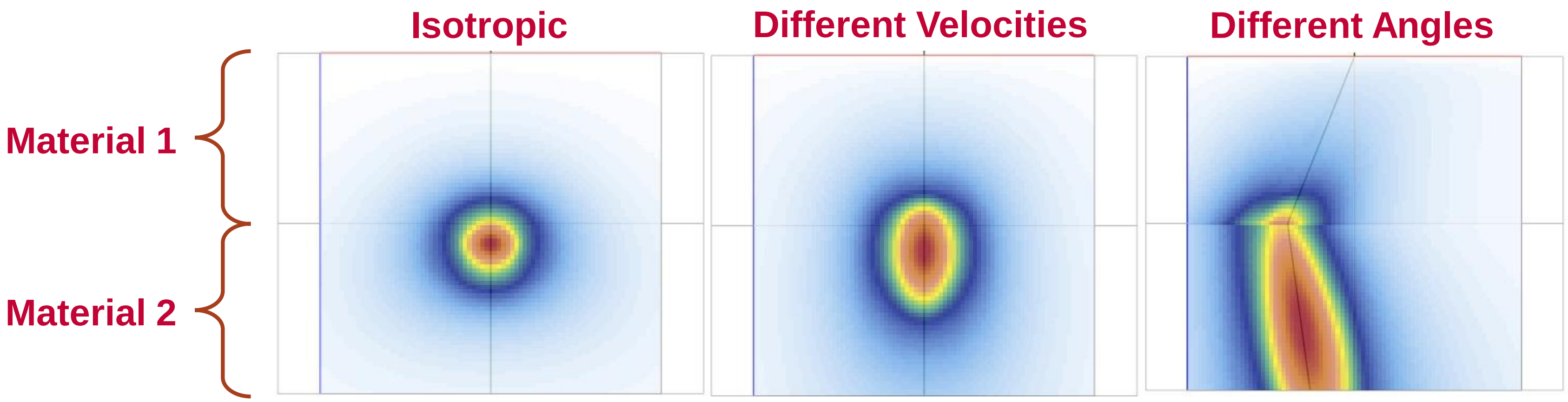
Coarse grain:
- **810 regions**
- **7 mm^2 avg.**
- **430 mm^2 max.**

Columnar



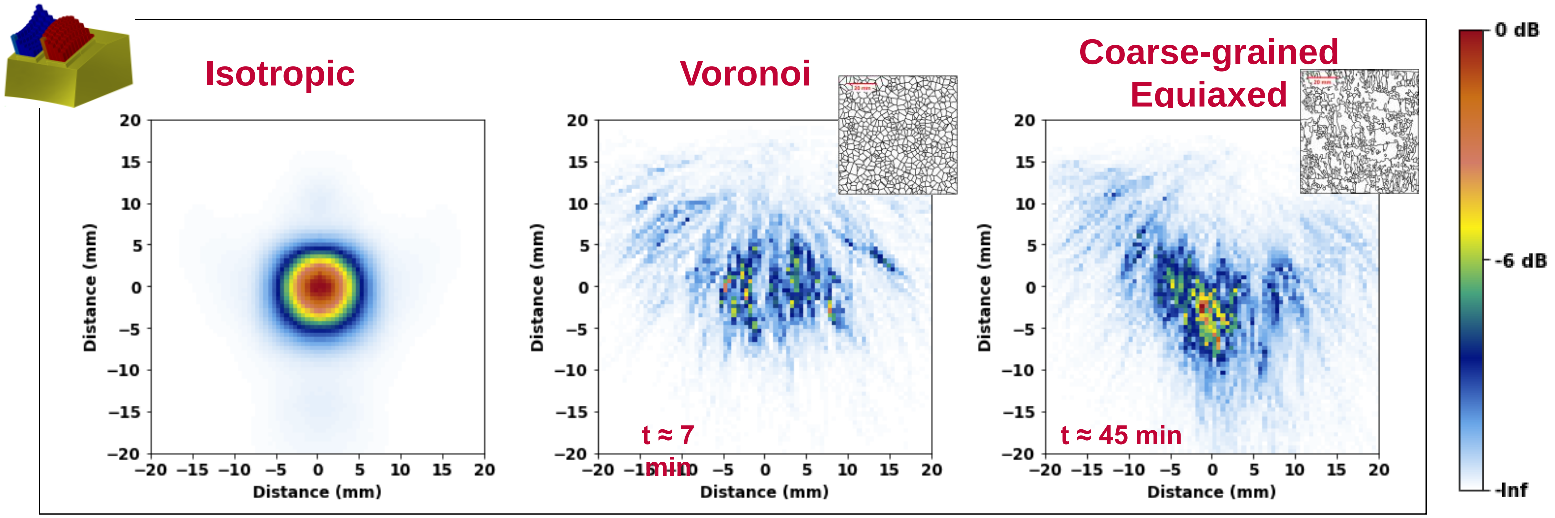
The Effect of Euler Angles on Beam Propagation

- CIVA uses velocity differences in the Voronoi model to simulate grain-to-grain changes in sound propagation.
- In the coarse-grained model (and real specimens), Euler angles affect the direction of preferred sound propagation by changing the crystalline orientation, but not the sound velocity.
- With hundreds of grains, the problem is essentially reduced to a “random walk” diffusion. Does the distinction still matter?

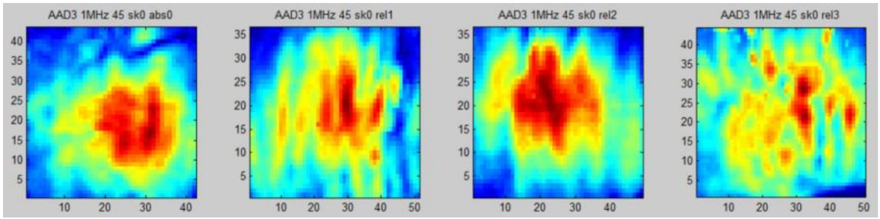


Coarse-grained Beam Simulation Results

- CIVA simulations were run with a 1 MHz phased-array probe and a 45° refraction angle. The beam was focused in the simulation plane to be consistent with experimental setup.
- Results show significant beam scatter in both coarse-grained scenarios.
- Beam scatter in the Voronoi case is qualitatively similar to that in the coarse-grain case.
- Simulation results are consistent with experimental results on the same specimen.



Experimental Results*

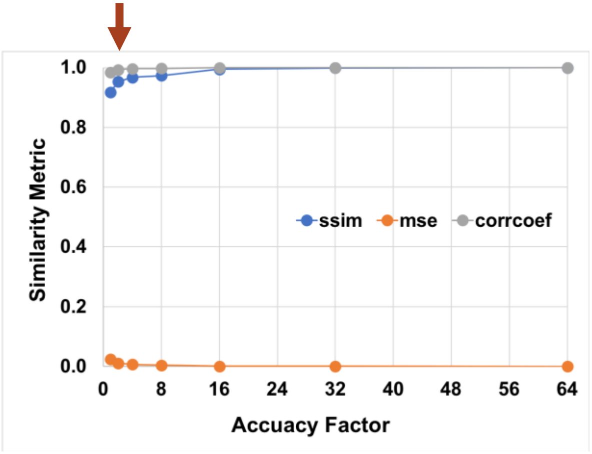


*From Crawford, et al., "Phased Array Ultrasonic Field Mapping in Cast Austenitic Stainless Steel." ML14155A165. 2014. Figure B.46.

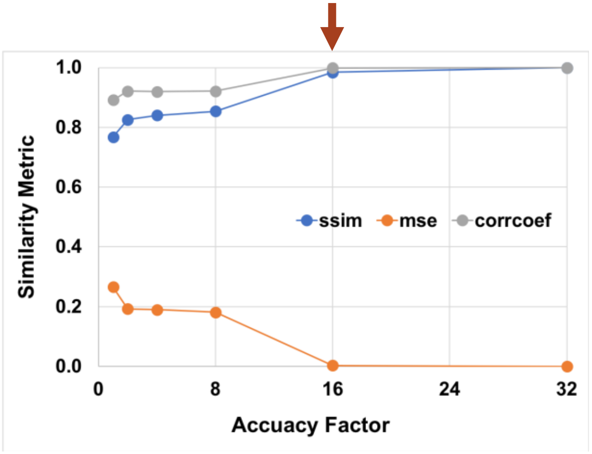
CIVA Accuracy Factor

- Image similarity metrics can help determine the CIVA accuracy factor needed for optimal simulations.
- The accuracy factor determines the level of meshing and has a strong affect on simulation time.
- Simulations were compared to the “ideal” case – the one with the highest accuracy factor.
- Voronoi regions need a relatively low accuracy factor. Realistic grains need a high accuracy factor, which translates to longer simulation times (many hours).

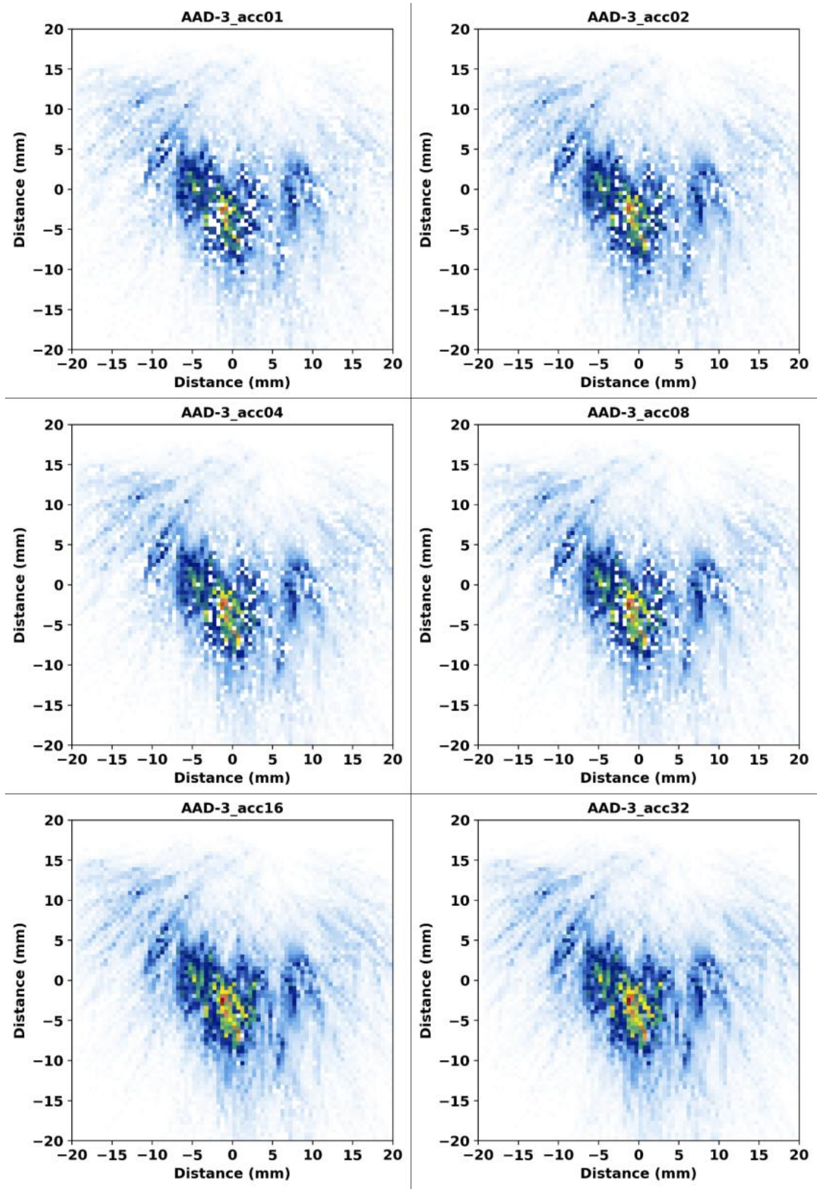
Voronoi



CASS



CASS



Conclusions

- Model approximations and limitations should be well understood prior to estimating detection capability. Realistic value ranges should be used with metamodels, and results should be considered critically.
- Empirical beam maps suggest that idealized weld geometries (e.g., Ogilvy) do not realistically represent beam scatter and beam formation through weld microstructure.
- Realistic weld geometries and microstructures can be created and loaded into CIVA. However, CIVA struggles to handle specimen definitions that have a large number of interface boundaries.
- Simulated beam profiles through realistic welds are qualitatively in agreement with experiments, showing scatter, reduced beam formation, and poor penetration through the weld. However, experimental scans show more scatter, less beam formation, and less sound penetration.
- It is unclear how accurately the weld properties need to be defined to minimize simulation uncertainty.

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Conclusions (continued)

- Attenuation in models is needed for simulations to better agree with experiment.
- Simulated flaw responses through welds are challenged by long computation times and uncertainties in weld properties. It is even more time consuming to include specimen frontwall/backwall/interface interactions, mode conversions, and noise, but it may be necessary to enhance realism.
- Simulations with low computational effort may be limited in their ability to estimate true flaw detection capability in the vicinity of welds or specimen geometry.
- Beam simulations can be predictive of flaw response, but they should not be used as surrogates for flaw response simulations.
- Voronoi-generated coarse-grained geometries may be a suitable and efficient representation of beam scatter through bulk CASS material, although there are limitations to CIVA’s ability to implement them.
- Modeling provides a valuable tool for predicting potential beam coverage and flaw detection, but results should be validated with empirical studies when possible.

Ongoing Research: Modeling & Simulation

- Integrate "true-state" austenitic weld microstructure information into simulations at different levels of detail.
  - At what resolution do results converge?
  - What is the simplest geometry that will give sufficiently realistic results?
- Establish the practical limitations of running beam and flaw response simulations with realistic microstructures.
- Continue to investigate how well beam simulations using realistic microstructures agree with experimental beam maps made on the same geometries. Determine which simulation parameters should be adjusted to improve agreement with experimental scans.
- Increase flaw response simulation realism:
  - Include specimen frontwall, backwall, and interface reflections.
  - Add mode conversions and attenuation.
  - Mimic realistic cracks by adding flaw morphology.
  - Determine appropriate levels and types of noise.
- Evaluate the new release of CIVA 2020 and other relevant commercial software platforms, as needed.
- Determine a standard method to evaluate UT simulation results from commercial software platforms used by industry.

How You Can Help

- We need information on industry planned use cases for modeling and simulation.
  - Helps focus efforts, should result in better targeted guidance documents based on NRC and industry research in this area
- What are the relevant inspection geometries and materials?
- Provide feedback with your experiences with model development and running simulations.
  - Success stories
  - Frustrations or concerns

Contact:
Carol Nove - NRC COR
Sr. Materials Eng.
RES/DE/CIB
Email: Carol.Nove@nrc.gov

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Thank you

NDE for composite repairs

Steve Kenefick
Principal Technical Leader

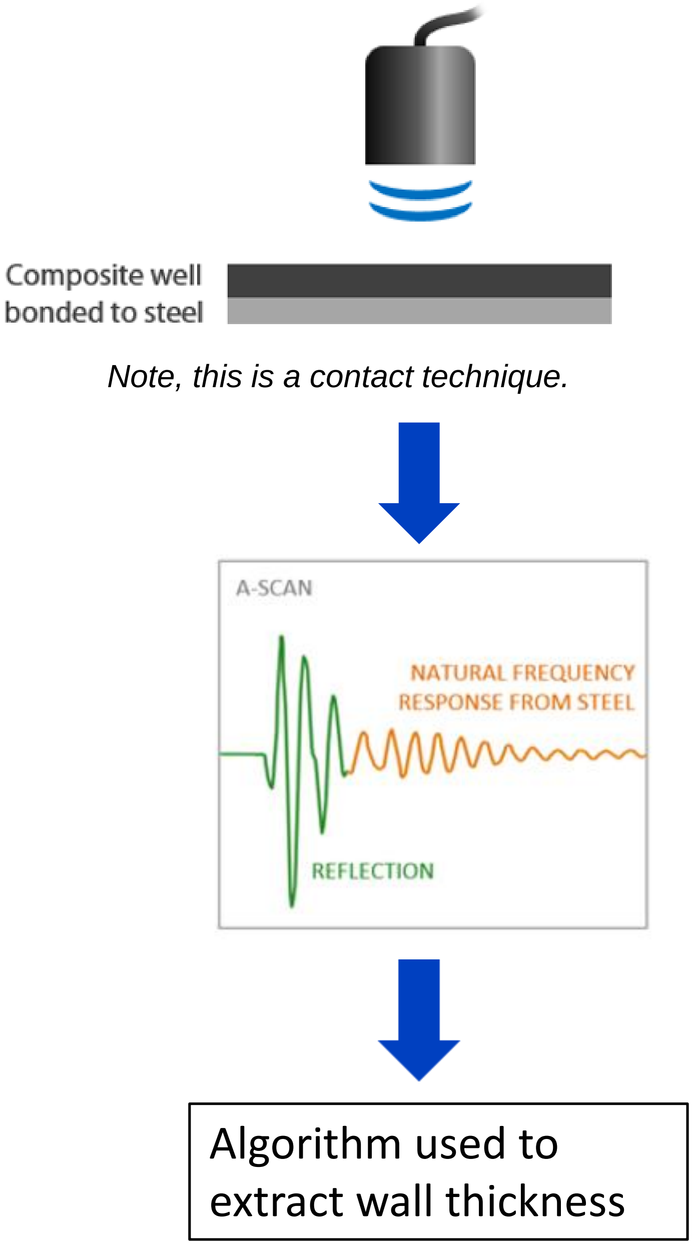
NRC/Industry NDE Technical Information Exchange Meeting
January 2020

Carbon Fiber Reinforced Composite (CFRC) Status

- Carbon Fiber Reinforced Composite (CFRC) repair being used to rehabilitate piping
  - Surry using to repair ASME Class 3 pipe under a relief request
- ASME Code Case N-871 “Internal Repair of Buried Class 2 & 3 Piping Using Carbon Fiber Reinforced Polymer Composites” has been issued
  - Revision in process
  - In-service examination of the metal substrate at terminal ends and examination for delamination being added
- Ultrasonics has <u>not</u> been demonstrated to be effective at penetrating CFRP due to high attenuation rate at typical NDE frequencies

Dynamic Response Spectroscopy (DRS)

- Basis of technology
  - Lower frequency (<1Mhz) transducer used to transmit ultrasonic energy through CFRP to excite steel substrate
  - Steel vibrates at its natural frequencies
  - Transducer collects returning energy
  - Algorithm used to extract frequency content to generate wall thickness measurement
  - C-scan wall thickness views generated
- Relatively new technology
  - EPRI engaged company developing technology early in the process through membership with Pipeline Research Council International (PRCI)



Initial Feasibility Studies of DRS on CFRP

- PRCI conducted a round robin assessment of NDE technologies on pipeline industry wraps
  - DRS showed potential
  - Other techniques had limited to no success

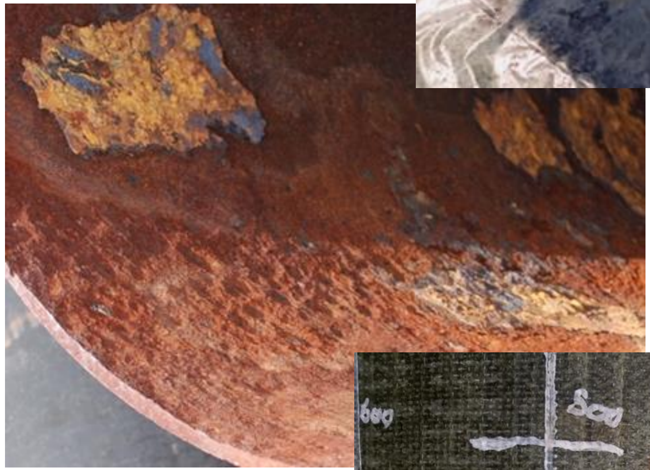
- EPRI conducted tests on a CFRP plate mock-up made by nuclear wrap supplier
  - DRS successfully penetrated CFRP
  - Results limited due to plate configuration

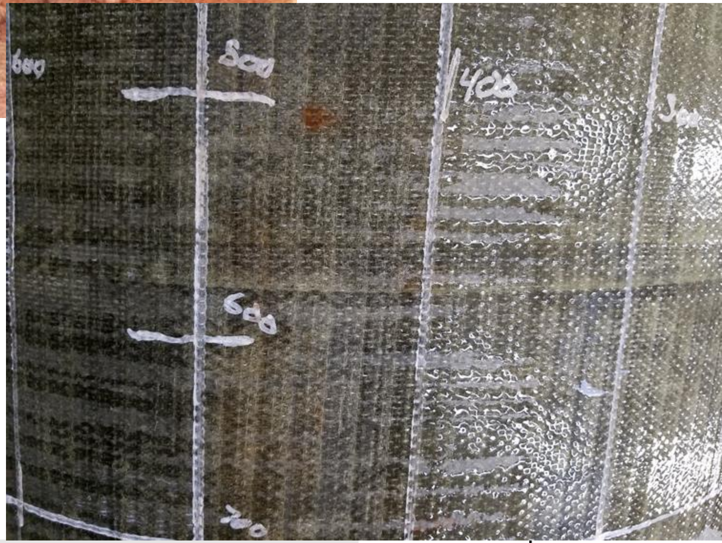
EPRI DRS Technology Assessment

- EPRI assessed DRS to determine if it could effectively penetrate CFRP and interrogate the metal substrate

- CFRP mock-up constructed of a field removed carbon steel pipe (30-in diameter x ~3-ft long x 0.375-in thick)
  - Significant internal corrosion
  - Varying damage morphologies
  - Wrapped with multi-layers of CFRP / 2 CFRP thicknesses

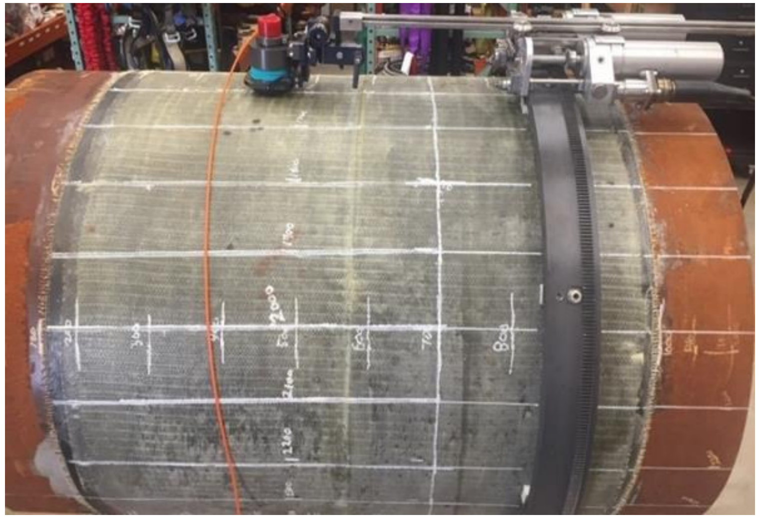
- Externally wrapped to assess detection and characterization capabilities of opposite side corrosion

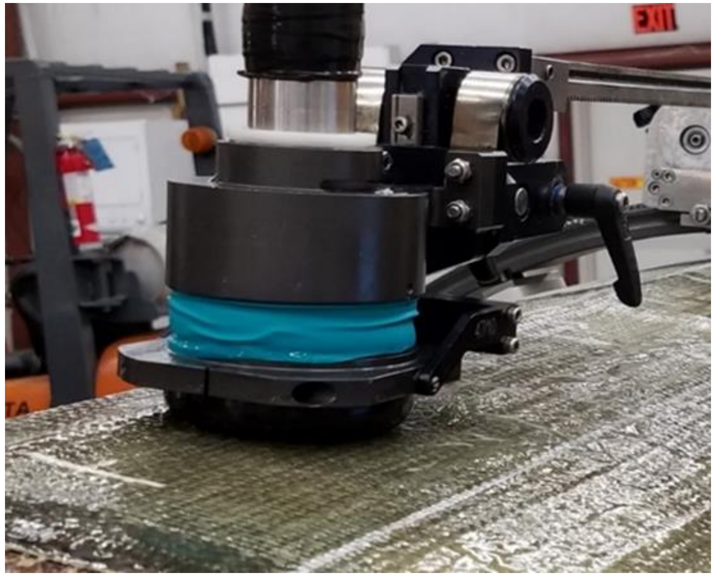




EPRI DRS Technology Feasibility Study

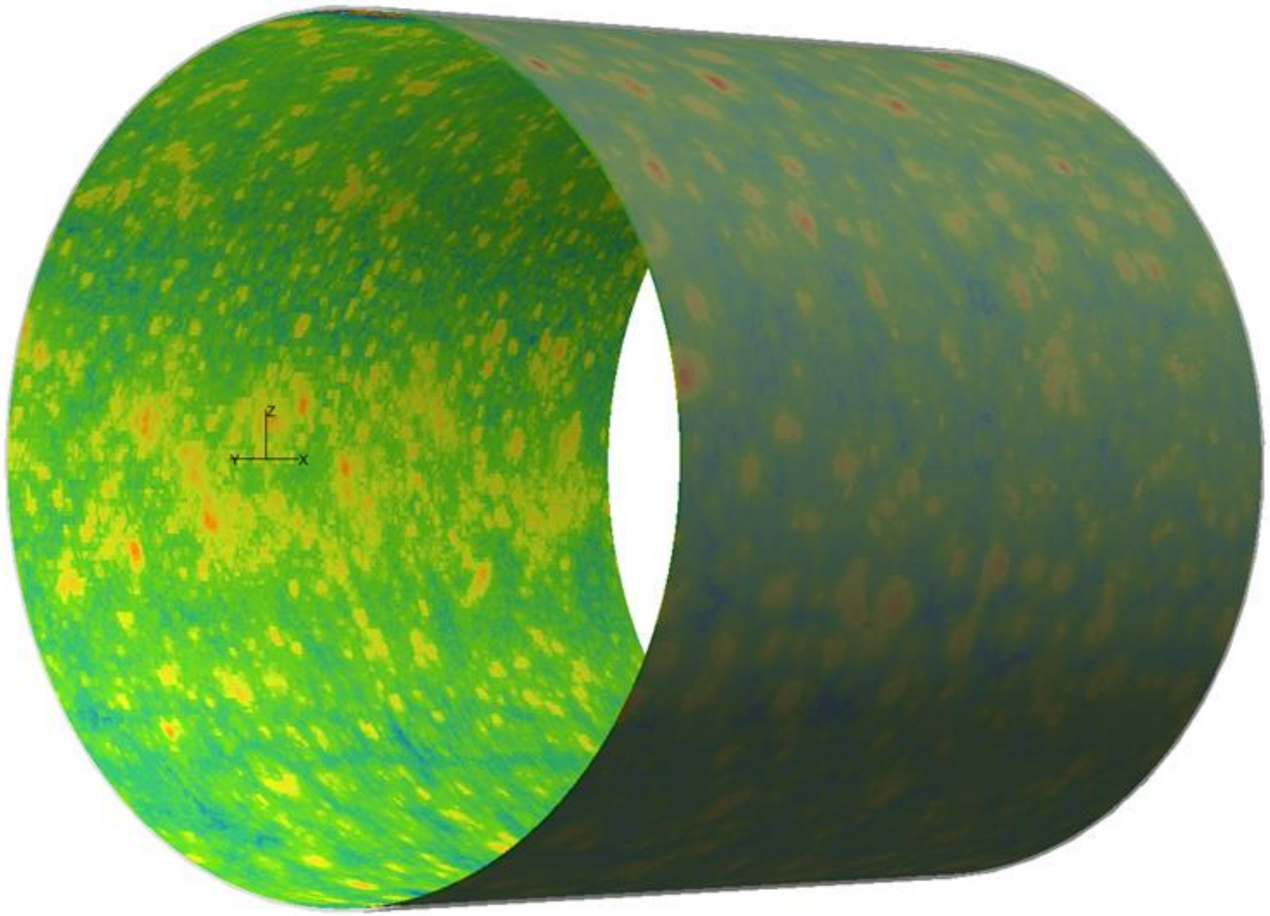
- High resolution encoded ultrasonic data collected prior to wrapping
  - 10 MHz dual element 0-degree contact probe
  - 1-mm (0.039-inch) axial by 4-mm (0.157-inch) circumferential increments
- DRS data collected through the CFRP wrap at same increments
- Ultrasonic and DRS measurements compared
  - Fine increments allow for a good comparison of ultrasonic and DRS data
  - ~1.9-million ultrasonic and DRS measurements for each were made
  - Ultrasonic and DRS wall thickness C-scan images were generated



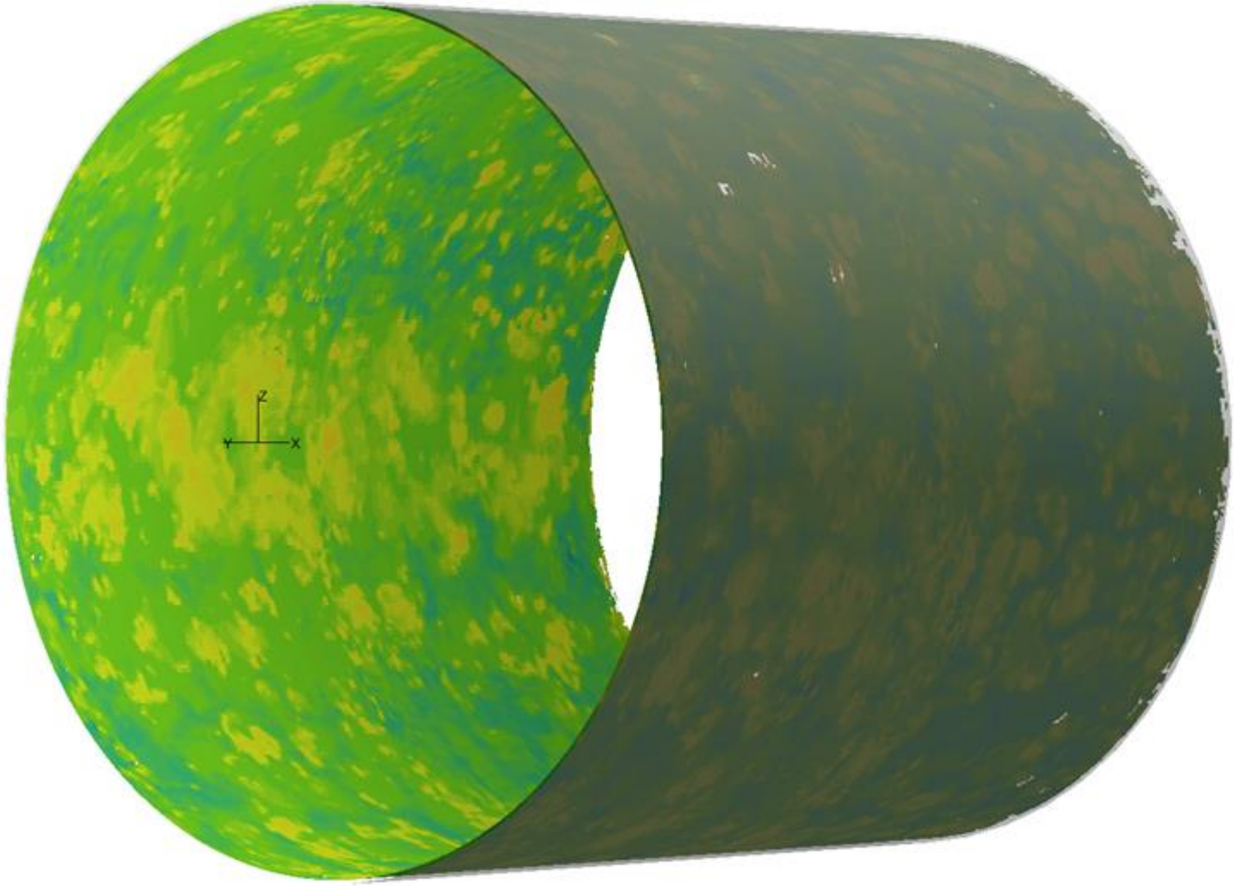


Results published: Non-contact Nondestructive Evaluation Technology: Dynamic Response Spectroscopy and Pulsed Eddy Current (EPRI Report 3002013174)

Visual Correlation Between Ultrasonic and DRS Images

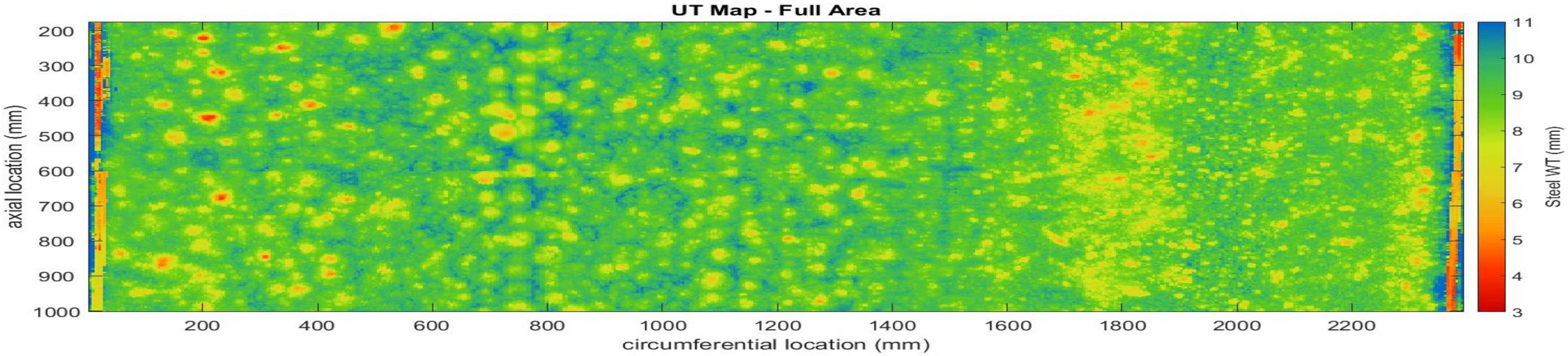


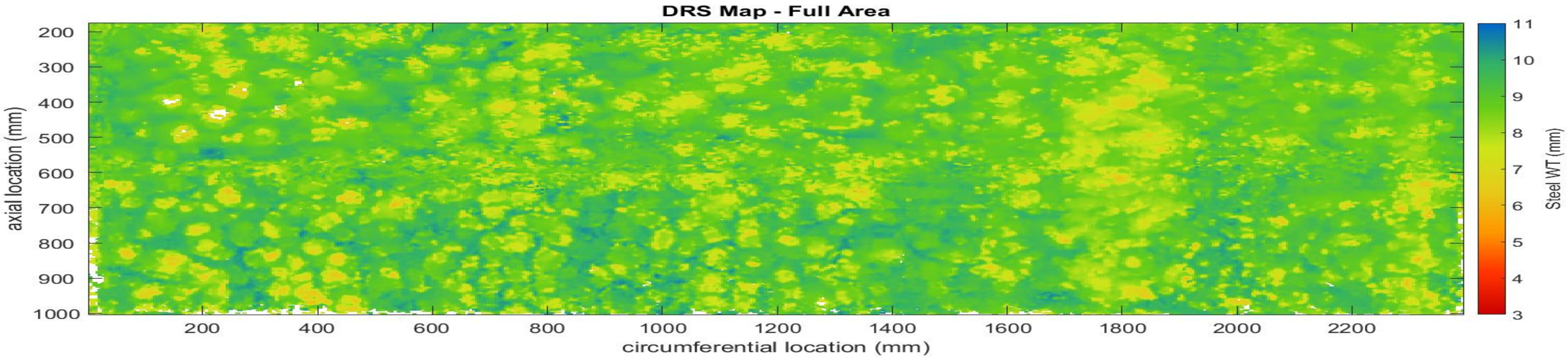
Ultrasonic Results



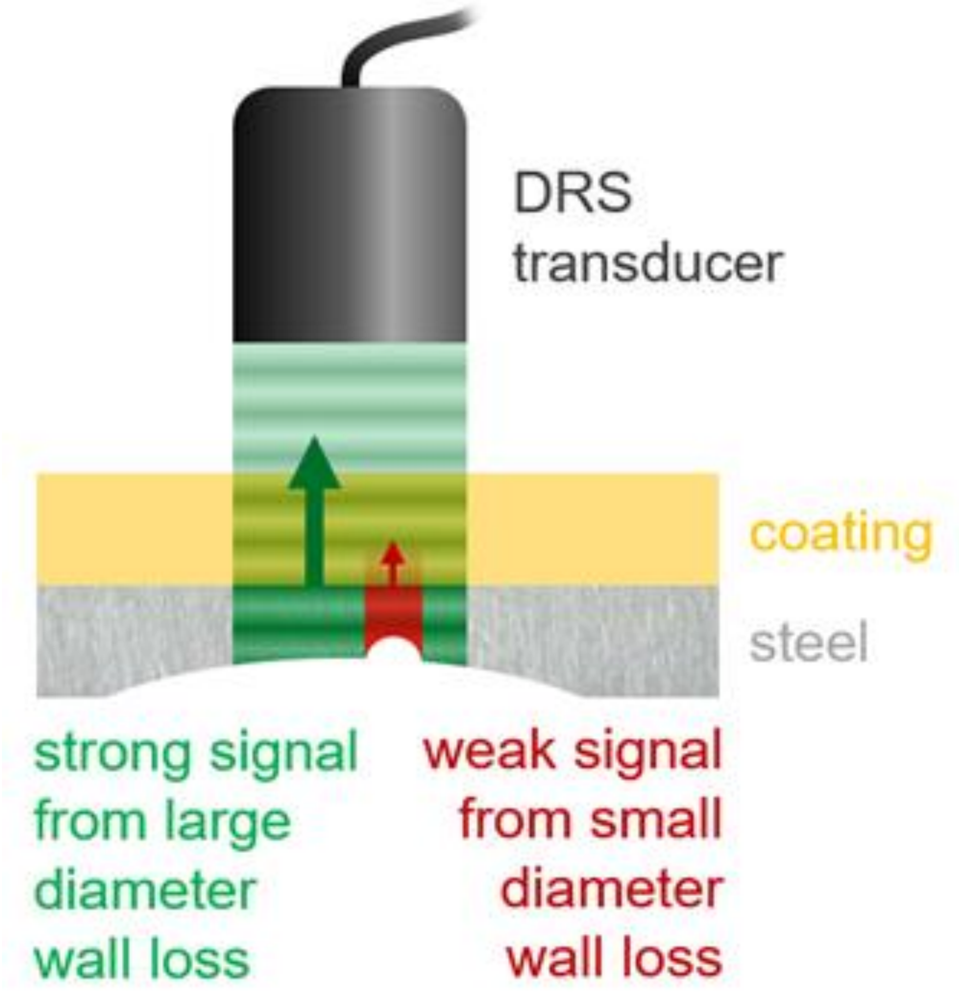
DRS Results

Visual Correlation Between Ultrasonic and DRS Images

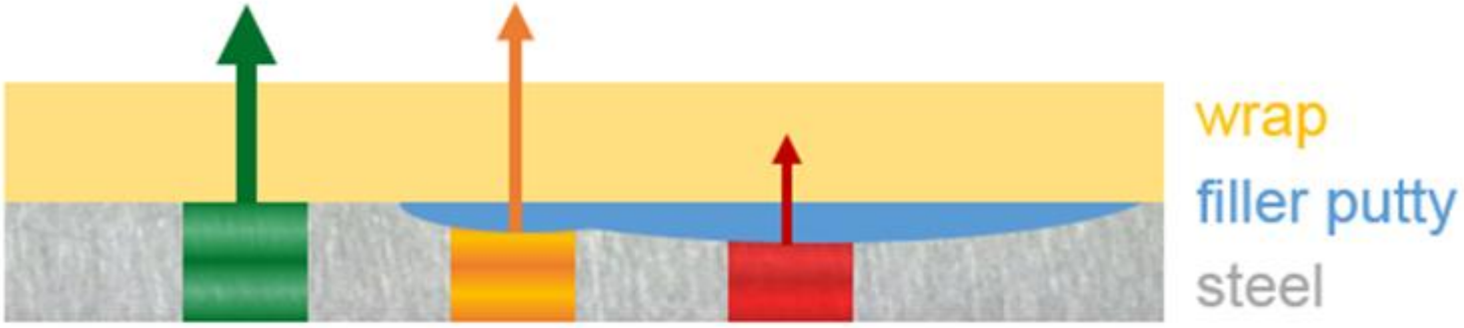




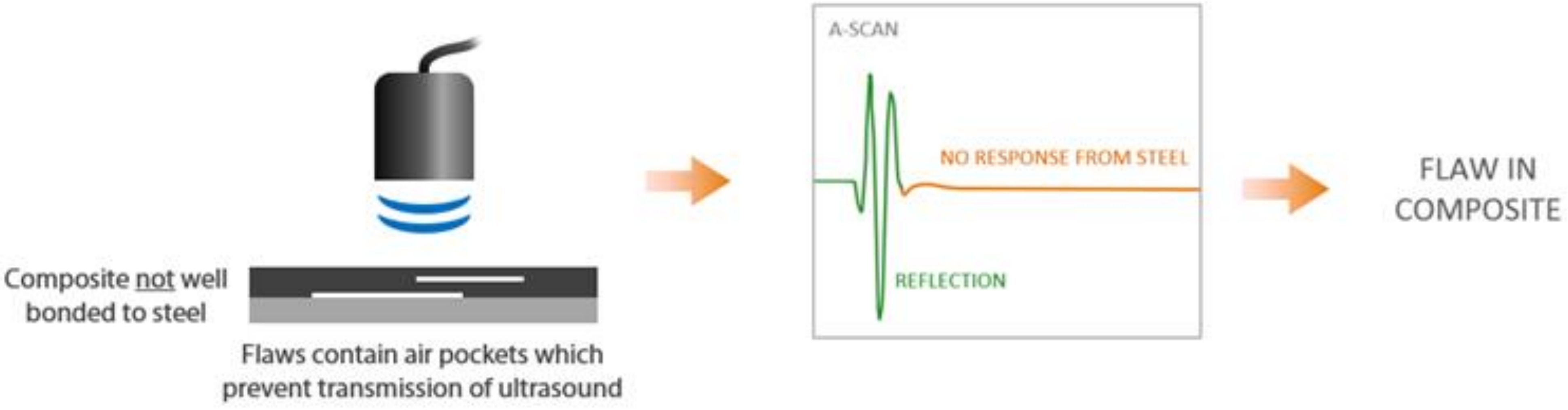
DRS Signal Response Limitations



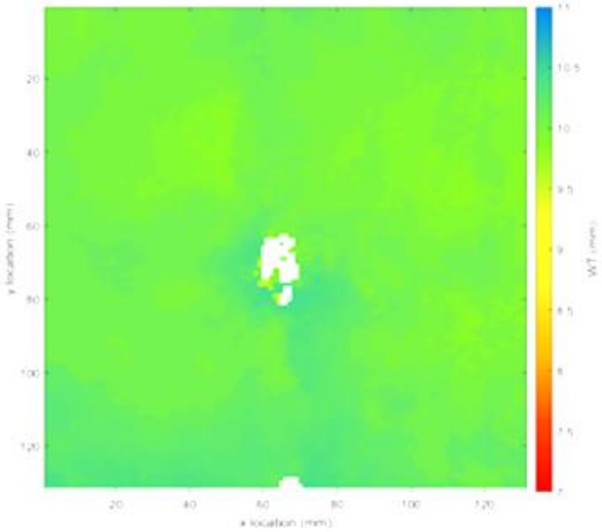
DRS limited in detecting and resolving small features due to the ratio of the probe to discontinuity size

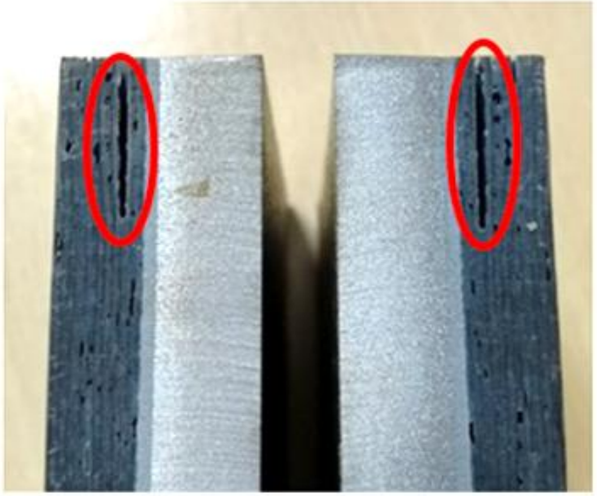


DRS Response to Flaws in Composite



Capable of detecting laminations and internal CFRP discontinuities as they inhibit transmission of energy into the substrate





Ongoing Research

- Expand DRS Assessment to:
  - Include 3 CFRP wrap manufacturers
  - Assess multiple CFRP thicknesses that manufacturers plan to install to remediate in-service pipes
  - Assess multiple substrate thicknesses
- Plan to assess other NDE methods
- Engage with outside organizations
  - ASME CFRP Code Case
    - Code case being expanded to address indoor applications
  - NRC public meeting on CFRP January 16th, 2020

Together…Shaping the Future of Electricity

Closing the day

Action items - new

-

Upcoming meetings

- ASME
  - Week of Feb 2
  - Las Vegas
- ASME
  - Week of May 10
  - Denver
- EPRI NDE Issues Meeting
  - Week of June 21
  - Fort Lauderdale

Public comment period

End-of-day announcements

- Public meeting on CFRP begins 1:00 in this room

End of Meeting

Safe travels!

AMM Roadmap Background

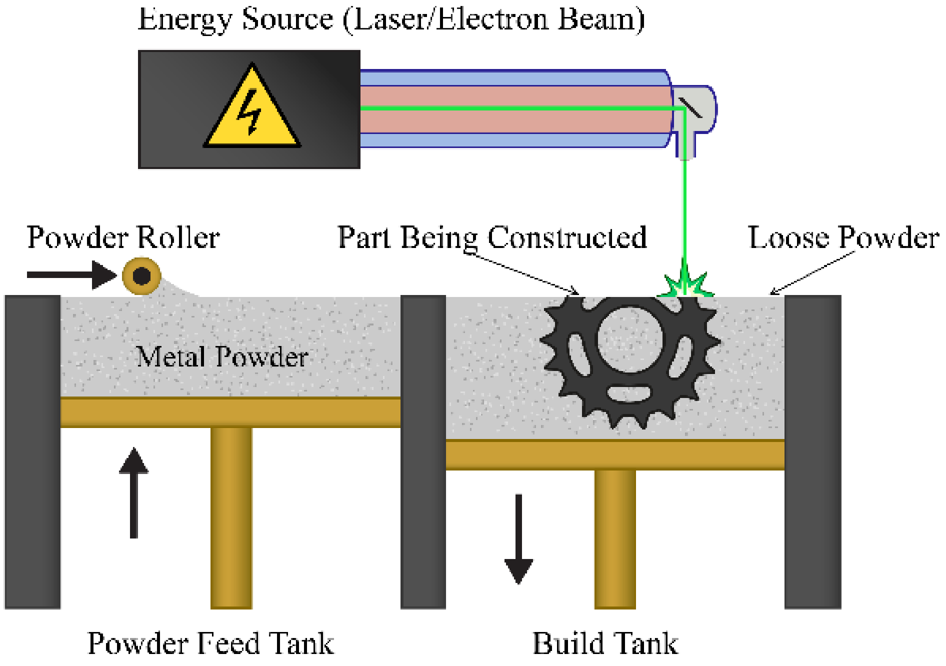
- Considerable industry interest in applying Advanced Manufacturing Methods (AMM) to production of nuclear system components
  - Extends to new plants (ALWRs, SMRs, ARs) and
  - Repair/ maintenance of operating plants
- AMM offer:
  - Production of near net shapes (reduced machining, waste)
  - Flexible production of limited quantities of unique shapes
  - Improved materials properties (in certain cases)
- Deployment is complicated by multiple candidate processes, lack of standards, ASME acceptance

Candidate AMM Processes for Nuclear Components

- **Powder Metallurgy-Hot Isostatic Pressing** – PM-HIP
  - ~4 ft (1.2m) diameter
    - Larger HIP allowing ~ 10ft (3.05m) diameter, est. completion 2023
- **Directed Energy Deposition AM** – DED-AM
  - ~ 500 lb. (227kg) max.
- **Powder Bed Fusion AM** – L-PBF or EB-PBF
  - ~ 50 lb. (23kg) max.
- **Advanced Cladding Processes** – e.g., Diode laser cladding
  - Further development/qualification needed

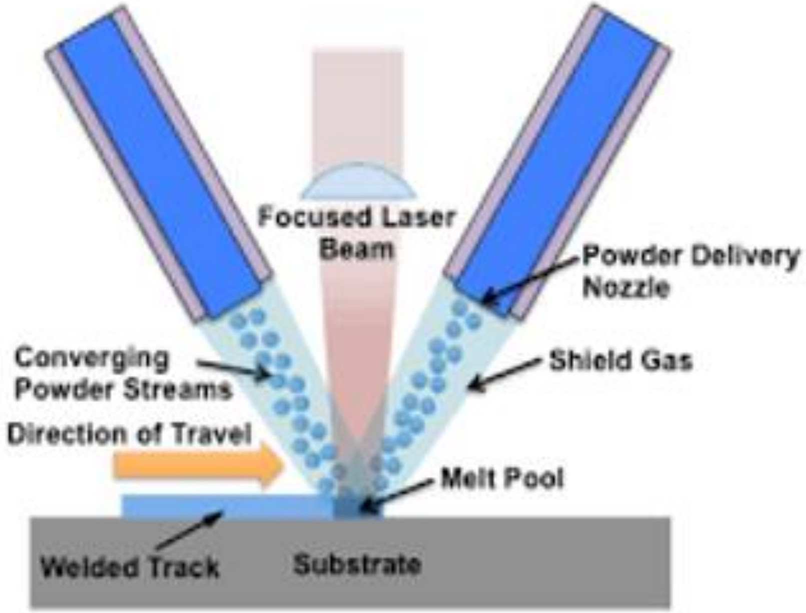
Background
--Laser-PBF vs. Directed Energy Deposition AM

Laser-PBF



courtesy of 3DEO

Directed Energy Deposition



Background

Laser-Powder Bed Fusion (L-PBF)

- Parts/Components **up to ~50lbs**
- Uses laser or electron beam to melt or fuse powder together in bed of powder

- **Common names**:
  - Direct laser metal sintering (DLMS)
  - Electron beam melting (EBM)
  - Selective laser melting (SLM)
  - Selective heat sintering (SHS),
  - Selective laser sintering (SLS)

Directed Energy Deposition (DED)

- Parts/Components **up to ~500lbs**
- Wire or powder fed through nozzle into laser or electron beam
- Fundamentally welding using robotics/ computer controls.

- **Common names**:
  - Electron Beam DED—Wire
  - Electron Beam-enabled Advanced Manufacturing (E-Beam)
  - Laser Direct Energy Deposition-Powder
  - Laser Direct Energy Deposition-Wire
  - Laser-Wire Directed Deposition
  - Wire Plus Arc AM (WAAM)
  - Shaped Energy Deposition (SED)
  - Bulk Area Manufacturing (BAM)

Roadmap Development (1) --Overview

- Compliments/refines NEI *"Regulatory Acceptance of AMM in Nuclear Energy"* Roadmap & Technical Report
- Nuclear plant components cover wide range of sizes, shapes, and materials
- Initial Roadmaps are focused on LWRs & ALWRs
  - Easily extended to SMRs and ARs (smaller sizes, similar materials)
- Central feature of each Roadmap is **ASME BPVC Standards Development & Regulatory Approval**
  - ASTM standards exist for some processes/materials
  - Other processes/materials currently lacking standards

Roadmap Development (2) --Overview

- Roadmap development generated based on component size/materials
  - This distinction avoids complications associated with addressing components on individual basis

- **Three DRAFT Roadmaps** considered herein:
  1. **Primary pressure boundary (Class 1) components**
  2. **Reactor internals**
  3. **Other components (Obsolete parts, Classes 2 &3, etc.)**

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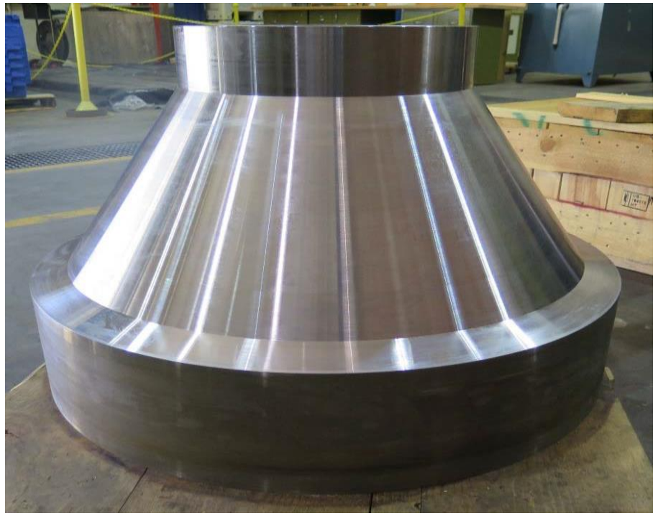
1. Primary Pressure Boundary (Class 1) Roadmap

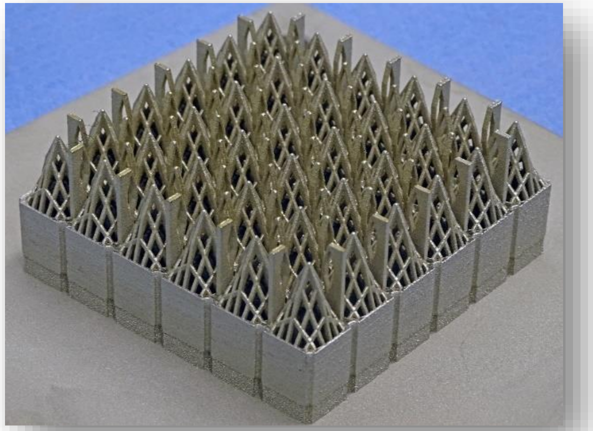
- Roadmap includes an initial sizing study to identify candidate components
  - Many large LWR Class 1 components exceed limitations of certain AMMs.



16" BWR Feedwater Inlet Nozzle (LAS)

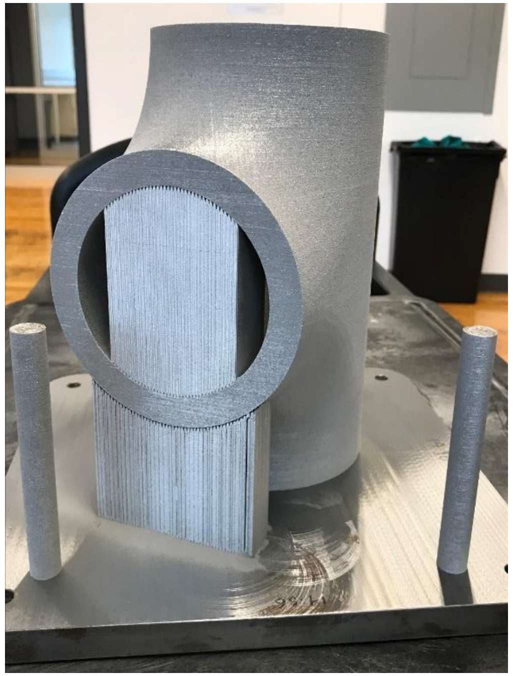
- Developments identified are specific to: size groups/processes/ materials
  - **Larger Class 1 components** can be manufactured **using PM/HIP**
    - Demonstration pieces of LWR components already produced
    - 316L already accepted by ASME, but other alloys require qualification testing and ASME approval
  - **Smaller Class 1 components** may be produced **by DED-AM or Powder Bed-AM**
    - Process development, qualification testing, ASME approval shown
    - Few Class 1 components candidates for Powder Bed AM (size limitation)

2. Reactor Internals Roadmap



- Internals Roadmap generally follows similar pattern set for Class 1
  - Up front sizing study
- Some significant differences:
  - No low alloy steel components
  - Fuel Hardware and Control Rod Drive components (unique shapes and materials)
  - High strength Ni-base alloys and cobalt-free alloys
- **Interaction with ASME is limited** for Internals Roadmap
  - Only core support structures require ASME approval
  - Interaction with NRC may be required for some Safety Related Internals
  - Other internals: free to use ASTM, AMS, etc. or no standard at all (a potential case for fuel hardware or control rod drive components)

3. All Other Components Roadmap --Obsolete Parts, Class 2 & 3, etc.



- Primary Pressure Boundary and Reactor Internals Roadmaps fully address needs of "All Other Components" category
  - e.g., ASME acceptance of a process/material for Class 1 immediately applicable to Class 2 & 3
  - <u>Other Components Roadmap may not be required</u>

- Sizing study to identify potential AMM candidate components still required
  - Complicated by the broad range of components in this category
  - Many likely Class 2 & 3 components and steam generator shell/internals
  - Outcome of sizing study may dictate development of separate Roadmap

Examples of Candidate AMM Components

Primary Pressure Boundary

Reactor Type	Component	AMM Process	Material
AP1000	Vessel Shell (Six ring segments)	PM/HIP	LAS
AP1000	Pressurizer Shell (Four ring segments)	PM/HIP	LAS
US EPR	Pressurizer Shell (Four ring segments)	PM/HIP	LAS
US APWR	Pressurizer Shell (Four ring segments)	PM/HIP	LAS
BWR	CRD Stub Tubes	PM/HIP	CC N-580
PWR	CRDM Housings	PM/HIP	A690
ABWR	Reactor Internal Pump Case	PM/HIP	LAS
AP1000	Recirculation Pump Case (top section)	PM/HIP	SS
BWR/PWR	Medium Size Valve Bodies and Bonnets	PM/HIP	SS
BWR/PWR	Reactor Vessel Nozzles	PM/HIP	LAS
BWR/PWR	Small Valves & Fittings	PM/HIP or DED	SS
BWR/PWR	Very Small Valves and Fittings	Powder Bed AM	SS

Reactor Internals

Reactor Type	Component	AMM Process	Material
AP1000	Core Barrel (Six ring segments)	PM/HIP	SS
Advanced PWRs	Core Barrel Nozzles	PM/HIP	SS
AP1000	Upper Guide Tube Components	PM/HIP	SS
AP1000	Control Rod Guide Cards	Powder Bed AM	SS
AP1000	Core Barrel Support Lugs	PM/HIP	A690
BWR/PWR	Dome Cooling Spray Nozzles	PM/HIP or DED	SS
EPR	Heavy Reflector Positioning Keys	PM/HIP	SS
ABWR/ESBWR	Control Rod Guide Tube Base Plate	PM/HIP	XM-19
ABWR/ESBWR	Steam Separator Swirlers	PM/HIP	SS
ABWR	Shroud Head Bolt Tees	PM/HIP	CC N-580
BWR	Fuel Spacers	Powder Bed AM	X-750
BWR	Fuel Tie Plates	Powder Bed AM	SS
BWR/PWR	Fuel Debris Filters	Powder Bed AM	SS
BWR/PWR	Control Rod Drive Components	PM/HIP, DED, or Powder Bed AM	SS or Co-Free Alloys

Other Components

Reactor Type	Component	AMM Process	Material
AP1000	Steam Generator Upper Shell (Six ring segments)	PM/HIP	LAS
AP1000	Steam Generator Lower Shell (Six ring segments)	PM/HIP	LAS
US EPR	Steam Generator Lower Shell (Six ring segments)	PM/HIP	LAS
US APWR	Steam Generator Lower Shell (Six ring segments)	PM/HIP	LAS
Advanced PWRs	Steam Generator Manways/Nozzles/ Handholes	PM/HIP	LAS
All LWRs	Class 2/3 Valve Bodies/Bonnets	PM/HIP or DED	SS
All LWRs	Class 2/3 Pipe Fittings	PM/HIP or DED	SS
Advanced PWRs	Steam Generator Internals	PM/HIP or DED	SS/A690
Operating BWRs	Jet Pump Beams	PM/HIP	X-750/718
All LWRs	Class 2/3 Small Valves and Fittings	Powder Bed AM	SS
BWR	Internals Repair Hardware	PM/HIP, DED, or Powder Bed AM	SS/XM-19/X-750
BWR/PWR	Very Small Valves and Fittings	Powder Bed AM	SS

AMM Roadmap -- Summary

- Two Roadmaps will likely cover >95% of components
  - Primary pressure boundary (Class 1) Roadmap
  - Reactor Internals Roadmap
- DRAFT Roadmaps are focused on LWRs & ALWRs
  - Easily expanded to SMRs and ARs in future

- Roadmap development generated based on component size/materials
- Central feature of each is ASME BPVC standards development & regulatory approval