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UT in lieu of RT

Kevin Hacker
Dominion Energy

Greg Selby
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Background

- Code Case N-831, “Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic Pipe” has been developed to allow the use of UT for weld acceptance examination
  - ASME Board approved October 20, 2016 and published in the 2017 Edition of Code Cases
- Major benefits over performing RT
  - Eliminates exclusion zone and allows work to continue in adjacent areas
  - Eliminates radiation safety concerns of using a source to perform RT
  - Eliminates the unnecessary repair of insignificant fabrication flaws
  - Takes advantage of latest NDE technology
  - Better detection capabilities for planar flaws
- Several utilities have submitted Alternative Request to use this Case

Next Step

- Code Case N-831 is limited to ferritic piping welds made as part of a repair/replacement activity
- Most repair/replacement welds are ferritic materials of various sizes
  - To prepare for unplanned weld R/R activities demonstrating a procedure for the full range of possible weld sizes is practical
- Austenitic weld R/R activities are less common and may be limited in sizes
  - It would be advantageous to have the ability to use UT in lieu of RT
- EPRI performed research to assess the effectiveness of UT to detect fabrication related flaws for austenitic piping welds
  - 3002010297, "Technical Basis for Substituting Ultrasonic Testing for Radiographic Testing for New, Repaired, and Replacement Welds for ASME Section XI, Division 1, Stainless Steel Piping" *(publicly available)*

Summary of EPRI Research

- Fabricated stainless steel mockups in accordance with N-831 requirements
- Mockups examined as single side access
- All flaws were detected and sized within N-831 criteria
- Demonstrated UT as effective for stainless steel fabrication flaw detection and sizing
- This report provides the technical basis for revising N-831 to include austenitic piping

Current Code Activities

- N-831 is being revised to include austenitic materials using EPRI report as the technical basis
- Revision to include addition of material through a procedure expansion demonstration
  - Through the personnel demonstration process
  - Specimens must include diameter and thickness range of new material
  - Must use same techniques already qualified
  - All flaws must be detected
- If expansion process is unsuccessful, a full demonstration must be performed

Status

- EPRI research completed and report published - June 2017
- Discussed concept of procedure expansion for austenitic piping at the August 2017 Code meeting
- Draft Code Case revision presented at the November 2017 Code meeting
  - Feedback provided by Task Group
- Comments incorporated into N-831-1 (draft) and will be presented at the February 2018 Code meeting
  - Expect endorsement through NDE Subgroup
- Updated the supporting white paper for the Code Case revision

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RPV Threads in Flange

Gary Lofthus
Southern Nuclear

Patrick O'Regan
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
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RPV Threads in Flange

- There are personnel safety, radiation dose and outage impact concerns associated with performing the volumetric examination of the reactor vessel threads in flange

- Industry has evaluated optimization options to minimize or eliminate these concerns

Current Examination Requirements

- Examinations required per ASME Section XI
  - Examination Category B-G-1
  - Volumetric examination each interval
- Other Codes/Countries have similar requirements

Figure IWB-2500-12
Closure Stud and Threads in Flange Stud Hole

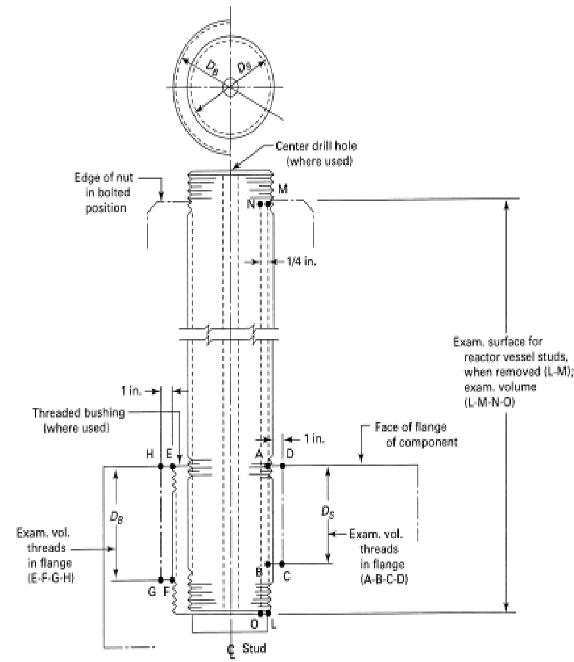

Table IWB-2500-1 (B-G-1)
Examination Category B-G-1, Pressure Retaining Bolting, Greater Than 2 in. (50 mm) in Diameter

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						
B6.10	Closure Head Nuts	Surfaces	Visual, VT-1	IWB-3517	Closure head nuts	Same as for 1st interval	Permissible
B6.20	Closure Studs	IWB-2500-12	Volumetric [Note (7)]	IWB-3515	Closure studs [Note (1)]		
B6.40	Threads in Flange	IWB-2500-12	Volumetric	IWB-3515	Threads in flange		
B6.50	Closure Washers, Bushings	Surfaces	Visual, VT-1	IWB-3517	Closure washer and bushings [Note (2)]		

Status

- Conducted an industry survey to collect data on the results of the RPV flange examinations as well as to gather insight into the negative aspects of having to conduct these examinations
- EPRI reports (3002007626 *(publicly available)* and 3002010354) were prepared capturing the survey information and providing the technical basis and recommendation for the elimination of the RPV Threads in Flange examination requirement
- Licensee Approvals
  - SNC (Vogtle Units 1 & 2 and Farley Units 1 & 2)
  - Dominion (Millstone, Units 2 & 3 and North Ann Units 1 & 2)
  - Exelon (19 units; BWR & PWR)
- Submittals under review
  - Duke (9 units; BWR & PWR)
  - Exelon (Fitzpatrick)
- Code Case N-864 has been approved by ASME

Remaining Actions

- Responding to NRC comments and RAIs for licensees that have already submitted requests
- Additional licensee submittals using ASME Code Case N-864
- Incorporate ASME Code Case N-864 into Regulatory Guide 1.147

CASES OF ASME BOILER AND PRESSURE VESSEL CODE

CASE
N-864

Case N-XXX
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 the examination requirements of Examination Category B-G-1, Item Number B6.40, are not required.

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N-711-1 Process and Tools

Gary Lofthus
Southern Nuclear

Pat O'Regan
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Applicability of N-711-1

- Applicable to examination category R-A (RI-ISI programs)

- Applicable to examination categories B-F, B-J, C-F-1, and C-F-2
  - Requires knowledge of applicable degradation mechanisms
  - Degradation mechanisms are determined in the same way as for RI-ISI programs

Limited Examination Coverage Requirements

- ASME Code Case N-711 provides a methodology that identifies alternative examination coverage requirements based on susceptibility to degradation and component configuration but has not been approved for use by NRC in Regulatory Guide 1.147 (RG1.147).

- Once approved by NRC, demonstration of the process for determining when the examination volume of primary interest (VPI) has been achieved is needed to support efficient use of the process by industry.

Degradation Mechanisms: IGSCC

Component Configuration:
Pipe to Cast Component

Ferrite/Carbon Content
within Resistant Region of Figure 1

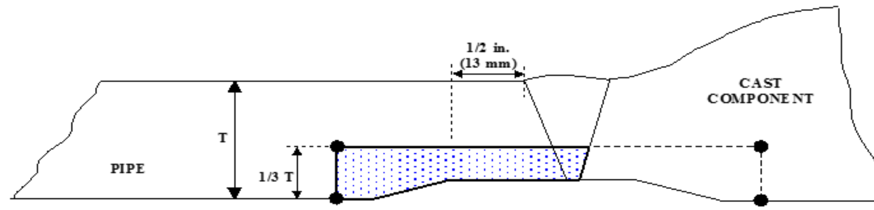

Figure G1

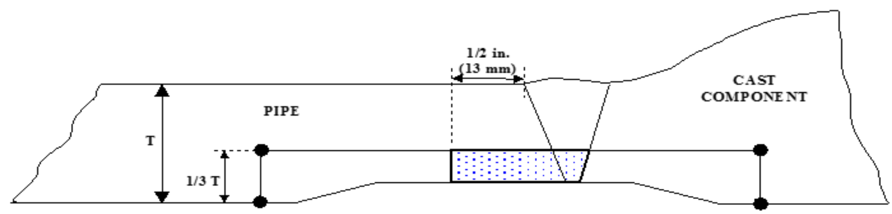

Figure G2

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Limited Examination Coverage Requirements

- For a number of examination locations, use of ASME Code Case N-711, allows for smaller examination volumes (VPI) as compared the required code volume (RCV).

- Examinations that do not meet >90% of the Code required volume, but do meet the VPI, will not require the development and filing of relief requests to the regulator. Thereby saving industry and regulatory resources.

Degradation Mechanisms: IGSCC

Component Configuration:
Pipe to Cast Component

Ferrite/Carbon Content
within Resistant Region of Figure 1

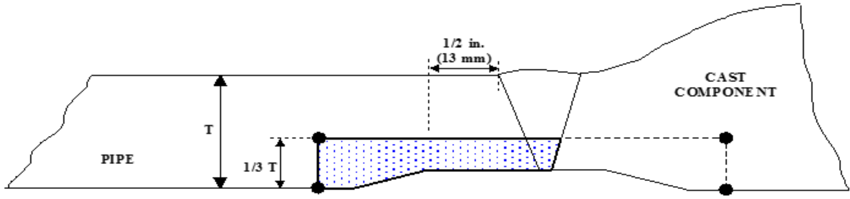

Figure G1

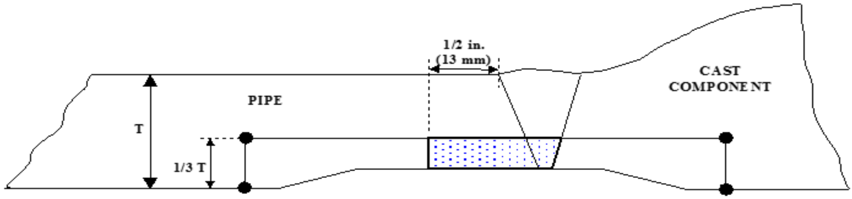

Figure G2

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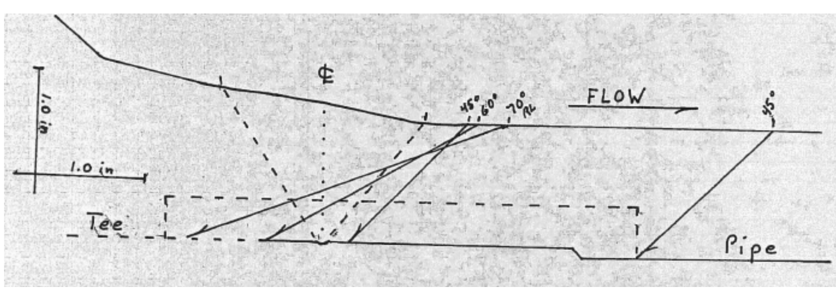
EPRI Research

- The project identified additional technical basis and changes to N-711 needed to gain NRC acceptance.
- Required changes processed via a revision to N-711 and approval through the ASME consensus process.
- In phase I of the project, a number of actual relief requests have been obtained from industry. These examples are being subjected to the N-711-1 evaluation process to demonstrate when the VPI is captured and when it is not.
- Phase II of the project will develop a software tool to automate and document the N-711-1 evaluation process.

Key Findings to Date

- N-711-1 approved by ASME
- NRC staff voted positive at working group, subgroup and SXI Standards Committee
- Collected and evaluated a number of plant-specific examples of limited examination coverage
- Evaluating these results against the N-711-1 volume of primary interest



CASES OF ASME BOILER AND PRESSURE VESSEL CODE

CASE
N-711-1

Case N-711
Alternative Examination Coverage Requirements for Examination Category B-F, B-J, C-F-1, C-F-2, and R-A Piping Welds
Section XI, Division 1

Inquiry: What alternative to the examination coverage requirements of Table IWB-2500-1, Examination Categories B-F and B-J, Table IWC-2500-1, Examination Categories C-F-1 and C-F-2, Case N-560 Examination Category B-J[1] and Examination Category R-A piping welds may be used when the required examination volume cannot be examined due to interference by a permanent item (e.g., non-bolted component support) or part geometry?

Reply: It is the opinion of the Committee that, when the examination has been completed and the required examination volume on Table IWB-2500-1, Examination Categories B-F and B-J, Table IWC-2500-1, Examination Categories C-F-1 and C-F-2, Case N-560 Examination Category B-J and Examination Category R-A piping welds, cannot be examined due to interference by a permanent item (e.g., non-bolted component support) or part geometry, and 1 or 2 is met, the alternative examination volume defined by the evaluation process of 3 may be used to determine acceptable examination coverage.

1 GENERAL

The examination coverage does not meet Case N-560 or Examination Category R-A requirements, as applicable, and one of the following conditions is met.

[1] Examination Category B-J, in this instance, applies to implementing risk-informed inservice inspection programs through the use of Case N-560.

(a) The inspection location of concern is risk Region 1A per Risk-informed Method A.[2]

(b) An inspection location selected for examination is based on the most limiting predicted severity of the postulated degradation mechanism. Examples of locations considered to be the most limiting are ones that experience the highest ΔT due to thermal transients and highest temperature for locations in PWR's susceptible to IGSCC.

(c) Selection of an alternative inspection location in accordance with the applicable risk-informed inservice inspection methodology will not improve examination coverage of the volume of primary interest (e.g., other locations have similar structural discontinuities).

2 EXAMINATION COVERAGE

The examination coverage does not meet the requirements of Table IWB-2500-1 or Table IWC-2500-1, and selection of an alternative inspection location meeting the same original selection criteria (e.g., Category C-F-1 structural discontinuity weld) will not improve examination coverage of the volume of primary interest.

3 EVALUATION PROCESS

(a) The Owner shall determine the degradation mechanisms associated with the weld. If the weld is Examination Category R-A, the Owner may use the degradation mechanism assessments developed to support the risk-informed inservice inspection examination requirements. If the Examination Category is B-F, B-J, C-F-1, or C-F-2, the Owner shall perform an assessment to determine the potential degradation mechanisms. This assessment shall use Table 1 to determine all applicable degradation mechanisms.

[2] Method A applies to plants implementing risk-informed inservice inspection programs through the use of Case N-577 and associated revisions or Supplement 1 of Nonmandatory Appendix R.

Results to Date are Promising – 10 examples

Design	Config	Damage Mech	Coverage Achieved		VPI Fully Examined		**<u>VPI Achieved w/o Weld Centerline Restriction</u>**
			Code	BE	YES	NO	
W PWR	Valve to Elbow	TASCS	50%	51.7%		✓	NO
W PWR	Pipe to Valve	IGSCC	50%	55%		✓	NO
W PWR	Pipe to Valve	IGSCC	50%	55%		✓	YES
GE BWR	Pipe to Elbow	None	50%	–		✓	YES
GE BWR	Valve to Pipe	TF	47.8%	–		✓	YES
		IGSCC				✓	YES
GE BWR	Pipe to Valve	TF	50%	–		✓	YES
GE BWR	Pipe to Safe End	TF	77.4%	–		✓	YES
GE BWR	Pipe to Sweepolet	None	50%	–		✓	YES
GE BWR	Tee to Pipe	None	50%	–		✓	NO
GE BWR	Pipe to Valve	TF	50%	–		✓	YES

The Road Forward

- N-711-1 expected to be incorporated into the next revision of Regulatory Guide 1.147
- Pilot plant relief request under development
- Report to be issued with examples and demonstration of the VPI process
- In 2018 a tool will be developed to automate and simplify the utility's determination of the VPI

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Risk-informed ISI Endorsement

Section XI Nonmandatory Appendix R

Gary Lofthus
Southern Nuclear

Pat O'Regan
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

RI-ISI Timeline

1996-1997	1998-1999	1999-2006	2006-Present
ASME Section XI	USNRC Approves Industry Reports	U.S. & Worldwide Industry Implementation	
Code Case N577 RI-ISI Method A	WOG Topical #14572-A “RI-ISI Method A”	25-30 US Reactors; Several Countries in Europe / Asia	~5 US Reactors + Several Countries in Europe / Asia
Code Case N-578 RI-ISI Method B	EPRI Topical #112657, Rev B-A “RI-ISI Method B”	60 US Reactors + Several countries in Europe	~50 US Reactors, Canada, Mexico, S. Africa & Several Countries in Europe
		Code Case N-716 EPRI Report #3002003029 “Streamlined RI-ISI”	~45 US Reactors

Initial Approval Process

- Pilot Plant Process
  - Topical Reports
  - Plant-specific evaluations provided to NRC
  - Substantial interactions

- Follow-on Process
  - Plant-specific relief request following industry/NRC agreed upon Template

Initial Approval Process

- Significant industry / NRC interactions
  - – 50 plant-specific approvals
  - – Updates to code cases and creation of Appendix R

Nondestructive Evaluation: Probabilistic Risk Assessment Technical Adequacy Guidance for Risk-Informed In-Service Inspection Programs

1021467-A

- PRA Technical Adequacy identified as generic issue
  - Regulatory Guide 1.200, rev 2 03/2009
    - – *An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessments Results for Risk-Informed Activities*
  - EPRI Topical Report #1021467-A approved by NRC
    - – *Probabilistic Risk Assessment Technical Adequacy Guidance for Risk-Informed In-Service Inspection Programs*
    - – Applies to both the EPRI Traditional (ASME Appendix R) and EPRI Streamlined RI-ISI (Code Case N716) Methodologies

Current Status

- EPRI Streamlined RI-ISI Methodology has been endorsed
  - ASME Code Case N716-1
  - Relief request / Request for alternative no longer required
  - Focuses limited NRC / industry resources on more important issues / components
- EPRI Traditional RI-ISI Methodology has not been endorsed
  - Latest version of 10CFR50.55a still requires plant-specific submittals as well as NRC review and approval

Code Case Number	Table 1 Acceptable Section XI Code Cases	Date
N-666	*Weld Overlay of Class 1, 2, and 3 Socket Welded Connections, Section XI, Division 1*	4/18/06
N-683	*Method for Determining Maximum Allowable False Calls When Performing Single-Sided Access Performance Demonstration in Accordance with Appendix VIII, Supplements 4 and 6, Section XI, Division 1*	2/28/03
N-685	*Lighting Requirements for Surface Examination, Section XI, Division 1*	2/28/03
N-686-1	*Alternative Requirements for Visual Examinations, VT-1, VT-2, and VT-3, Section XI, Division*	1/10/07
N-695	*Qualification Requirements for Dissimilar Metal Piping Welds, Section XI Division 1*	5/21/03
N-696	*Qualification Requirements for Appendix VIII Piping Examinations Conducted from the Inside Surface, Section XI, Division 1*	5/21/03
N-697	*Pressurized Water Reactor (PWR) Examination and Alternative Examination Requirements for Pressure Retaining Welds in Control Rod Drive and Instrument Nozzle Housings, Section XI, Division 1*	11/18/03
N-700	*Alternative Rules for Selection of Classes 1, 2, and 3 Vessel Welded Attachments for Examination, Section XI, Division 1*	11/18/03
N-705	*Evaluation Criteria for Temporary Acceptance of Degradation in Moderate Energy Class 2 or 3 Vessels and Tanks, Section XI, Division 1*	10/12/06
N-706-1	*Alternative Examination Requirements of Table IWB-2500-1 and Table IWC-2500-1 for PWR Stainless Steel Residual and Regenerative Heat Exchangers, Section XI, Division 1*	1/10/07
N-712	*Class 1 Socket Weld Examinations, Section XI, Division 1*	5/12/04
N-716-1	*Alternative Piping Classification and Examination Requirements, Section XI, Division 1*	1/27/13
N-730	*Roll Expansion of Class 1 Control Rod Drive Bottom Head Penetrations in BWRs, Section XI, Division 1*	10/04/06
N-731	*Alternative Class 1 System Leakage Test Pressure Requirements, Section XI, Division 1*	2/22/05
N-733	*Mitigation of Flaws in NPS 2 (DN 50) and Smaller Nozzles and Nozzle Partial Penetration Welds in Vessels and Piping by Use of a Mechanical Connection Modification, Section XI, Division 1*	7/01/05
N-735	*Successive Inspection of Class 1 and 2 Piping Welds, Section XI, Division 1*	10/12/06

Revision 17 of RG 1.147, Page 7

ASME Section XI - Appendix R

- Licensees and NRC will benefit from endorsement of Appendix R
  - Eliminates relief requests
- Endorsement could reflect guidance in EPRI Topical Report #1021467-A as approved by NRC

NONMANDATORY APPENDIX R 2013 SECTION XI

NONMANDATORY APPENDIX R
RISK-INFORMED INSPECTION REQUIREMENTS FOR PIPING

ARTICLE R-1000
INTRODUCTION

R-1100 SCOPE

(a) When an Owner chooses to use this Appendix, the requirements of Section XI, Division 1 shall apply, except for the alternatives and exemptions provided by this Appendix. In addition, all of the provisions of this Appendix are mandatory for the piping within the boundaries of the piping for which this Appendix will be used to satisfy the requirements of IWB-2500, IWC-2500, or IWD-2500.

(b) The risk-informed selection processes described in Supplements 1 and 2 may be applied to all Classes 1, 2, and 3 piping systems, an individual Class of piping (e.g., Class 1 piping), to all piping in Examination Category B-F, B-J, C-F-1, or C-F-2, or to one or more individual piping systems (e.g., Reactor Coolant System). Boundaries for the scope of all piping systems, or portions thereof, (i.e., portions of piping needed to include a complete Examination Category of piping, a piping system, or a Class of piping) to be considered for evaluation in accordance with either risk-informed selection process shall be clearly defined. When not applying either process to all systems in a Class of piping, the piping systems that are not evaluated shall be examined in accordance with Examination Category B-F, B-J, C-F-1, or C-F-2, as applicable.

(c) Application of this Appendix for plants that do not have an existing deterministic inservice inspection program is in the course of preparation.

R-1200 PIPING SUBJECT TO EXAMINATION

R-1210 BOUNDARY REQUIREMENTS

As an alternative to the examination requirements of IWB-1210, IWC-1210, or IWD-1210, as applicable, the examination requirements of this Appendix shall be used for Class 1, 2, and 3 piping evaluated by a risk-informed process. Piping in systems evaluated as part of the plant Probabilistic Risk Assessment (PRA), but outside the current Section XI examination boundaries, may be included.

R-1220 PIPING EXEMPT FROM EXAMINATION

In lieu of the exemptions of IWB-1220, IWC-1220, or IWD-1220, as applicable, piping segments and their structural elements shall be evaluated in accordance with the requirements of Supplement 1 or 2 to determine if any exemptions may be applied.

R-1230 RISK-INFORMED SELECTION PROCESS

(a) High Safety Significant (HSS) piping structural elements shall be examined in accordance with R-2500.

(b) The risk-informed selection processes in this Appendix are specified in Supplements 1 and 2. Each process identifies how to classify piping segments and their piping structural elements, based on their safety significance, as HSS or Low Safety Significant (LSS).

(c) If using Supplement 1, HSS or LSS is determined by the process described in 4.2.4 through 4.2.8 of Supplement 1, and if using Supplement 2, HSS is determined to be Risk Category 1, 2, 3, 4, or 5, and LSS is Risk Category 6 or 7 as defined in 3.3.2 of Supplement 2.

R-1300 OWNER'S RESPONSIBILITY

R-1310 ADEQUACY OF THE PRA

The PRA shall meet the requirements of ASME RA-S with the RA-Sa addenda and the RA-Sb addenda to the extent required to support the development and application of a risk-informed inservice inspection program. All PRA weaknesses or deficiencies identified by regulatory or peer review shall be explicitly accounted for during the analysis used to support the risk-informed inspection program. The resolution of all PRA issues shall be documented.

R-1320 PROGRAM INTENT AND PRINCIPLES

The development or update of a risk-informed inspection program in accordance with this Appendix shall meet the intent and principles outlined in USNRC Regulatory Guide 1.174, Revision 1, November 2002, and Regulatory Guide 1.178, Revision 1, September 2003.

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Single-side Qualifications for N-711-1

Gary Lofthus
Southern Nuclear

Carl Latiolais
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Design and Fabricate Austenitic Samples

- Code Case N-711-1 has been ASME approved
  - Provides a prescriptive, step by step process, that enables the user to determine the Volume of Primary Interest (VPI)
- If the applicable Volume of Primary Interest (VPI) is fully examined using qualified techniques, a request to the regulatory body is not required even if the ASME volume is not fully covered

Degradation Mechanisms: IGSCC

Component Configuration:
Pipe to Cast Component

Ferrite/Carbon Content
within Resistant Region of Figure 1

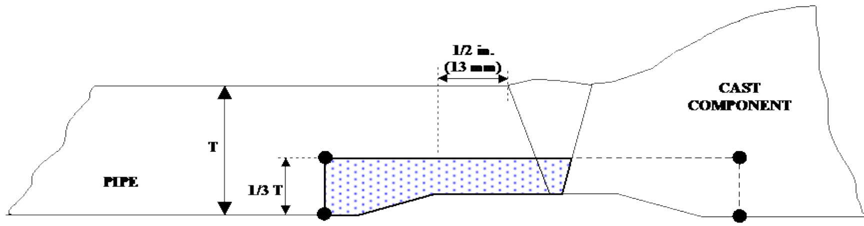

Figure G1

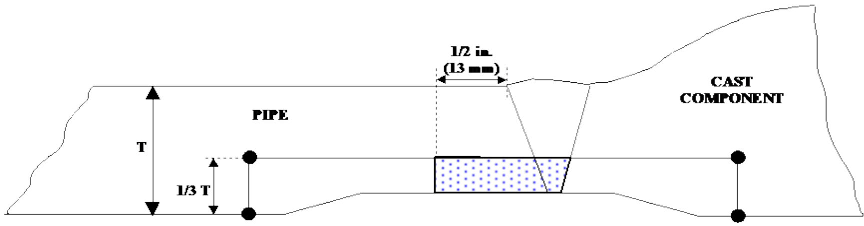

Figure G2

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Design and Fabricate Austenitic Samples

- Current Appendix VIII sample sets do not contain flaws located in the entire VPI, which could result in procedures with limitations (e.g. axial flaw detection on far side of weld, limited ASME volume coverage)

- This project is designing and fabricating samples that have flaws focused on VPI
  - Potentially allow for an unlimited qualification of the VPI
  - Augment the current Appendix VIII sample set

Degradation Mechanisms: IGSCC

Component Configuration:
Pipe to Cast Component

Ferrite/Carbon Content
within Resistant Region of Figure 1

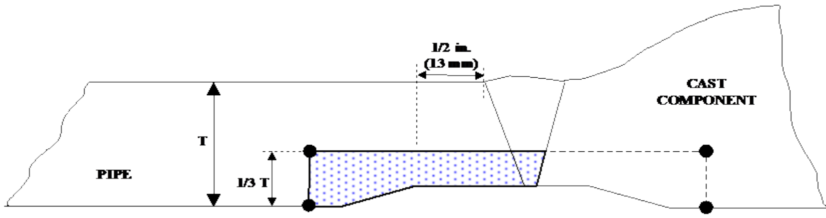


Figure G1

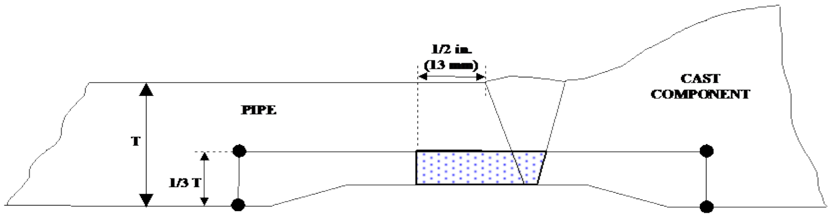
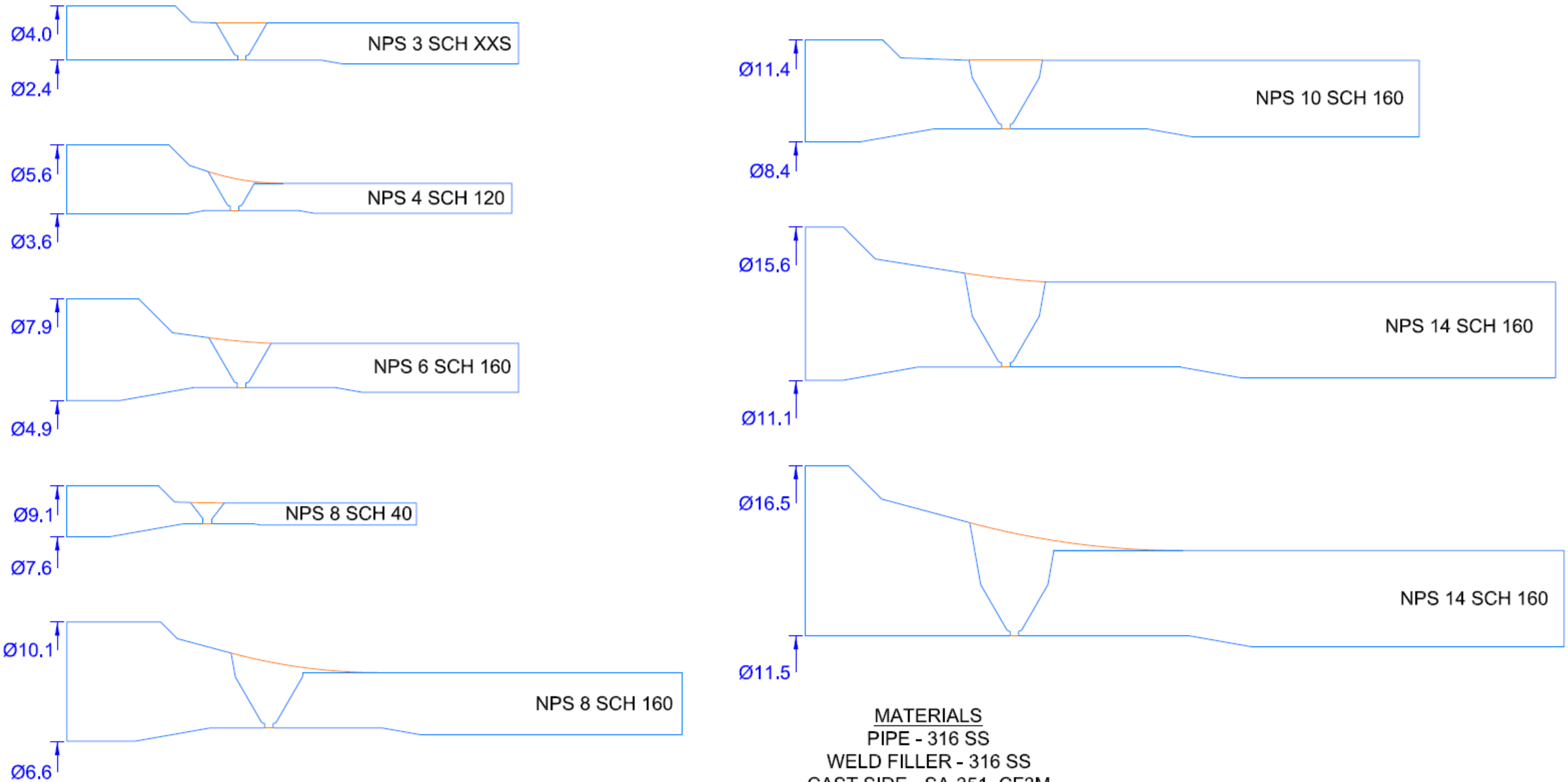


Figure G2

Sample Matrix

Pipe Size (NPS)	Weld Taper Angle (Deg.)	Thickness at Weld Centerline (in.)
3" Sch XXS	0	0.6
4" Sch 120	18	0.5
6" Sch 160	8	0.7
8" Sch 40	2	0.3
8" Sch 160	15	1.0
10" Sch 160	0	1.0
14" Sch 160	9	1.3
14" Sch 160	15	1.5

Sample Matrix



MATERIALS
PIPE - 316 SS
WELD FILLER - 316 SS
CAST SIDE - SA-351, CF3M

Schedule

- 2017
  - Fabricate specimens
  - Integrate into the PD program
  - It was estimated that the samples would be ready to support qualification during the fourth quarter 2017 however;
    - Vendor had welding issues due to properties of the cast material, which has delayed delivery
    - Worked with vendor to solve these issues and developed a detailed repair plan
    - 20 of the 25 samples have been accepted
- 2018
  - The remaining 5 samples should be finalized and accepted in Q1 2018
  - Demonstration activities targeted to start in Q2 2018

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ET Acceptance Criteria and Code Cases

Kevin Hacker
Dominion Energy

Greg Selby
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
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Background

- Relevant guiding documents that currently provide the basis for ET acceptance criteria do not reflect the ET capability results collected over the past decade

- This may result in implementation of overly sensitive surface ET techniques that may be prone to false calls

- The use of a shallow notch is disconnected from the IGSCC, PWSCC, and ODSCC morphology evidence collected at plants, which indicates that SCC is branched with a large subsurface crack network

- This requirement drives ET technology toward the implementation of sensors that are optimal for notch detection, but are not optimal for SCC detection. These sensors have high sensitivity and shallow penetration and can be prone to false calls

Project Objectives

- Review relevant Code documents that provide demonstration requirements and acceptance criteria for ET surface examinations in the context of newly available surface examination results

- Develop a technical basis document that can be used as a guidance to revise the applicable documents

Relevant Guiding Documents For Surface ET

- ASME Section XI, Division 1, Appendix IV, Eddy Current Examination, Supplement 2
- ASME Section XI, Division 1, Code Case N-770-2, Alternative Examination Requirements for Class 1 PWR Piping and Vessel Nozzle Butt Welds Fabricated with UNS N06082 or UNS W86183 Filler Material With or Without Application of Listed Mitigation Activities
- ASME Section XI, Division 1, Code Case N-773, Alternative Qualification Criteria for Eddy Current Examinations of Piping Inside Surface
- ASME Section XI, Division 1, Code Case N-766-1, Nickel Alloy Reactor Coolant Inlay and Onlay for Mitigation of PWR Full Penetration Circumferential Nickel Alloy Dissimilar Metal Welds in Class 1 Items

Summary of ET Requirements

- Section XI, Mandatory Appendix IV, Supplement 2
  - The flaw-grading units shall be cracks or notches
  - The maximum depth of a crack or compressed notch shall be 0.040 in. (1.02 mm)
  - Machined notches shall have a maximum width of 0.010 in. (0.25 mm) and a maximum depth of 0.020 in. (0.51 mm)
- Code Case N-770-4
  - ET to be performed in accordance with mandatory Appendix IV, Supplement 2
- Code Case N-773
  - Provides alternative requirements to Appendix IV Supplement 2 when using ET together with UT to examine inside surfaces of austenitic welds
  - Demonstration flaws shall be cracks or notches
  - The demonstration flaws shall have a maximum opening dimension of 0.0019 in. (50µ)
- Code Case N-766-1
  - States that the acceptance criteria for inlay or onlay surface rounded indications with a major dimension >1/16 in. (1.5 mm) are not permitted

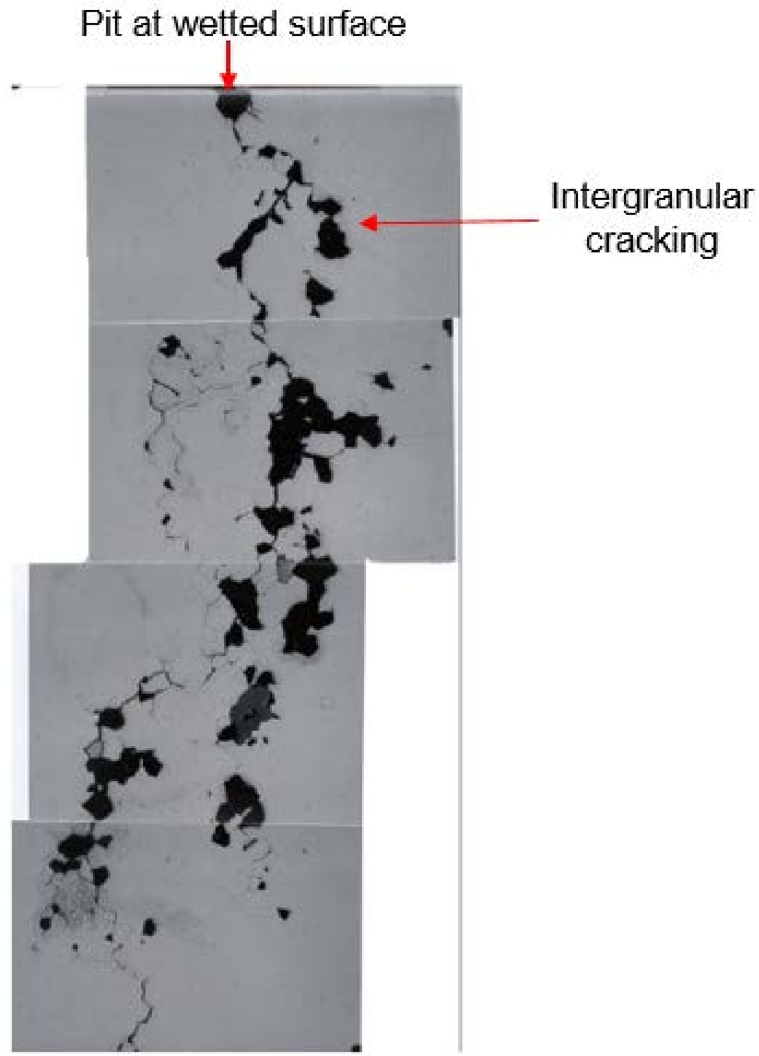
Relevant OE and Laboratory Evaluation

- Industry OE Evaluated
  - V.C. Summer RPV Hot Leg Weld Cracking (2000)
  - Oconee 3 CRDM Cracking (2002)
  - North Anna 2 CRDM Cracking (2002)
  - Beaver Valley 2 CRDM Cracking (2006)
  - Davis-Besse CRDM Cracking (2010)

- Laboratory Evaluation
  - EPRI Administered Vendor Blind Demonstrations (2003)
  - EPRI Report 1021058 (2010)

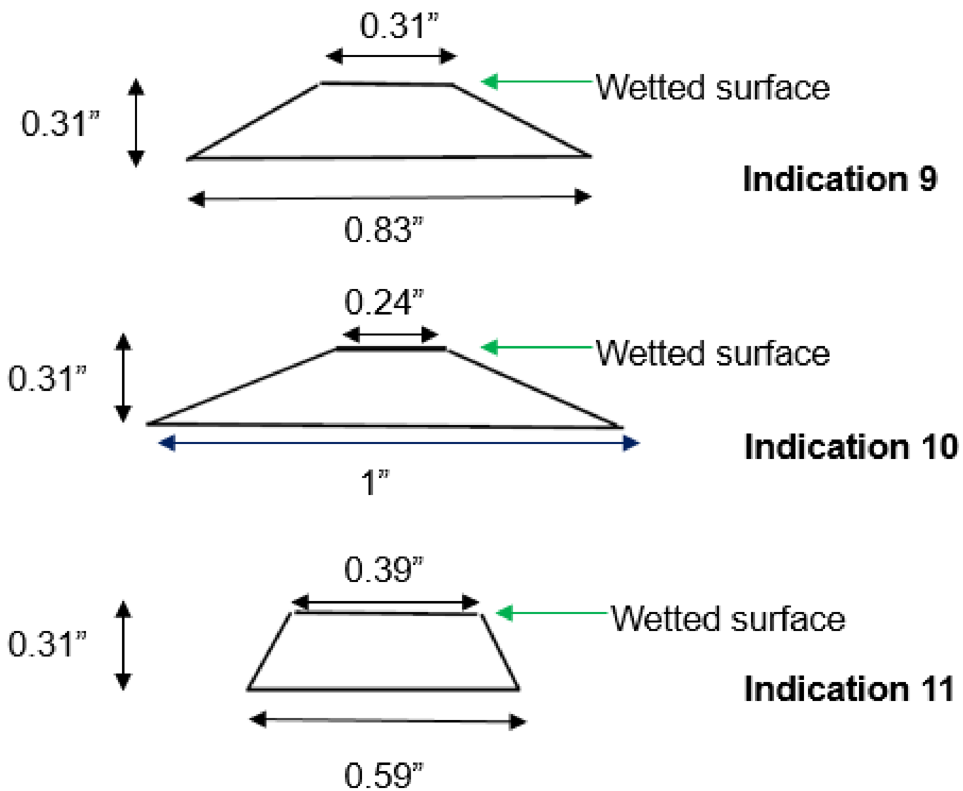
Typical PWSCC Morphology

- An example of a PWSCC crack obtained from a CRDM penetration
- The crack network shows a pattern with crack branching in the subsurface region along the grain boundaries
- The figure also shows the damage initiating at a localized surface pit



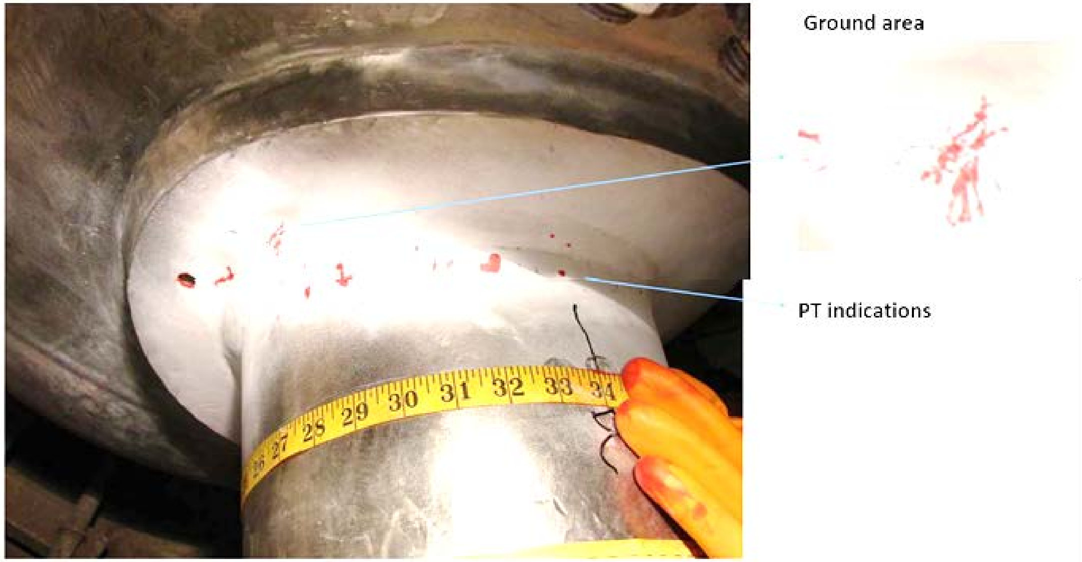
J-Groove Weld Sectioning Results Showing Crack Length Variation with Depth

- Sectioning on selected damaged J-groove welds
- Cuts were made 0.31 in. (8 mm) below the wetted surface at the location of three ET indications, and the surface and subsurface crack lengths were compared
- Crack lengths increased as the cracking propagated into the material



ODSCC Morphology Example in Austenitic Steel Surfaces

- PT indications on the surface are predominantly isolated rounded indications
- Upon grinding one of the affected areas, a three-dimensional cracking structure was uncovered in the subsurface region



Summary

- Components affected by SCC exhibit flaw morphologies that have a large subsurface structure when compared to the surface defect
- Relevant documents that guide surface examination demonstrations include acceptance criteria requirements for detection of short surface defects
  - These requirements are an incomplete representation of SCC
  - Some requirements are based on PT
- The "short defect" requirements have driven some ET equipment designers to develop probes with high sensitivity that are prone to false calls
- Evaluations performed with a different flaw target that included a larger subsurface structure found:
  - Probes having low resolution and deeper penetration exhibited superior signal-to-noise ratio to high sensitivity probes

Conclusions

- ET and PT methods should use different acceptance criteria for detection and procedure qualification

- ET demonstration test sets should include defects with subsurface morphologies instead of small shallow surface flaws or notches

- MRP-423, "Technical Basis for Surface Eddy Current Demonstration in Materials Susceptible to Stress Corrosion Cracking" (public) has been published and will be used to support Code changes

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Design for Inspectability

Gary Lofthus
Southern Nuclear

John Lindberg
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Overview of Issue

- Section XI, IWA- 2200(c) requires essentially 100% coverage for all examinations
- Welds connecting austenitic pipe to cast component configurations have material and geometric considerations that limits 100 % examination coverage from both sides
- For these configurations, the industry has been unable to qualify ultrasonic examination procedures to Appendix VIII requirement to obtain essentially 100% coverage from both sides of the weld.
  - Thus, examination coverage is limited to only single sided coverage and does not meet regulatory requirements.
  - Operating plants are typically granted relief from the 100% coverage requirement;
  - New Plants are required to achieve 100% examination coverage for all pre-service and inservice examinations.

ASME – Task Group on Inspectability

- ASME formed Section XI – Task Group on Inspectability (TG-I) to try to resolve the issue
  - members include stakeholders from Section III, XI, and industry
- Charter
  - The Task Group shall have responsibility for developing and proposing Code revisions and Code Cases concerning the examination of items that do not allow the Code required examination coverage, based on either material type or configuration. The initial focus shall be on new plant construction. Those configurations being addressed shall include but not limited to 1) pipe-to-valve, 2) pipe-to-pump, and 3) pipe-to-fitting. The material to be addressed is austenitic material, either cast or forged, that currently does not allow full Code examination coverage with single sided access. Another issue is cast stainless steel, where no Appendix VIII examination qualification exists at present. The Task Group shall refer potential Code actions to the appropriate Subgroups as needed.
- The Task Group reports directly to the BPV XI Executive Committee.

Actions discussed and in process

- A list of potential actions have been discussed and prioritized
  - Section XI actions focus around the use and implementation of Code Case N-711-1, "Alternative Examination Coverage Requirements for Examination Category B-F, B-J, C-F-1, C-F-2, and R-A Piping Welds"
    - Uses a volume of primary interest (VPI) versus code required volume
    - EPRI is fabricating mock-ups for procedure development and qualification for use in implementing N711-1 criteria
  - Section III actions focus around identifying the challenges meeting Section XI examination criteria for existing pump, valve, and other configuration and component designs resulting in limited exam coverage
    - White papers are being developed to assist in providing a technical basis to support any future code actions.
  - Other items being pursued
    - Development of Appendix VIII, Supplement 9 – CASS (CC N-838)
    - Use of Technical Basis from Code Case N-481 – Request for Alternative
    - Other techniques - RT

TG-I - Action Item List

Action	Near (N) or Long (L) Term	Subject	Sponsor	Status
TGI-1	N	Develop List of Potential Solutions	ALL	Complete
TGI-2	N	Validate That Record 14-955 Actions Are Covered By The TG	D. Henry/ Gionta	Active
TGI-3	N	Provide EPRI Priority List to Support The TG	Lindberg	Active
TGI-4	L	Use Of N-711-1 (How to Use for New Plants) and Pilot Applications.	O'Regan	Active
TGI-5	N	EPRI Mockups for Procedure Development/ Qualification	Latiolais	Active
TGI-6	N	Get Better Understanding of Limitations of Pump and Valves	Tucker/Klein	Active
TGI-7	N	Identify Other Configurations Where Design Rules Could Resolve.	Ferlisi/ Matthews	Active
TGI-8	L	Development of Digital RT For Use in Section XI Volumetric Exams	D. Henry	Active
TGI-9	N	Use of Technical Basis from Code Case N-481	Bamford	Active
TGI-10	L	Qualification of Single-Sided Access Examination Procedures	Latiolais	Active
TGI-11	L	Cast Stainless Steel – Appendix VIII – Supplement 9	Latiolais	Active
TGI-12	L	Refine Section XI Examination Volumes	TBD	Active
TGI-13	N	Use of Proposed and Docketed Requests for Alternatives	Thomas	Active
TGI-14	L	Cast Austenitic Stainless Steel – Need Industry Operating Experience Data to Support Changing Section XI Examination Requirements.	EPRI	Active
TGI-15	L	Evaluate Fitness for Service (FFS) Techniques That Could Be Used to Justify Limited Coverage for UT Examinations	Paul Donovan	Active
TGI-16	N	Evaluate Attachment 1 Flow Chart of Actions	Dan Lieb	Active

Issues facing Utilities – Code Case N-711-1

- Code Case N-711-1 has an alternative that utilities would like to consider for examination volume and coverage. This code case was revised in August 2016 to incorporate NRC comments. Thus far, no one in the industry is using this code case.
  - Someone would have to be the first plant in the industry to request an alternative to the NRC to utilize this code case for our examination volume.
  - The code case allows for the examination of the "Volume of Primary Interest (VPI)
- Currently, operating plants have to submit relief requests for single side stainless steel examinations where we only obtain 50% coverage.
  - These relief requests are submitted for multiple intervals.
  - The coverage issues have not changed and we keep submitting the relief requests every ten years for limited examinations (regulatory burden).

Issues facing Utilities – Code Case N-711-1

- By submitting an alternative, we could follow the code case and not have to submit relief requests in accordance with 10CFR50.55a.

- For new plant PSI, we are not allowed to submit for limited examinations based on impracticality or design.
  – Currently there has been work for a technical approach to not examine 100% of the volume of specific austenitic welds. The Technical Basis is very similar for this Technical Basis and the one utilized for Code Case N-711-1.

Issues facing Utilities – Code Case N-711-1

- The N-711-1 approach could be used for operating plants, working with EPRI and the NRC to reduce the number of relief requests.
  - Code case is not approved in the regulation.
- Working with EPRI and Westinghouse; 54 configurations were identified at Vogtle 3 and 4. Need to determine if changes will be needed to qualified Appendix VIII ultrasonic examination procedures to be able to examine the volume of primary interest (entire weld nugget); listed in code case N-711-1).
  - EPRI is fabricating UT test specimens to be used to assess the impacts to current PDI procedure and qualification.
  - When utilities submit an alternative for the operating units, they will need the results from the test specimen assessment

Issues facing Utilities – Code Case N-711-1

- Submittal dates for the first operating units are not yet clear. Early work has begun on the technical basis and support for alternative relief request (similar to flange ligament relief request).

- While there is still work to do, this may help reduce the number of relief requests submitted to the NRC by utilities each year at the end of their interval.
  - If successful, the next step would be to work with ASME Section XI Code Changes (non-mandatory appendix).

Questions

Together…Shaping the Future of Electricity

Human Factors

Kevin Hacker
Dominion Energy

Myles Dunlap
EPRI

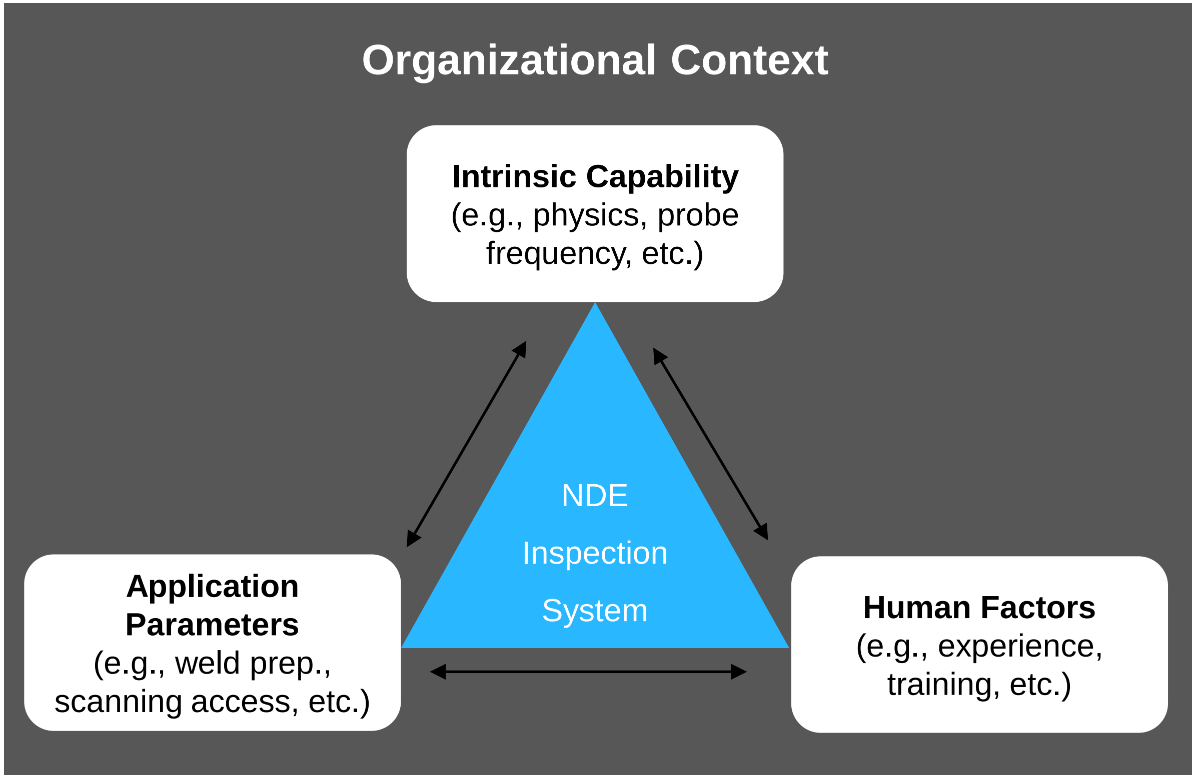
NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Outline

- NDE Reliability and Human Factors Considerations
- EPRI's NDE Human Factors Research
- NDE's Future with Human Factors Involvement
- 2018 Research Activities
- Summary

NDE Reliability – The Big Picture

- The *Modular Reliability Model*[1,2] defines four primary influencing factors of NDE reliability: intrinsic capability, application parameters, human factors, and organizational context.
- Human factors and organizational context have received the least amount of research.
  - Provides new opportunities for NDE reliability



Content sourced from 1, 2.

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

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

Human Factors Considerations

- The end user, operator, examiner
  - Physical characteristics such as ergonomics
  - Psychological factors such as decision making
- Scenarios and tasks
  - What is the person trying to accomplish?
  - What training and procedures are available?
- Equipment and tools
  - Human-system interface
  - Tool design
- Environment of use
  - Physical environment
  - Management and organizational factors
  - Regulatory considerations

Research Focus

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

<u>Field</u>

<u>Training/Laboratory</u>

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Research Methodology

- A multi-method approach is being taken to research and investigate the human factors associated with performing manual UT within the nuclear industry:
  - Literature review
  - Review of operating experiences
  - On-site observations
  - Personas and scenarios for NDE examiners
  - High-level task analysis (currently underway)

Publicly available report at
www.epri.com

Human Factors in Nondestructive Evaluation (NDE): A Literature Review and Field Observations.
EPRI, Palo Alto, CA: 2017. 3002010462.

Literature and Operating Experience Review

- Human performance literature for the nuclear NDE industry is relatively small, qualitative and lacks empirical validation of causal factors for NDE reliability.

- EPRI experts provided operating experience of over a dozen real events that have occurred in the past ten years.
  - Incidences of reported human errors during NDE leading to reportable consequences is statistically low.

Literature and Operating Experience Review

- Two nuclear power plants were visited by human factors specialists to observe manual ultrasonic testing.
  - Listen to present-day examiners and others describe challenges and opportunities to continue to ensure low error rate across the industry.

- Examiner experiences or perceptions are rarely considered or measured.
  - Personas, scenarios, and a task analysis for NDE UT examiners will help guide research activities.

Personas and Scenarios

- Human-centered design focuses on ensuring the "end user" is appropriately observed, heard and represented in design decisions.
- Usually the "end users," in this case examiners, are not present when important design decisions are made – the personas can be there to represent them.
- Purpose of personas is to create reliable and realistic representations of key "end users" based on user research.
  - The persona describes realistic background and goals of the hypothetical examiner.
- EPRI created personas, and scenarios, for each manual UT examiner level[1].

1: NDT Certification Systems. https://www.asnt.org/MajorSiteSections/NDT-ResourceCenter/Codes_and_Standards/NDT_Certification_System.aspx. Retrieved September 22, 2017.

Level II Examiner Persona

Adam

Adam has worked in the nuclear power industry for over 12 years. He has been Level II certified for eight of those years. He prefers to work in the field so he has postponed pursuing his Level III certification. He's proud to be one of the few with his experience and skills, and works hard to not become complacent - after all, there's never been an undetected flaw on any of his inspections. As a mentor, Adam wants to pass along his tips and tricks to the younger guys, the ones that make him responsible for everyone's safety.

"*I like the action during outages and when working in the field – time flies by.*"

About the Job

Usually works 60 hours a week or more during outages and has time off usually in summer and winter months.

Spends about a fourth of his workday doing each:

- Reviewing historical data and procedures
- Calibrating equipment and working with a Level 1
- Conducting an inspection
- Completing documentation and reporting findings

About the Challenges

Pressure to not make any mistakes, he doesn't want to be known as "that guy" who made a mistake as it will go down in history of the forever.

Has to oversee his Level I, double check and cross reference all the procedures and applicable documents to ensure all the paperwork and the calibrations are done correctly while dealing with the industrial environment with health risks, background noise and activity.

He is the go to person for both his Level III and his Level I who both depend on him. There is an extremely large amount of cognitive load for him.

He hopes to have a good relationship with his team members to help work go smoothly - that open and casual communication will help mitigate the stress.

Current Research Activities

- A high-level task analysis is being conducted to identify and prioritize the actions and processes required for an NDE examiner to complete their job.

- To ensure critical tasks receive the attention they deserve in:
  - Training
  - Procedures
  - Equipment design
  - And other human factors considerations

- Interviewed current day practicing NDE examiners.
  - Conducted anonymous one-on-one phone interviews.
  - Anonymized interview data has been collectively shared between EPRI and NRC.
  - Themes in examiner responses are being identified and will be prioritized accordingly.

The Demographics of Examiners Interviewed

- EPRI interviewed 31 current-day ultrasonic examiners and NRC interviewed another set of examiners.
  - Through our MOU collaboration the collective data set was significantly increased for each research team.
  - Ultimately, this allowed for a larger amount of examiners to be interviewed and our data becomes much richer.
- Mix of Utility and Vendor
- Mix of Level II and III
- Mix of geographic regions

	Level II	Level III	Total
Vendor Employee	8	7	*15*
In-house Utility Employee	6	10	*16*
Total	*14*	*17*	*31*

Interview Questions

- In early 2017, interview questions were pilot tested and fine tuned with ultrasonic and NDE Subject Matter Experts (SMEs) at EPRI.
- Open-ended questions were asked in order to hear the examiner's "voice."

Section	Question
Task Analytic	What high-level tasks do examiners perform when conducting a manual ultrasonic test?
	For these tasks, which ones would you say are most important?
	Which ones are more error prone?
Challenges and Opportunities as a UT Examiner	Training: Could be improved and how?
	Training: Are unnecessary and why?
	Job: Faster or better?
	Job: More satisfying, i.e., improve the examiners experience?
	Job: If you could change one thing about your job?
Differences between PD and Field	Describe the differences between performing UT in Performance Demonstration (PD) and in the field?
Influencing Factors for PD and Field	Describe what affects you most in PD? … most in field?

What are We Hearing from Current-Day NDE Examiners?

- Responses from each interviewee and for each interview question are currently being analyzed.
  - This will identify key human performance issues as experienced by current day examiners.
  - The industry has been terrific in their response!
- For example:

Question	UT Examiner Responses
What aspects of training could be improved, and how?	"…look at more flawed samples. More training equals a better examiner." "Training needs to be on good mockups, situations you run into in the field,…" "…the part I like to stress is scenario training for new examiners." "…just scanning samples is very valuable."

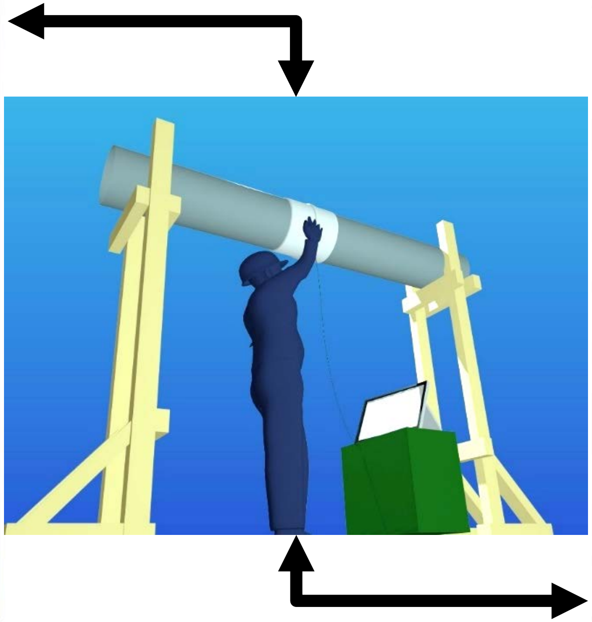
Examiners are requesting access to practice samples

An Example of Addressing Human Factors with Technology Innovation

Conditions in laboratory environment

Simulator in Simulated Environment

Conditions in field environment



An ultrasonic testing simulator is a missing link!

Virtual NDE: Ultrasonic Data Player (VNDE) v1.0. Electric Power Research Institute, Palo Alto, CA: 2015. Product ID 3002005493.

2018 Research Activities

- EPRI and NRC will co-lead workshop(s) with representatives from multiple NDE stakeholder groups.
  - The location(s) and structure of the workshop(s) are being determined.

- Workshop(s) will focus on soliciting feedback from industry stakeholders regarding the human factors as identified by the analysis of examiner interview data in order to:
  - Prioritize the list of human factors
  - Provide suggestions for addressing the list of human factors

- Prioritization will identify the “low-hanging fruit” for manual UT and provide definitive direction for future research.
  - Several metrics can be used for prioritization such as degree of improvement, difficulty of achieving, available technologies, safety considerations, etc.
  - Involvement and input from industry stakeholders is necessary.

Summary

- Human factors research can help prioritize and guide interventions to lessen the affects of extreme work settings on NDE examiner performance.
- NDE human factors literature lacks a significant amount of repeat empirical validation and the occurrence of NDE failures in the industry are statistically very low.
  - This makes the identification and validation of causal human performance factors more difficult. What factors should and can be addressed?
- A task analysis is being performed to identify the actions and processes required for an NDE examiner to complete their job and to ensure they receive the attention they deserve in research.
  - Hearing from current day examiners, in their own words, was of the utmost importance.

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Summary (continued)

- EPRI and NRC communicate on-going research activities via monthly video/tele-conference calls.

- EPRI and NRC will co-lead workshop(s) in 2018 to gather input from NDE stakeholders on human factors for manual UT.
  - To be involved in these workshop(s) please contact:
    - Myles Dunlap, mdunlap@epri.com, (704) 595-2715

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PD Program Update

David Anthony
Exelon

Carl Latiolais
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Piping Program Personnel Qualification Activities November 2016 to November 2017 (1 of 3)

- Personnel Qualifications (General Statistics)
  - **138 Non-Encoded**

Test Type	Detection	Length	TWS
Austenitic w/ IGSCC	15	7	0
Austenitic w/o IGSCC	27	15	0
Ferritic (Supplement 12)	26	21	0
Ferritic Only	0	0	0
Weld Overlay	0	0	0
Dissimilar Metal Welds	2	2	1
IGSCC Requalification	8	6	8
WOL Requalification	0	0	0

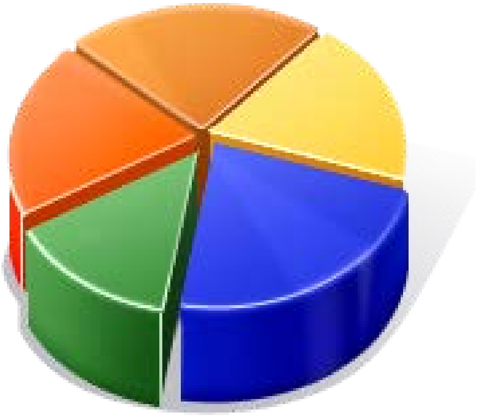
Piping Program Personnel Qualification Activities November 2016 to November 2017 (2 of 3)

- Personnel Qualifications (General Statistics)
  - **119 Encoded**

Test Type	Detection	Length	TWS
Austenitic w/ IGSCC	9	7	14
Austenitic w/o IGSCC	0	0	0
Ferritic (Supplement 12)	7	7	14
Ferritic Only	0	0	0
Weld Overlay	0	0	0
Dissimilar Metal Welds	17	13	17
IGSCC Requalification	9	5	0
WOL Requalification	0	0	0

Piping Program Personnel Qualification Activities November 2016 to November 2017 (3 of 3)

- Personnel Qualifications (General Statistics)
  - **34% (87/257)** of piping personnel qualifications used phased array
    - Non-Encoded qualifications = **32% (44/138)**
    - Encoded qualifications = **36% (43/119)**



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RPV Personnel Qualifications Activities November 2016 to November 2017

- Personnel Qualifications
  - Non-Encoded
    - 1 Candidates, Supplement 8 (Bolting)
    - 4 Candidates, Supplement 4 & 6 (RPV Welds)
  - Encoded
    - There were no encoded qualifications during this time frame

Procedure Qualifications - Piping & RPV May 2017 to November 2017

- RPV
  - None

- Piping
  - Encoded Supplement 10 (DM) procedure qualification
  - Encoded Supplements 10 & 2 (DM & Austenitic) ID procedure qualification
  - Non-Encoded Supplement 3 (Ferritic) procedure expansion thickness greater than 7.0”

PDI Pass Rates Update

Piping Pass Rates 2011 to Present (11/21/2017)

Initial (Non-Encoded)

Non-Encoded	# Candid. 1st Attempt	# Passed 1st Attempt	# Candid. 2nd Attempt	# Passed 2nd Attempt	# Candid. 3rd Attempt	# Passed 3rd Attempt	% Pass rate 1st Attempt	% Pass rate 2nd Attempt	% Pass rate 3rd Attempt	% Yield
AUST. DETECTION (NO) IGSCC	104	57	40	23	21	9	54.81	57.5	42.86	85.58
LENGTH SIZING (NO) IGSCC	95	76	19	14	5	3	80	73.68	60	97.89
AUST. DETECTION / W IGSCC	60	32	24	13	6	4	53.33	54.17	66.67	81.67
LENGTH SIZING / W IGSCC	49	34	10	9	4	3	69.39	90	75	93.88
SUPPLEMENT 12 FERRITIC DET.	132	79	36	27	9	5	59.85	75	55.56	84.09
SUPPLEMENT 12 FERRITIC LENGTH	123	81	30	23	8	6	65.85	76.67	75	89.43
FERRITIC DETECTION	10	4	5	1	2	0	40	20	0	50
LENGTH SIZING FERRITIC	4	4	0	0	1	1	100	0	100	125
DEPTH SIZING (NO) IGSCC	13	9	7	4	1	0	69.23	57.14	0	100
DEPTH SIZING / W IGSCC	52	32	13	7	3	2	61.54	53.85	66.67	78.85
DEPTH SIZING SUP.12 FERRITIC	60	36	19	10	4	2	60	52.63	50	80
DEPTH SIZING FERRITIC	0	0	1	0	0	0	0	0	0	0
WOR - SUPPLEMENT 11	39	30	8	6	1	0	76.92	75	0	92.31
DISSIMILAR METAL WELDS - DET	25	19	3	3	0	0	76	100	0	88
DISSIMILAR METAL WELDS - LENGTH	22	19	3	3	0	0	86.36	100	0	100
DISSIMILAR METAL WELDS - TWS	15	7	4	2	0	0	46.67	50	0	60

Piping Pass Rates 2011 to Present (11/21/2017)

Initial (Encoded)

Encoded	# Candid. 1st Attempt	# Passed 1st Attempt	# Candid. 2nd Attempt	# Passed 2nd Attempt	# Candid. 3rd Attempt	# Passed 3rd Attempt	% Pass rate 1st Attempt	% Pass rate 2nd Attempt	% Pass rate 3rd Attempt	% Yield
AUST. DETECTION (NO) IGSCC	0	0	0	0	0	0	0	0	0	0
LENGTH SIZING (NO) IGSCC	0	0	0	0	0	0	0	0	0	0
AUST. DETECTION / W IGSCC	26	14	7	5	3	2	53.85	71.43	66.67	80.77
LENGTH SIZING / W IGSCC	19	14	4	4	1	1	73.68	100	100	100
SUPPLEMENT 12 FERRITIC DET.	20	14	3	2	1	1	70	66.67	100	85
SUPPLEMENT 12 FERRITIC LENGTH	16	13	2	2	1	1	81.25	100	100	100
FERRITIC DETECTION	4	3	1	0	1	0	75	0	0	75
LENGTH SIZING FERRITIC	4	4	0	0	0	0	100	0	0	100
DEPTH SIZING (NO) IGSCC	0	0	0	0	0	0	0	0	0	0
DEPTH SIZING / W IGSCC	26	15	11	10	0	0	57.69	90.91	0	96.15
DEPTH SIZING SUP.12 FERRITIC	20	13	8	7	0	0	65	87.5	0	100
DEPTH SIZING FERRITIC	4	4	0	0	0	0	100	0	0	100
WOR - SUPPLEMENT 11	17	13	0	0	0	0	76.47	0	0	76.47
DISSIMILAR METAL WELDS - DET	44	37	2	2	0	0	84.09	100	0	88.64
DISSIMILAR METAL WELDS - LENGTH	41	33	5	4	0	0	80.49	80	0	90.24
DISSIMILAR METAL WELDS - TWS	32	14	15	7	3	1	43.75	46.67	33.33	68.75

Piping Pass Rates 2011 to Present (11/21/2017)

Requalification

Non-Encoded	# Candid. 1st Attempt	# Passed 1st Attempt	# Candid. 2nd Attempt	# Passed 2nd Attempt	# Candid. 3rd Attempt	# Passed 3rd Attempt	% Pass rate 1st Attempt	% Pass rate 2nd Attempt	% Pass rate 3rd Attempt	% Yield
AUST. DETECTION / W IGSCC	155	105	50	22	22	13	67.74	44	59.09	90.32
LENGTH SIZING / W IGSCC	138	105	28	19	7	2	76.09	67.86	28.57	91.3
DEPTH SIZING / W IGSCC	48	31	15	11	5	4	64.58	73.33	80	95.83
WOR - SUPPLEMENT 11	26	19	2	2	0	0	73.08	100	0	80.77

Encoded	# Candid. 1st Attempt	# Passed 1st Attempt	# Candid. 2nd Attempt	# Passed 2nd Attempt	# Candid. 3rd Attempt	# Passed 3rd Attempt	% Pass rate 1st Attempt	% Pass rate 2nd Attempt	% Pass rate 3rd Attempt	% Yield
AUST. DETECTION / W IGSCC	59	41	19	16	4	3	69.49	84.21	75	101.69
LENGTH SIZING / W IGSCC	51	44	5	4	3	3	86.27	80	100	100
DEPTH SIZING / W IGSCC	31	20	10	7	2	2	64.52	70	100	93.55
WOR - SUPPLEMENT 11	5	5	0	0	0	0	100	0	0	100

RPV Pass Rates Since the Start of the Program

(Non-Encoded)

Non-Encoded	# Candid. 1st Attempt	# Passed 1st Attempt	# Candid. 2nd Attempt	# Passed 2nd Attempt	# Candid. 3rd Attempt	# Passed 3rd Attempt	%Pass rate 1st Attempt	%Pass rate 2nd Attempt	%Pass rate 3rd Attempt	Yield %
Shell (inner 15%) OD (Detection)	158	44	95	47	38	20	27.8	49.5	52.6	70.25%
Shell (inner 15%) OD (Length Sizing)	83	76	7	6	1	1	91.6	85.7	100.0	100.00%
Shell (inner 15%) OD (Depth Sizing)	85	49	36	26	8	4	57.6	72.2	50.0	92.94%
Shell (outer 85%) OD (Detection)	149	80	62	35	21	17	53.7	56.5	81.0	88.59%
Shell (outer 85%) OD (Length Sizing)	83	71	10	7	2	2	85.5	70.0	100.0	96.39%
Shell (outer 85%) OD (Depth Sizing)	85	62	19	14	2	2	72.9	73.7	100.0	91.76%
Noz-to-shell and IR OD (Detection)	54	33	11	9			61.1	81.8		77.78%
Noz-to-shell and IR OD (Depth Sizing)	21	14	5	3	2	2	66.7	60.0	100.0	90.48%

RPV Pass Rates Since the Start of the Program

(Encoded)

Encoded	# Candid. 1st Attempt	# Passed 1st Attempt	# Candid. 2nd Attempt	# Passed 2nd Attempt	# Candid. 3rd Attempt	# Passed 3rd Attempt	%Pass rate 1st Attempt	%Pass rate 2nd Attempt	%Pass rate 3rd Attempt	Yield %
Shell (inner 15%) OD (Detection)	116	49	43	25	18	10	42.2	58.1	55.6	72.41%
Shell (inner 15%) OD (Length Sizing)	75	66	9	7	2	2	88.0	77.8	100.0	100.00%
Shell (inner 15%) OD (Depth Sizing)	75	42	32	11	21	16	56.0	34.4	76.2	92.00%
Shell (outer 85%) OD (Detection)	116	80	23	15	6	5	69.0	65.2	83.3	86.21%
Shell (outer 85%) OD (Length Sizing)	90	74	16	11	5	4	82.2	68.8	80.0	98.89%
Shell (outer 85%) OD (Depth Sizing)	90	44	45	29	16	8	48.9	64.4	50.0	90.00%
Shell (inner 15%) ID (Detection)	172	115	55	48	5	5	66.9	87.3	100.0	97.67%
Shell (inner 15%) ID (Length Sizing)	136	126	8	6	2	1	92.6	75.0	50.0	97.79%
Shell (inner 15%) ID (Depth Sizing)	139	99	39	29	8	5	71.2	74.4	62.5	95.68%
Shell (outer 85%) ID (Detection)	180	102	75	45	24	18	56.7	60.0	75.0	91.67%
Shell (outer 85%) ID (Length Sizing)	133	97	36	30	3	3	72.9	83.3	100.0	97.74%
Shell (outer 85%) ID (Depth Sizing)	134	65	71	39	25	4	48.5	54.9	16.0	80.60%
Noz-to-shell and IR OD (Detection)	40	18	23	10	10	4	45.0	43.5	40.0	80.00%
Noz-to-shell and IR OD (Depth Sizing)	31	18	7	5			58.1	71.4		74.19%
Noz-to-shell and IR ID (Detection)	67	32	31	25	16	9	47.8	80.6	56.3	98.51%
Noz-to-shell and IR ID (Length Sizing)	38	33	3	3			86.8	100.0		94.74%
Noz-to-shell and IR ID (Depth Sizing)	40	32	6	4	2	1	80.0	66.7	50.0	92.50%

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Bolting Pass Rates

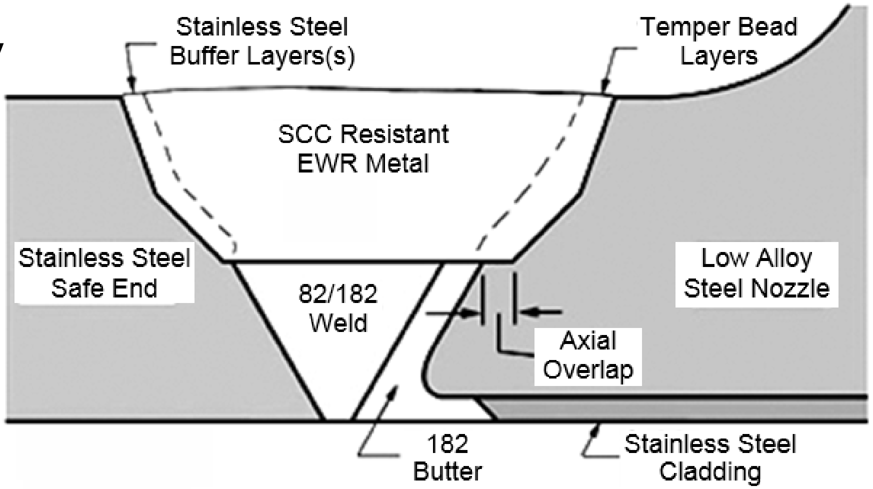
Examination Type	# Candid. 1st Attempt	# Passed 1st Attempt	# Candid. 2nd Attempt	# Passed 2nd Attempt	# Candid. 3rd Attempt	# Passed 3rd Attempt	%Pass rate 1st Attempt	%Pass rate 2nd Attempt	%Pass rate 3rd Attempt	Yield %
From End	334	266	56	49	5	3	79.2	87.0	60.0	95.21%
From Bore	93	58	21	6	4	3	62.2	29.4	66.7	72.04%

Pass Rates Summary

- PDI continues to monitor pass rates
- No significant changes have been observed since last update

Current and Future PD Program Appendix VIII Activities

- Programmatic
  - Reconciliation to 10CFR50.55a is underway
  - Continue ASME Section XI Code support
  - Continue PDI generic procedure revision process
- Sample Fabrication
  – Needed to support PDI program and to address field configurations
    – Fabricating 2” through 36” UT reference standards to support program/industry
    – Fabricated Safety Injection configuration (Westinghouse 2-loop) to support procedure add-on
    – Fabricated Excavation & Weld Repair (EWR) specimens to support Code Case N-847 (MRP Project)
    – Fabricating samples to support N-711-1



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Program Efficiency Improvements

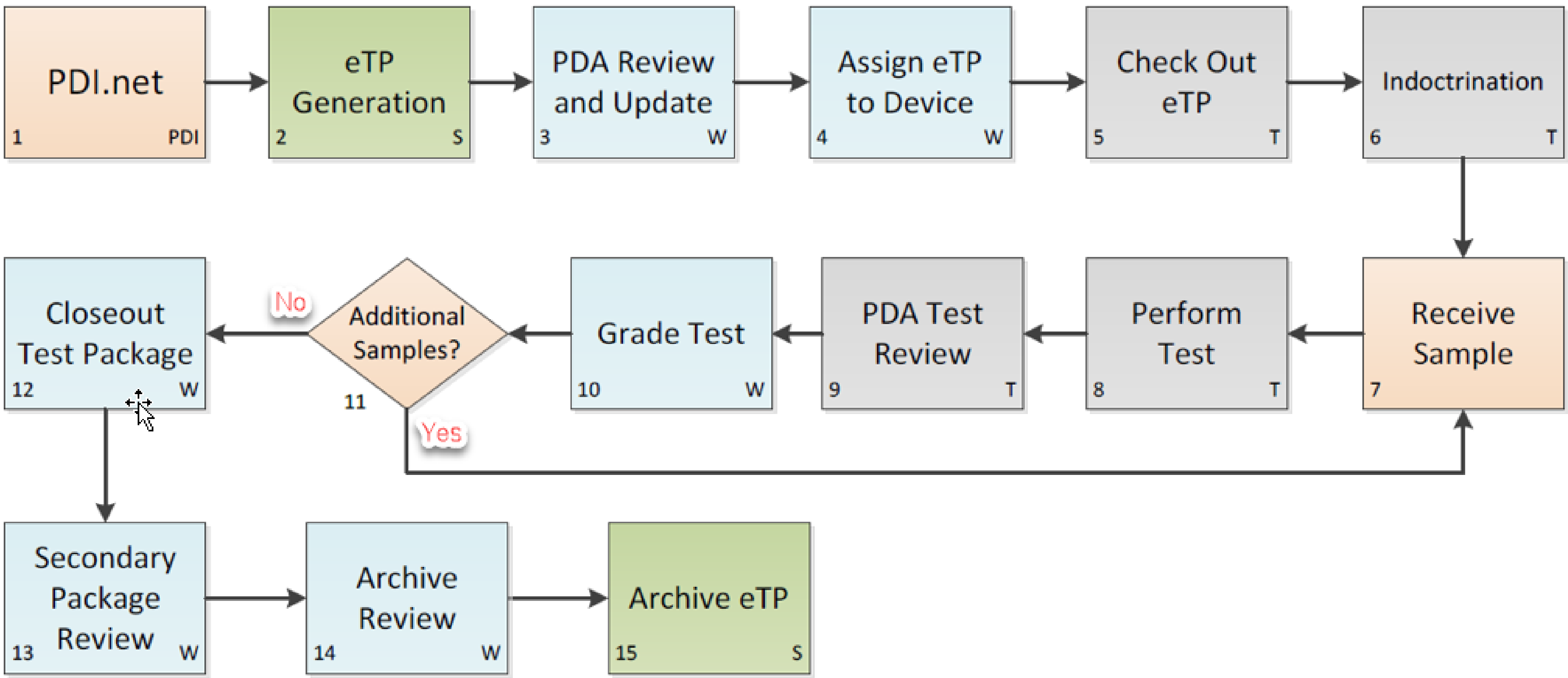
Objectives

- Convert current paper work process to an electronic process
  - Reduce paperwork
  - Reduce human error
  - Improve the work flow
  - Reduce the time needed to document/complete process
  - Allow for more efficient archiving

Overview

- The process of conducting a Candidate Ultrasonic Performance Demonstration Test is traditionally conducted using paper for communication of information between the candidate and the PDA
- With the introduction of eTP's (electronic Test Packages), the information between candidate and PDA is communicated electronically
- The candidate is provided with a computer that is configured to facilitate the communication of information in a secure and reliable way
- The eTP process starts with the creation of a Candidate Test and ends with the generation of the final QA records, including archiving

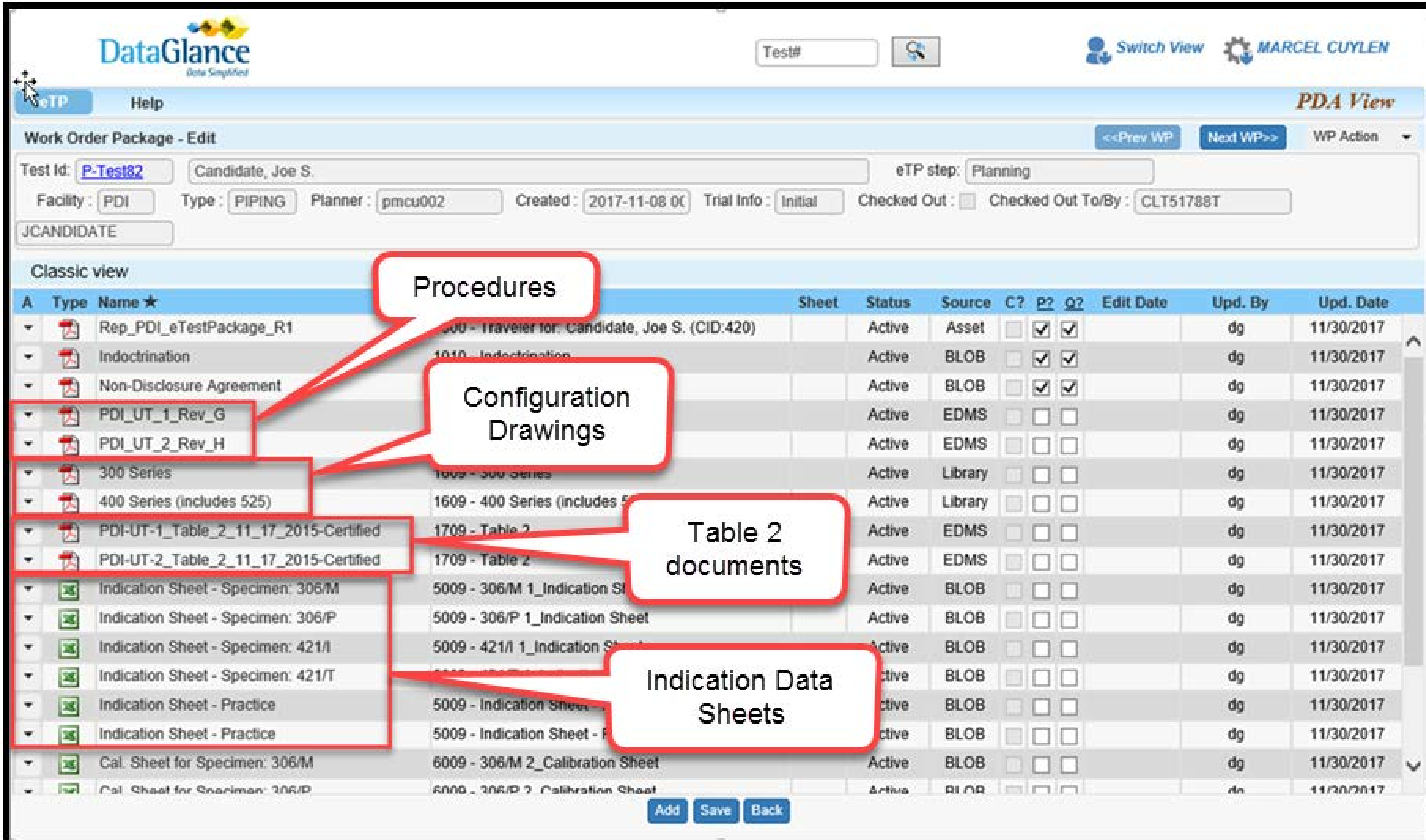
The Process



Legend

PDI = PDI.net
S = Automatic System Process
W = Workstation Activity
T = Tablet Activity

Sample eTP documents list (PDA View)



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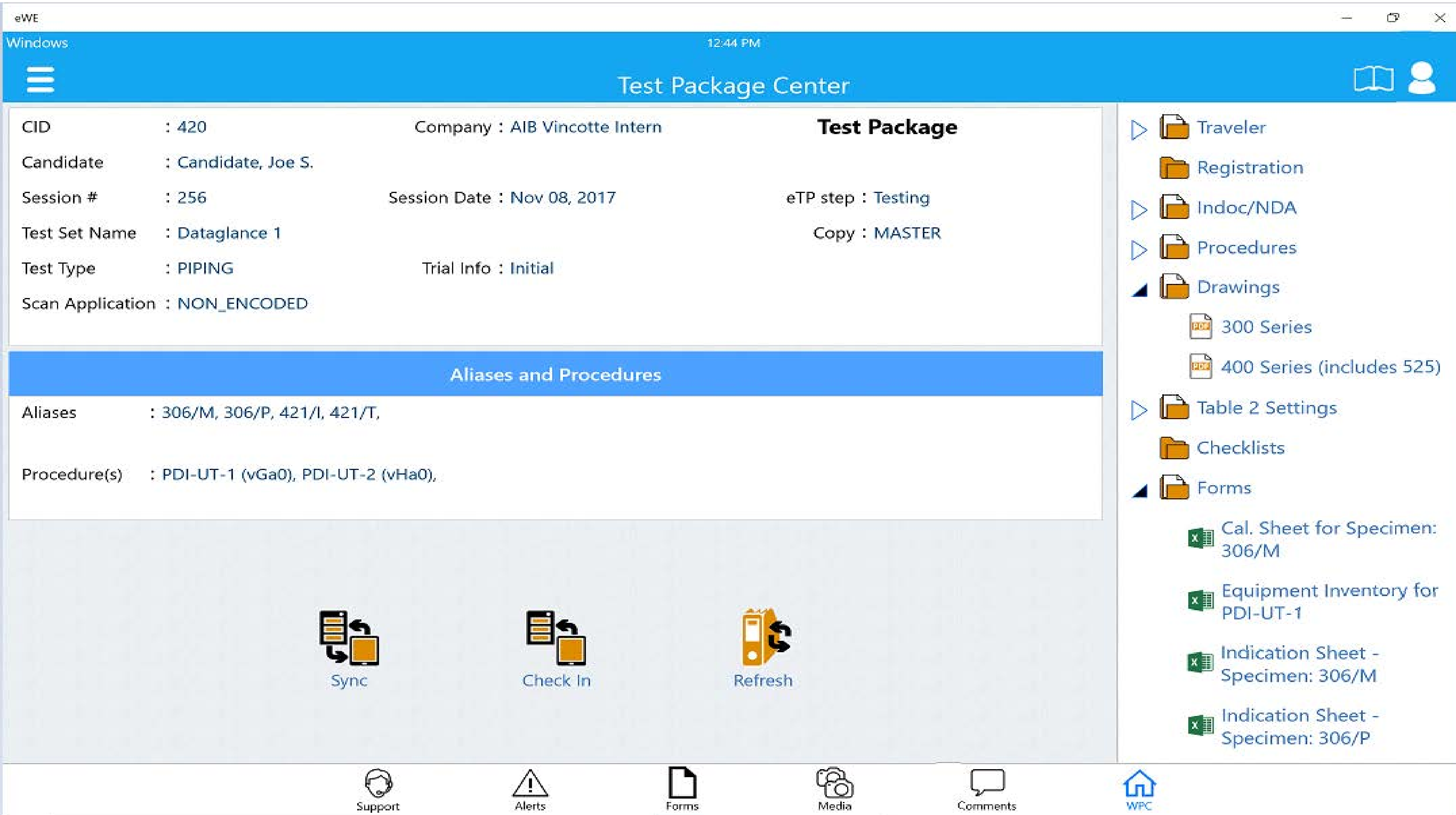
PDA Workstation

- The PDA accesses the workstation via an internet browser
- The PDA assigns the eTP to a specific tablet of workstation provided to the candidate
- The PDA manages the flow of documents available to the Candidate
  - Indoctrination information
  - Equipment Inventory, Calibration Sheet, Indication Data Sheet for the first Specimen next
  - Calibration Sheet(s), Indication Data Sheet(s) for subsequent Specimens last
- The PDA manages the grading of submitted Indication/Calibration data sheets
- The PDA indicates (checkbox) those documents to be included in the final QA document

Sample Candidate View



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Candidate Device (Tablet or Workstation)

- The Candidate checks out the eTP assigned by the PDA
- All documents necessary to perform the test are available to the candidate
- The Candidate uses finger / stylus / keyboard to fill information on the various documents (many fields have auto fill capability to reduce time for paperwork)
- The PDA performs the check-out review with the candidate and “Red Inks” the calibration and indication data sheets for a specimen prior to submission
- The Candidate (or PDA) checks in the eTP for the reviewed specimen

Completed Test Activities

- The final graded sheets (in PDF) are added to the eTP (not viewable by the candidate)
- The final test is graded and the Grading Report (from PDI.net) is added to the eTP
- The Candidate PDQS is added to the eTP (passed test only)
- The PDA performs the test package review and "checks" items on the eTP "Traveler" checklist
- The Reviewer performs the test package review and "checks" items on the eTP "Traveler" checklist
- The eTP is submitted to the "Records Manager" who generates the final QA Record as:
  1. A single PDF that contains all QA documents
  2. A folder that includes all the individual QA documents

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IGSCC Requalification Update

Kevin Hacker
Dominion Energy

Carl Latiolais
Ronnie Swain
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

IGSCC Requalification Update

- Project was initiated to determine if there are Code or Regulatory requirements or commitments to perform 3-year UT requalifications for examiners performing IGSCC examinations
- A literature search of the following documents was performed to determine the current requirements for IGSCC requalification:
  - ASME Appendix VII
  - ASME Appendix VIII
  - 10CFR50
  - NUREG 0313
  - NRC Generic Letter 88-01
  - BWRVIP-75A
  - NRC correspondence dating back to mid 1990's
- Result – there are no Code or Regulatory requirements to perform periodic IGSCC requalification

IGSCC Requalification Update

- The industry has discontinued the expectation of three-year requalification for IGSCC applications
- The initial IGSCC qualification program will continue to be implemented in accordance with Appendix VIII qualification requirement
- The IGSCC requalification program will continue to be available for those who wish to apply the requalification process

IGSCC Requalification Update

- The Industry NDE Program is continually evaluating opportunities to improve NDE reliability; several recent examples include:
  - Recently developed “UT Operator Training for SCC” - includes guided practice and review of relevant industry OE
  - Recently developed “UT Operator Training for Weld Overlay Examination” – CBT includes review of relevant industry OE
  - Virtual UT simulator technology is currently being evaluated as a method of exposing examiners to SCC UT data
- Report 3002011675, Intergranular Stress Corrosion Cracking (IGSCC) Requalification Study Project Report - Study of Ultrasonic Examiner Requalification Requirements for IGSCC Detection, IGSCC Through-Wall Sizing, and Weld Overlay Examination
  - Published December 2017; publicly available
  - This closes the industry activity

discussion

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Industry Activities for NDE Reliability Improvement

Kevin Hacker
Dominion Energy

Greg Selby
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Improving NDE Reliability

- Improving NDE Reliability is a significant attribute of the industry NDE Program
- Several of the key 2017 products related to NDE reliability improvements will be presented:
  - Phased Array UT Procedure Optimization
  - Site Level III and In-Service Inspection Coordinator - Succession Planning Tool
  - Virtual UT Simulator Technology
  - Virtual Mockups

Phased Array UT Procedure Optimization

Phased Array UT Procedure Optimization

- EPRI phased array UT procedures have been identified as complex, bulky and difficult for field implementation
- These procedures have been selected for optimization to make them more concise and user friendly
  - Updated five procedures in 2016
- Procedures Status for 2017:
  - Manual Phased Array Ultrasonic Testing of Reactor Pressure Vessel Welds - Procedure: PDI-UT-12 Revision E (issued August 16, 2017)
  - Manual Phased Array Ultrasonic Examination of Reactor Pressure Vessel Nozzle-to-Shell Welds and Nozzle Inner Radius Regions-Procedure: PDI-UT-13 Revision H (issued September 7, 2017)
  - Procedure for Encoded Phased Array Ultrasonic Examination of Dissimilar Metal Piping Welds – Procedure: EPRI-ENC-DMW-PA-1 Rev. 0 (issued November 1, 2017)

Phased Array UT Procedure Optimization (continued)

Procedure: EPRI-ENC-DMW-PA-1

Qualified Technique Sheet Revision and Summary of Change Document

Raster Scan Techniques

Appendix 1 - Configuration Matrix Raster Scan Techniques

STANDARD CONFIGURATIONS		
OmniScan Tech. Sheet ID	**Dynaray Tech. Sheet ID**	**Topaz Tech. Sheet ID**
RS-OMNI-STD-01	RS-DYN-STD-01	RS-TOPAZ-STD-01
RS-OMNI-STD-02	RS-DYN-STD-02	RS-TOPAZ-STD-02
RS-OMNI-STD-03	RS-DYN-STD-03	RS-TOPAZ-STD-03

COMPLEX CONFIGURATIONS		
OmniScan Tech. Sheet ID	**Dynaray Tech. Sheet ID**	**Topaz Tech. Sheet ID**
RS-OMNI-CPLX-702/X	RS-DYN-CPLX-702/X	RS-TOPAZ-CPLX-702/X
RS-OMNI-CPLX-716/X	RS-DYN-CPLX-716/X	RS-TOPAZ-CPLX-716/X
RS-OMNI-CPLX-716/2/X	RS-DYN-CPLX-716/2/X	RS-TOPAZ-CPLX-716/2/X
RS-OMNI-CPLX-719/X	RS-DYN-CPLX-719/X	RS-TOPAZ-CPLX-719/X
RS-OMNI-CPLX- CESYS-80	RS-DYN-CPLX- CESYS-80	RS-TOPAZ-CPLX- CESYS-80
	RS-DYN-CPLX- BVSG	

Line Scan Techniques

Appendix 2 - Configuration Matrix Line Scan Techniques

STANDARD CONFIGURATIONS		
OmniScan Tech. Sheet ID	**Dynaray Tech. Sheet ID**	**Topaz/Zircon Tech. Sheet ID**
LS-OMNI-STD-01	LS-DYN-STD-01	LS-TZ-STD-01
LS-OMNI-STD-02	LS-DYN-STD-02	LS-TZ-STD-02
LS-OMNI-STD-03	LS-DYN-STD-03	LS-TZ-STD-03

COMPLEX CONFIGURATIONS		
OmniScan Tech. Sheet ID	**Dynaray Tech. Sheet ID**	**Topaz/Zircon Tech. Sheet ID**
LS-OMNI-CPLX-702/X	LS-DYN-CPLX-702/X	LS-TZ-CPLX-702/X
LS-OMNI-CPLX-716/2/X	LS-DYN-CPLX-716/2/X	LS-TZ-CPLX-716/2/X

Notes: 1) When viewing this document electronically, the blue text in the flow chart above contains embedded links. Clicking a link will route to the first page of that section.

2) When viewing this document electronically, all pages in the procedure and technique sheets have a “BACK TO INDEX” button in the lower right corner. Clicking this button will navigate back to this page.

3) When viewing this document electronically, the first page in the procedure and technique sheets have a "PRINT SECTION" button. Clicking this button will print that specific section.

Site Level III and In-Service Inspection Coordinator - Succession Planning Tool

Site Level III and In-Service Inspection Coordinator - Succession Planning Tool

- Provides an electronic tool for succession planning that is specific to the NDE Site Level III and ISI Program Coordinator positions
- Allows users to select the attributes with respect to education, experience, certifications, and training that are essential for the individual to transition into the role
- Produces a report that will show any existing gaps and some potential training resources

Succession Planning Tool

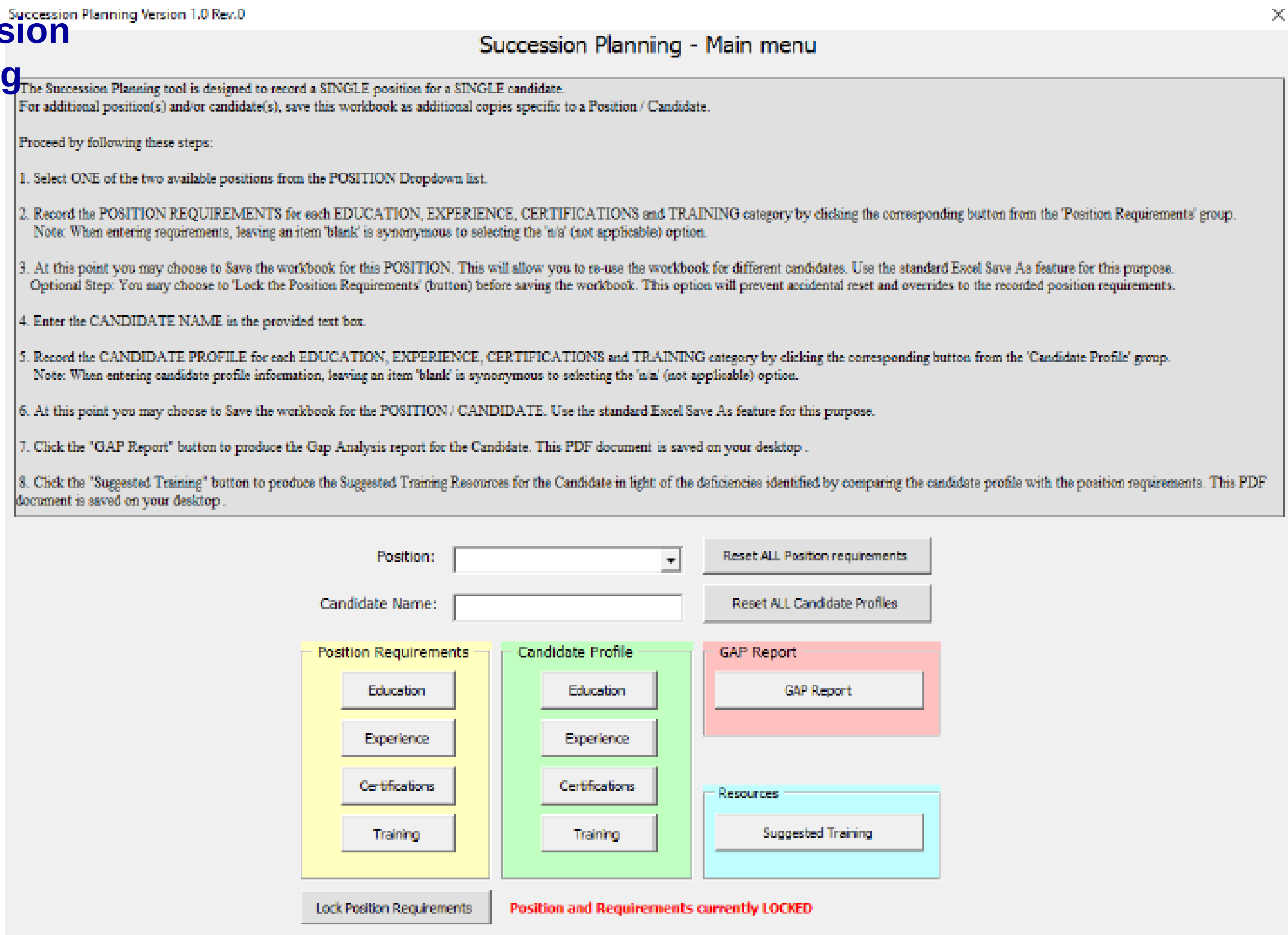


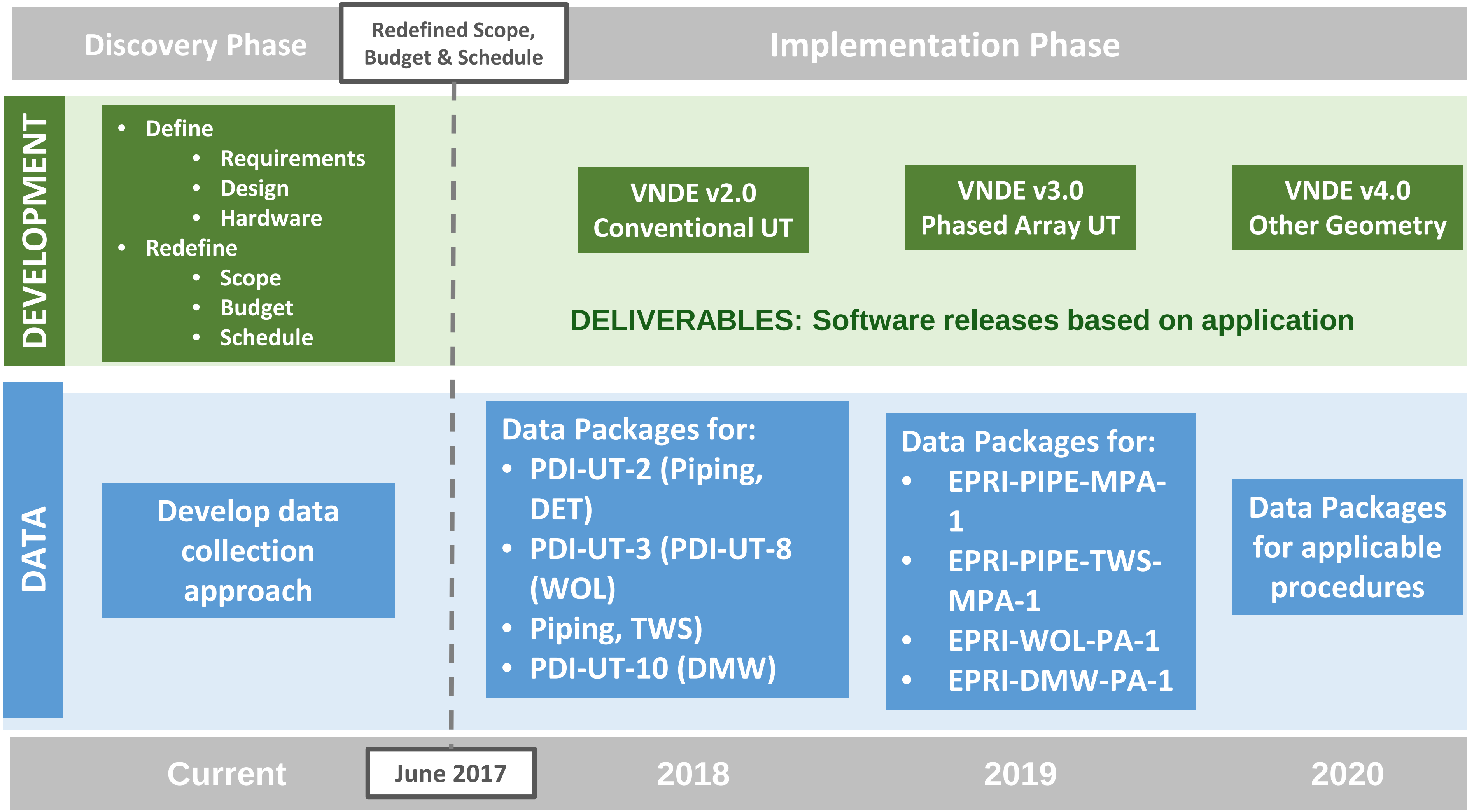
Figure 3-1
Succession Planning Tool main menu

Virtual UT Simulator Technology

Virtual UT Simulator Technology

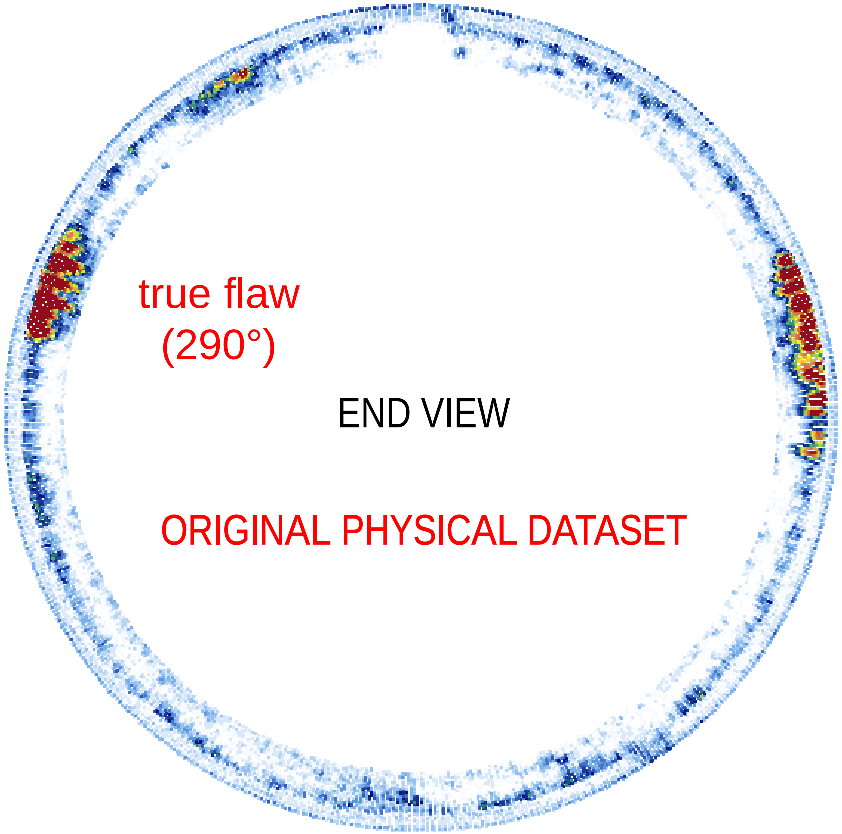
- Virtual ultrasonic tool to provide the NDE workforce with a cost-effective opportunity to hone and maintain their ultrasonic examination skills
- Potential benefits:
  - Improved reliability obtained in having a workforce that has the opportunity to train and practice continuously
  - Reduces the need of costs associated with manufacturing mockups for practice
  - Sharing of operational experience
  - Provide training for specific configuration needs
  - Support pre-job planning, to familiarize the examiner with the specific application to be examined
- Virtual NDE can promote NDE reliability, learning and enhance its experience

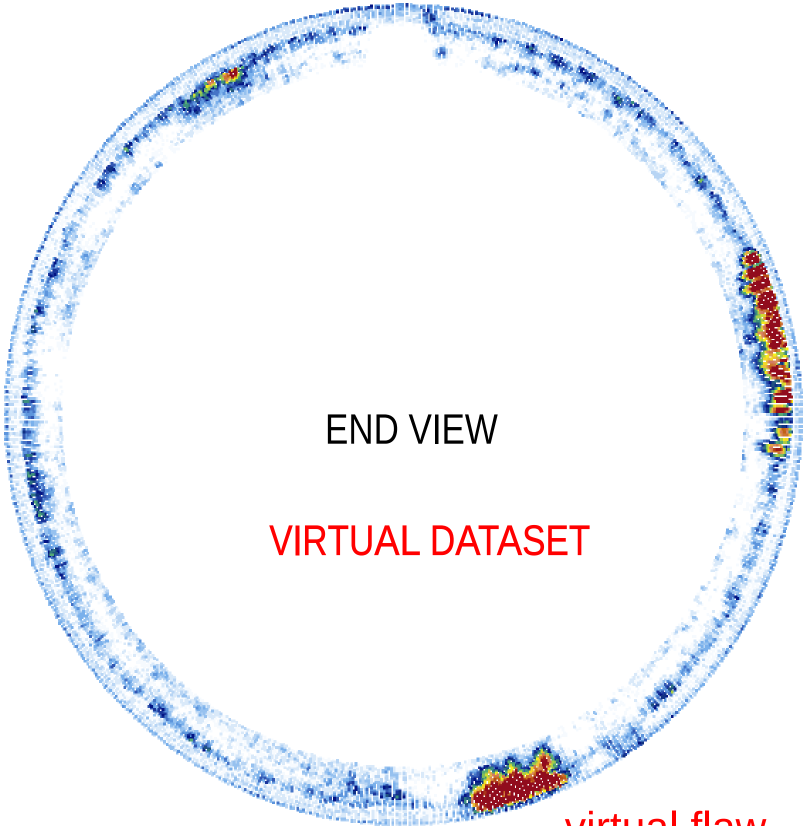
Plan & Deliverables



Leveraging Virtual Test Specimen Technology

- **Virtual Mockups**
  - Simulators extend the applicability of Virtual Mockups to manual scans
  - Specimen inventory becomes practically limitless





Virtual Mockups

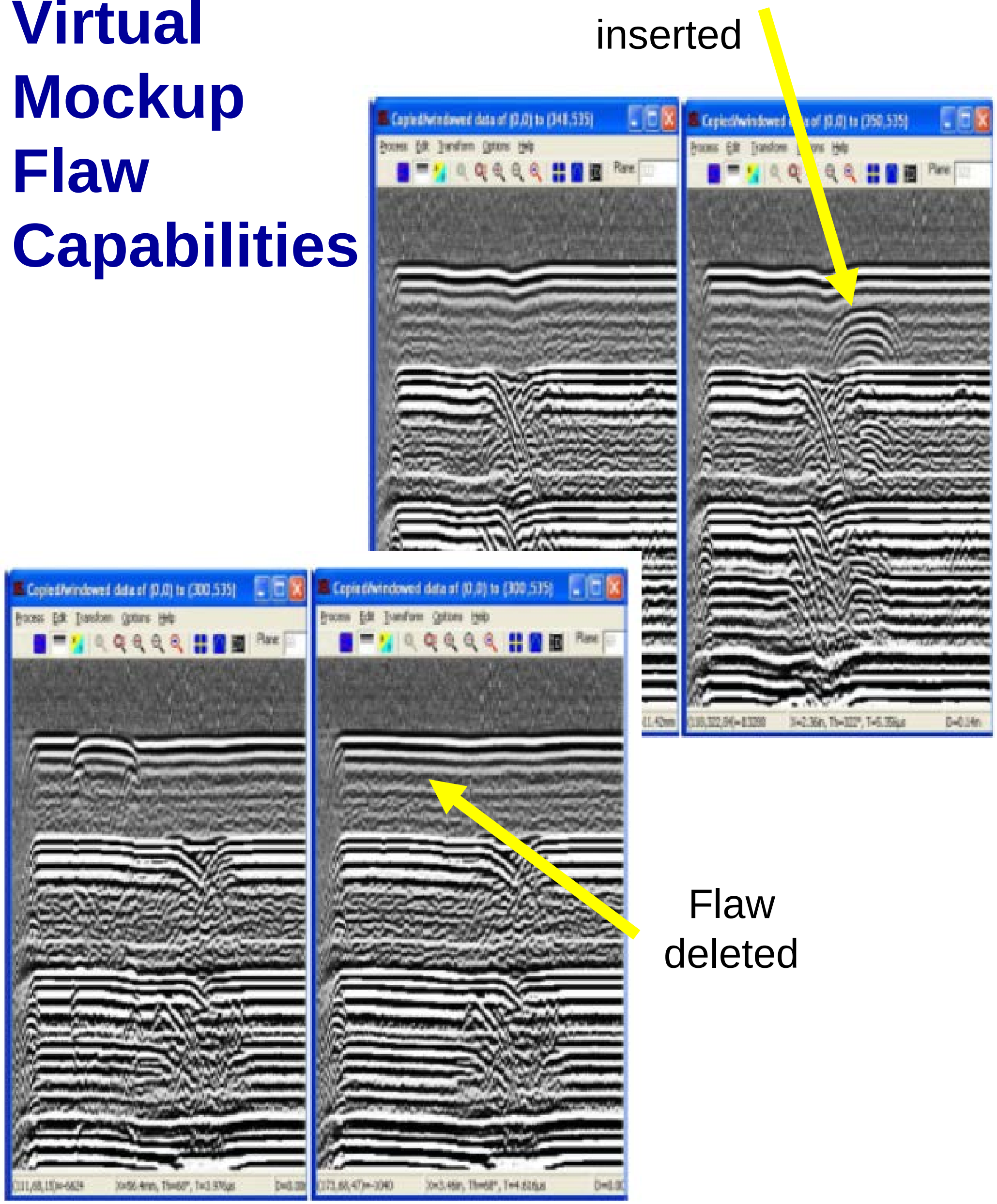
Virtual Mockups

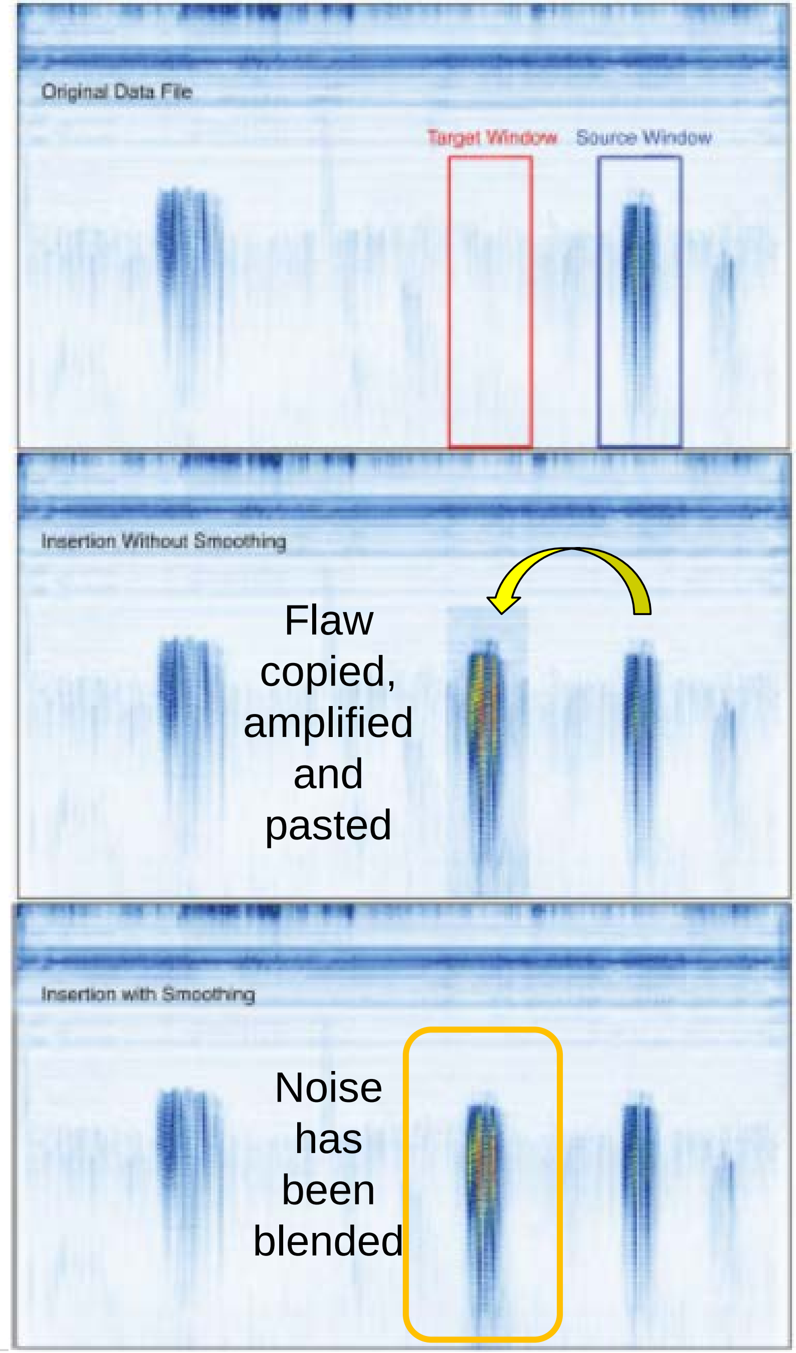
- Initiative to develop the capability to generate virtual mockups began in 2012
  - A Feasibility Study into Electronic Implantation of Flaw Responses into Previously Recorded Ultrasonic Data: NDE Training Utilizing Virtual Flaw Technologies - 3002003022
    - Report detailing results of last phase of project
  - NDE Training Data Utilizing Virtual Flaw Technologies - 3002004414
    - Data set of all data generated during the past phase
      - Phased array DM data
      - Conventional piping data
      - TOFD CRDM data

Creating Virtual Mockups

- Manipulation of previously collected data
  - Add flaws, remove flaws, flip flaws, stretch flaws, change amplitude
  - Apply smoothing to blend implanted flaw into data
  - Noise additions to add random noise patterns to implanted data to better blend with existing data
  - Axis Exchange operations can be used to implant flaws that are located along the scan axis into new data along the index axis and vice versa
- Process is a good fit under certain conditions
  - Previously collected data is available
  - Flaw response desired is available in data taken with same probe / frequency / procedure
- Have not attempted creating flaws and inserting them into data

Examples of Virtual Mockup Flaw Capabilities





2017 Status

- Two sets of phased array virtual mockups were created from a series of source phased array ultrasonic data
  - Existing flaws have been masked and moved
  - Virtual mockups were used to support training
  - Unable to identify as data from a virtual mockup
- Able to create mockups to support the UT Simulator
- Current mockup generation process is complex and time intensive
  - Working on simplifying the process
- Virtual Mockups - A Feasibility Study into Electronic Implantation of Flaw Responses in Previously Recorded Data - 3002010539

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High-Impact Examinations with Low Value

Kevin Hacker
Dominion Energy

Carl Latiolais
Robert Grizzi
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Background

- There are many NDE examinations being performed that are considered to have low value due to the history of few or no relevant indications being identified and therefore no nuclear safety benefit
- Many of these examinations also have a high outage impact due to personnel safety and radiation dose concerns, and outage schedule associated with preparation (scaffolding, insulation removal, weld surface preparation, insulation reinstallation, and scaffold removal) and performing the examinations
- Initiated by the EPRI 2016 NDE Work Plan project *'Identification and Assessment of Low-Value Examinations with High Outage Impacts'*

Objective

- Develop technical bases for optimization of selected examination requirements

- Conducting research on the top 5 ranked examinations (2017-2018)
  – Class 1 & 2, Non-Reactor Vessel Nozzle Inside Radius Sections
  – Class 1 & 2, Non-Reactor Vessel Nozzle-to-Vessel Welds
  – Class 1 & 2, Non-Reactor Vessel Welds
  – Reactor Vessel Interior Inspections (B-N-1 Exams)
  – Class 1 & 2, Pressure Retaining Bolting greater than 2" in Diameter

Approach

- Identification of applicable components
- Original basis for examination, if it can be determined
- Degradation Mechanisms – Relevancy and/or Mitigation
- Operating Experience, examination data, and results (fleet survey)
- Existing Resources
  - Previous, successful relief requests
  - Industry guidance documents that supersede ASME Code requirements
  - Redundancy of inspections due to other industry activities (e.g. VIP, MRP)
- Existing Code Cases in support of desired change
- Perform fracture mechanics (PFM & DFM) and engineering analysis

Tasks

- Enable Implementation
  - Based on research results,
    - Provide input to ASME Code Committees
    - Develop a generic relief request template that could be used while Code changes are processed
- Identification of (5) pilot plants, one for each examination type
- Establish technical bases for all 5 examinations
- Produce 5 generic RRs for submittal
- Draft Code Cases

Project Status

- Notable Items to Date
  - Two meetings with the NRC to introduce and discuss technical approach
  - To date have received OE survey responses from 69 Domestic, 5 International units

- In Process
  - Lead utilities have been defined, collecting component information
  - Continuing to collect and compile survey results

Target schedule

- Reactor Vessel Interior Inspections (B-N-1 Exams)
  - Draft Technical Basis in process of review
  - Draft Code Case – Q1 2018
  - Draft Relief Request – Q1 2018
- Class 1 & 2, Pressure Retaining Bolting greater than 2” in Diameter
  - Draft Technical Basis – Q3 2018
  - Draft Code Case – Q4 2018
  - Draft Relief Request – Q4 2018
- Class 1 & 2, Non-Reactor Vessel Nozzle Inside Radius Sections, Nozzle-to-Vessel Welds, and Vessel Welds
  - Draft Technical Basis – Q1 2019
  - Draft Code Case – Q1 2019
  - Draft Relief Requests – Q2 2019

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EPRI NDE Program

Selected projects

Greg Selby
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Topics

- Automated analysis of remote visual examination data
- Concrete
  - Alkali-silica reaction
  - Dry cask storage systems
  - Modeling and simulation
  - NDE capability demonstration

Automated Analysis of Remote Visual Examinations

Greg Selby

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Discussion

- Background and progression
  - Three independent approaches
  - Began about 2014
- Remote visual examination (RVT) data
  - Image processing to clean the data
  - Registration and mosaic construction
  - Feature extraction to classify objects
  - Unsupervised and supervised learning
- Summary

RVT – Remote visual examination

Background

- Three independent approaches
  1. Crack detection in concrete, and stress corrosion cracking in stainless steel components (RPV internals)
     – University of Southern California, then Purdue (the researcher moved)
  2. SCC in stainless steel components
     – University of North Carolina – Charlotte
  3. SCC in stainless steel components
     – EPRI staff

Background - Progression

- **USC/Purdue**
  - Used data sets from EPRI specimens
  - Published EPRI report #3002007205, "Exploratory Study on Vision-Based Algorithms to Size Cracks in Different Materials, March 2016
  - Developed and released EPRI beta software, "Automated Crack Detection "CRAQ", January 2016
  - Published EPRI report #3002007814, "Remote Visual Testing Image Analysis", July 2016
- **UNCC**
  - Incorporates machine learning
  - Uses RVT data from EPRI specimens
  - Detection algorithm continued to improve with new data
  - Addressed illumination variability
  - UNCC published research results in IEEE papers

USC – University of Southern California

UNCC – University of North Carolina (Charlotte)

IEEE – Institute of Electrical and Electronics Engineers

Background – Research progression

- **EPRI** – Project "Automated Analysis of Remote Visual Data" started 2015, completed 2017
  - Uses data sets from EPRI specimens
    - New data given every year
  - Continual improvement in results
  - Results presented in workshops
  - Work continues in 2017-2019 project "Field application of RVT Automated Data Analysis Technology"
- **EPRI** - "Field application of RVT Automated Data Analysis Technology"
  - Started in 2017, 3 year project
  - Apply results and lessons learned from previous projects
  - Refine algorithms and processes for field application of automated RVT analysis processes
  - Use historical field data for machine learning algorithm development and refinement
  - Pilot, trial demonstration possible in 2019

RVT – Remote visual examination

RVT automated data analysis algorithms/processes

- Overview of image processing steps:
  1. Multistage filtering to clean the data
     - Remove radiation noise
     - Remove scratch and illumination artifacts
     - Enhance crack, grind, splotch, etc.
     - Secondary filtering to remove “noise clouds”
  2. Inter-frame registration and generation of a mosaic image
  3. Shape and texture feature extraction
  4. Supervised and unsupervised machine learning for crack and deep grind

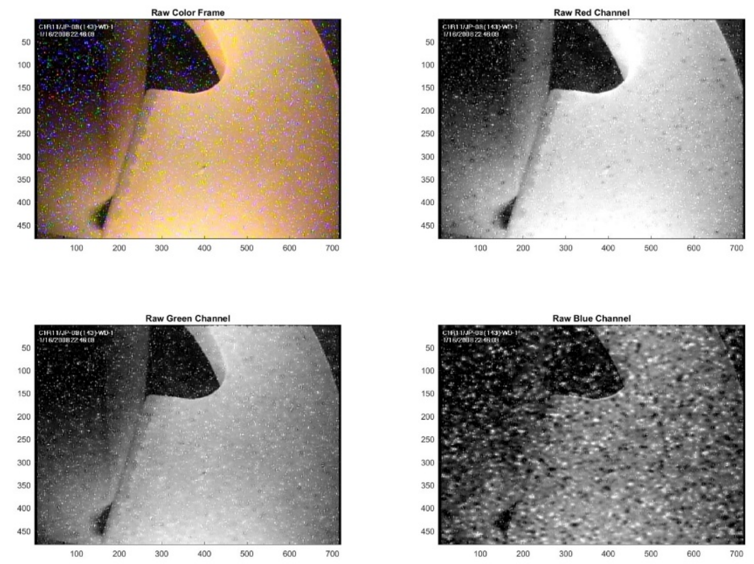
RVT – Remote visual examination

De-nosing

- Gamma radiation noise changes pattern each frame making visual inspection distracting
- Illumination varies more gradually
  - Some areas of the images are more heavily exposed
  - Multiple adjacent frames are considered together
- Scratches and surface splotches

- Multi-stage filtering is performed in realtime in graphics processor unit (GPU)

Image and RGB individual frames showing radiation noise - most degradation is in blue channel



GPU – graphics processor unit
RGB – Red-green-blue

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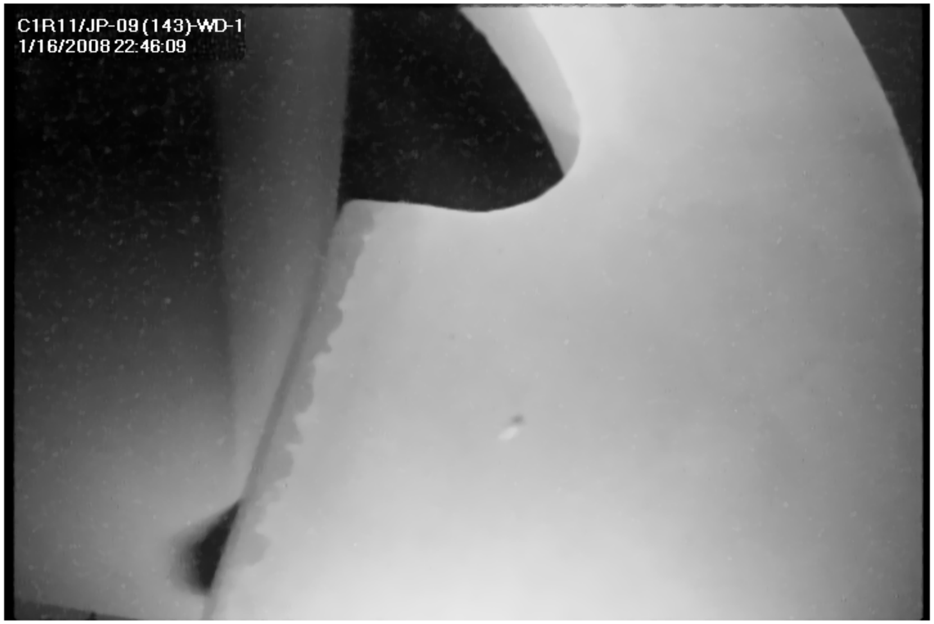
Monochrome image from jet pump
Filter time is ~12msec on TitanX GPU card

Raw Frame

DS-BEF Frame



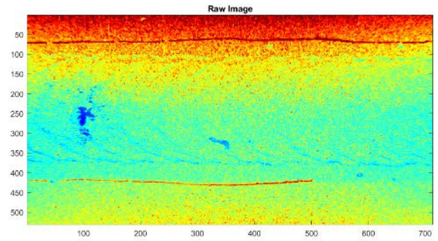
Filter leaves edges intact and does not distort surface feature

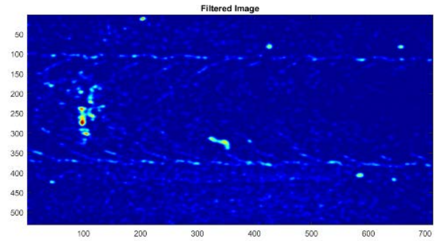
GPU – graphics processor unit

Normalizing illumination and filtering scratches

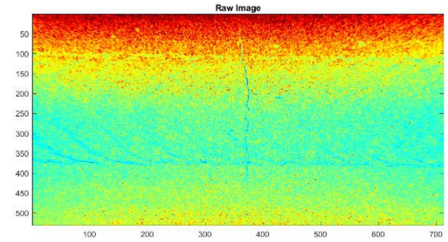
- Example in pseudo-color to show actual pixels without human visual filtering that gray scale offers
- Shows removal of background illumination and scratches and enhancement of crack and splotches
- Registration and Mosaic from 600 frames at 3 FPS

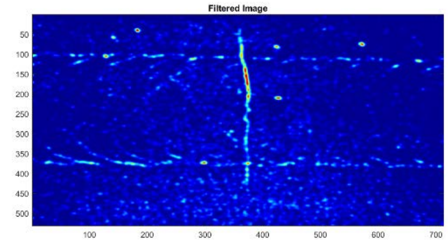
Scratch





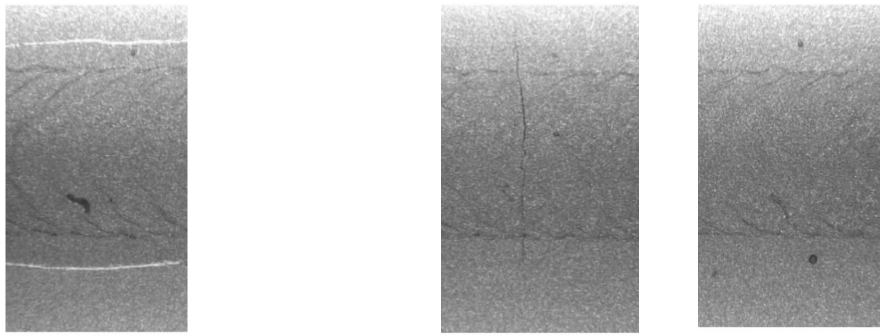
Crack

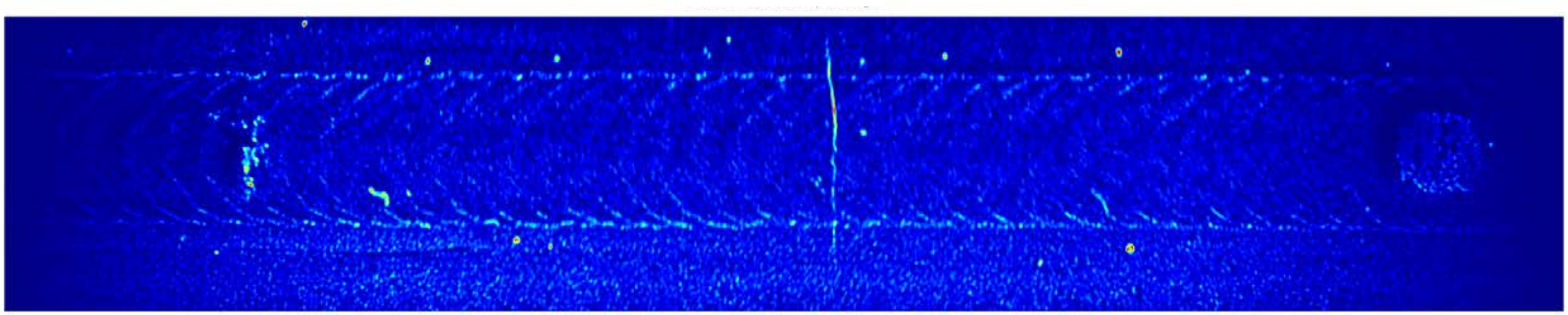




FPS – Frames per second

Filtering, registration and Mosaic generation example

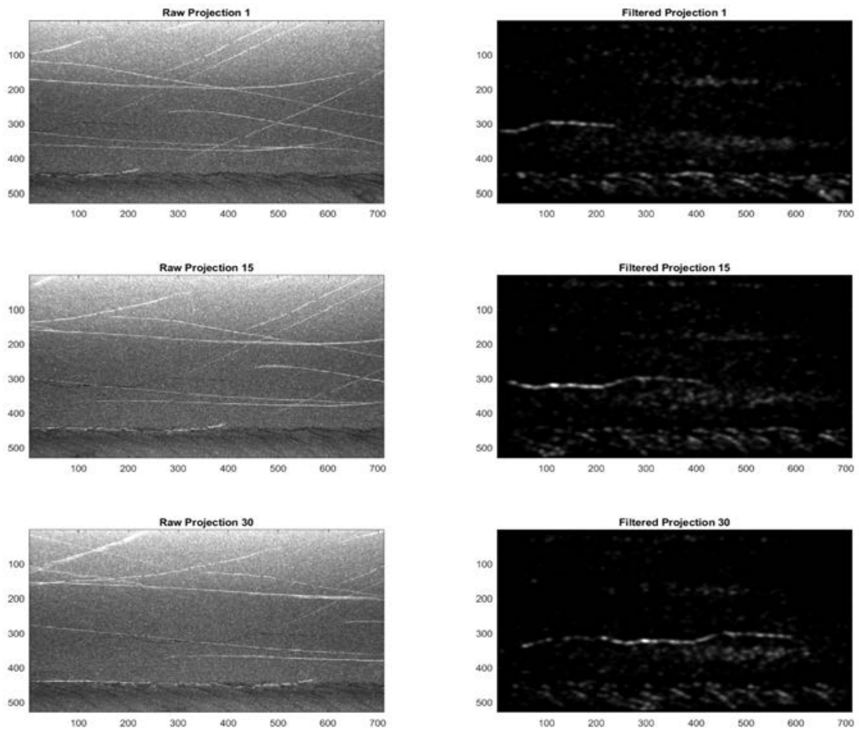




Example 2 - primary filtering in high scratch noise

Example 2 is low SNR crack with complex scratches

- Same Primary filter to remove scratch and enhance crack
- Mosaic shows amorphic cloud noise that is enhanced by the primary filtering
- Secondary filter removes cloud noise and preserves crack
- All primary and secondary filters (along with registration) are doing in low level GPU code



[1] Remove nonuniform illumination

[2] Remove scratch targets

[3] Enhance low SNR crack targets

GPU – graphics processor unit
SNR – Signal-to-noise ratio

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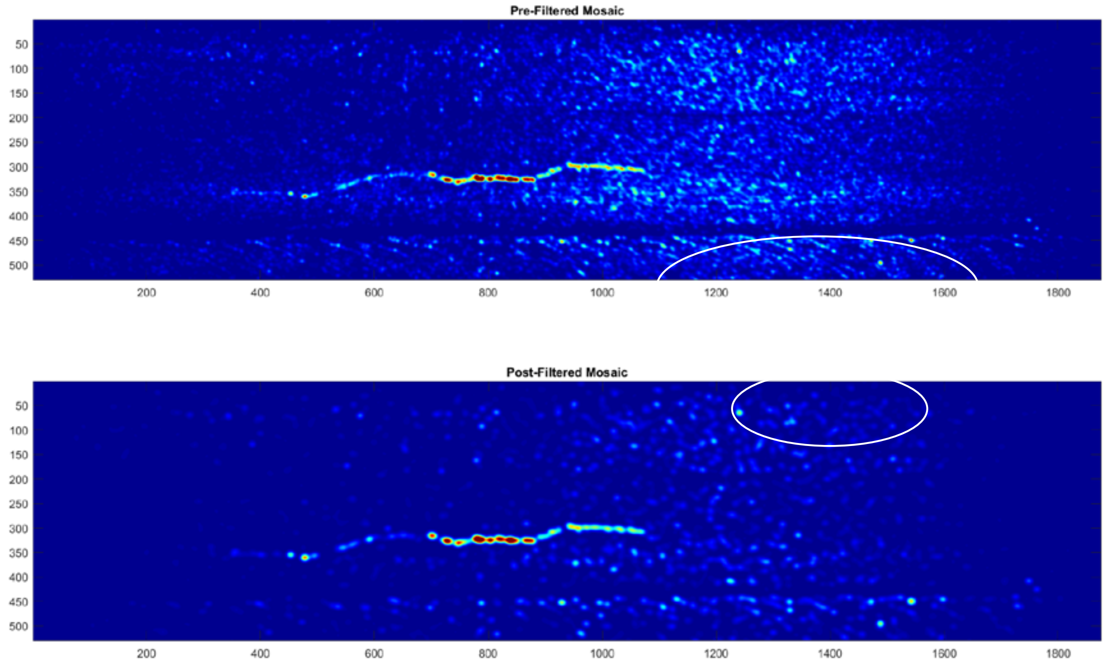
Mosaic image with cloud noise and secondary filter



Summary of Filtering and Mosaic Stage

- Filter, registration and Mosaic construction have simplified the raw data
- A single 2D image built from 2D-time stream is easier to analyze
- The filtered Mosaic is an optimal display for human analysts as well as automated analysis

Machine Learning Stage – Feature Extraction

Filtered data is now high in information

- Extract features such as shape and texture
- Supervised learning to map features to classes, e.g. crack
- Unsupervised learning to find clusters of features in space such as common texture

Texture is local structure variation that is not random

- Each pixel in the image has an associated texture field
  - Currently using a 21x21 window to measure texture around each pixel

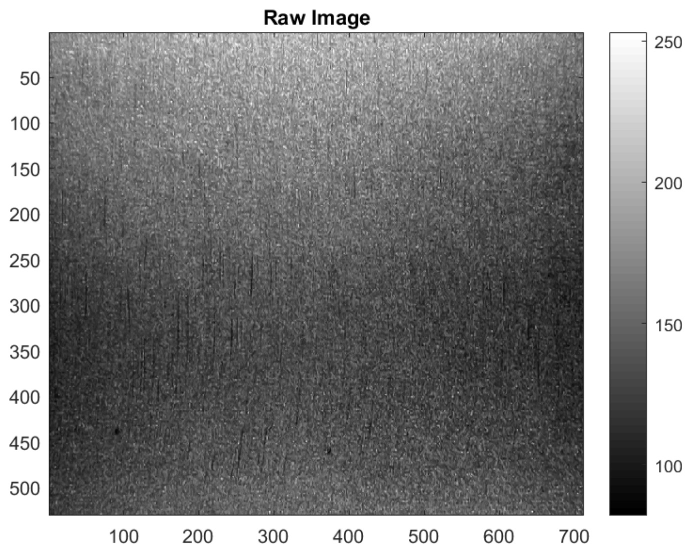
Grind/Gouge region extraction

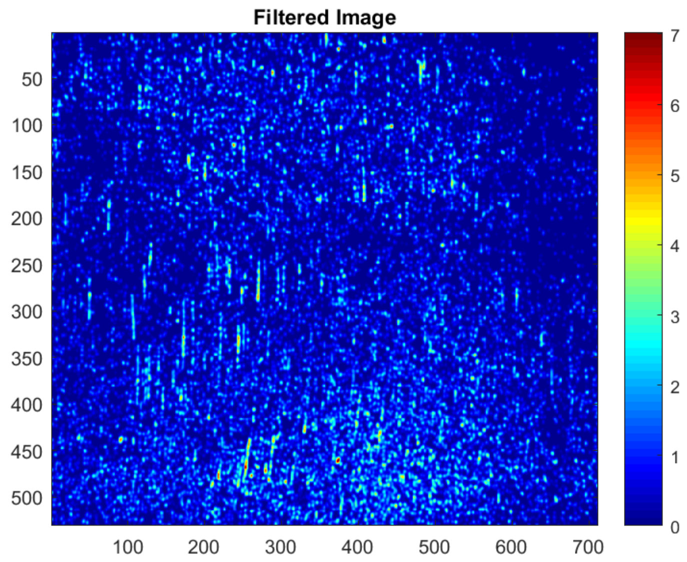
- These are large area changes in surface texture
- Amplitude Histogram shows amplitude thresholding is not a clean method to segment

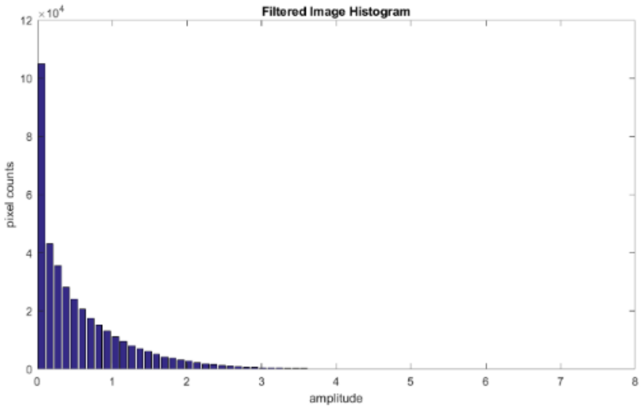
Texture Features and Unsupervised Learning

- Create an 11-element texture feature vector for each pixel
- Cluster into three groups and display clustered pixels
- Secondary filter extracts shapes from the high energy texture cluster; resulting image is deep grind

Raw and filtered image of grind region







Histogram of amplitude shows no clear threshold to separate regions of image

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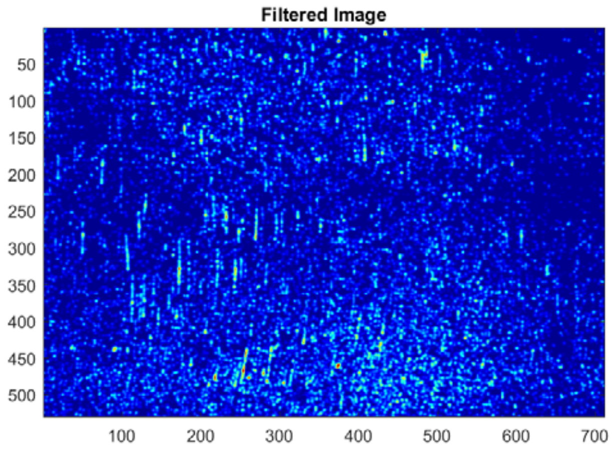
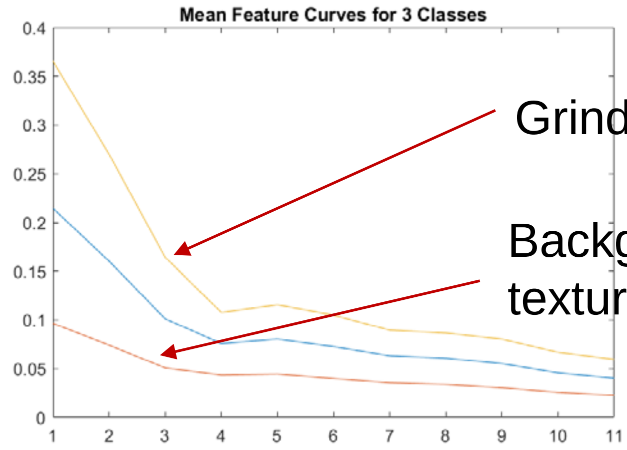
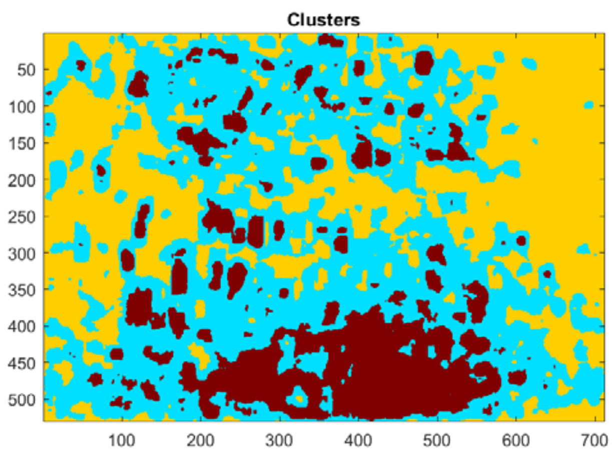
Filtered image and high texture energy pixels

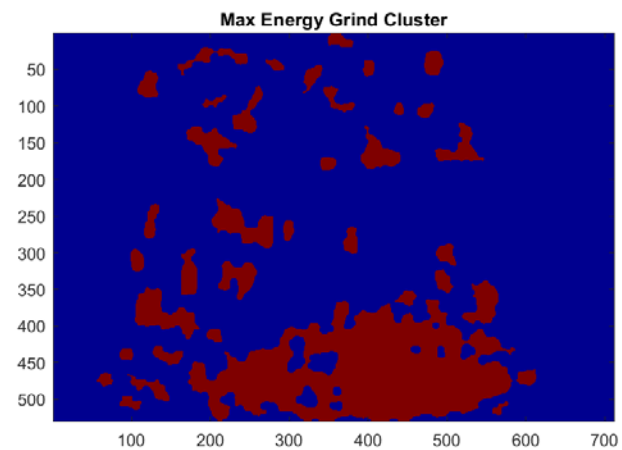




Grind cluster

Background low texture energy





Large amorphic blob is rough region and deep grind

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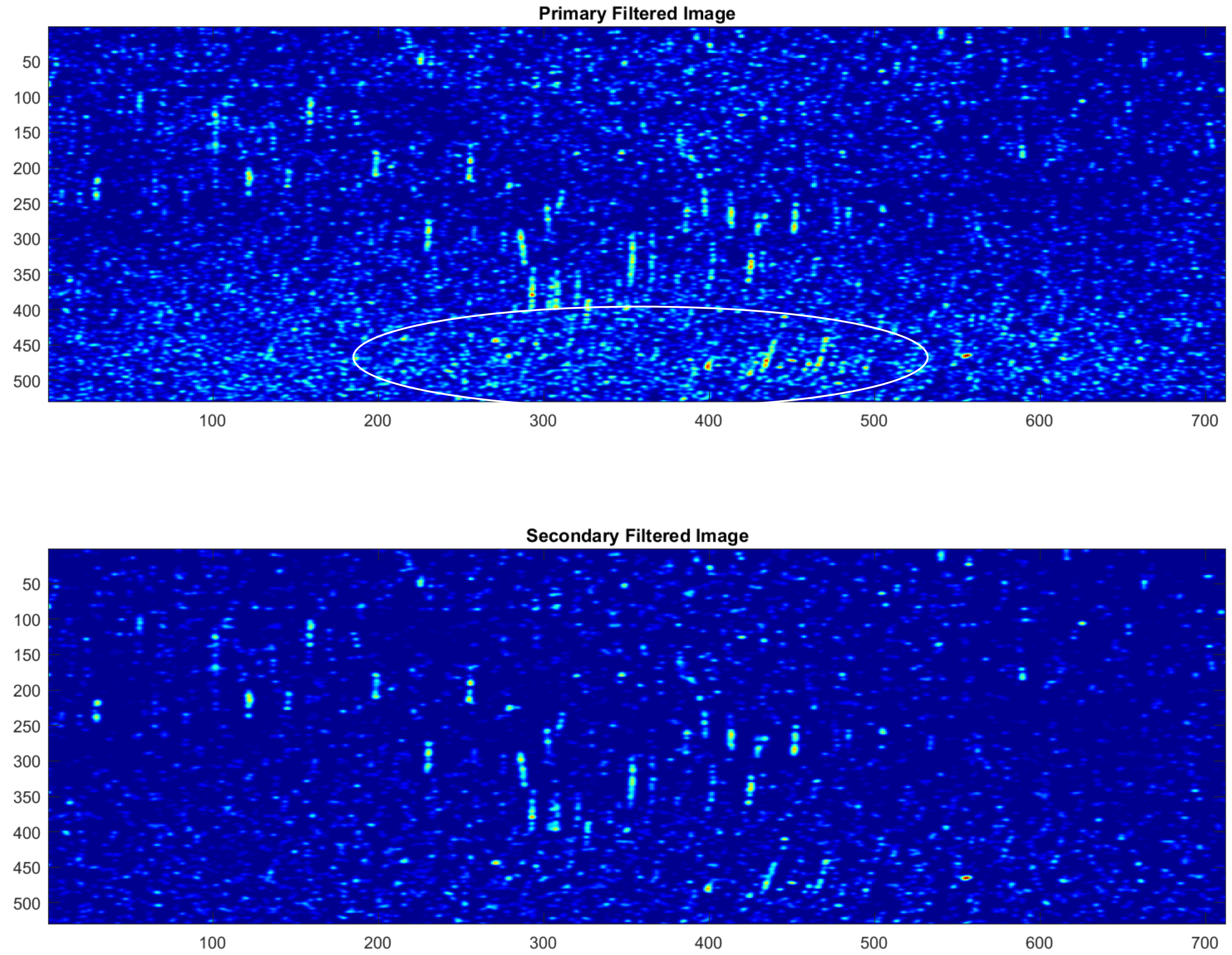
Primary and Secondary filtered regions



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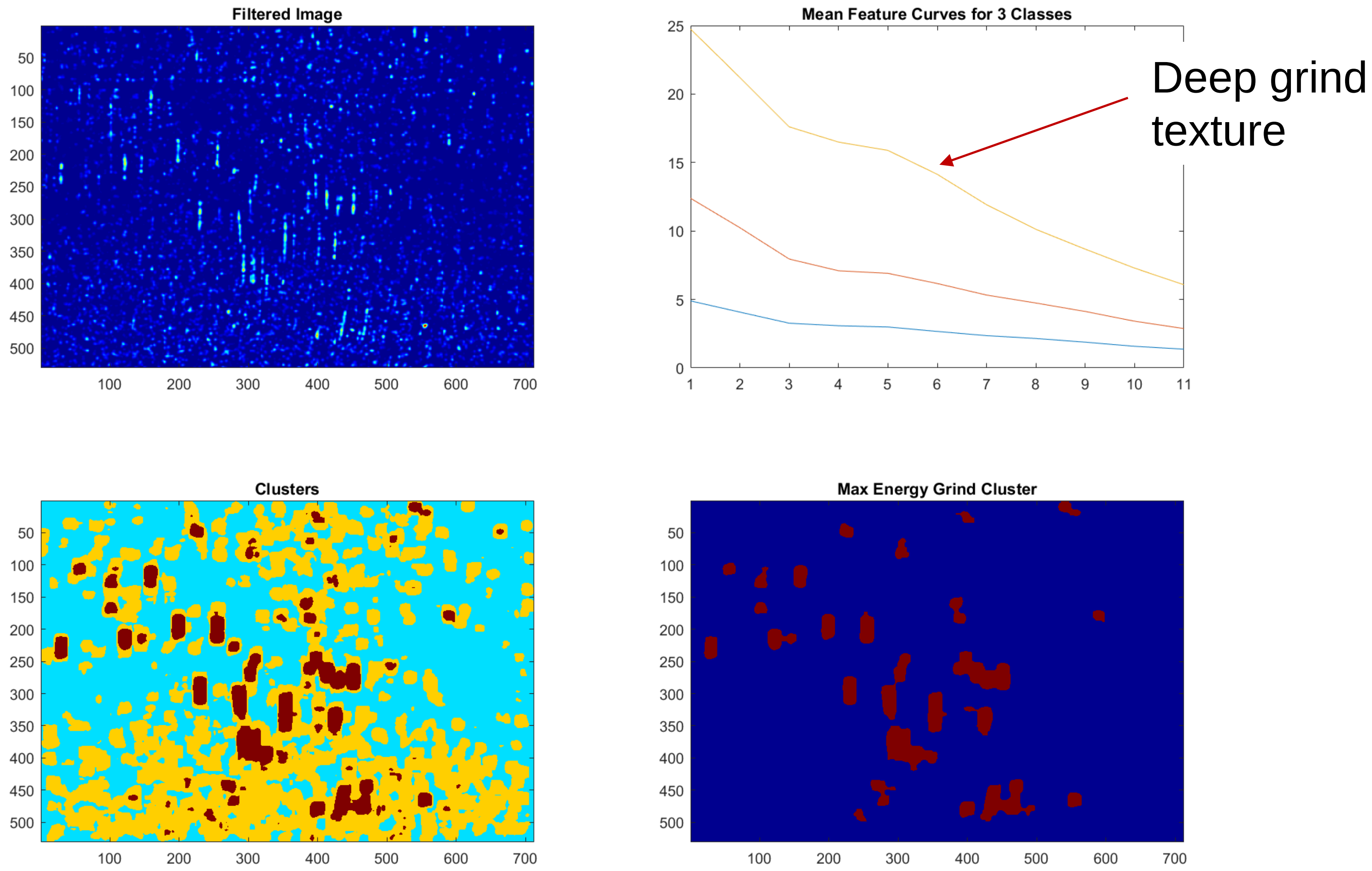
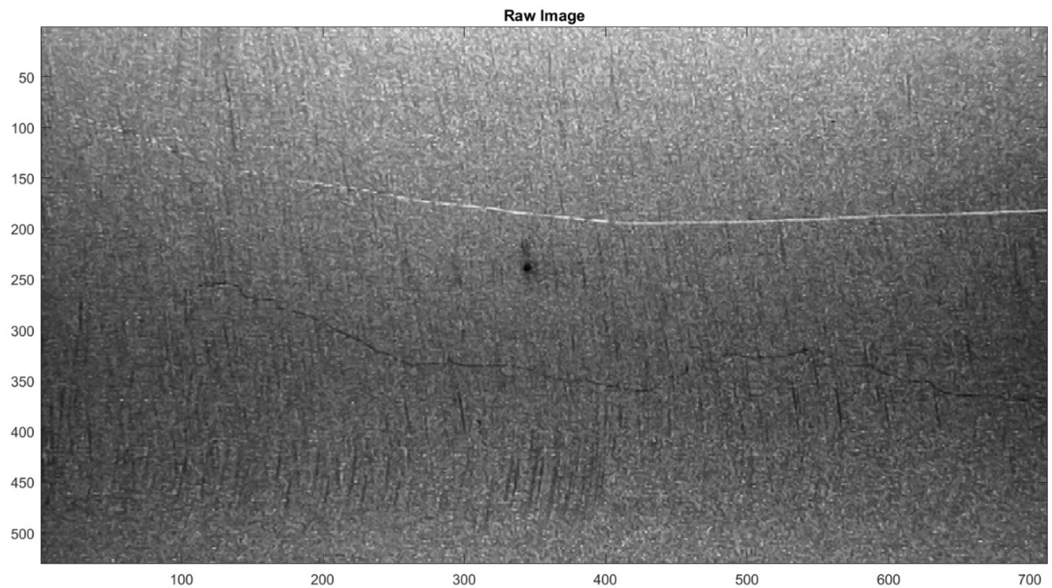
New cluster profile shows high texture energy slabs



Summary of unsupervised texture segmentation

- Each pixel is described by a texture vector
- Cluster analysis shows high energy cluster is grind region
- Classification of grind based on shape of texture pixels and class membership

Deep grind vs crack segments



Weak crack inside

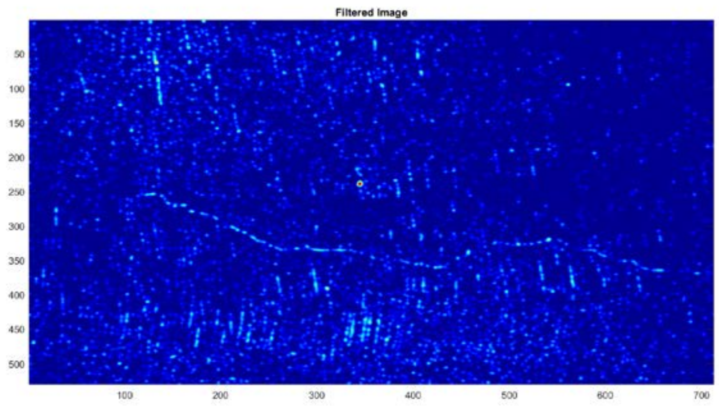
Grind region

- Fragmented low SNR cracks have same shape as deep grind segments
- In unsupervised clustering, the crack and grind segments are in the same cluster
- Supervised learning shows different texture energy signatures
  - Classification shows accuracy over 90% to be able to separate crack segments and grind
  - Shape features include random distribution of grind vs crack segments aligned

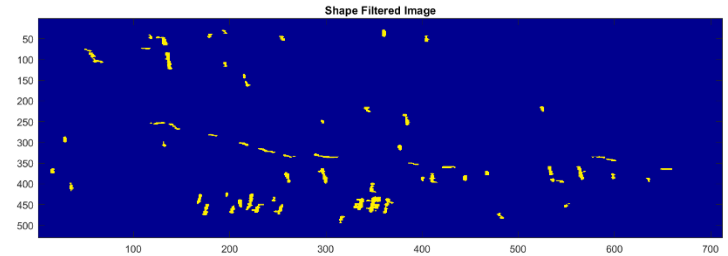
SNR – Signal-to-noise ratio

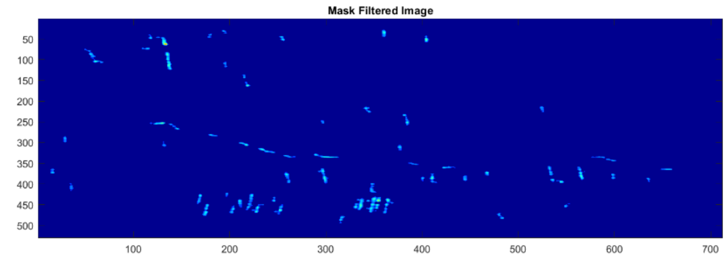
Shape Filtering for crack vs. grind

Enhanced crack and grind showing crack fragmentation



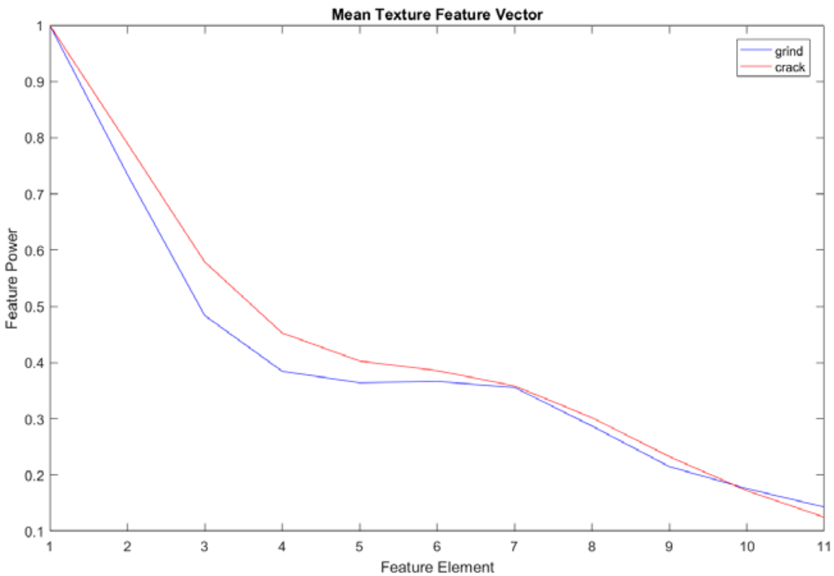
Shape filtered (elongated blobs) masks and image



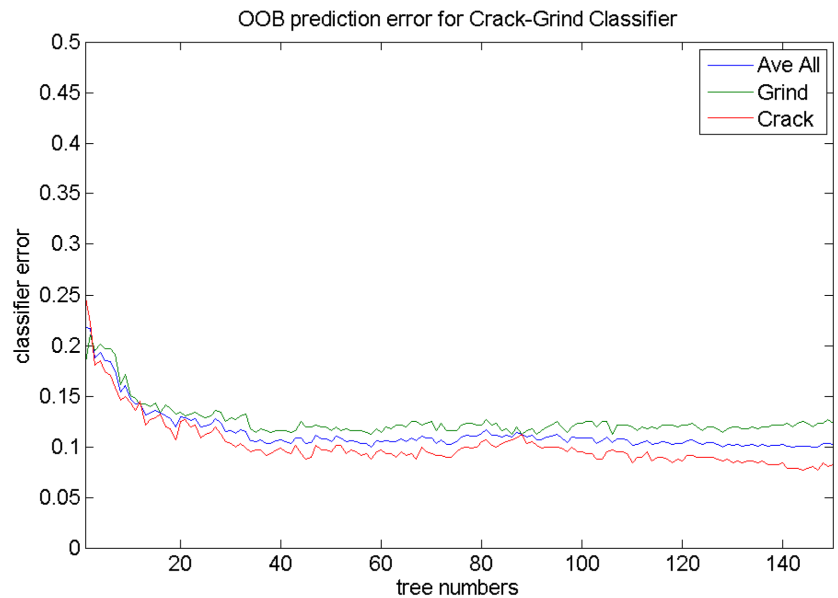


- This blob angle filter will fail as a classifier if crack is same orientation as grind
- Shows how the texture metric of each pixel in the blob can separate crack and grind fragments with 90% accuracy if the crack is in a different direction than the grind marks

Texture based classification of crack/grind fragments



These are the average 11-element texture feature vector for all pixels in crack and deep grind



Random Forest classifier shows 90% accuracy in being able to classify pixels as being crack or deep grind fragments

Summary

- Multistage filtering to remove radiation noise
- Image Filtering Stages
  - Remove scratch and illumination artifacts
  - Enhance crack, grind, splotch, etc.
  - Secondary filtering to remove “noise clouds”
- Inter-frame registration and Mosaic generation
- Shape and Texture features
- Supervised and Unsupervised learning for crack and deep grind

- Other technology
  - Deep CNN (convolutional neural network)
  - CNN learns feature extraction
  - Layers of convolutions
  - Current focus is to build ensemble classifiers that integrate methods

CNN – Convolutional neural network

Questions, discussion

Together…Shaping the Future of Electricity

Mitigation and Repairs of ASR Affected Concrete Structures

Maria Guimaraes
Program Manager
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Overview

Alkali silica reaction, or ASR, can affect concrete structures that were built using reactive aggregates. As a result of this degradation, affected structures begin to expand.

The ASR reaction can be represented as follows:

Reactive Aggregate + Alkalis + Moisture =

Expansive Gel

- It is difficult, if not impossible in several structures, to completely stop the alkali aggregate reaction in concrete.
- However, it is possible to act on the inputs of the reaction to slow it down.

ASR – Alkali-silica reaction

Report Overview

1 - Introduction

2 - Factors to Consider when Selecting a Repair Option

3 - Controlling Moisture Availability

4 - Chemical Treatment

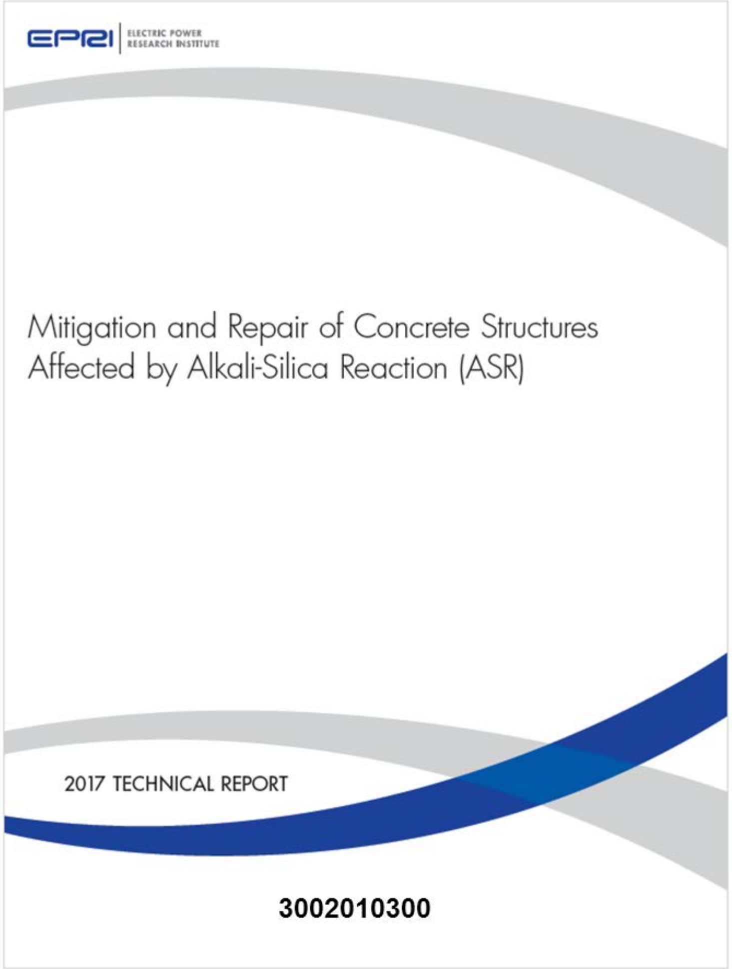
5 - Structural Mitigation

6 - Geometric Correction

7 - Local Replacement

8 - Case Studies – Nuclear Plants Affected by ASR

9 - Summary - Conclusions


ELECTRIC POWER RESEARCH INSTITUTE

Mitigation and Repair of Concrete Structures Affected by Alkali-Silica Reaction (ASR)

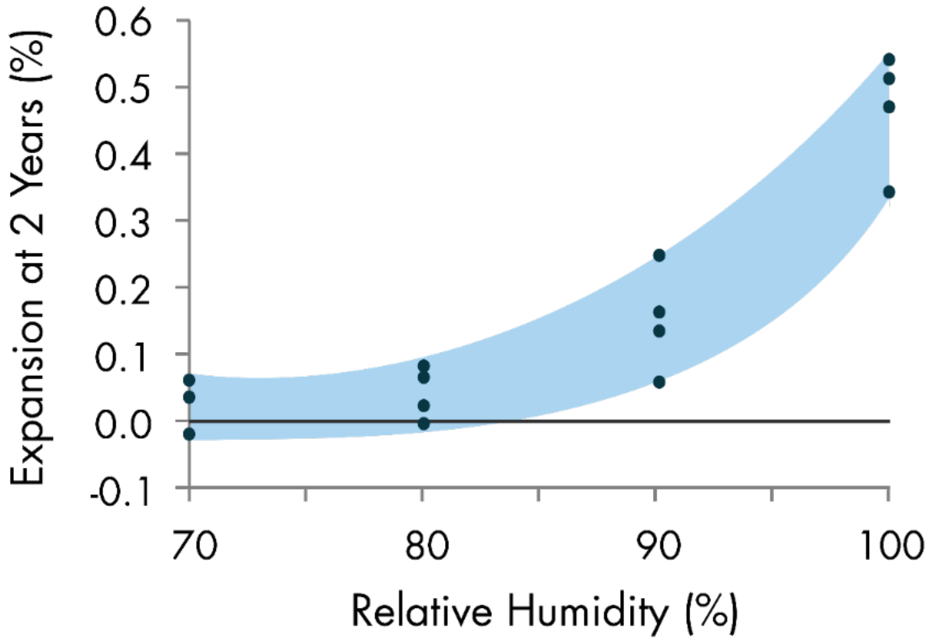
2017 TECHNICAL REPORT

3002010300

ELECTRIC POWER RESEARCH INSTITUTE

Methods - Controlling Moisture Availability

Method	Notes
Water management	• Most effective way to prevent ASR. • It will **not** reduce the moisture content in large elements
Crack sealing	• Temporary solution if residual expansion is expected
Geomembranes	• Intended to prevent moisture access to concrete • Full water tightness is hard to obtain • Does not allow moisture evaporation
Penetrating sealers	• Current application techniques can only deliver sealant to the outer layer
Coatings	• Prevents moisture access to concrete. • It will **not** reduce the moisture content

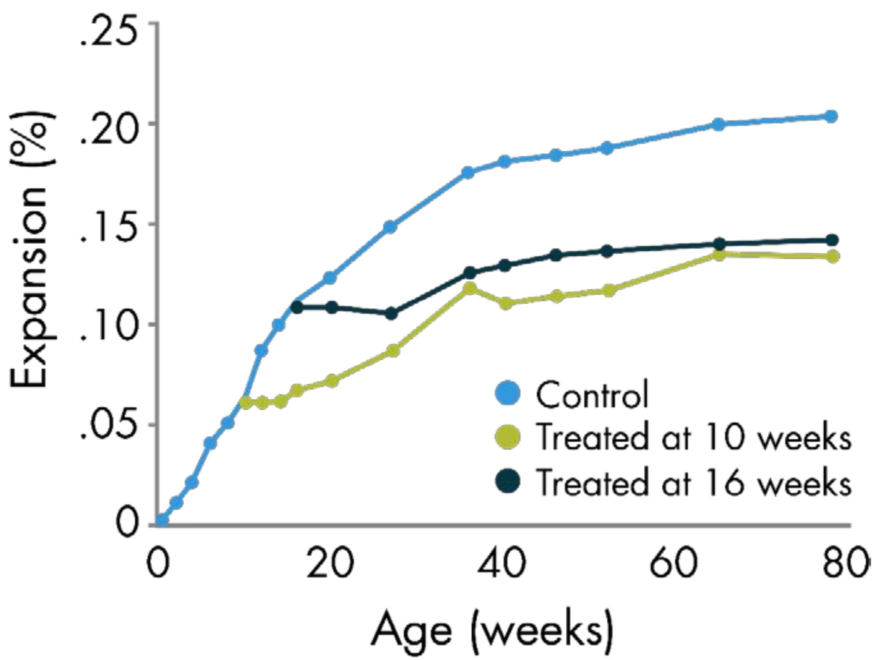


Data from Pedneault, A., Development of testing and analytical procedures for the evaluation of the residual potential of reaction, expansion, and deterioration of concrete affected by ASR, Laval University, Québec City, Canada, 1996.

ASR – Alkali-silica reaction

Methods – Chemical Treatment

Method	Notes
Lithium injection	• Alters ASR gel to make it non-expansive • Very efficient when used in the mix design • Very low depth of penetration (~5 cm)
CO_2 injection	• Acts on the availability of alkali • Published literature not complete • Increases carbonation • Very low depth of penetration • **Not recommended**



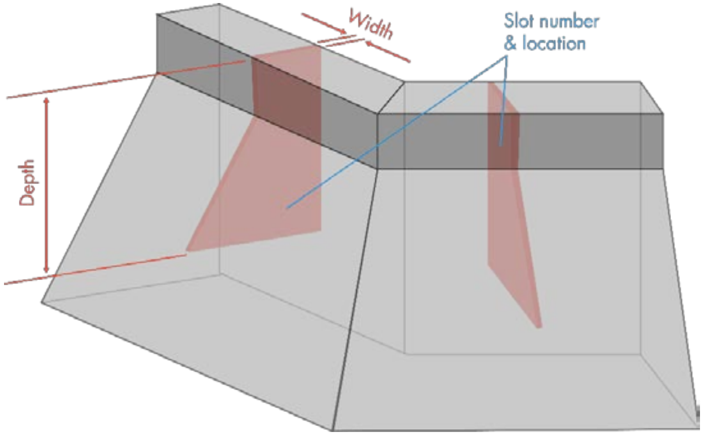
After Thomas, M.D.A. & Stokes, D.B., Lithium Impregnation of ASR-Affected Concrete: Preliminary Studies, Proceedings of the 12th ICAAR, Vol. 1, pp. 659–667, 2004.

ASR – Alkali-silica reaction

Methods – Structural Mitigation

Structural mitigation of ASR-affected structures is used to restrain the ASR-induced expansion; maintain or restore the structural integrity; and/or relieve internal stresses.

Post-tensioning
Fabric Strengthening
Reinforced concrete jackets
Stress Relief



Case studies show that predicting deformation after the application of some of these techniques (such as stress relief) is difficult if not sometimes impossible.

ASR – Alkali-silica reaction

Methods – Geometric Correction – Local Replacement

Geometric Correction

Concrete swelling from ASR depends on moisture exposure, presence of reinforcement, and the restraining effects of the adjacent parts.

Because of that it can cause uneven displacements that result in shifting or tilting of equipment affecting their serviceability.

- Gates
- Turbines
- Doors
- Generator stator

Local Replacement

When ASR expansion cannot longer be accommodated, the most cost-effective approach can be:

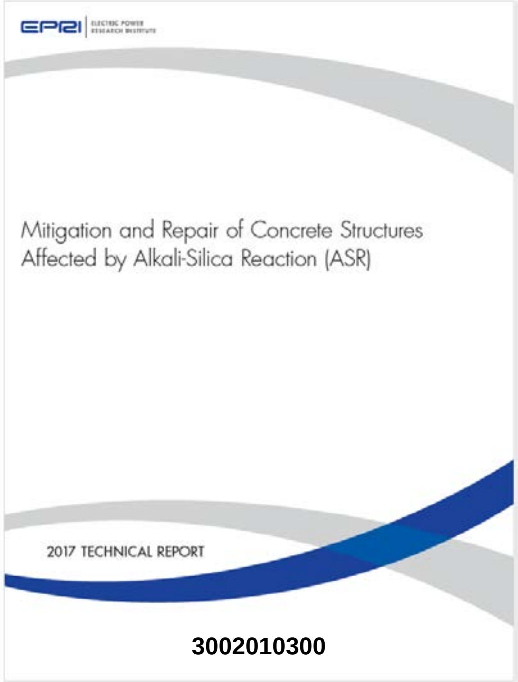
- To replace the damaged part of the concrete structure.
- To replace non-concrete parts to adapt them to the new concrete and to adapt them for future ASR.

ASR – Alkali-silica reaction

Summary

- Repair and mitigation techniques for concrete affected by ASR are limited in scope and in general **more effective for thin structures such as those found in the transportation industry**.

- The selection of a repair and mitigation technique for an ASR affected structure should be preceded by an in depth modelling analysis. **Several cases studies are reported in this document where repairs were not successful and impacted the structure negatively.**



ASR – Alkali-silica reaction

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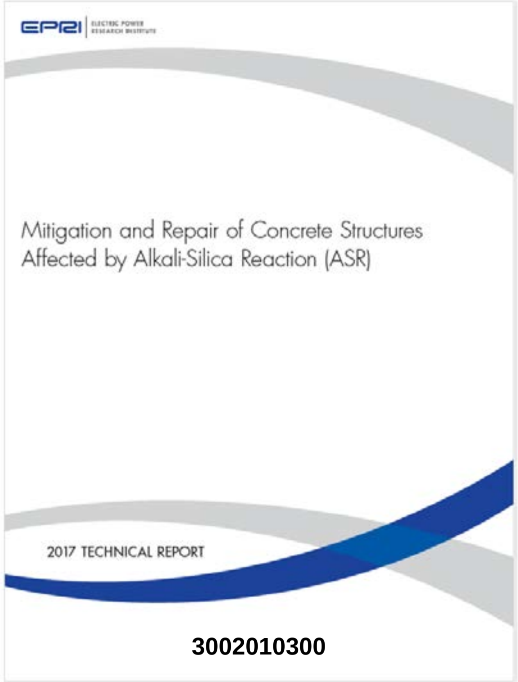
Summary

- Repair and mitigation options often include techniques that will not address the ASR issue, but will correct the symptoms of the degradation. **These techniques should be carefully considered as an approach to deal with ASR degradation.**

- EPRI is developing aging management guidance for licensees experiencing ASR


Mitigation and Repair of Concrete Structures Affected by Alkali-Silica Reaction (ASR)

2017 TECHNICAL REPORT

3002010300

ASR – Alkali-silica reaction

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Inspections and Aging Management for Concrete Overpacks

Sam Johnson
Technical Leader
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Presentation Overview

- Summary of Previous Research
- Current Research Overview
- 2017 Activities
- 2018 Activities

Previous Research Performed on this Topic

EPRI Technical Report 3002005508
publicly available

Who should read it?

- Utility personnel in charge of aging management of ISFSI and DCSS

Key Findings

- Concrete overpacks for dry cask storage systems are susceptible to degradation and proper aging management should take place to ensure functionality
- Visual inspections and other NDE methods can be used to detect concrete degradation; however, applications and limitation can change depending on the overpack design

ISFSI – Independent spent fuel storage installation

DCSS – Dry cask storage system

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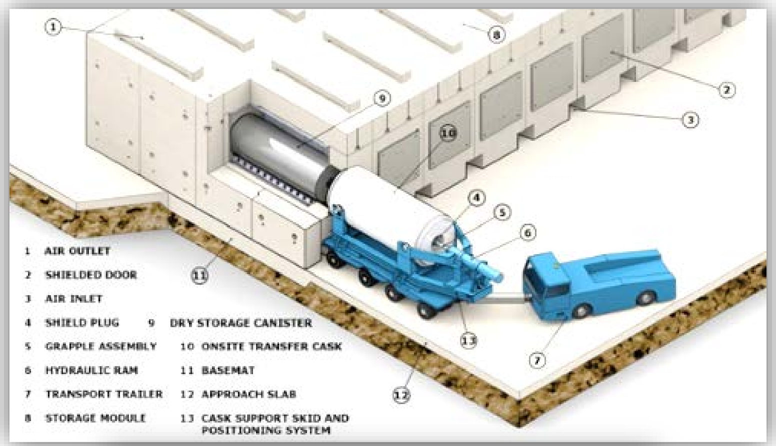
Field Demonstration of Concrete NDE Inspections for Dry Cask Storage Systems

Issue: Investigate various NDE techniques that can be used to detect concrete defects and degradation; however, no NDE methods other than visual inspections have been performed on dry cask storage systems at this time.



Description: Perform field demonstrations of concrete NDE techniques on unloaded dry cask storage systems. Include multiple techniques for detecting reinforcement corrosion, delaminations, cracks, and voids.

Benefits: Insight into which methods are more suitable for dry cask storage systems as well as highlight any challenges or gaps faced by these applications.

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First Field Demonstration

- Demonstrated NDE techniques on an unloaded NUHOMS system.
- The Purpose of the demonstration was to identify limitations with the NDE techniques when used on these thick concrete structures.




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NDE Technologies used in Demonstration

Impulse Response

Ultrasonic Shear Wave

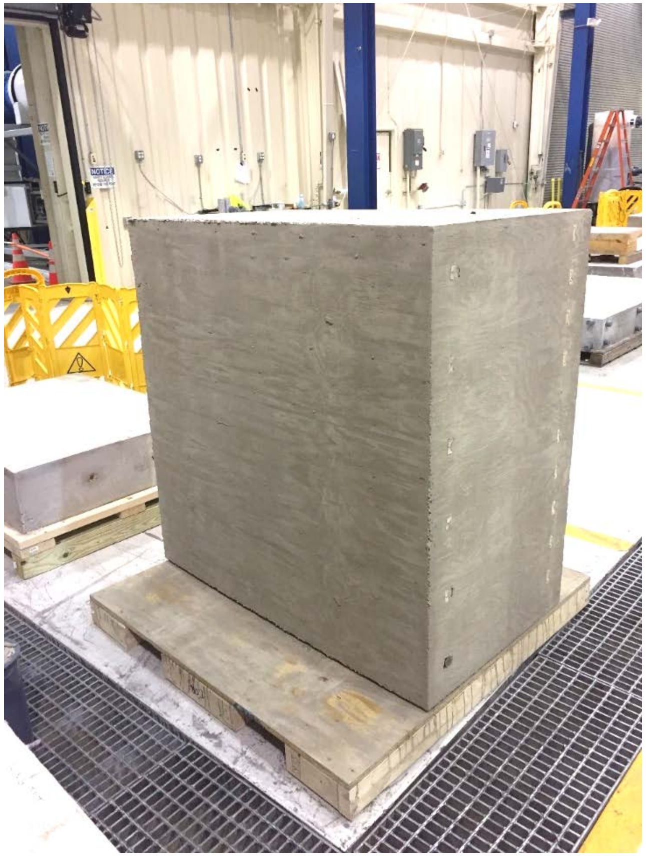
Ground Penetrating Radar

Ultrasonic Shear Wave

Impact Echo

EPRI's Representative Mock-up

- A large representative mock-up was built at EPRI to assess the NDE techniques' abilities for detecting concrete defects on these types of structures.
- Defects were placed in known locations to determine the reliability of the NDE techniques.
- Different reinforcement layouts on either side of the mock-up allows EPRI to represent the two major concrete overpack designs with only one mock-up.



2018 Activities

- Assessing the NDE techniques on the representative mock-up.
- The second field demonstration for the concrete cylinder overpack design.
- Participation in the Extended Storage Collaboration Program (ESCP) meetings.
- An EPRI technical report will be published in the 4th quarter of 2018.

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Modeling Wave Propagation in Concrete

Salvador Villalobos, P.E.
Technical Leader
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Modeling and Simulation of Wave Propagation in Concrete

The objectives of this study were:

- To develop a model of a mockup and run simulations for different scenarios/defects
- To research wave propagation in concrete for the impact echo method and shear wave array
- Compare the results between modeling and actual tests results

Challenges:

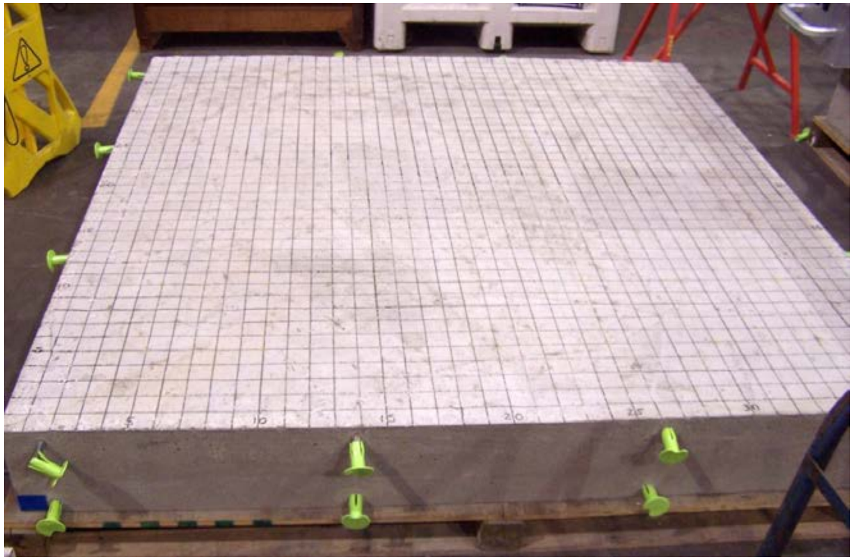
- No commercially available software dedicated to wave propagation in concrete
- A code/algorithm was developed each method the two methods

Advantages of Modeling and Simulation

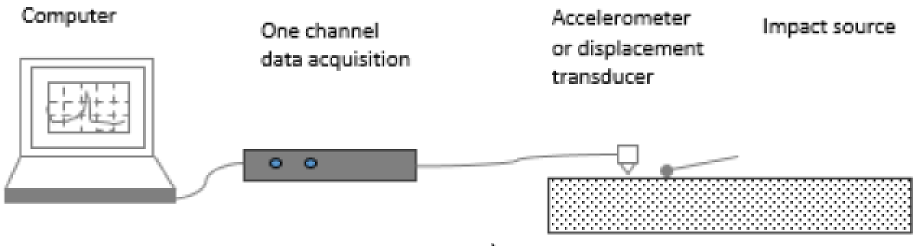
- Validate the use of a technique for a specific application
- Allows the user to obtain expected results once the model is validated
- Increases the level of confidence of a technique before deployment
- Reduces the cost of fabricating mockups to validate a technique

Mockup Used for the Study

- Concrete slab (2.00 m x 2.00 m x 0.24 m)
- Used in a previous study for the deployment of commercially available NDE methods
- Lightly reinforced
- Embedded delaminations at different depths (50 and 100 mm)



Impact Echo

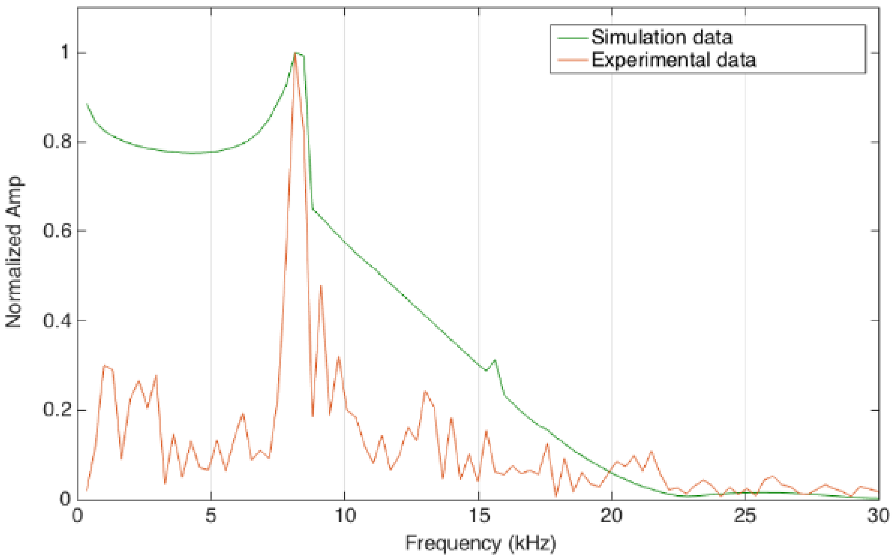


Fundamentals

- Relies on the propagation and reflection of stress waves
- Uses an impactor, accelerometer, DAQ unit, and computer
  - Impactor generates waves. Different diameter impactor = different contact time.
  - Accelerometer detects the displacement and time
  - DAQ and computer collect and process data
- Frequency can be correlated to the thickness
- Testing performed on a point by point basis, either a grid or individual test locations

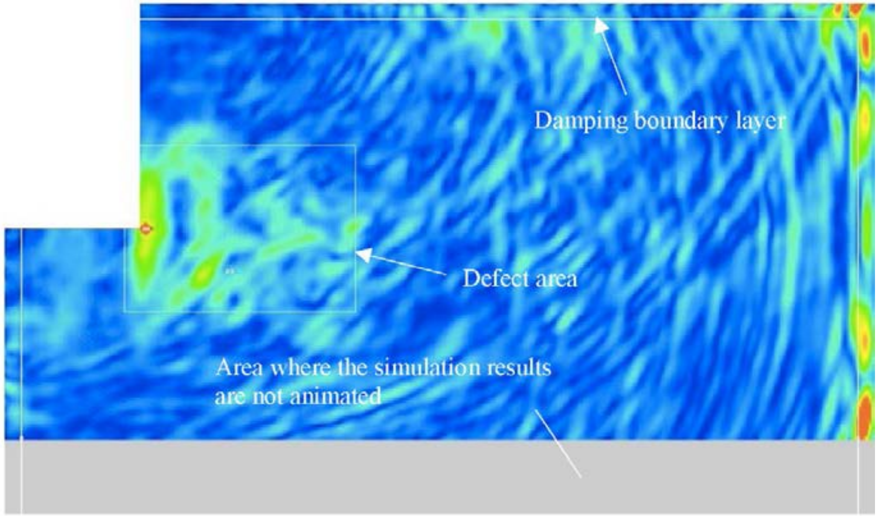
Impact Echo

- Selected because the method is well established
- Generated a finite element model to simulate wave propagation; 5 mm mesh size
- Data from the mockup (wave velocity, density, and modulus of elasticity) were input into the model
- Impactor size in testing affects capability of extracting the frequency content
- Impact duration was also simulated
- 2D and 3D simulations were performed
- Flexural and thickness response were simulated
- Damping boundary applied to 3D model

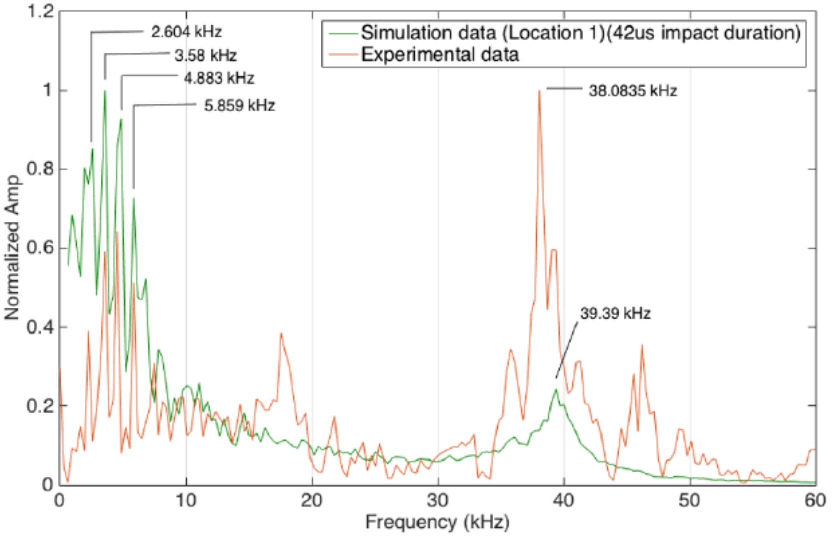


2D Simulation results for a solid region - 8.137 kHz

Impact Echo



Animation of Von Mises stresses for wave propagation



3D Simulation results for a shallow delamination

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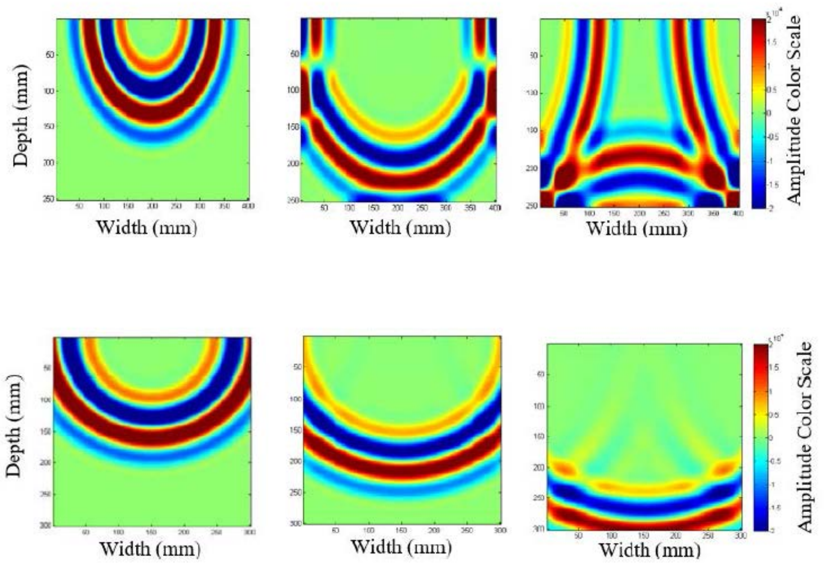
Shear Wave Tomography

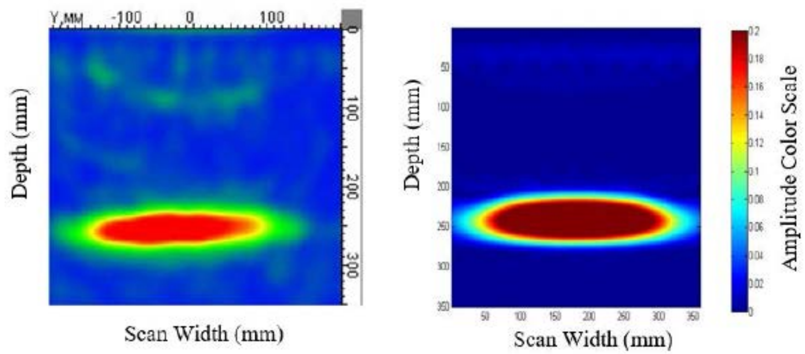
- State of the art technology for NDE of concrete
- 50 kHz assuming a uniform media
- Elastodynamic Finite Integration Technique (less computationally demanding than FE)
- Fortran 90/95 used for numerical simulation
- Matlab for visualization of the results
- Absorbing boundary due to the reconstruction of a small area
- Modulus of elasticity and wave velocity used as the main input parameters



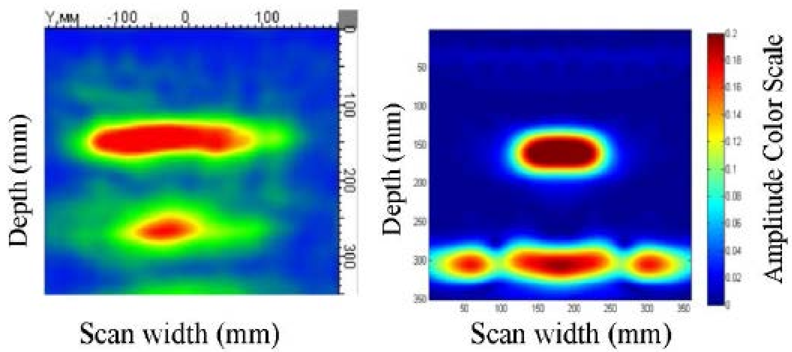
Comparison of data sets without *(top)* and with *(bottom)* an absorbing boundary

FE – Finite element

Shear Wave Tomography



Defect free 235 mm
experimental (left)
simulation (right)



Defect at 150 mm
experimental (left)
simulation (right)
(simulation only covers a portion of the array)

Summary

- Modeling and simulation were performed for the Impact echo and shear wave tomography methods
- Assumed uniform media in both methods and used input for material properties and dimensions
- In general good correlation between experimental results and modeling

Impact Echo

- The finite element method is very heavy computationally
- 2D model is less computationally demanding and provides similar results as the 3D

Shear Wave Tomography

- Less computationally demanding than FE
- Only 2D simulations were performed

FE – Finite element

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Develop Capability Demonstration Program for Concrete

Paul Weeks
Technical Leader
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Overview

- 4 year joint project with Materials Ageing Institute (MAI) in France
- Design flawed mockups for determining capabilities of current and future NDE techniques and/or equipment used in concrete testing
  - Same design mockups will be constructed in France
  - Creates opportunity to perform the same evaluation in both locations and share results

Current Status

- Status at end of 2017, the second year of the project
  - Mockup preparation and drawings completed
  - Mockups at EPRI in Charlotte have been poured
    - MAI personnel witnessed the pouring of samples
      - Lessons learned of all activities in project are shared
  - Detailed measurements of flaw types and locations were recorded prior to pouring

MAI – Materials Ageing Institute

Defects in Mockups

Delaminations

- Cardboard wrapped in duct tape
  - Cardboard was covered in plastic to waterproof and stiffen
- Modeling response evaluated
  - Response from air gap and carboard is similar based on modeling results (EPRI report 3002010303)

Defects in Mockups

Honeycombs

- Fabricated in the lab
- Coated with paste
- Embedded in concrete

Tendon voids and cut tendons

- Grouted and ungrouted tendons

Defects in Mockups

Plates

- Studs
  - Stud attached – not welded
  - Missing stud
  - Partially cut stud

- Holes in plate material

- Notches in plate material near welds

2018-2019 EPRI Activities

- Perform in-house validation of mockups and flaws
  - Fingerprinting to document as-built condition

- Invite concrete service vendors and equipment manufacturers to test on samples

- Document capabilities and results in 2019

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MRP NDE Activities

Harry Smith
Exelon

Kevin Hacker
Dominion Energy

Jack Spanner
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

MRP NDE Topics

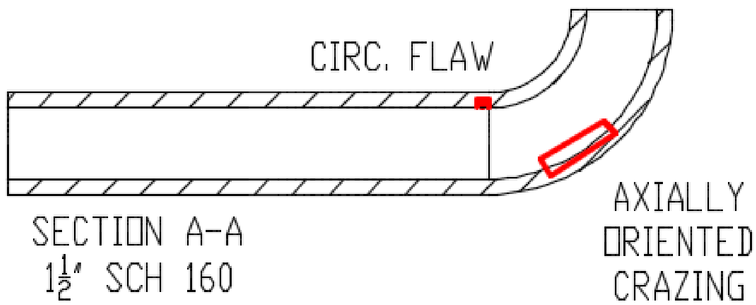
- Thermal fatigue (TF)
- Baffle-former bolts (BFBs)
- 2017 Deliverables

Thermal Fatigue OE Inspection Challenges

- TF Cracking Morphologies Changing
  - RCS High Pressure Injection Nozzle cracking (3 inch OD)
    - Axial cracks on the nozzle side without craze cracking
    - Examination from the nozzle side may be difficult due to geometry
  - RCS Drain cracking (2 inch OD)
    - Weld cracks initiating in the heat-affected zone then propagating into the weld
    - Elbow skewed cracks
- TF Cracking from March 2016 through May 2017
  - 7 locations with TF cracking
  - New source of in-leakage resulted in one through-wall due to cross-flow

Thermal Fatigue

- To respond to the OE, Inspection TAC:
  - Revised the thermal fatigue examination procedure recommendations
    - Distributed a supplemental sheet for use with PDI UT-2
    - Distributed revised generic thermal fatigue examination procedure
  - Revised MRP-23 (tech basis for UT procedures)
  - Updated MRP-36 (CBT)
  - Fabricated 7 additional mockups
    - 1.5 to 8.5 inch NPS
- Delivered in December 2017



RCS Drain Line Mockup

Adding TF Mockups to Virtual UT System Specimens for Training/Practice (MRP-421)

- Waveforms from simulated thermal fatigue flaws are used
- Administrator assembles flaws into virtual specimens
- Personnel playback data by “scanning” specimen with mouse
- Nine specimens were delivered
  - 1.5 to 8.5 inch NPS
  - Includes data from latest mockups and RHR Tee

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Baffle Former Bolts

- Since March 2017, UT or VT indications have been detected in 60 BFBs
  - Five units examined
- Revised bolting protocol distributed via MRP letter 2017-018 in August
  - Details on next slide

Baffle plates and bolts

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Bolting Qualification Protocol Revision

- Procedure qualification
  - Requires that all flaws must be detected
    - Minimum population is 30
    - For 30 flaws, this results in 92.6% POD at 90% confidence (binomial calculation)
  - Applicable to all internal bolting
  - Plan to implement for Fall 2018 outages
- Personnel qualification
  - Detect at least 80% of flaws; minimum population 10
  - False calls: 10% or less
- MRP-228 Rev. 3 will include the new bolting protocol
  - Scheduled for mid-2018 publication

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BWRVIP NDE Activities

Chris McKean
Exelon

Jeff Landrum
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Topics

- Update on 2017 inspection vendor demonstrations
- Update on off-axis core shroud UT demonstrations and examinations
  - Proposed characterization guidelines
- Jet pump beam NDE activities
  - New mock-ups
  - Developed phased array examination techniques
- BWR water level instrument penetration update
  - Eddy current array technique development
- Core spray fabrication flaws (update)
  - 2017 update & plans for 2018
- Jet pump diffuser DF-3 backing ring welds

Update on Inspection Vendor Demonstrations

Ultrasonic demonstrations performed or documented during 2017

2017 inspection vendor UT demonstrations

- (7) Core shroud weld demonstrations
  - H1 shroud flange-to-cylinder weld
    - (1) immersion UT
    - (1) contact UT
  - H6b core plate support ring-to-cylinder weld
    - (1) line scan pattern
    - (1) raster scan pattern
  - (2) Off-axis / “atypical” flaw techniques
    - Different vendors
  - H4 and vertical plate-to-plate welds
- (1) Jet pump mixer, diffuser, tailpipe, and adapter weld demonstration

2017 inspection vendor UT demonstrations

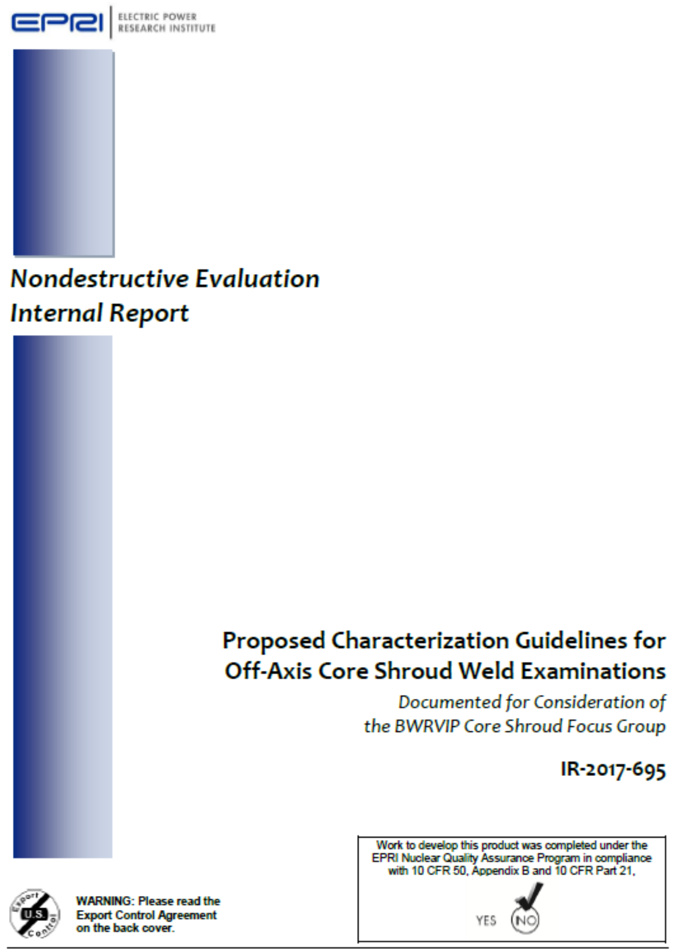
- (7) Core spray weld demonstrations
  - P1 thermal sleeve-to-junction box weld
  - P2 junction box-to-cover plate weld
  - P3 junction box-to-header pipe weld
  - P4 pipe-to-elbow welds (included elbow-side scan technique)
  - P5, P6, & P7 collar fillet welds
  - BWR/6 coupling welds
  - P8a and P8b shroud penetration welds
- (2) Jet pump hold-down beam demonstrations
  - "Group 2" type
  - "Group 2" & "Group 3" type (1st demo of "Group 3" beams)

Update on off-axis UT examinations

- Three inspection vendors have now successfully demonstrated ability to detect and size off-axis core shroud flaws
  - All used matrix phased array probes and electronic beam skewing
  - Ultrasonic examinations performed at five US BWRs so far, more UTs are planned
  - EVT-1 examinations performed at additional BWRs

Proposed off-axis UT characterization guidelines

- Demonstrated techniques are capable of detecting the expected minor “off-axis” branching inherent to parallel IGSCC flaws
- EPRI “Internal Report” (IR) prepared for consideration of Core Shroud Focus Group
- Report proposes new characterization guidelines
  - Minimize incorrect characterization of IGSCC as “atypical”
  - Standardize process across multiple inspection vendors
  - Standardize UT & VT results
- Only applies to regions where off-axis exams are performed where parallel flaws are also located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Nondestructive Evaluation
Internal Report

Proposed Characterization Guidelines for Off-Axis Core Shroud Weld Examinations

Documented for Consideration of the BWRVIP Core Shroud Focus Group

IR-2017-695

WARNING: Please read the Export Control Agreement on the back cover.

Work to develop this product was completed under the EPRI Nuclear Quality Assurance Program in compliance with 10 CFR 50, Appendix B and 10 CFR Part 21.

YES NO

Proposed Off-axis UT characterization guidelines

- Minor "perpendicular components" of parallel flaws are not to be characterized as being "atypical" unless they:
  - propagate into austenitic weld material
  - have through-wall depths that are larger than the evaluated parallel flaw
  - extend a significant distance from the evaluated parallel flaw (i.e. propagate outside the HAZ)
  - contain multiple segments / branches
  - are located on the opposite surface as the evaluated parallel flaw
- Perpendicular flaws not associated with parallel flaws are considered "atypical" unless they are associated with the HAZ of an intersecting weld
  - Applies to vertical weld flaws identified during an off-axis examinations of a horizontal weld, or vice-versa

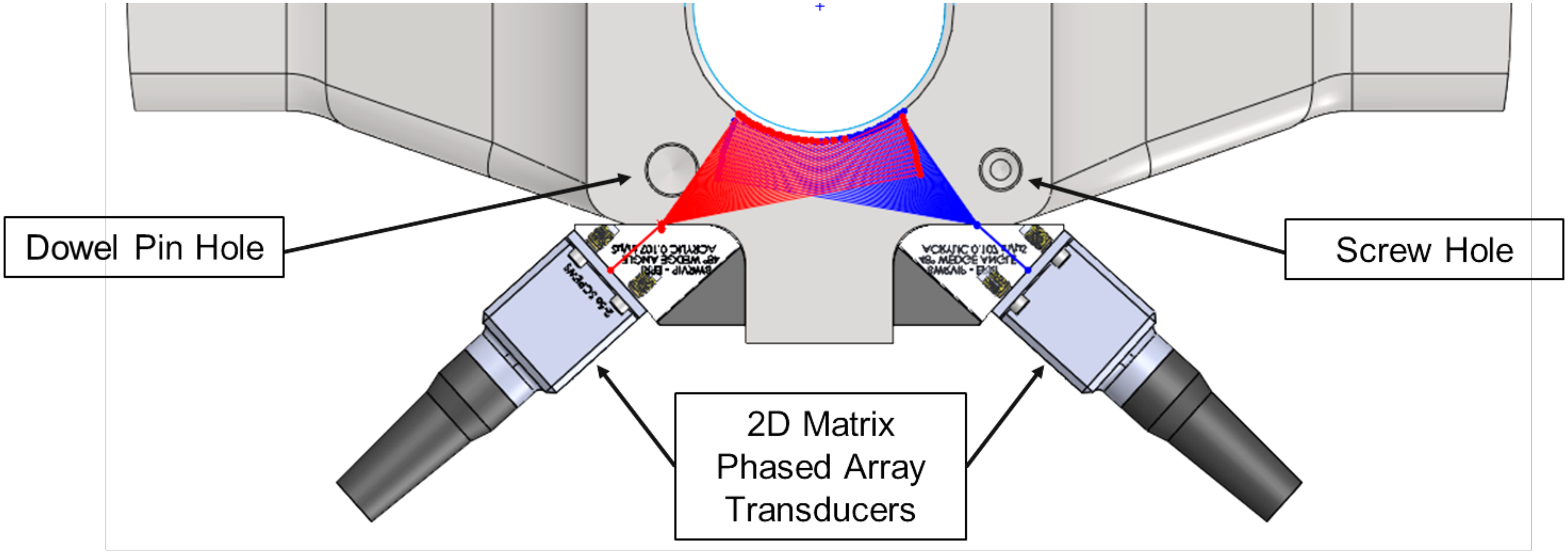
Group 3 Jet Pump Beam Mock-ups and Examination Technique Development

Project goals

- Fabricate "Group 3" jet pump beam mock-ups
  - Procured three X-750 jet pump beams
- Develop UT techniques to support mockup fabrication process
  - Characterize geometric or metallurgical reflectors prior to flaw implantation
  - Characterize flaw responses
  - Provide data to ensure the flawed mockups are fit for purpose
- Increase BB-1 examination capabilities beyond the widely used "go – no-go" amplitude based criteria
- Provide a robust UT technique that could be used by licensees / inspection vendors before beam installation

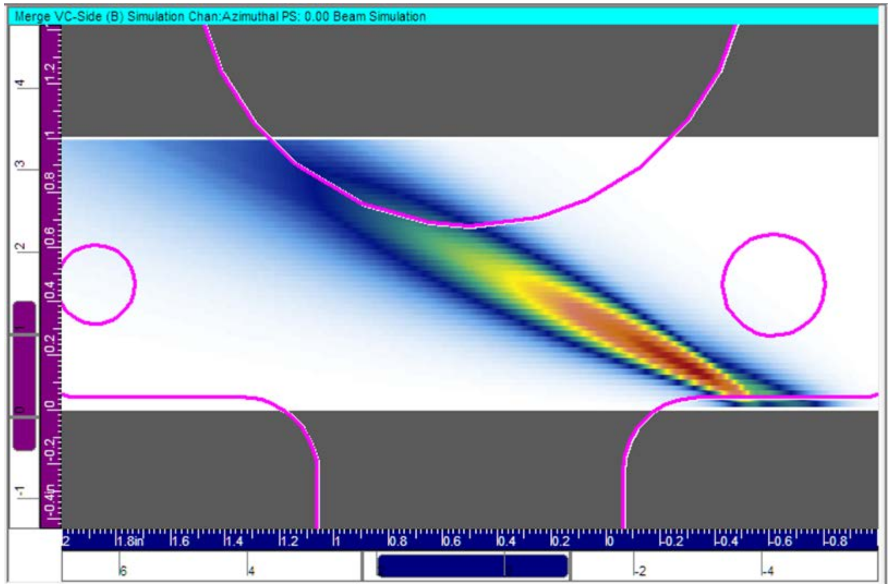
New phased array BB-1 technique

- Previously BB-1 inspection regions have been examined using amplitude-based "go – no-go" evaluation criteria
  - Static conventional immersion probes
  - BB-1 region cannot be supplemented using EVT-1 interrogation
  - "False calls" have been confirmed during replacement activities
- Phased array technique provides enhanced capabilities

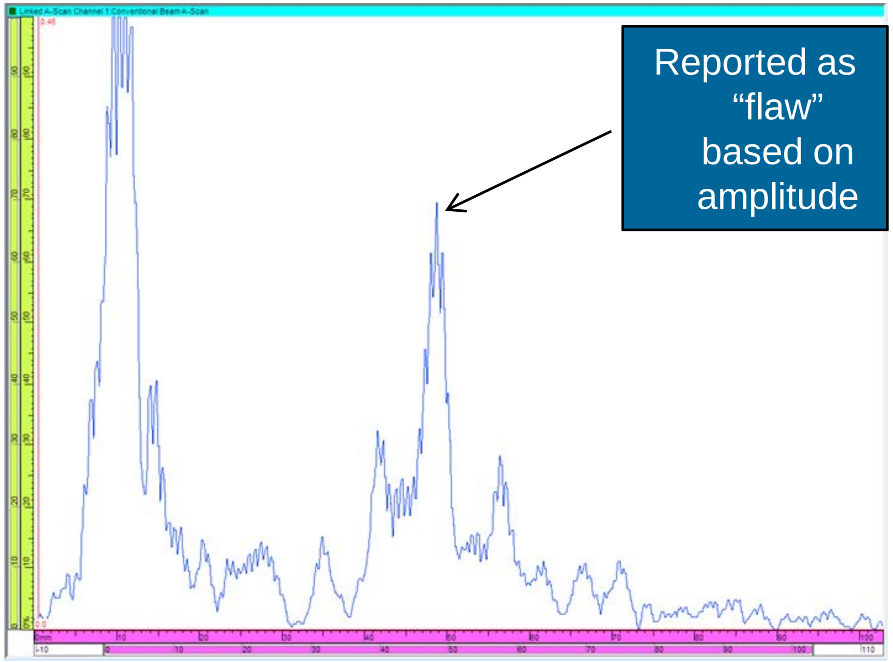


Existing BB-1 examination techniques

Ultrasonic Beam Modeling of Typical Examination using Fixed Conventional Transducer



Previous BB-1 techniques:
Ultrasonic A-scan response from flaw



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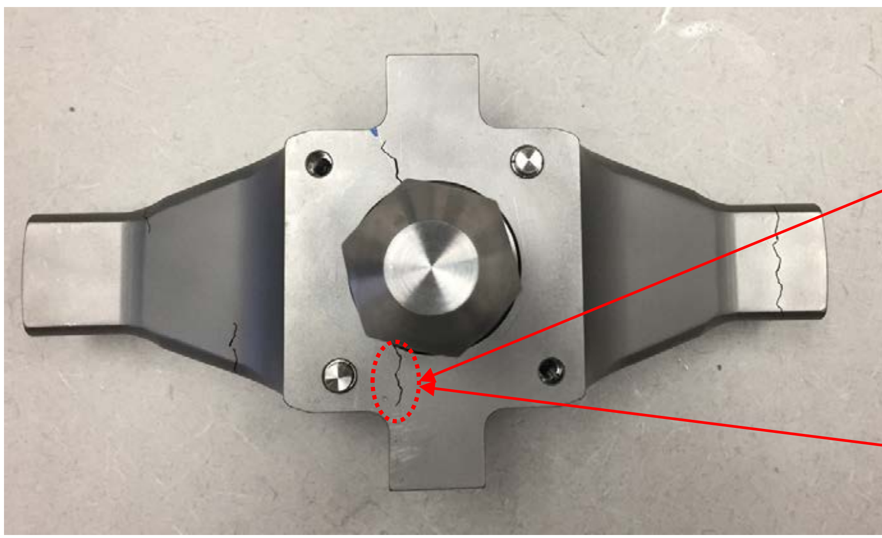
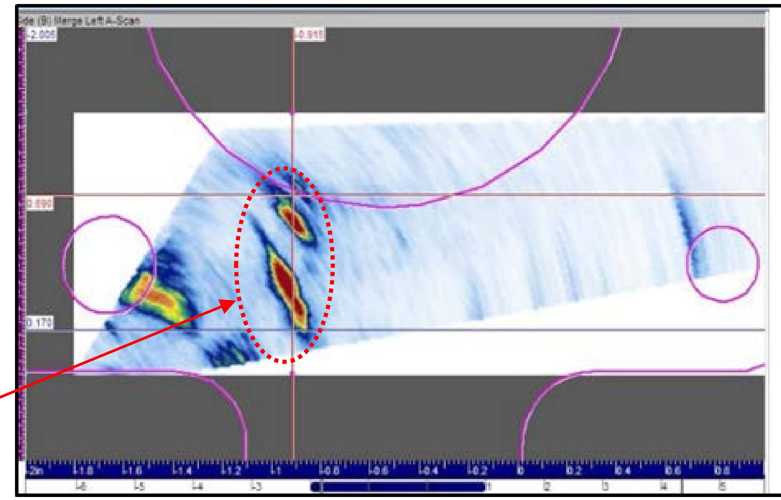
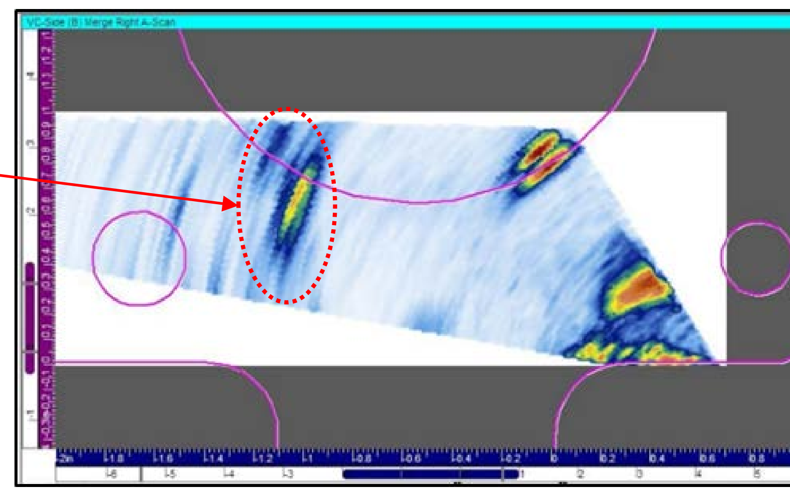
New BB-1 phased array technique

BB-1 flaws
(locking plate and keeper removed)



New BB-1 phased array technique
Images flaw = provides length and depth





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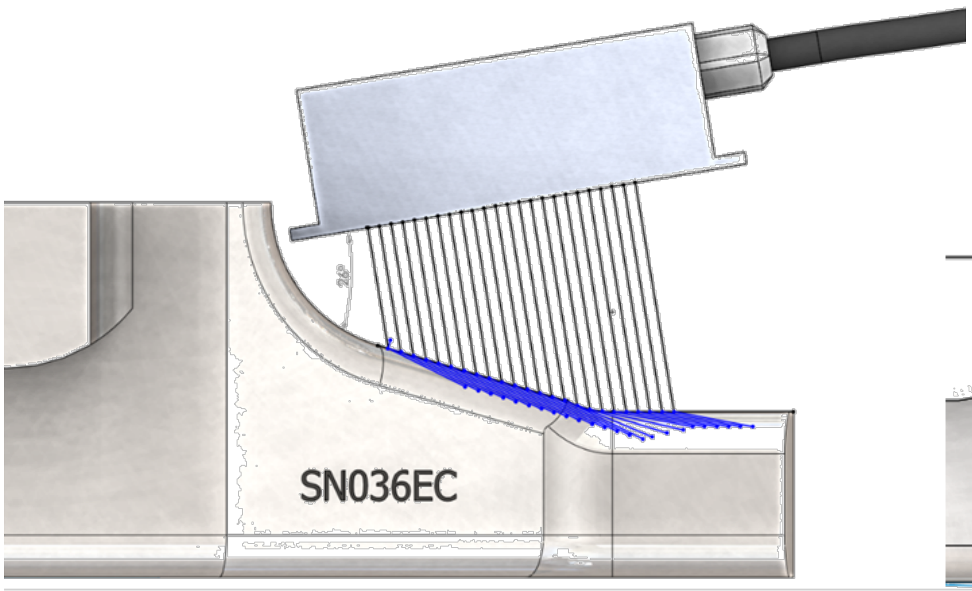
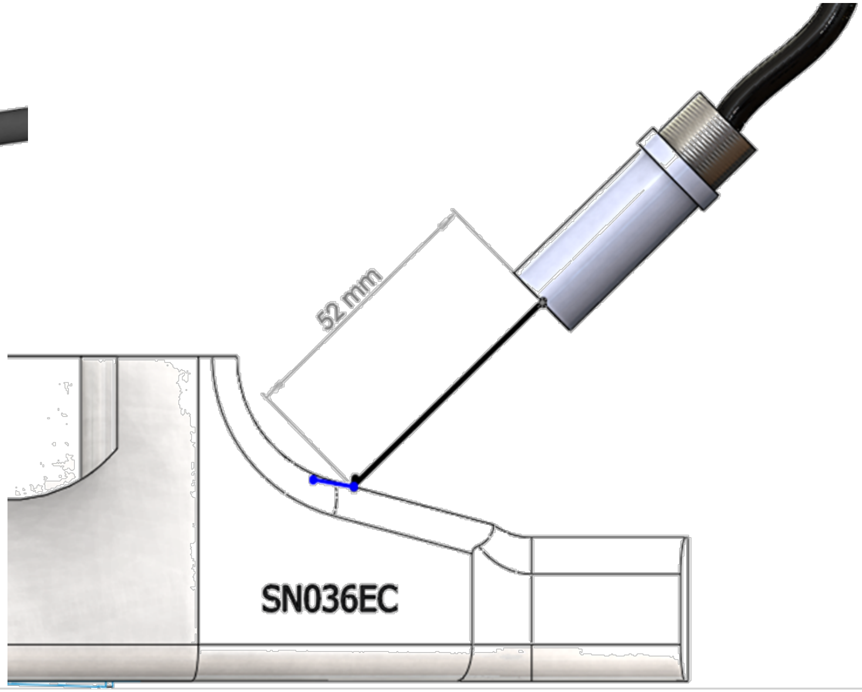
BB-2 and BB-3 examination technique

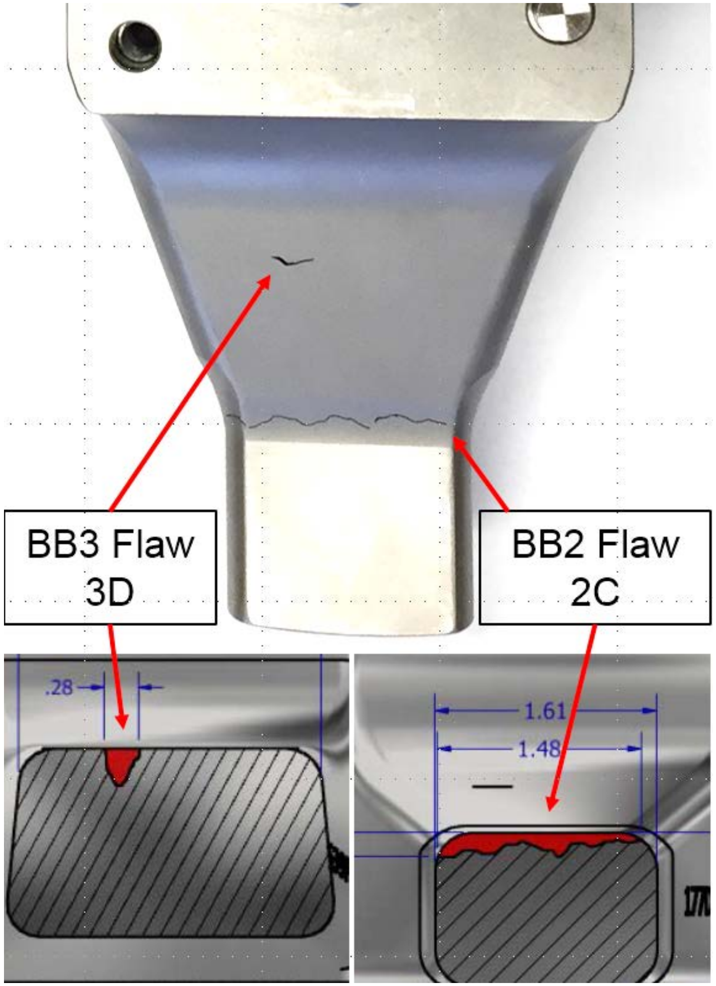
- Phased array technique developed for BB-2 and BB-3 regions
  - Electronic linear scan using immersion phased array
  - Conventional immersion probe used to supplement phased array scans
  - Improves characterization ability by obtaining flaw length and depth information



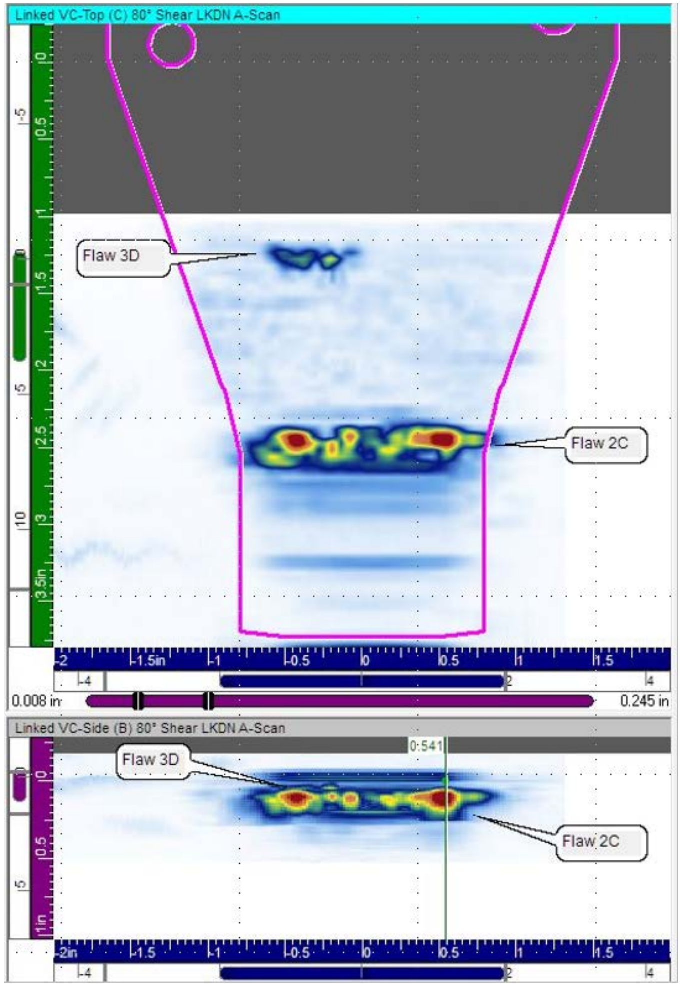


BB-2 and BB-3 flaws

Example of mock-up flaws



Ultrasonic responses



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Jet Pump Beam Project Status

- "Group 3" mock-ups added to BWRVIP demonstration set
- BWRVIP developed phased array techniques that enhanced ability to interrogate "Group 3" beams
- An inspection vendor further developed the EPRI/BWRVIP techniques
  - Made compatible with their robotic in-vessel examination tool
  - Included both "Group 2" and "Group 3" jet-pump beam designs
  - Supported examinations at US BWR/4 during Fall 2017 outage season

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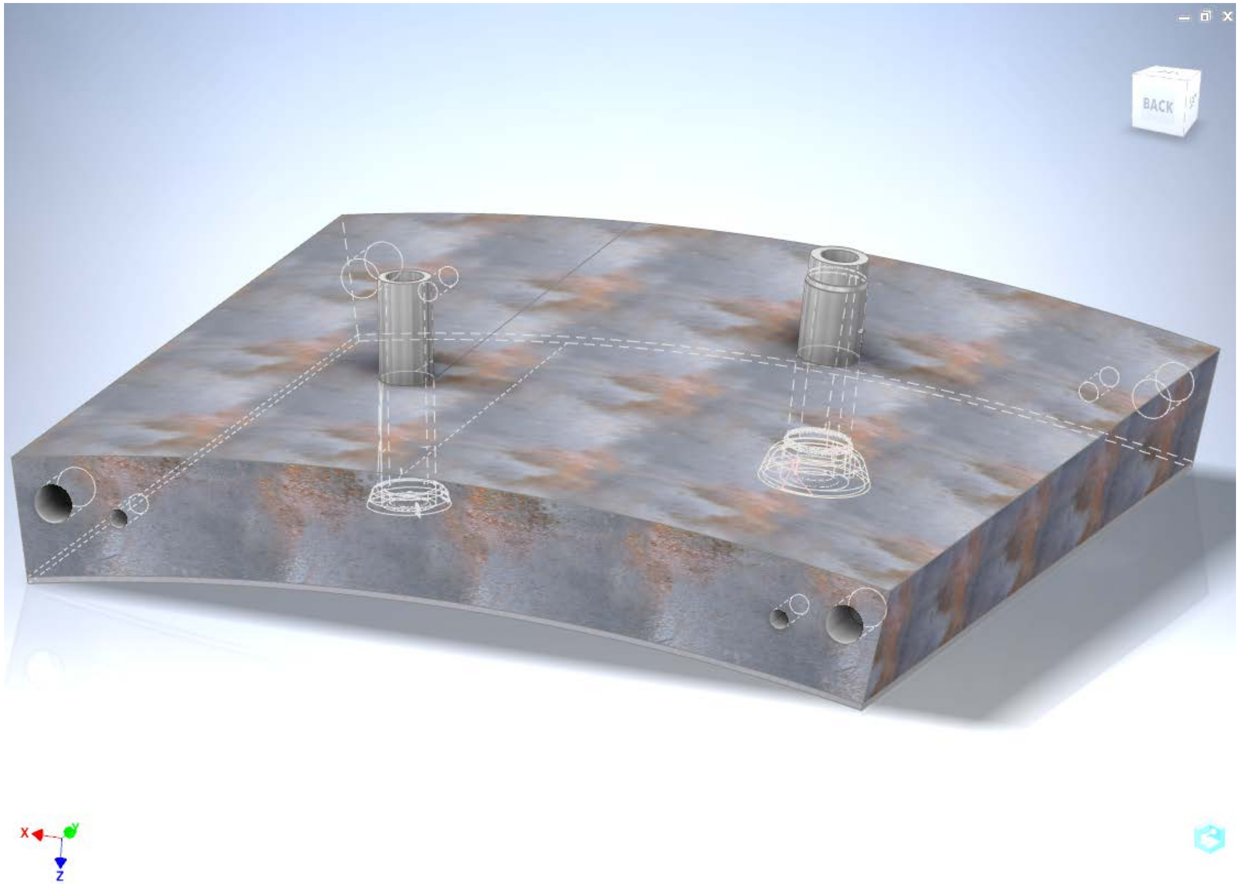
BWR Water Level Instrument Penetration Update



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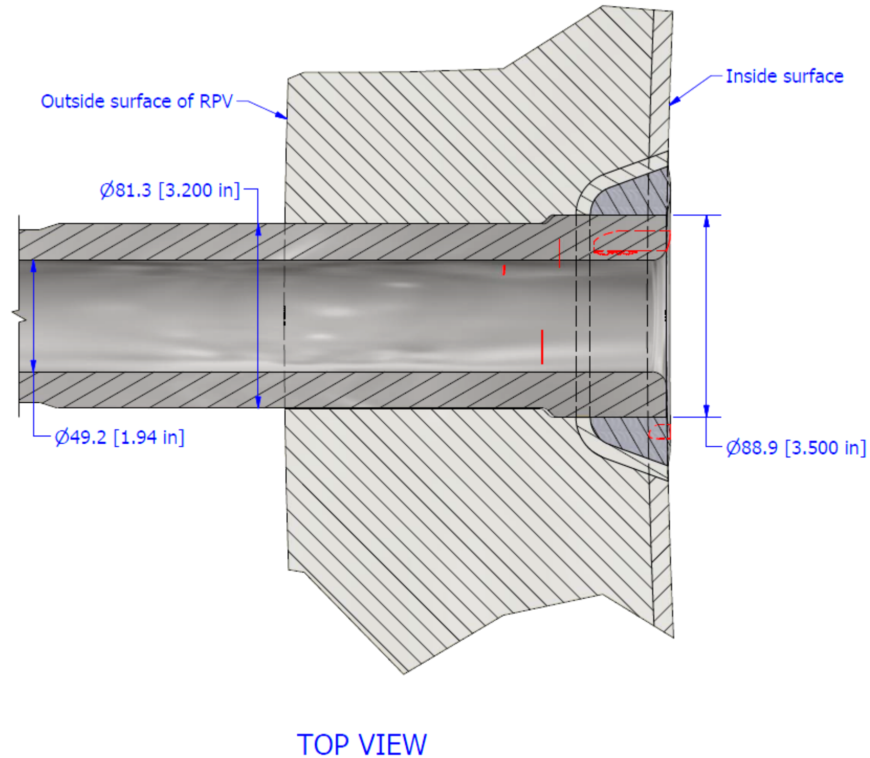
Project Status

- Manual phased array technique used during repair operations at US BWR/4 during spring 2017 outage season
  - Scanning performed from outside surface of RPV
  - Limitations still exist with interrogation of penetration tube material
- EPRI/BWRVIP developing eddy current array (ECA) technique
  - In-vessel robotic scans performed from inside the RPV
  - One eddy current array for interrogation of J-groove weld surface
  - One eddy current array for inside surface of penetration tube

Ongoing 2018 activities

- Initial ECA probes being developed, to be tested during first half of 2018
- Final optimized ECA probe designs scheduled for second half of 2018
- May also investigate ultrasonic techniques from inside the penetration tube
  - Similar to PWR CRDM penetrations except no extension below weld



Planned Activities

Core spray piping

- Embedded fabrication flaws are difficult to build
- Two inspection vendors have now scanned core spray mock-up containing implanted fabrication flaws – additional vendors to follow
- BWRVIP plans UT in 2018 followed by destructive examinations (DE) to validate "as-built" condition of specified fabrication flaws
  - Validate flaw manufacturers ability to fabricate realistic weld-fabrication flaws
- DE report will be shared with participating inspection vendors
- BWRVIP Inspection Committee will evaluate benefit of adding fabrication flaws to demonstration set
  - Can UT reliably characterize indications in thin-wall core spray piping?

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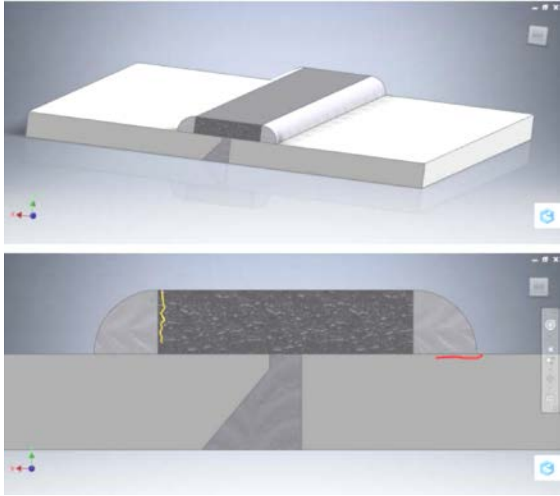
Jet pump diffuser-to-adapter DF-3 welds



- New action item to study backing ring weld locations
- Ultrasonic examinations are performed from inside surface
  - Currently only interrogate diffuser butt-weld and diffuser base material (backing rings are on OD)
  - No interrogation of backing ring
- Visual examinations are performed from outside surface
  - Interrogate backing ring material and fillet weld HAZs
  - No interrogation of diffuser material under backing ring
- Study ability of UT to interrogate regions examined by EVT-1
- A simple feasibility study mock-up (image) and UT development is planned

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BWRVIP NDE Activities

- Questions or comments?

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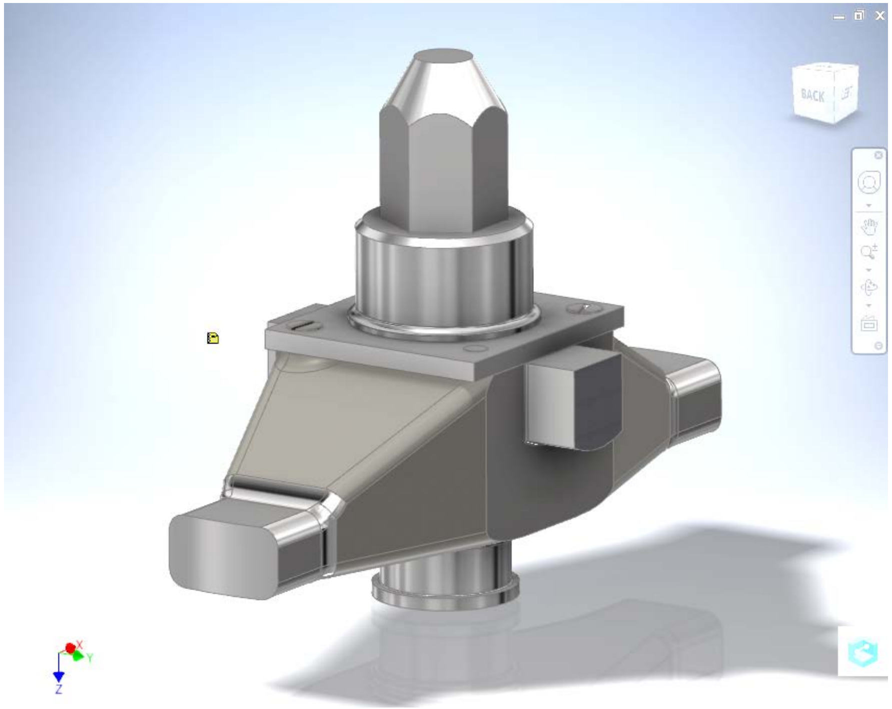
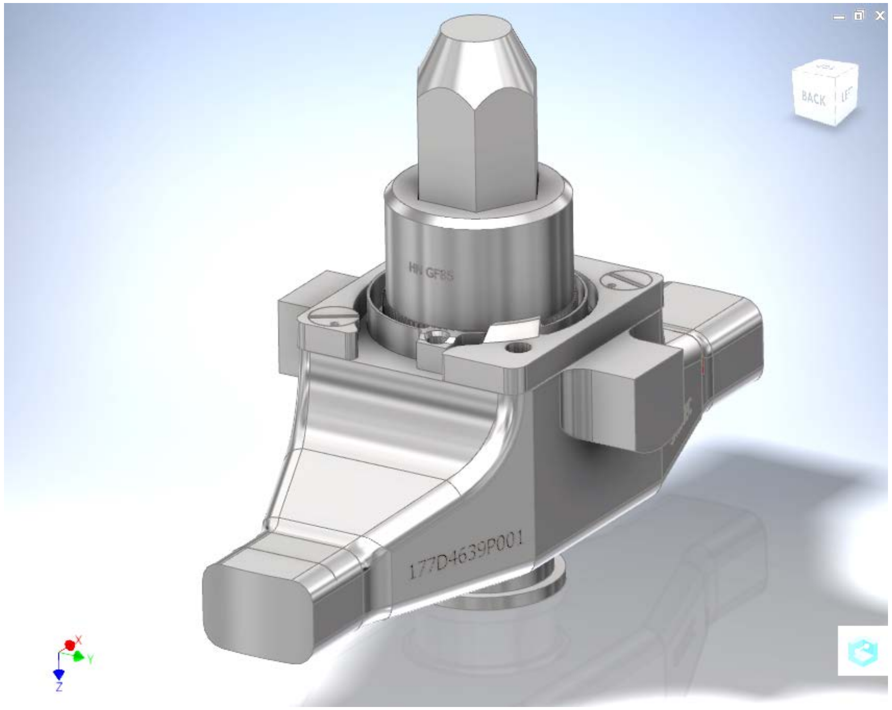
Backup slides

Group 2 type jet-pump beam

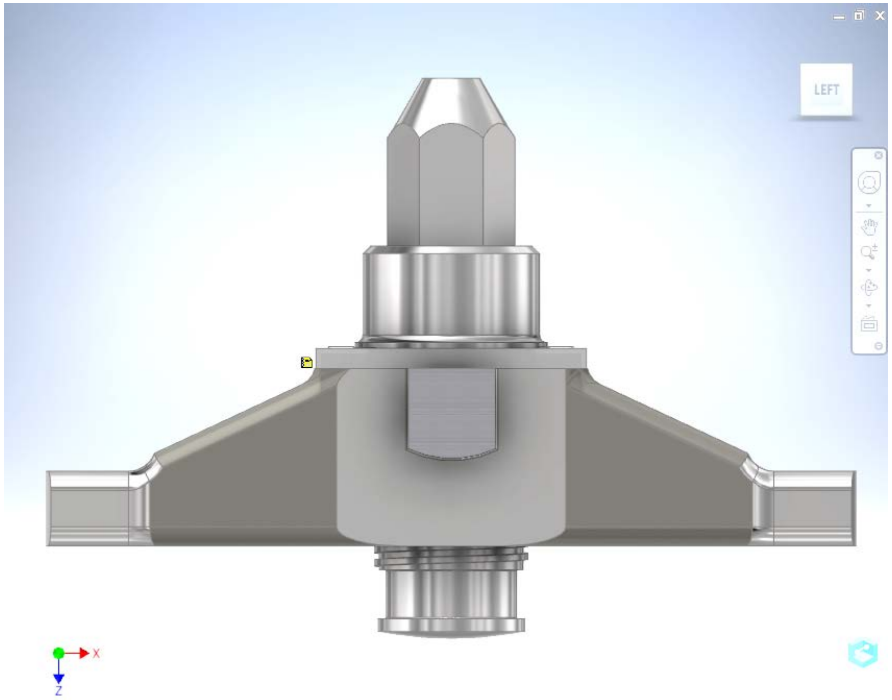
Group 3 type jet-pump beam



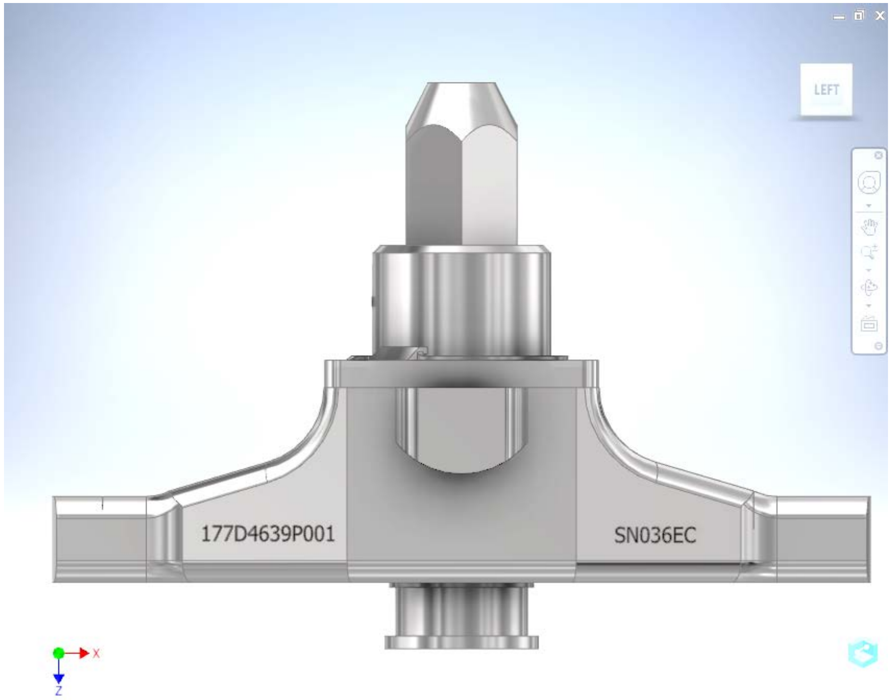


Backup slides

Group 2 type jet-pump beam

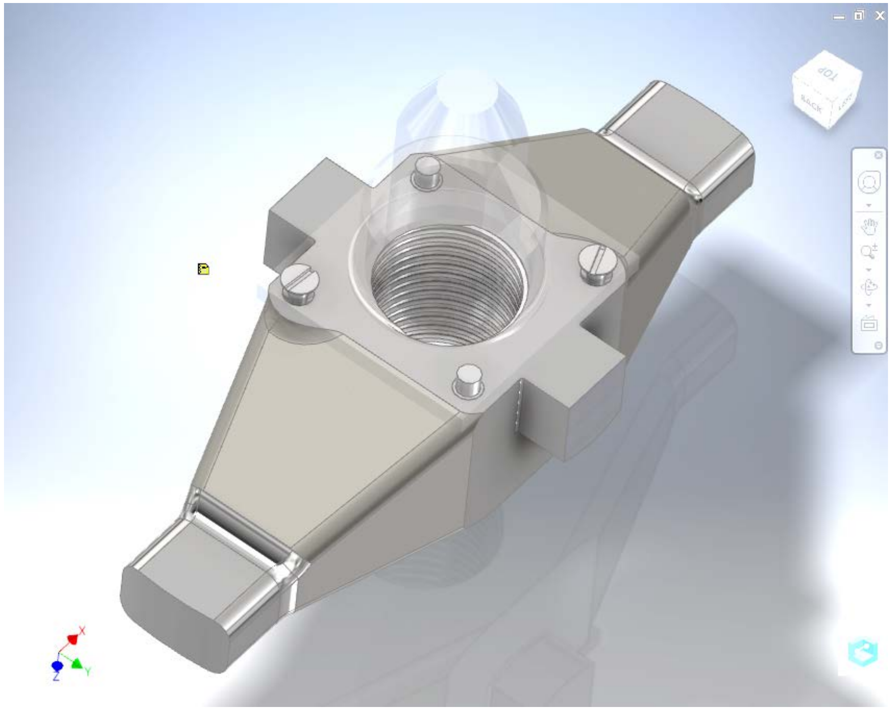


Group 3 type jet-pump beam

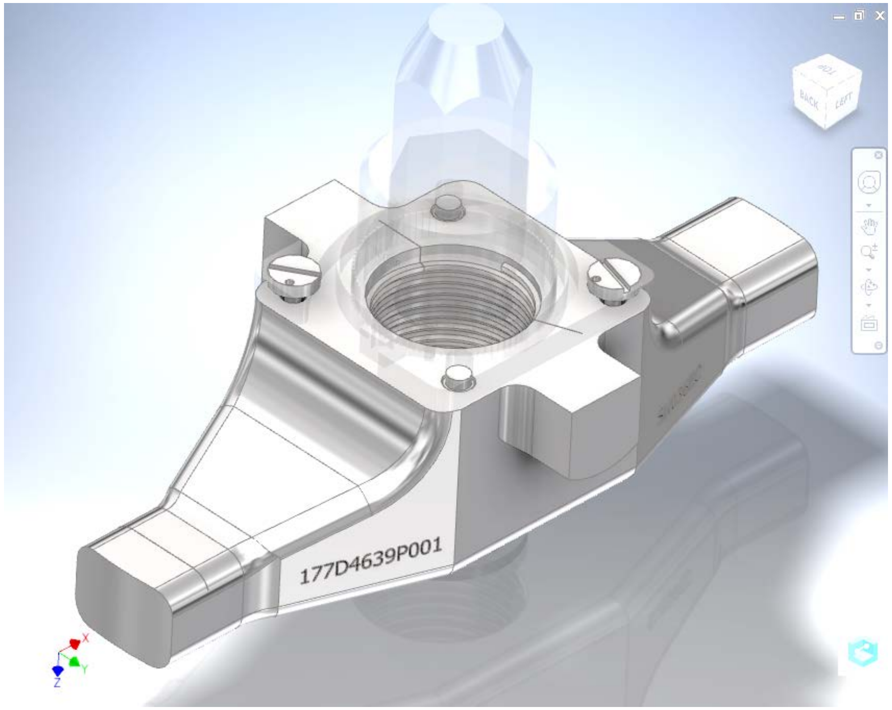


Backup slides

Group 2 type jet-pump beam
Locking plate and keeper removed



Group 3 type jet-pump beam
Locking plate and keeper removed



Cast Austenitic Stainless Steel (CASS) Update

Kevin Hacker
Dominion Energy

Doug Kull
Carl Latiolais
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Content

- CASS Round Robin Study (RRS)
- CASS Round Robin Study Follow Up Research
- CASS Demonstration Technical Basis

CASS Round Robin Study (RRS)

CASS Round Robin Study Objectives

- Assess current ultrasonic examination techniques for the detection and sizing of flaws in CASS material
- Quantify the performance of the current NDE technology in terms of probability of detection (POD) and false calls
- Identify any issues in the current CASS mockup manufacturing techniques
- Provide data to support the development of Section XI Appendix VIII Supplement 9 Qualification Program

CASS Round Robin Study

- 5 organizations submitted results in the round robin study
  - Equipment/Component Manufacturers
  - NDE Service Providers
  - National Laboratories
- UT Techniques
  - Encoded UT
  - Low frequency (< 1.0 MHz) and non-low frequency probes (1.0 MHz and higher)
  - Raster and line scan
- Data Sets
  - 5 raster scan data sets
  - 2 line scan data sets

CASS Round Robin Study Format

- Testing conducted in a secure blind fashion
- Data collected and analyzed in accordance with the participating organization’s written procedure
- Data was analyzed one side at a time to assess single sided performance
  - Many field configurations are limited to single side access
  - Assessment must reflect field implementation conditions
- Grading was performed using processes similar to those used for other Appendix VIII Supplements (e.g., detection, missed detection, false call, length, etc.)
  - Grading was applied uniformly for all organizations
  - Provides a consistent process
  - Grading criteria may change to address CASS specific issues during future detailed evaluation of results

CASS Round Robin Study Test Specimens

- 20 samples
  - Qty. 6 – 12" OD (360° segments)
  - Qty. 4 – 28" OD (90° segments)
  - Qty. 10 – 36" OD (60° segments)
- 89% of the material from vintage material
  - Canceled Plants
  - Surplus Material
  - Wrought to Cast
  - Cast to Cast
- Combination of grown and implanted flaws

Test Specimen Design Considerations

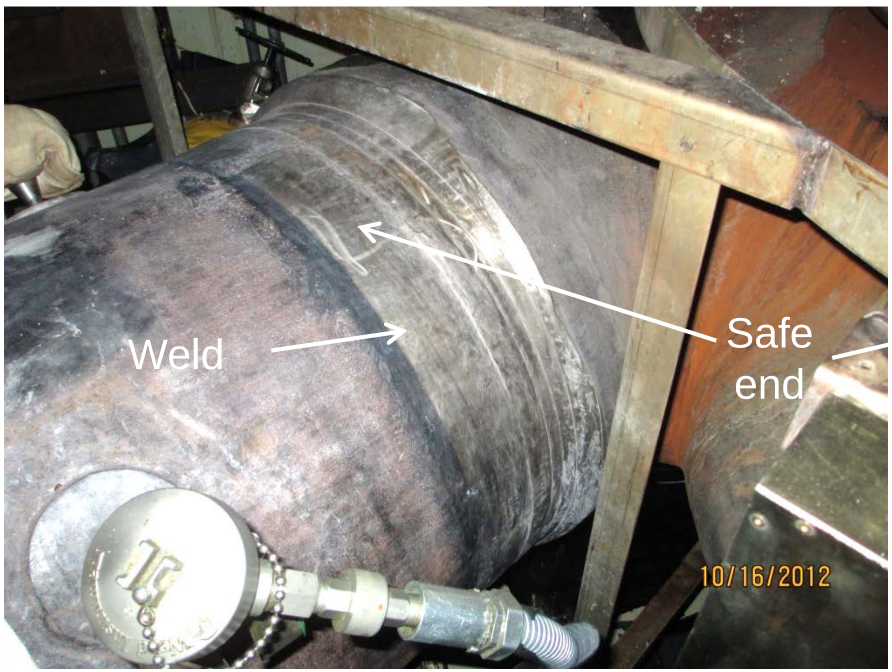
- Representative of known field conditions
  - Contain geometric conditions that require discrimination from flaws (e.g., counterbore and weld root conditions)
  - Typical limited scanning surface conditions (e,g., weld crowns and, diametrical shrinkage)
- Contain both circumferential and axial flaws
- Flaw heights range between approximately 10% and 85%

Test Specimen Design Considerations

Table 1. PWR Limited Coverage Welds in Appendix A by Weld Configuration

Component Description	Number of Welds	Examination Description	Percent Coverage Claimed	Range of Diameters, inches
RCP nozzle CASS safe–end-to-CS elbow[(b)]	24	Single-sided from CS elbow side	(a)	30 and 36
RCP nozzle CASS safe–end-to-CS pipe[(b)]	24	Single-sided from CS pipe side	(a)	30 and 36
CASS safe–end-to-CS nozzle[(b)]	18	Single-sided from CS nozzle side	(a)	12

Source: Report PNNL-26157, Rev. 1



RCP Discharge CASS SE to Pipe
Source: Utility Supplied

RCP Suction CS Elbow to CASS SE
Source: Utility Supplied

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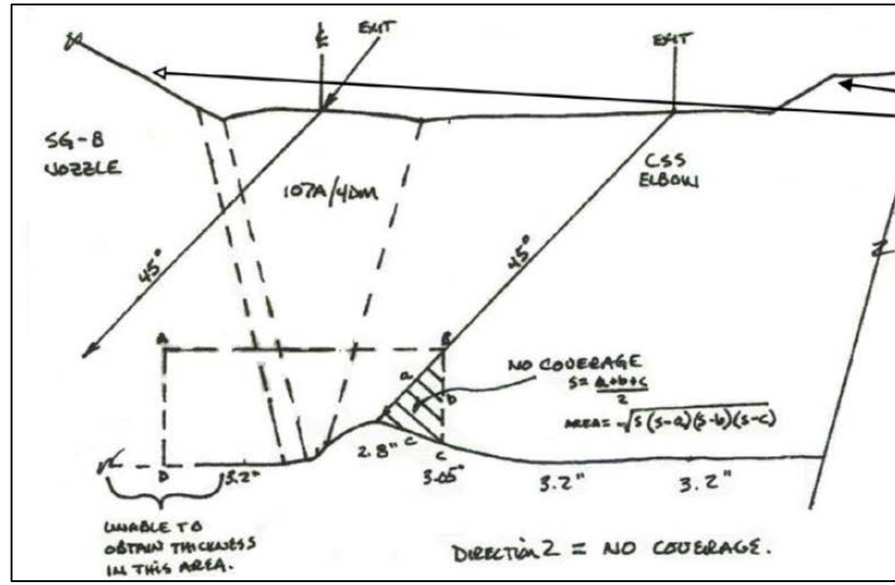
Test Specimen Design Considerations

Westinghouse 3-loop RCS
Nozzle to CASS Elbow Weld
Source: Utility Supplied



Source: Report# PNNL-26157, Rev. 1

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CASS Round Robin Study Results

- Performance varied among the participating teams
- Full Summary of Results may be found in EPRI Report 3002010314
  - Currently under revision and expect to be republished early 2018
- Average performance:

	Single-sided	Dual-sided
Detection	53%	69%
False Calls	23%	37%
Length Sizing RMS	1.08”	1.07”
Depth Sizing RMS	0.47”	0.47”

  - Results include only flaws with TWE greater than 25%
  - Dual-sided results are an approximation based on a combination of the longest and deepest call from either side

CASS Round Robin Study Summary

- General
  - All organizations used encoded phased array
  - All organizations used typical DMW or low frequency techniques

- Detection
  - All participants have missed detections and false calls
  - Most had issues distinguishing between geometry and flaws
  - Single side scan access has a significant impact on far-side detection (high angles less effective)

CASS Round Robin Study Summary (continued)

- Length Sizing
  - Inconsistent (accurate sizing, under sizing, over sizing)
  - Ranges from small deviation (approx. 0.1”) to significant deviation (exceeding 2.0”)

- Depth Sizing
  - Most depth sizing errors have reported flaw heights smaller than actual
  - Common to see a flaw base response with good SNR but receive very little from upper portions of the flaw

CASS Round Robin Study
Follow Up Research

CASS Round Robin Study Follow Up Research

- The Round Robin Study collected data with procedures/techniques that achieved different levels of flaw detection and sizing capabilities
- Improvements are needed to reliably detect and size flaws
  - Must understand the limitations of the current techniques and technology
  - Understand the component conditions that may affect performance
    - Single- or dual-sided access
    - Weld crown conditions
    - Flaw size and orientation
    - Thickness
- Final procedures and techniques must be capable of being implemented for realistic field conditions
- Project *Improve Examination Capabilities of Complex Cast Components* started in November 2017

Improve Examination Capabilities of Complex Cast Components: Project Tasks

- Review Round Robin data and results to assess techniques, personnel, and mockups
- Identify detection trends related to flaw size, orientation, and proximity to ID & OD geometric conditions
- Evaluate performance of individual organizations
  - Best performance / flaw by flaw basis
  - Best techniques / can they be enhanced
  - Can results be correlated based on flaw sizes – what is the effect of flaw size on detectability and ability to size and characterize
  - Is there a regime in which detection and characterization is possible at a level consistent with traditional performance demonstration requirements, or must alternative criteria be developed
- Evaluate grading criteria used for initial assessment of the Round Robin results

Improve Examination Capabilities of Complex Cast Components: Project Tasks (continued)

- Technique enhancement assessment
  - Possible technique enhancements based on the review of results
  - Define best available practices based on review of results
  - Evaluate new technologies not utilized during the RRS (if applicable)
- Evaluate use of flaw length to determine depth
  - Based on engineering analysis
- Evaluate if the detection of axial flaws is important in maintaining structural integrity
  - If not, then focus solely on the safety significant circumferential flaws

Improve Examination Capabilities of Complex Cast Components: Project Tasks (continued)

- Evaluate removal of weld crowns
  - Does weld crown removal facilitate gains in detection and sizing capabilities that would be necessary to enable qualifications
- Destructive interrogation
  - Select flaws for destructive analysis
    - After all NDE development work has been performed
    - Target the flaws with detection & sizing issues
  - Investigate reasons for poor flaw responses

RRS Review - Preliminary Observations

- Round robin study report summarizes overall results from all data
- The follow-up research will include more in-depth interrogation of the same data (in process)
  - Initial Analysis
    - Raster techniques only
    - Data sets with top 3 performance for detection
    - Includes only flaws detected in all 3 data sets
    - Looking for a common link between flaws with 100% detection
  - Additional analysis in progress
    - Common false call occurrences
    - Individual flaw length/depth sizing errors
    - Normalization of error measurements (e.g. RMSP)

Data Review - Preliminary Observations (continued)

- Detection
  - A number of flaws were not detected by any organization
  - Data sets with better detection results also had significantly higher false call rates
  - Simulated dual-sided examination results showed better probability of detection but showed an increase of false call rate
- Length Sizing
  - Tendency towards under-sizing for both single sided and simulated dual sided examinations
  - Length sizing error is generally significantly larger for longer flaws
  - The longer the flaw the higher the tendency to under-size
    - One data set did not show this tendency – all others did

Data Review - Preliminary Observations (continued)

- Depth Sizing
  - Depth sizing results showed only minor differences between single-sided and simulated dual-sided access
  - Depth sizing results have shown a general tendency for under-sizing
    - The deeper flaws had greater tendency to be undersized
  - One organization had linear correlation between measured and true flaw depths when normalized with component thickness
    - Tendency to undersize flaws
- Assessment of Flaws
  - In the beginning stages of this task
  - Very low detection rate for axial flaws
    - Likely due to the existence of weld crowns

CASS Performance Demonstration Technical Basis

Background

- The MRP Inspection TAC funded a project to develop a technical basis for demonstration and qualification for the ultrasonic examination of CASS piping
  - Based on draft rule requiring a demonstration program for CASS
  - Need requirements for demonstration prior to starting PD program development and mockup fabrication
  - Must be able to meet the demonstration requirements
- *Materials Reliability Program: Supplement 9 Draft - Qualification Requirements for Cast Stainless Steel Piping Welds (MRP-424),* 3002010517
  - Still in draft form due to current technology unable to meet these requirements
  - Further work is required to assess current technology and draft demonstration requirements to determine what is appropriate

Inputs

- The following documents were used as technical input:
  - NUREG/CR-4464, Performance Demonstration Tests for Detection of Intergranular Stress Corrosion Cracking
  - ASME Section XI Appendix VIII Supplement 2
  - ASME Section XI Appendix VIII Supplement 10
  - EPRI Report 3002007383, Technical Basis for ASME Code Case N-838: Flaw Tolerance Evaluation (MRP-362, Rev. 1)
  - EPRI Report 1025217, Cast Austenitic Stainless Steel Study Annual Report
  - EPRI Report 3002010314, Cast Austenitic Steel Round Robin Study
  - Statistical method to justify the demonstration flaw depth distribution allocation

Approach

- *Task 1*: Estimate Current Examiners Capability
  - Technical Inputs: EPRI Reports *Cast Austenitic Steel Round Robin Study* and *Inside Surface Examination Techniques for Cast Stainless Steel*
- *Task 2*: Test Design
  - Technical Inputs: NUREG/CR-4464 - “Power Curves”’; MRP-362 - Critical Flaw Size; Section XI – Appendix VIII – Supplements 2 and 10
- *Task 3*: Assess Performance of Current Examiners
  - Identify performance trends from the CASS Round Robin
- *Task 4*: Report
  - *Supplement 9 - Draft - Qualification Requirements for Cast Stainless Steel Piping Welds*
- Periodic progress updates were presented at ASME Code meetings, TG CASS

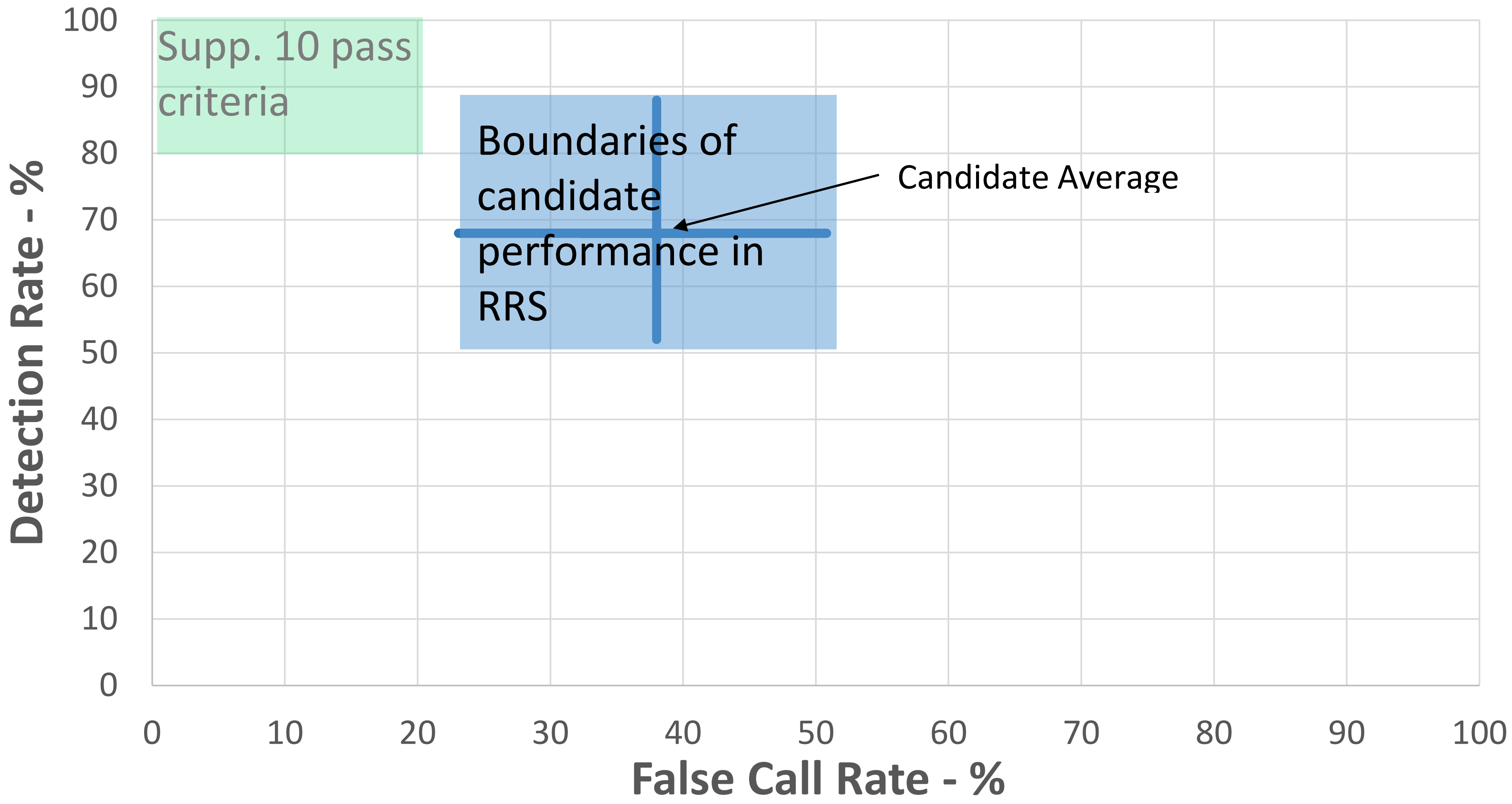
Proposed Qualification Requirements

- Draft Supplement 9 structure mirrors that of Supplement 10
- Adopted the detection test grading units methodology described in NUREG/CR-4464
- Flaw depth distribution incorporates the flaw tolerance evaluation results included in MRP-362
  - Only flaws with depths greater than 25% are to be used
  - All flaws with depths greater than 75% must be detected

Proposed Qualification Requirements (continued)

- Procedure demonstration **must detect all flaws**
- Length sizing RMS error not to exceed 1.00”
- Depth sizing normalized RMS error not to exceed 0.1 (10% of the wall thickness at the flaw location)
- Personnel demonstration:
  - Minimum of 80% of flaws are detected
  - Maximum of 20% of false calls are recorded
  - All flaws with depths > 75% are detected

Round Robin Detection and False Call Rate
Flaw Depths > 25% - Simulated Dual Access Results



- Some flaws were not detected by any of the participating candidates

Round Robin Length Sizing Results

CASS Inside Surface Evaluation Length Sizing Results

Team	UT Length Sizing RMS Error inch
A’	0.93
B’	0.57
C’	0.82
Average	0.77

CASS Round Robin Length Sizing Results

Candidate	UT Length Sizing RMS Error inch	
A	0.85	
B	0.74	
C	2.36	← Outlier
D	0.92	
E	0.79	
F	0.98	
G	0.71	
Average	1.07	
Acceptance Criterion	1.00**	

** Proposed criterion

Round Robin Depth Sizing Results

Candidate	UT Depth Sizing RMS Error inch	UT Depth Sizing Normalized RMS Error*
A	0.54	0.25
B	0.49	0.23
C	0.43	0.30
D	0.38	0.16
E	0.51	0.26
F	0.47	0.19
G	0.48	0.22
Average	0.47	0.23
Acceptance Criterion	0.125	0.10**

*RMS of (each error divided by the wall thickness at the flaw location)

** Proposed criterion

Summary

- Additional work needs to be done:
  - Address the current technology capability gaps
  - Assess alternative for determining flaw depths
    - Consider engineering analysis based on flaw length
  - Evaluate if the detection of axial flaws is important in maintaining structural integrity
    - Focus on the safety significant circumferential flaws

- NDE Program will continue with these evaluations and propose Supplement 9 demonstration requirements

Discussion

Together…Shaping the Future of Electricity

Research under the MOU:

Ultrasonic Modeling and Simulation

Kevin Hacker
Dominion Energy

Mark Dennis, Myles Dunlap
EPRI

NRC / Industry NDE Technical Information Exchange Meeting
Washington, DC
January 2018

Outline

- Introduction to Ultrasonic Beam Simulations
- Conducting Ultrasonic Beam Simulations
- Experimental versus Simulated Beam Width Measurements
  - 0° Longitudinal Waves
  - 45° Shear Waves

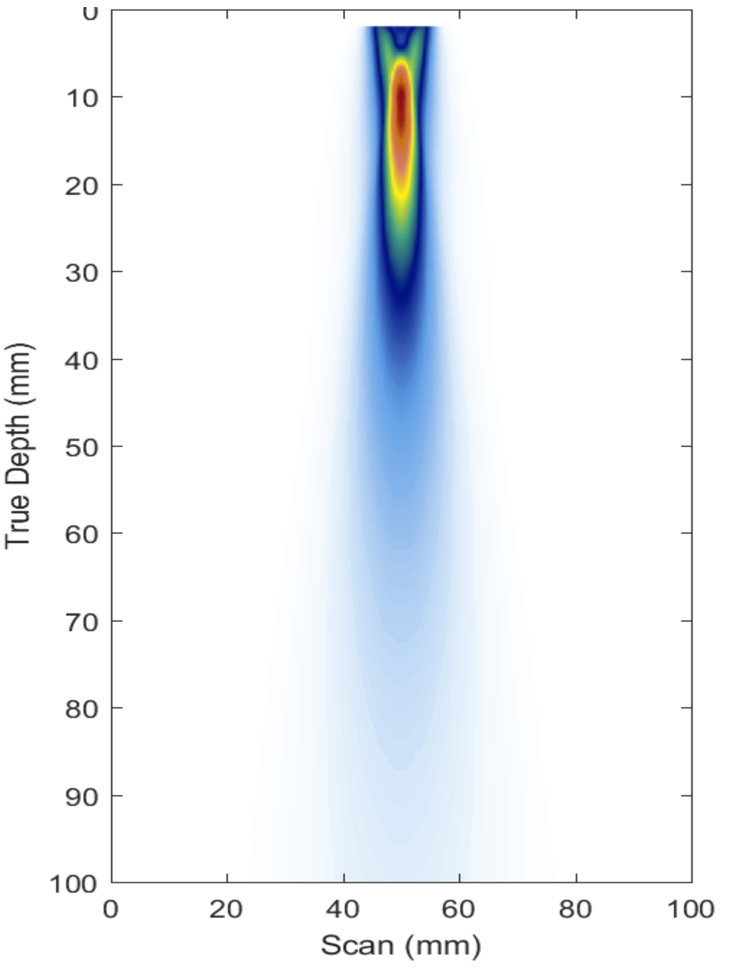
www.epri.com

Technical Update 3002010408, Evaluation of Ultrasonic Simulation Software: Summary of Recent Results – Quantitative Ultrasonic Beam Profiles of Conventional Single-Element Probes

Introduction to Ultrasonic Beam Simulations

Defining a Beam Simulation

- For this presentation, an ultrasonic beam simulation will be considered as a mathematical model used to image the maximum acoustic sound intensity for a given material and ultrasonic probe configuration.



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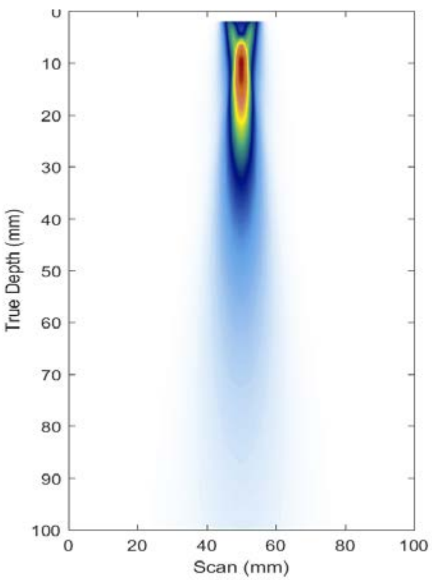
Defining a Beam Simulation

- The magnitude of the sound pressure varies throughout the radiated sound pressure field.
  - Pressure variation occurs in both depth, width, and time.
  - Significant pressure variation occurs near the transducer, in the near-field.
- The magnitude of the sound pressure, shown in each image, is relative because an image is normalized to its maximum value.
  - These maps alone do not infer the detectability of an indication. More work is need to make such an inference.
- Beam simulation models are dependent on numerous input variables such as
  - Probe width, frequency, bandwidth, number of elements, etc.
  - Material velocity, density, etc.



Beam Simulations in Practice

- In this study we will use beam simulations to predict the width of sound fields and then compare those results to experimental data.
  - The width of the sound field will be investigated based on parameters such as probe frequency, diameter, and ultrasonic wave mode.

- Software capable of performing ultrasonic simulations are: CIVA, PZFlex, UltraVision, Wave2000/3000, etc.
  - For this study UltraVision 3.8R16 (UV) and CIVA 2016 were selected for conducting simulations.

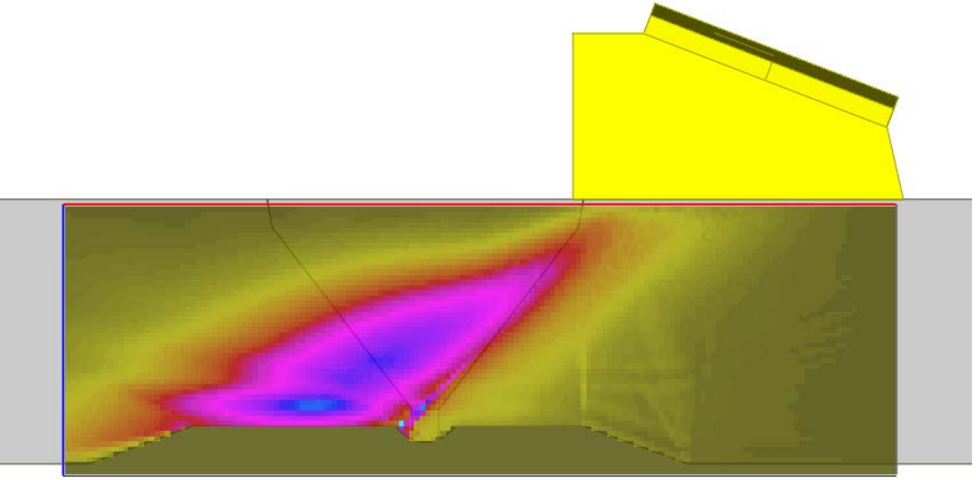
Beam Simulations in Practice

- As a long term goal it would be beneficial to make inferences of ultrasonic examinations using models and simulations.

  - Nuclear utilities have submitted ultrasonic simulations supporting their relief requests. Its important to be able to assess the reliability of such ultrasonic simulations.

Beam Simulations in Practice

- Ultrasonic beam simulations are often used in sensor design and coverage calculations.
- These beam simulations provide relative measures of ultrasonic energy and cannot directly determine flaw detectability.
- The development of an approach, supported by a technical basis, to transfer these ultrasonic beam simulations to flaw detectability would be beneficial.



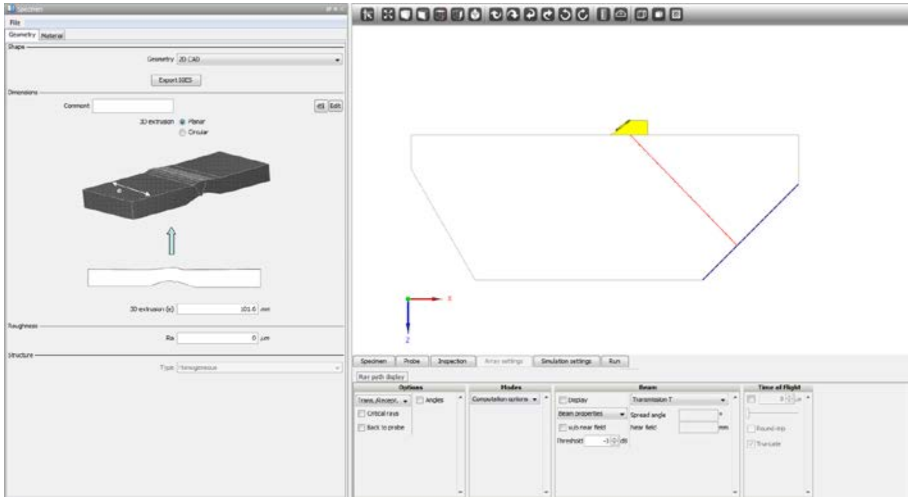
Conducting Ultrasonic Beam Simulations

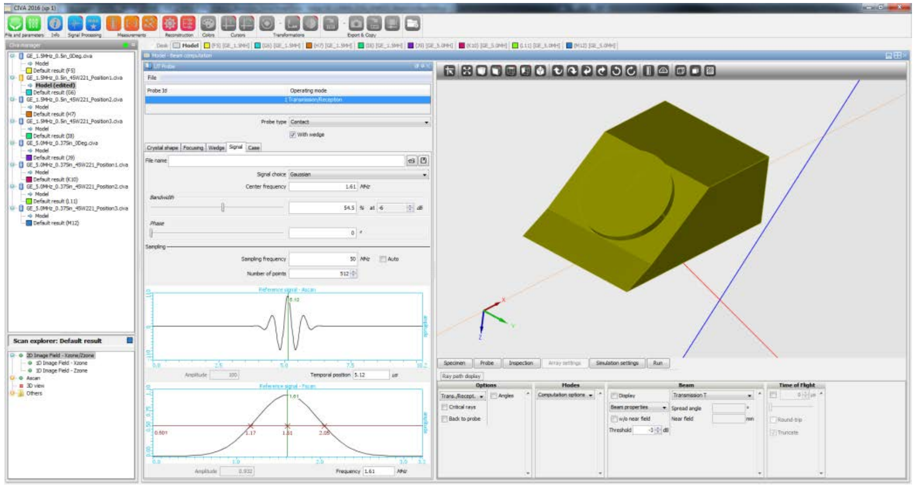
Simulation procedure: CIVA

CIVA 2016 http://www.extende.com

- A Beam Computation is launched from the UT Module

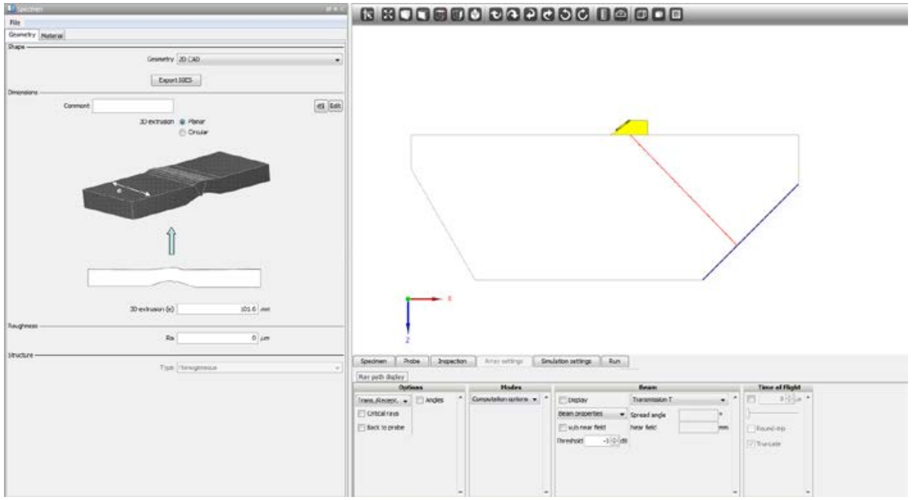
- Specimen geometry is built:
  - Default geometry is provided such as plate, cylinder, elbow, etc.
    - Plate was used for all test cases.
  - Custom 2D and 3D Computer-Aided Design (CAD) files can be imported
  - Material: Aluminum (density 2710kgm^{-3}; longitudinal speed 6350ms^{-1}; transverse speed 3100ms^{-1})

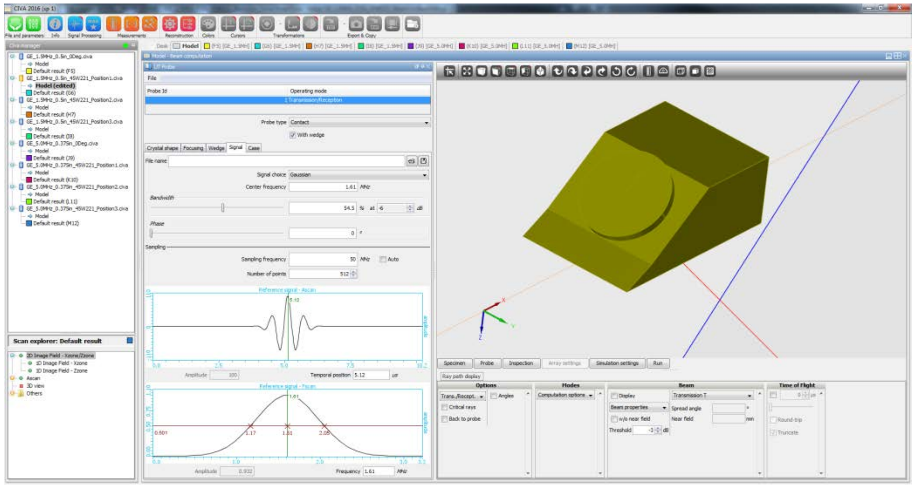




Simulation procedure: CIVA

- Probe and wedge information is populated:
  - CIVA can handle single elements and varying types of arrays (including custom)
  - Focusing is flat; no focusing is applied
  - CIVA contains flexible options to provide user with fine control over signal





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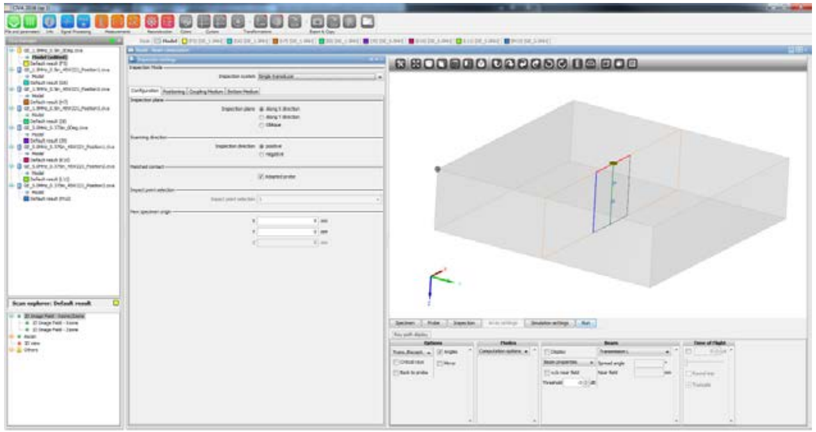
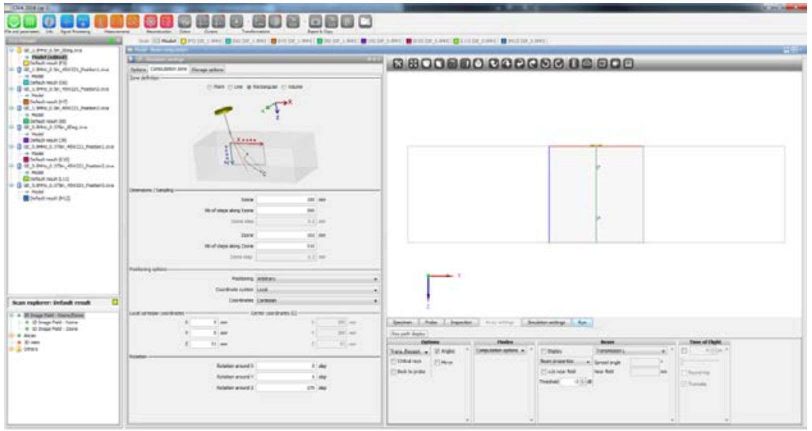
Simulation procedure: CIVA

- Observation regions are 2D or 3D:
  - Defines the location of the beam simulation and determines where the sound intensity images are taken.
  - For this study the observation region was taken along the center of the probe for all test cases.
- Simulation settings:
  - Define the size of the observation region and its grid resolution
  - For this study all CIVA simulations had a pixel size of 0.5mm×0.5mm (45°SW) or 0.1mm×0.1mm (0°LW)
- Simulations performed at a single probe position in direct mode only.





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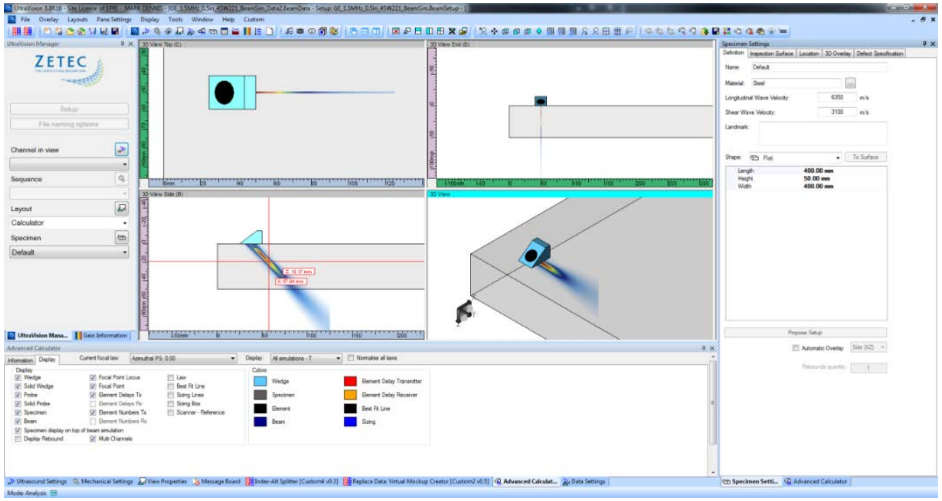
Simulation procedure: UltraVision

- Specimen settings are populated using Specimen Settings tool:
  - A flat block is modeled in UltraVision because it ignores geometrical boundaries in beam simulation
  - Dimensions 400mm × 400mm × 102mm
  - Material properties (density 2710kgm^{-3}; longitudinal speed 6350ms^{-1}; transverse speed 3100ms^{-1})
    - UV and CIVA models had identical material properties, but it required the use of UV's Material Manager.



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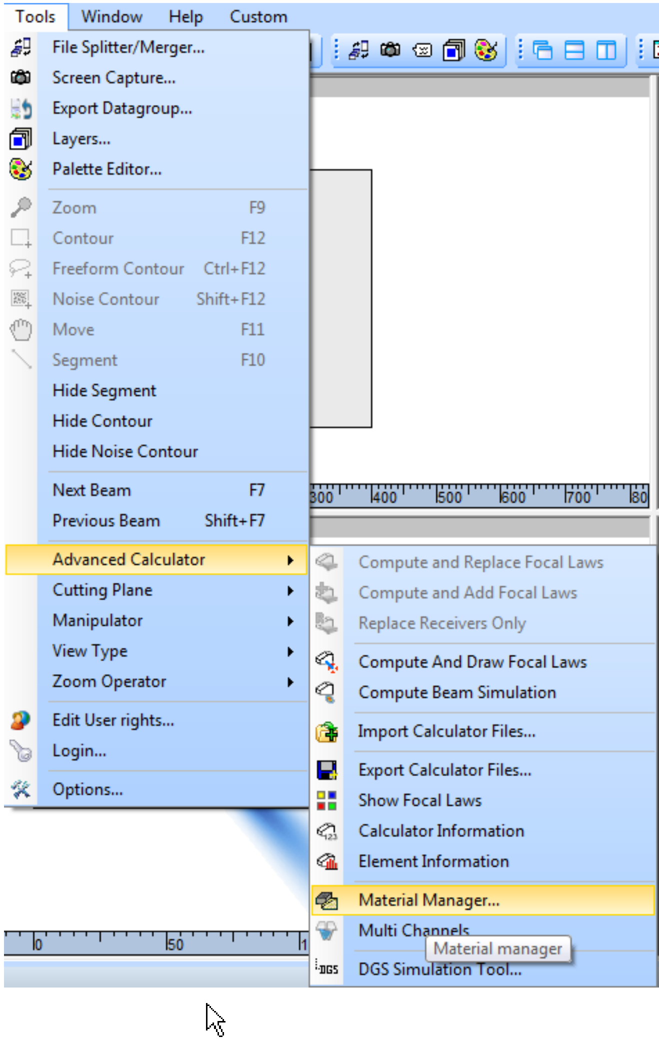
Simulation procedure: UltraVision

- Advanced material definition:
  - Typically only the longitudinal and transverse speeds can be entered for a material
  - Materials can be edited and audited in detail the "Materials Manager" selectable under the "Advanced Calculator" submenu
- If not existing, then a .xml "UTDatabase.db.xml" is created
- File contains comprehensive definitions and properties of user-defined materials
  - Useful also for controlling the definitions and properties of existing materials in the UltraVision database



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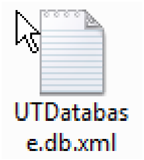
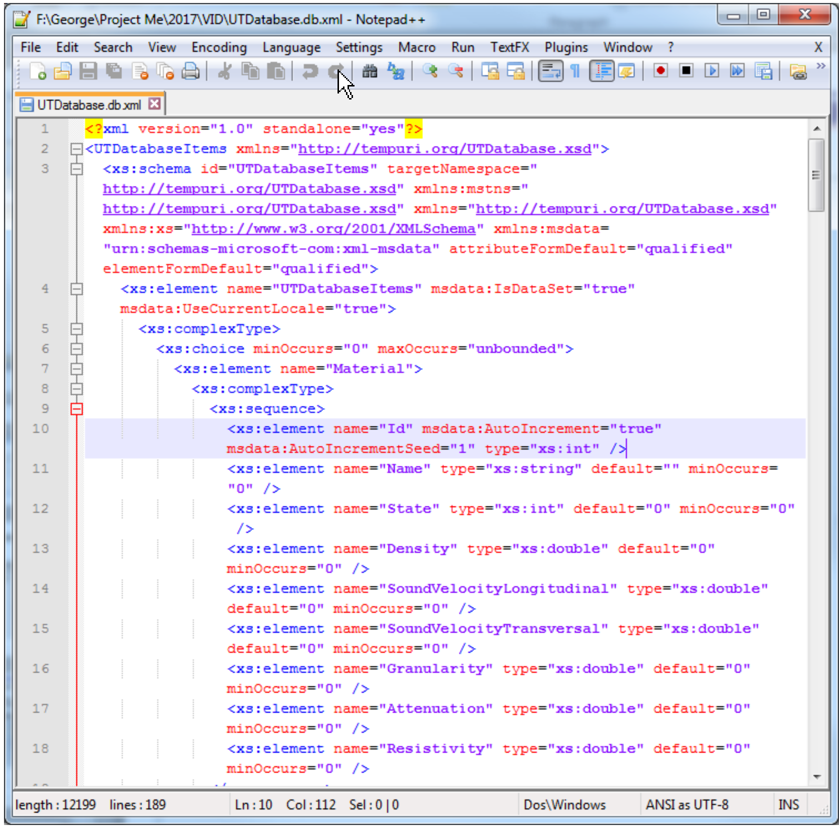
Simulation procedure: UltraVision

- The database is human-readable and fully editable



- Following material properties were controlled:
  – Name and state*
  – Density
  – Longitudinal and Transverse speeds*

  – *also controllable via the GUI



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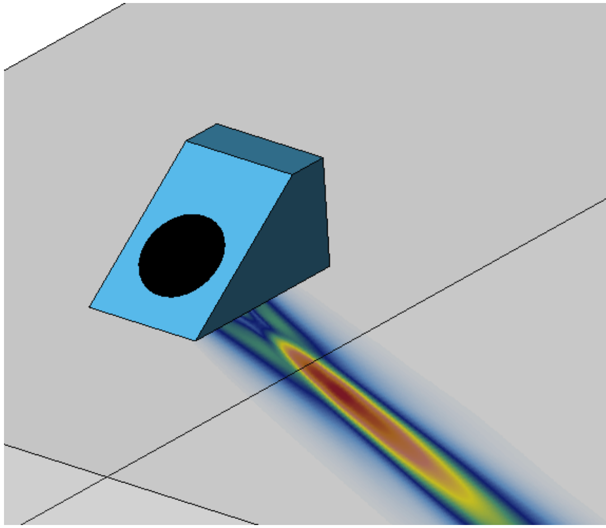
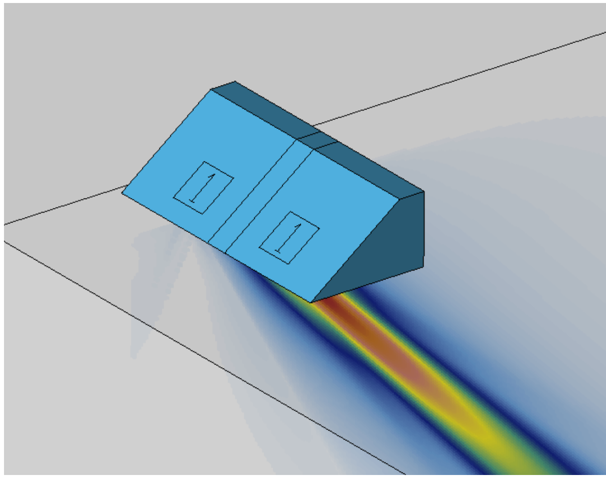
Simulation procedure: UltraVision

- Probe and wedge details are defined using Advanced Calculator tool:
  – Pitch-catch configuration with a 1-dimensional array was used to model conventional transducers.
    - UV does not support individual Transmission and Reception beam maps for circular conventional transducers. Therefore, pitch-catch with a rectangular element array was used to more accurately represent the experimental setup.
  – Longitudinal and shear waves are set for the 0° and 45° mapping blocks respectively
  – Probe element shape is rectangular





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Experimental versus Simulated Beam Width Measurements

Research Study Overview

Overview

- Goals:
  - To study the beam width of conventional 0° LW and 45° SW UT probes
  - Benchmark UV and CIVA against experimental beam width results.
- Experiment
  - Aluminum mapping blocks were used to study ultrasonic beam shapes.
  - Conventional UT data are collected and analyzed to yield the maximum ultrasonic energy striking the face of interest.
    - Ultrasonic beam widths were measured using phased array ultrasonic testing (PAUT) probes.
- Simulation
  - Simulated data are generated and analyzed to yield the maximum ultrasonic energy striking the face of interest.
- Comparison:
  - The -3dB and -6dB beam widths are quantitatively compared between experimental and simulated methods.

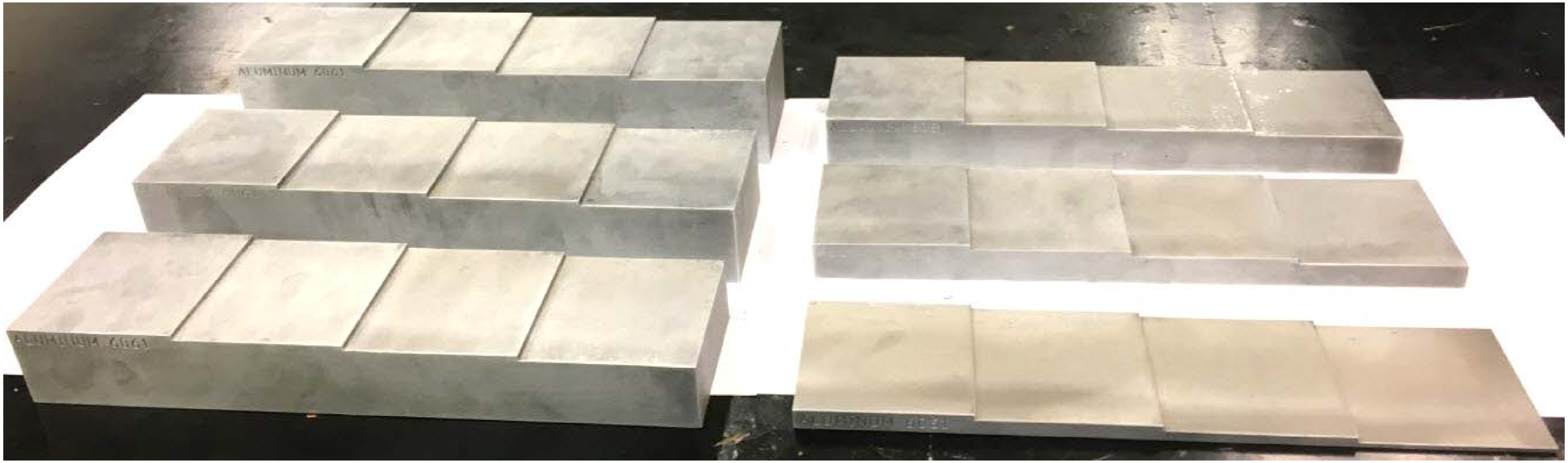
Experimental versus Simulated Beam Width Measurements

0° Longitudinal Waves

Mapping Block - 0° Insonified Face

- Flat blocks, of various thicknesses, were tested.
  - 23 thicknesses were tested: 5.08 mm (0.2 inch) to 60.96 mm (2.4 inch) at 2.54 mm (0.1 inch) intervals

- All test blocks were aluminum.



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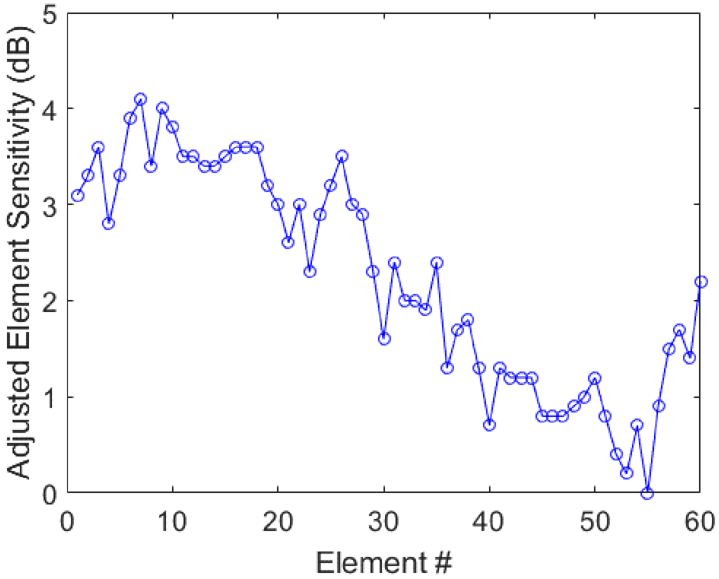
Apparatus

- Transmission probe (Tx):
  - GEIT Conventional Probes (2.25 and 5.0 MHz)
    - 2.25 MHz 12.7mm (0.5inch) dia.
    - 5.0 MHz 9.5mm (0.375inch) dia.
  - Circular shaped element
  - No wedges
- Receiving Probe (Rx):
  - Olympus PAUT probes (2.25 and 5.0MHz)
  - 60 elements with 1mm element pitch
  - Elements were balanced for sensitivity.
- Data were collected using the Zetec ZIRCON instrument and analyzed using Zetec UltraVision 3.8R16
  - Probes are triggered in pitch-catch mode

Transmission Probes (Tx)

Receiving Probe (Rx)



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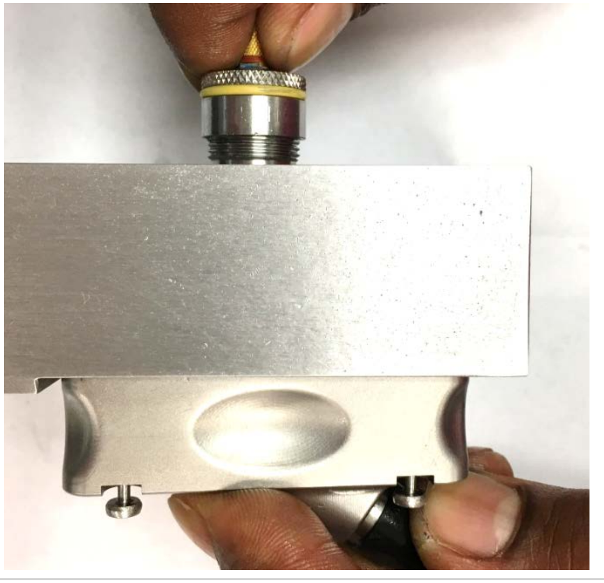
Experimental Procedure - 0° Insonified Face

- A conventional probe was placed on one surface for transmission (Tx)
- Opposite surface PAUT probe measured beam width (Rx)
- Beam width measurements were made using:
  - Tx = Conv. probes 2.25 MHz with Rx = PAUT 2.25 MHz
  - Tx = Conv. probes 5.0 MHz with Rx = PAUT 5.0 MHz
- Plates exchanged to measure beam width at different depths.

Tx = Conventional Probe

Plate Thickness Was Varied

Rx = PAUT Probe



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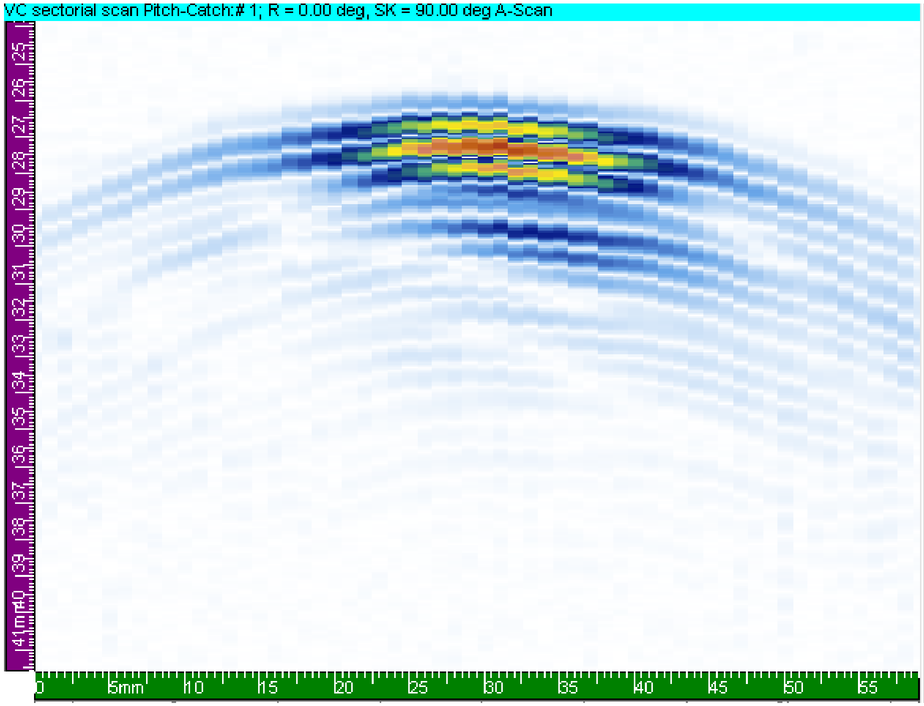
Experimental Data Analysis – 0° Insonified Face

- The experimental data had a nearly symmetric wave front (see below).
  - Qualitatively, the wave's energy was well distributed.
- The -3dB and -6dB points were taken from an interpolation of the raw uncorrected sector scan.
  - Each vertical column (60 total), in the image, is a measurement from an individual PAUT element (60 elements).
  - Find the maximum amplitude then measure -3dB and -6dB from its location.
    - 1mm resolution because 1mm elemental pitch.



UltraVision - Raw Sectorial View

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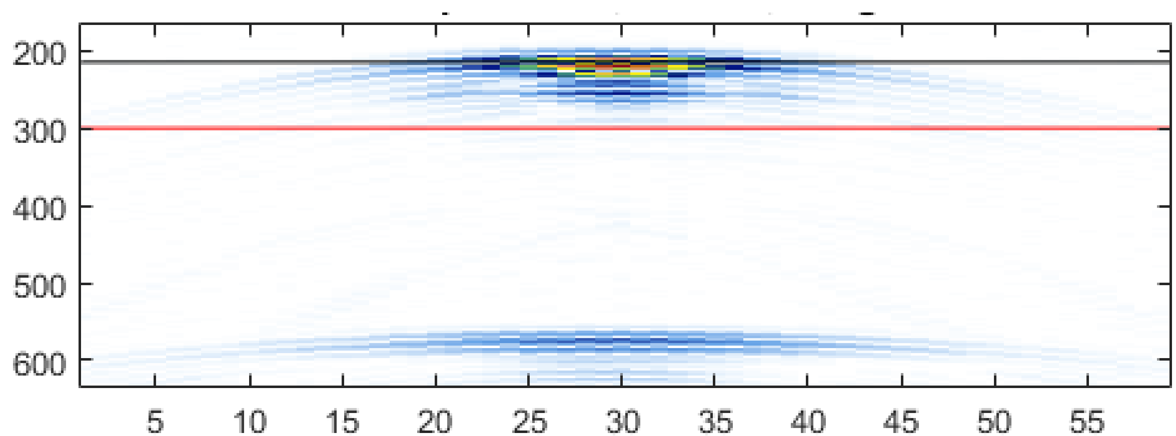
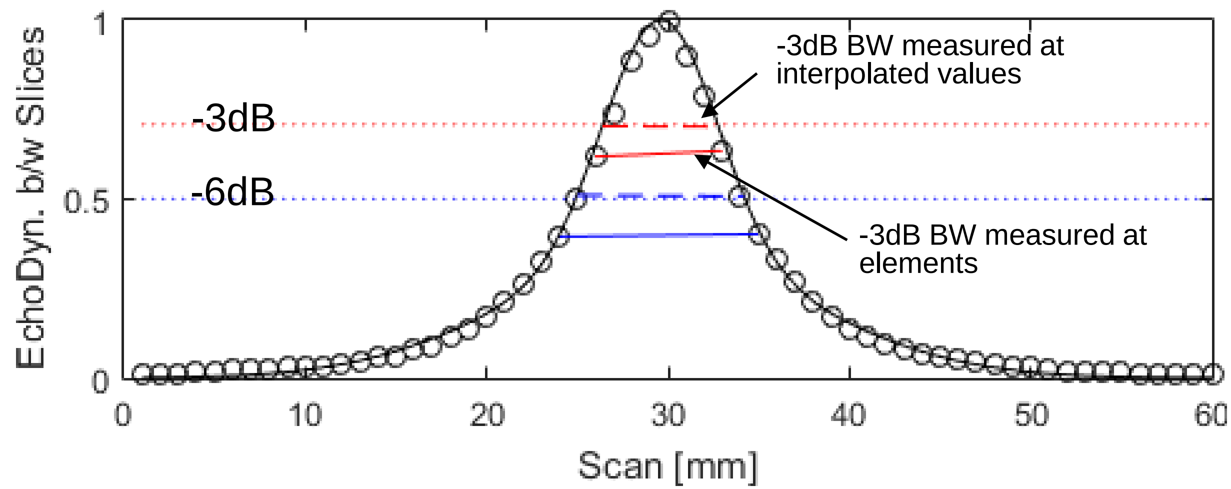
Experimental Data Analysis – Interpolation

- The echodynamic curve was interpolated (Gaussian) to improve the accuracy of measuring the -3dB and -6dB beam widths.

Raw Sectorial View

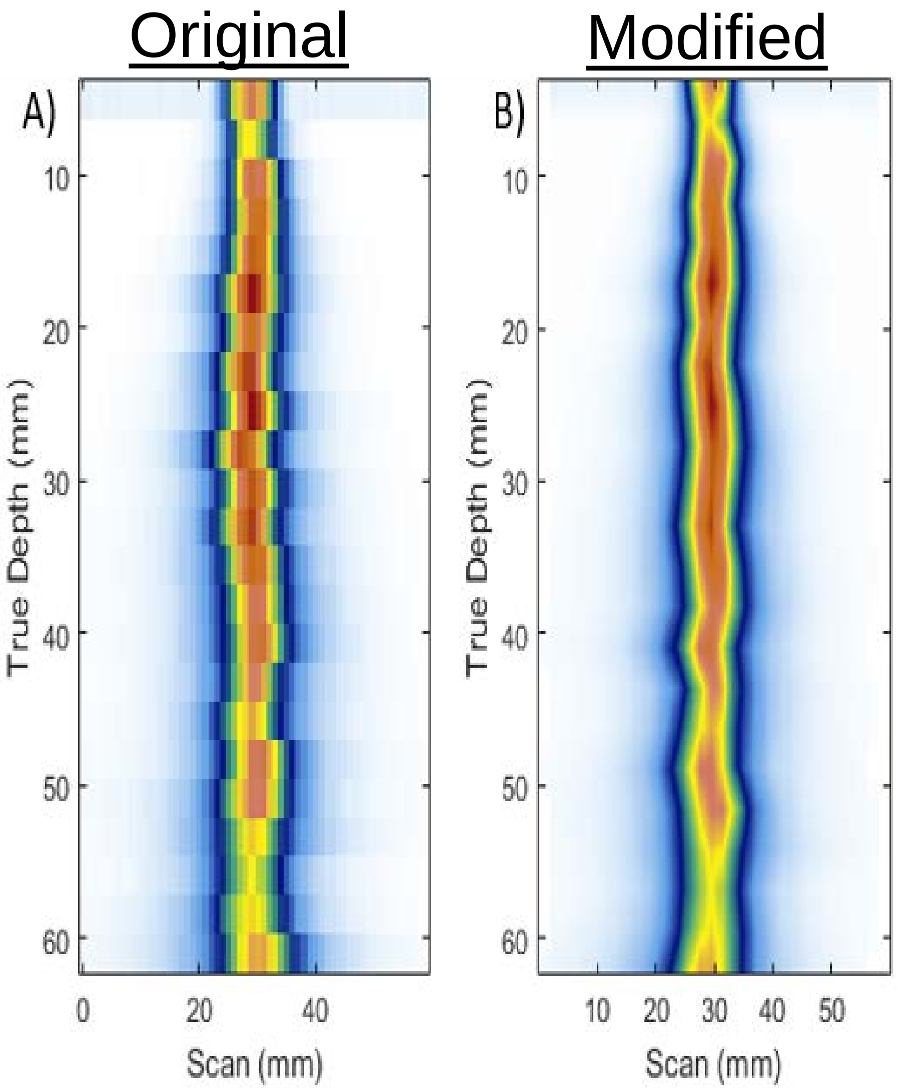


Normalized Echodynamic Curve



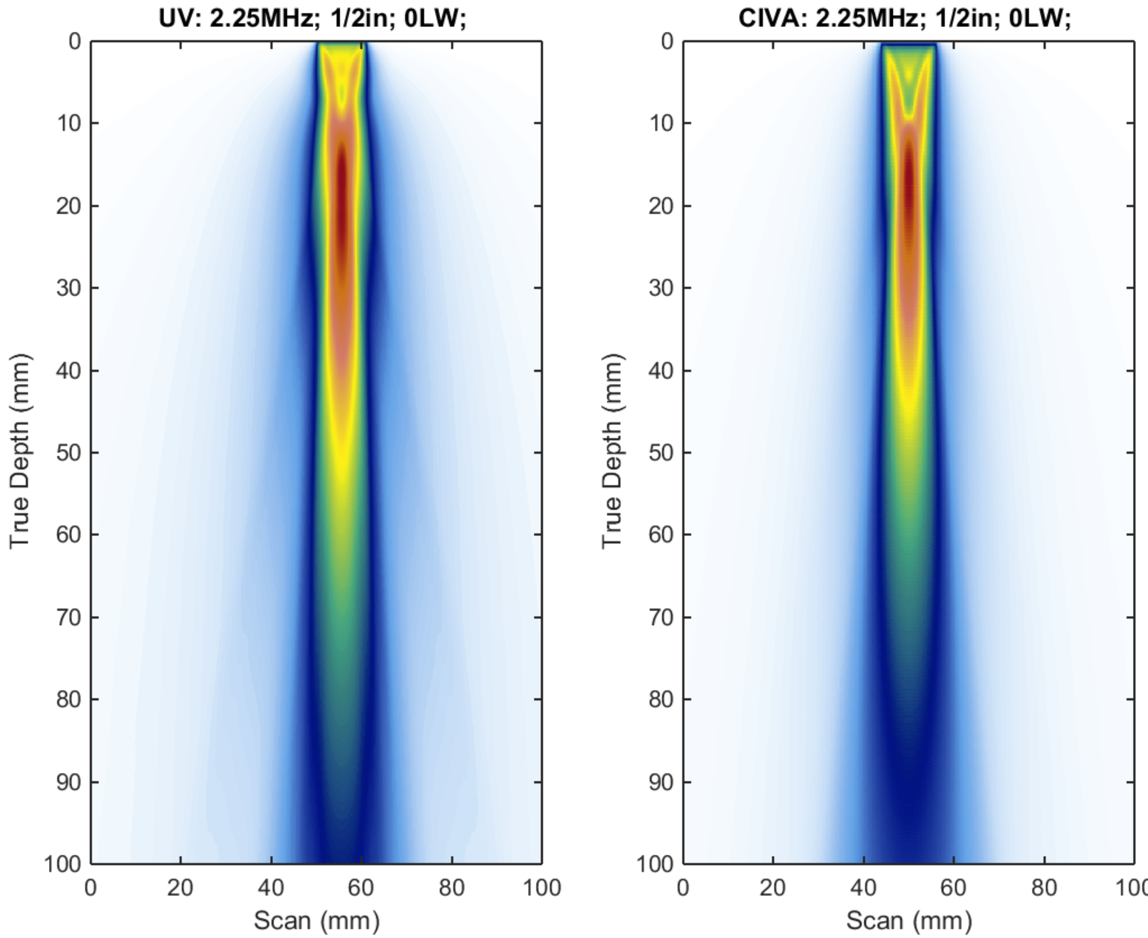
Experimental Beam Map Construction

- The echodynamic curves for each test specimen can be arranged to create an experimental beam intensity map.
  - Original image is the echodynamic curve from each raw uncorrected sector scan with no interpolation.
  - Modified image has the echodynamic peaks aligned and is smoothed.



Simulation Procedure - 0° Insonified Face

- Used CIVA 2016 and UltraVision 3.18R16.
  - Grid pixel size – 0.1mm x 0.1mm
- Specimen was drawn as a flat aluminum block
- Longitudinal Waves
- Observation plane was placed through the center of the transmission transducer.

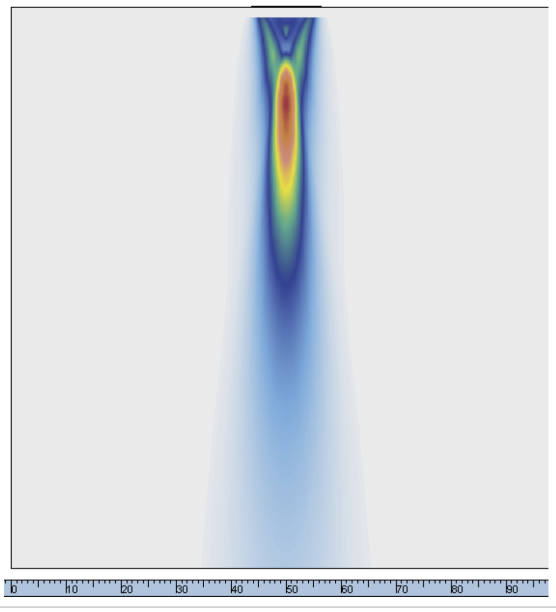


UltraVision – Element Shape

- UV does not support transmission and reception beam intensity maps for circular elements.
- Assumed rectangular elements with surface areas equivalent to the circular elements; conventional circular model will cause underestimation of the beams width and intensity distribution.

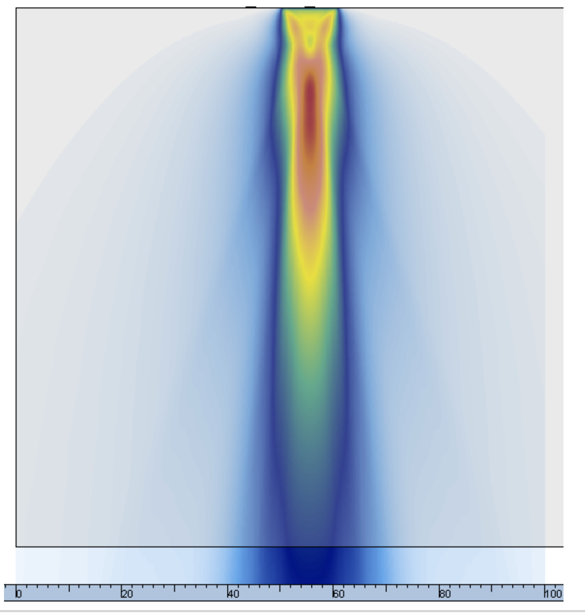
<u>Conventional - Circular</u>

Pulse-Echo



<u>1D Linear - Rectangular</u>

Pitch-Catch



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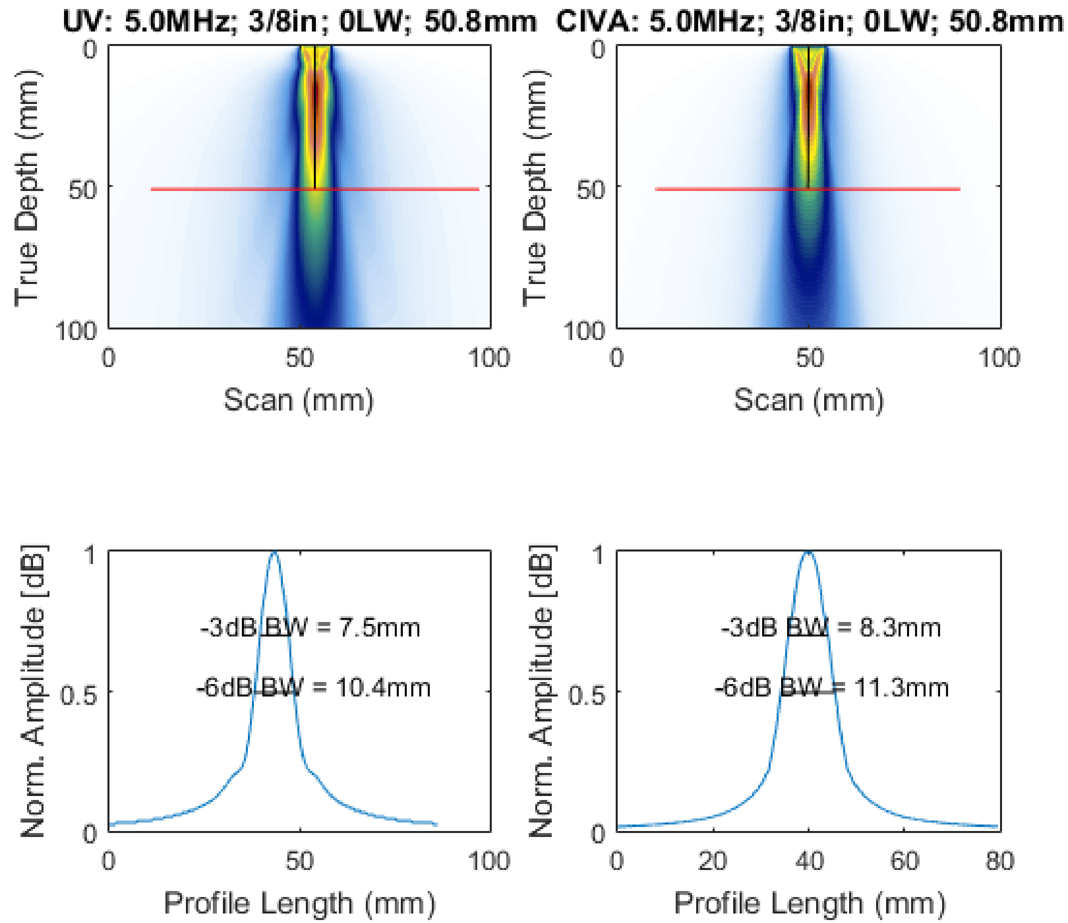
Simulation Data Analysis – 0° Insonified Face

- How the -3dB and -6dB beam widths were measured for each simulation package:
  - A MATLAB[1] program was written by EPRI staff to measure the beam width at specified thickness values, which match the experimental plate thickness.
  - Allowed for a consistent measurement technique between each UV and CIVA beam simulation images.

1: MATLAB is a computational software developed by MathWorks, Inc.

Simulation Data Analysis – 0° Insonified Face

- Red line is a slice through the image and it represents the insonified face of the test blocks.
- Beam intensity along the red line is shown in the lower images.
  - Normalized to its relative maximum.
  - Simulated beam widths are measured from these lines and compared to PAUT measurements.

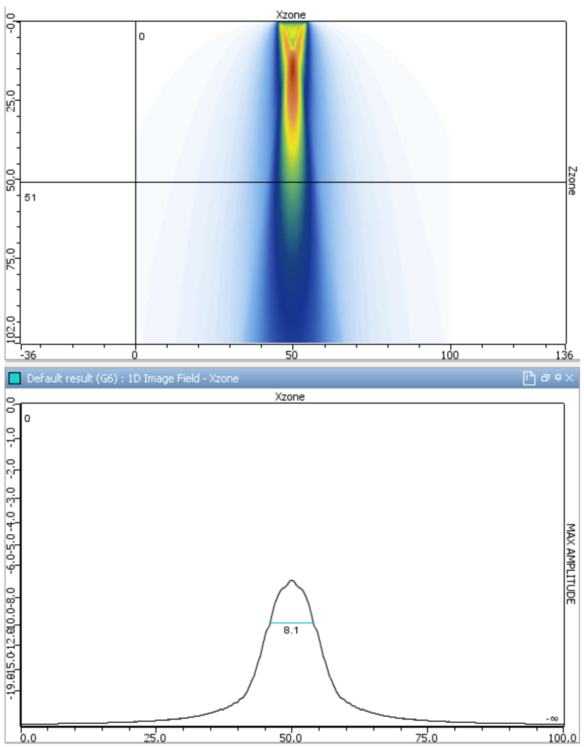


1: MATLAB is a computational software developed by MathWorks, Inc.

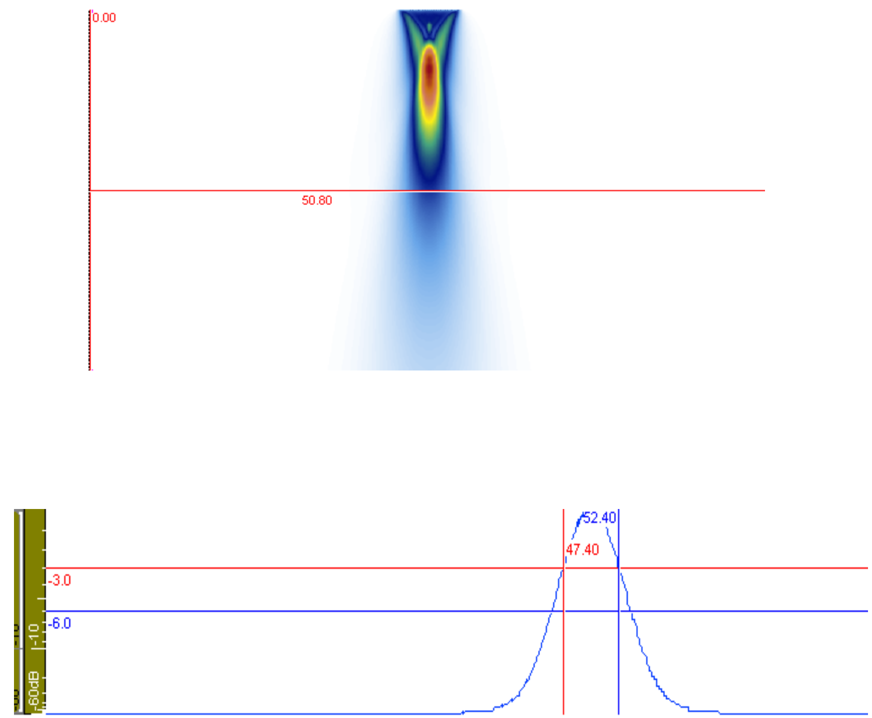
An Alternative Method for Simulation Data Analysis – 0° Insonified Face

- Each software has built-in image analysis tools for measuring amplitude variation.
  - Beam width measurements can be performed within each respective software.

CIVA



UltraVision



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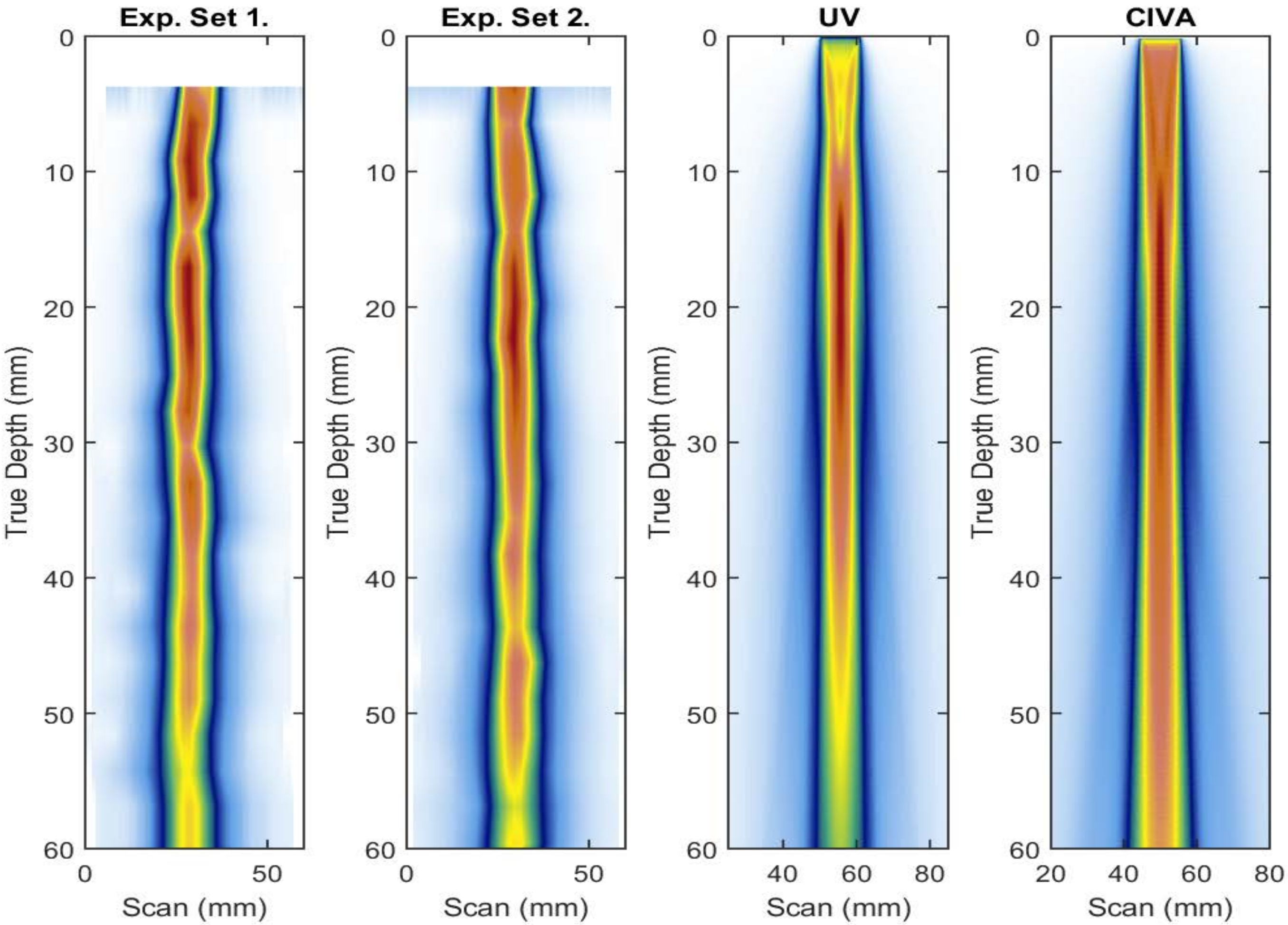
Test Cases - 0°LW

- Two 0° LW test cases:
  - Test Cases 1 and 2 are for 0°LW
  - No wedge
  - For each test case the beam width was measured at 23 thicknesses: 5.08 mm (0.2 inch) to 60.96 mm (2.4 inch) at 2.54 mm (0.1 inch) intervals

Test Cases	Transmit Probe (Tx)	Receive Probe (Rx)	Mapping Face Angle/Wedge Angle
1	GEIT 2.25MHz, 1/2"Ø	60el, 2.25MHz Olympus PAUT Probe	0°/No Wedge
2	GEIT 5.0MHz, 3/8"Ø	60el, 5.0MHz GEIT Olympus PAUT Probe	0°/No Wedge

Test Case 1 – Beam Simulation Results

- Tx: 2.25 MHZ; ½" Ø; 0° LW with Rx: 2.25 MHz PAUT
- Beam simulation images for UV and CIVA



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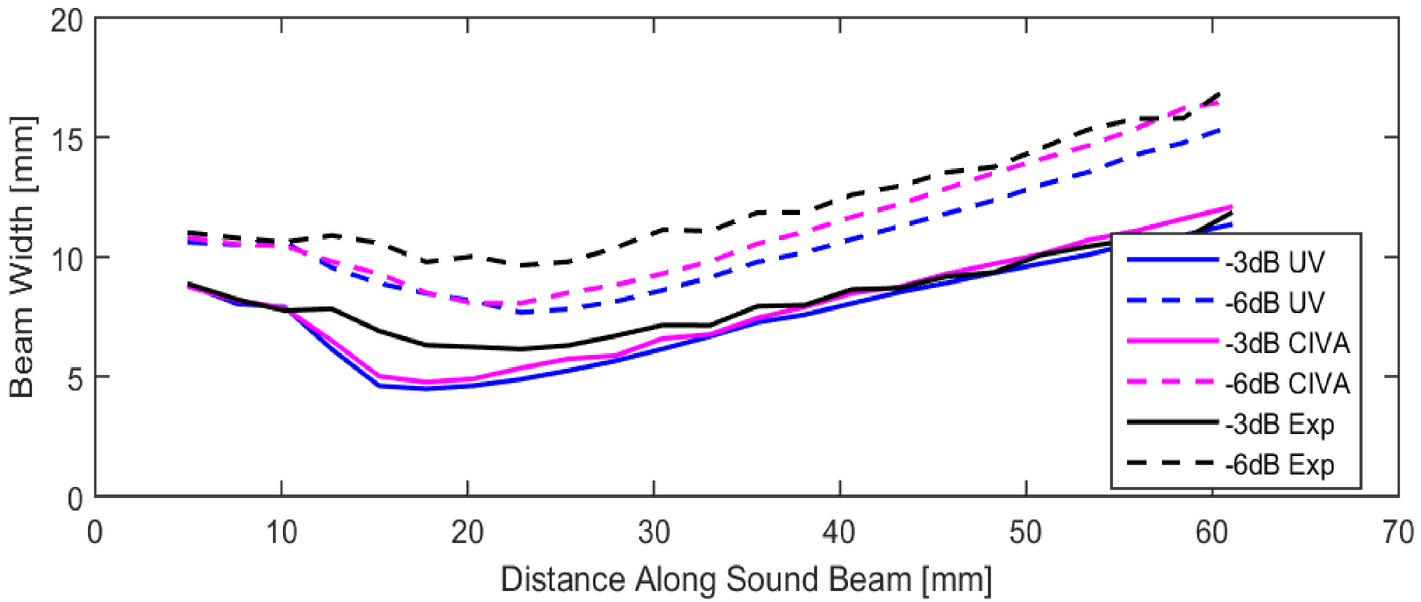
Test Case 1 – Beam Width Measurements

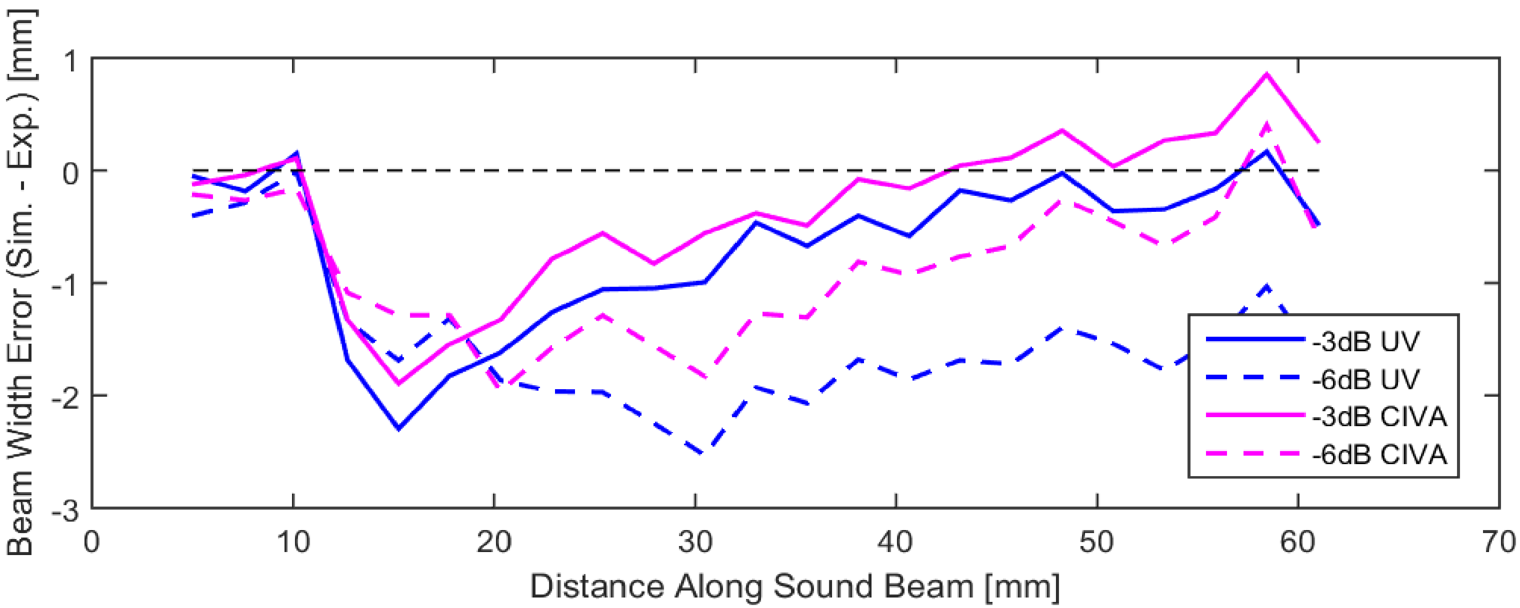
- Tx: 2.25MHZ; ½”Ø; 0°LW with Rx: 2.25MHz PAUT
- Beam width has a sharp decrease followed by an increase as the specimen thickness increases.



Metric	Exp.	UV	CIVA
Depth of max. amplitude [mm]	20.3	16.4	17.4

Test Case 1 – Beam Width Measurement Errors

- Tx: 2.25 MHZ; ½" Ø; 0° LW with Rx: 2.25 MHz PAUT
- Beam Widths Errors: Simulation – Experimental
  - 0 mm on the y-axis would be a perfect agreement



Depth	UV – Experiment		CIVA – Experiment	
	-3dB [mm]	-6dB [mm]	-3dB [mm]	-6dB [mm]
Average	-0.7	-1.5	-0.3	-0.9
Std. Dev.	0.7	0.6	0.7	0.6

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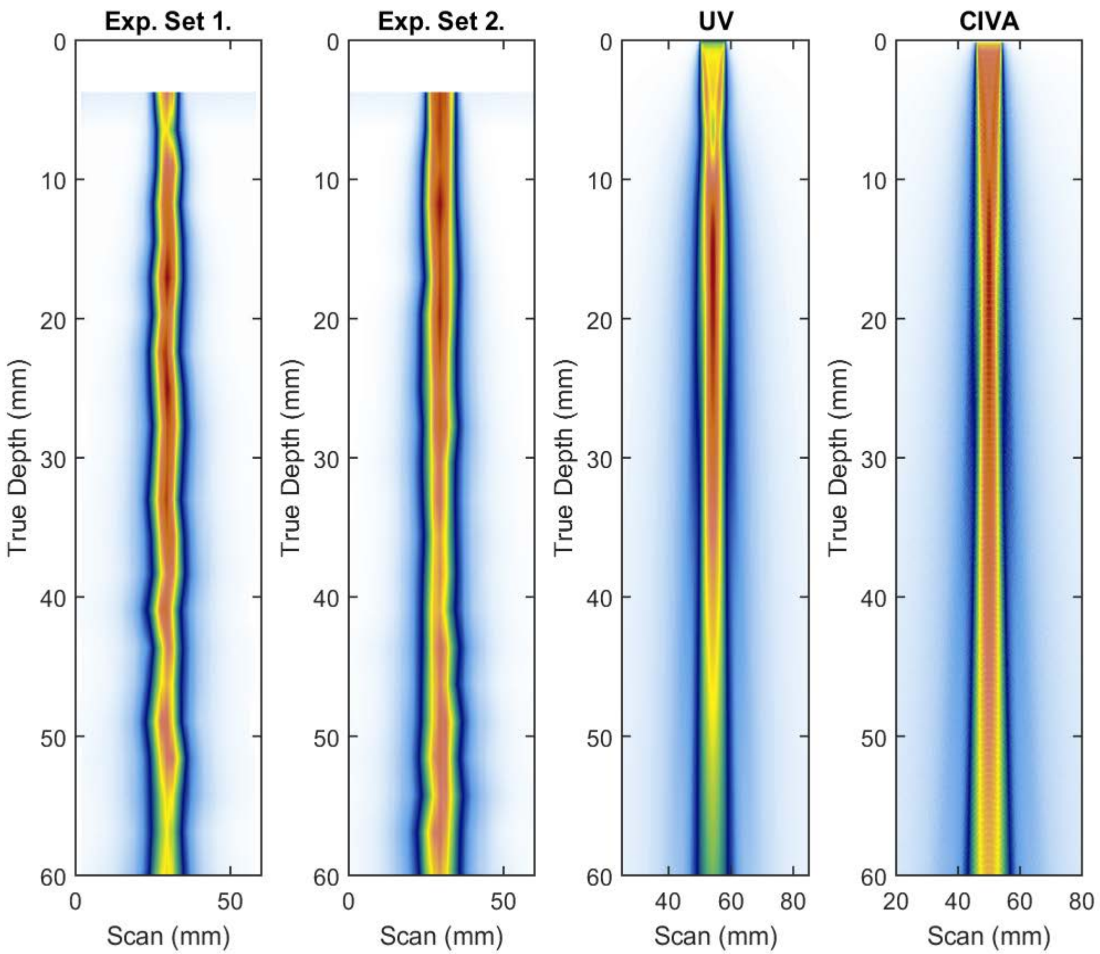
Test Case 2 – Beam Simulation Results

- Tx: 5.0 MHZ; 3/8” Ø; 0° LW with Rx: 5.0 MHz PAUT
- Beam simulation images for UV and CIVA



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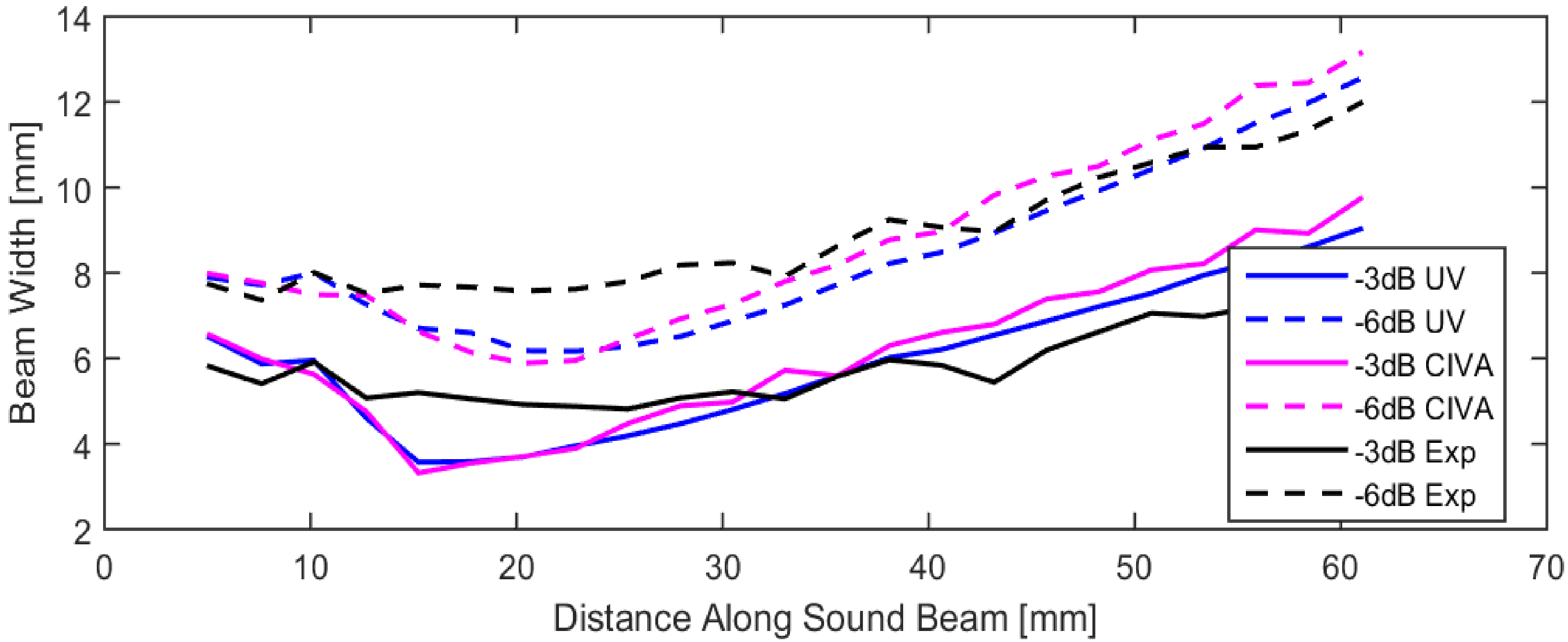
Test Case 2 – Beam Width Measurements

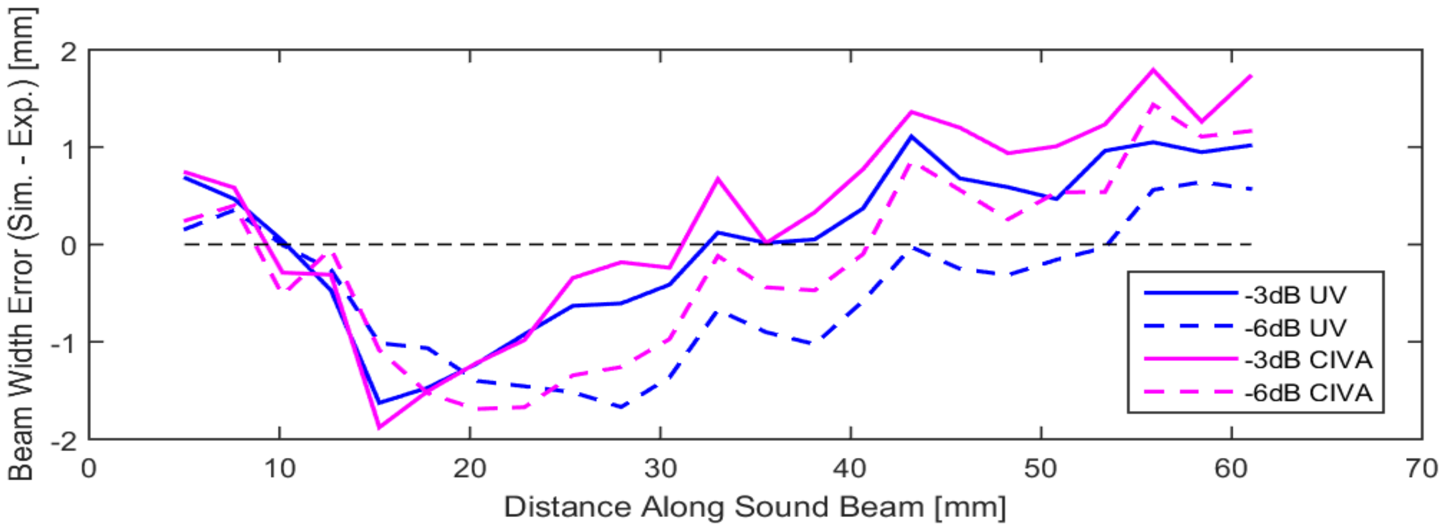
- Tx: 5.0 MHZ; ½" Ø; 0° LW with Rx: 5.0 MHz PAUT
- Beam widths are similar for the simulation packages.



Metric	Exp.	UV	CIVA
Depth of max. amplitude [mm]	15.2	16.0	16.1

Test Case 2 – Beam Width Measurement Errors

- Tx: 5.0 MHZ; ½” Ø; 0° LW with Rx: 5.0 MHz PAUT
- Beam Widths Errors: Simulation – Experimental
  - 0mm on the y-axis would be a perfect agreement



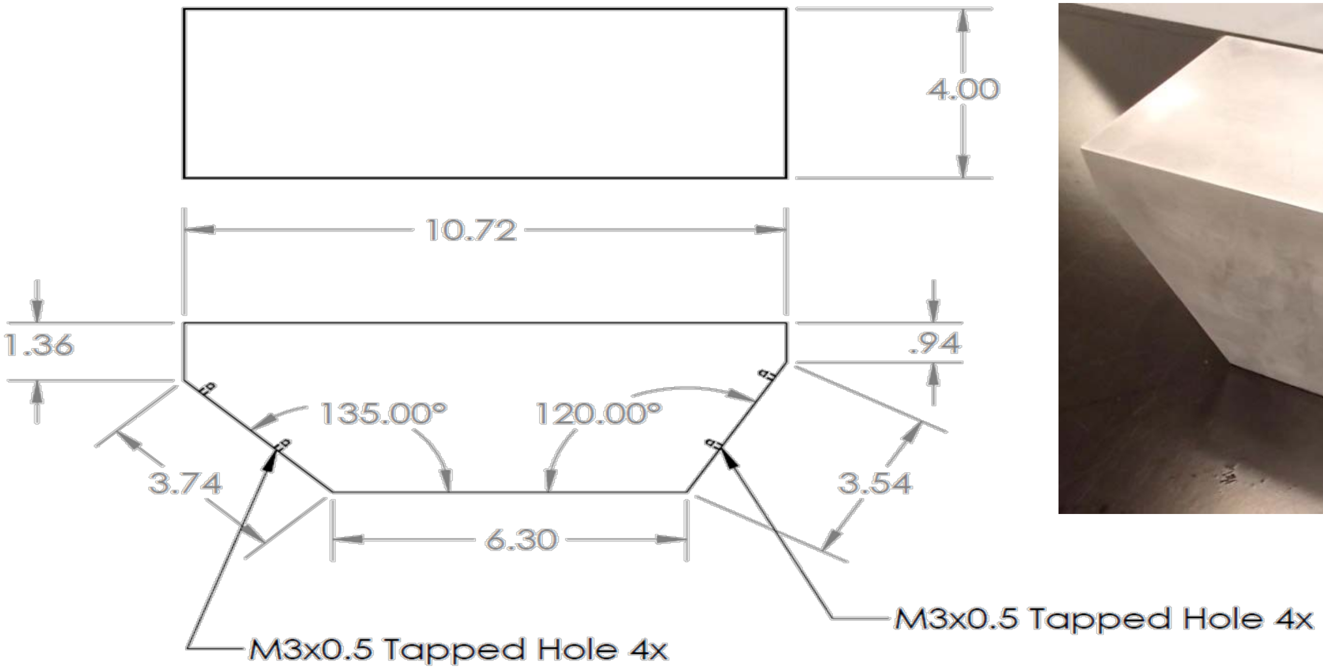
Depth	UV – Experiment		CIVA – Experiment	
	-3dB [mm]	-6dB [mm]	-3dB [mm]	-6dB [mm]
Average	0.1	-0.5	0.3	-0.2
Std. Dev.	0.8	0.7	1.0	0.9

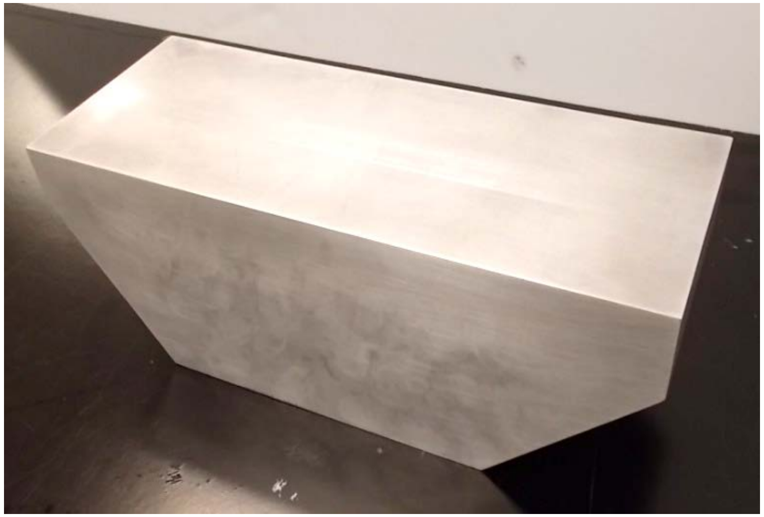
Experimental versus Simulated Beam Width Measurements

45° Shear Waves

Mapping Block - 45° Insonified Face

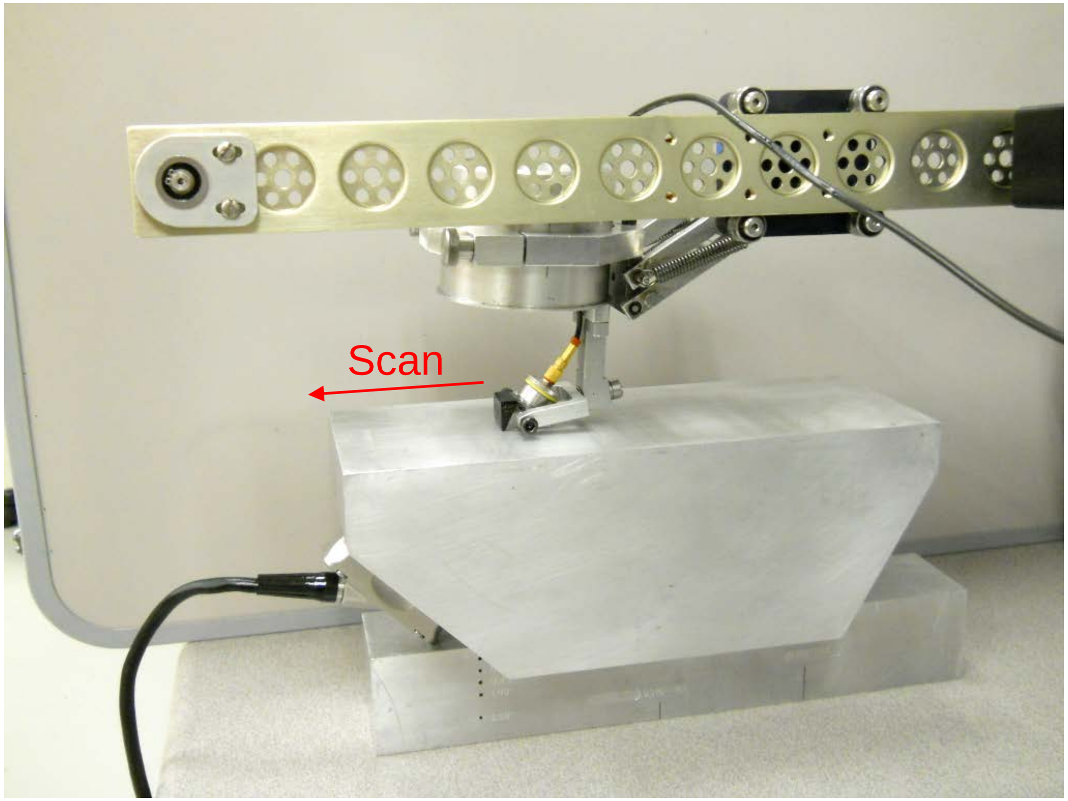
- Mapping Block constructed of aluminum
  - Dimensions shown in inches
- A conventional probe scanned the top surface
- A PAUT probe was mounted on the 45° face
  - A PAUT probe could be mounted on either face





Procedure – Encoded with PAUT Probe Receiving

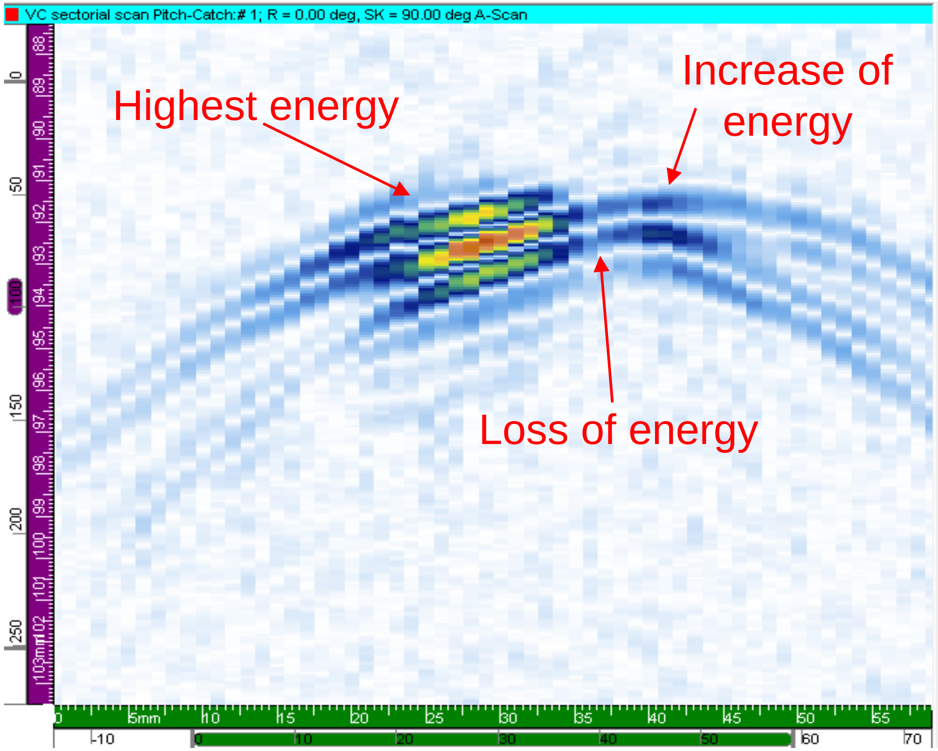
- 45° Insonified Face
- The conventional transducer scanned the top surface, and its movement was encoded, while the stationary PAUT received the ultrasonic energy on the insonified face
  – Scanned for maximum, -3dB, and -6dB amplitudes



- Data were collected and analyzed using Zetec UltraVision 3.8R16
  – Pitch-Catch setup
  – PAUT transducer: 2.25 and 5.0MHz; 60 elements; 1mm element pitch

Experimental Data Analysis – 45° Insonified Face - PAUT

- Experimental data had an asymmetric wave front (see below).
  - Wave front energy had a loss and then increase of energy.
  - Hypothesis – front of the wedge' damping material is reducing/cutting-off portions of the wave's energy.
- The -3dB and -6dB points were taken from the raw uncorrected sector scan at the center of the PAUT probe (element #30).
  - Each vertical column (60 total), in the image, is a measurement from an individual PAUT element (60 elements).
  - Find the maximum amplitude then measure -3dB and -6dB from its location.
    - 1mm resolution because 1mm elemental pitch.



UltraVision - Raw Sectorial View

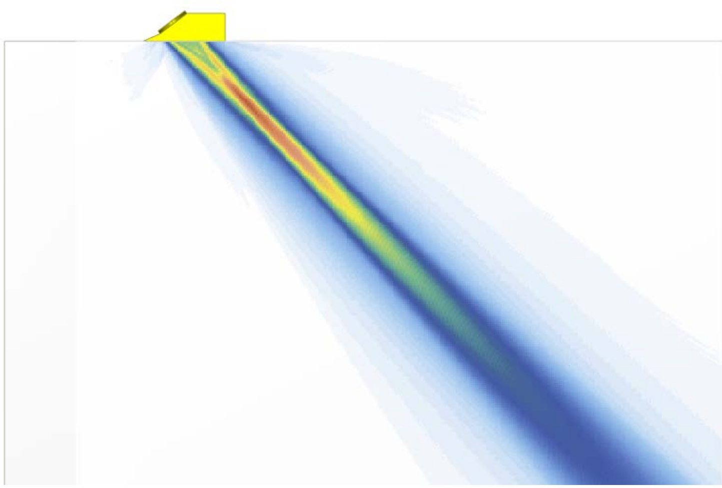
Simulation - 45° Insonified Face

- Simulations were performed at a single probe position using CIVA 2016 and UltraVision 3.8R16.
- Rectangular Pitch-Catch 1D array was used in UV.
- Specimen was modeled as a flat aluminum block in both UV and CIVA.
  - A flat block was modeled in UltraVision because it ignores geometrical boundaries.
  - A flat block was also modeled in CIVA to create an observation plane similar to UltraVision.
- Shear Waves

CIVA

Observation plane – Probe Center

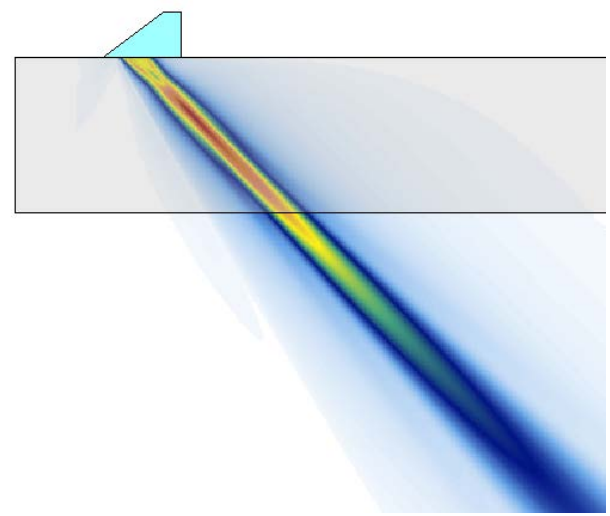
0.5mm x 0.5mm



UltraVision

Observation plane - Tx Element Center

0.5mm x 0.5mm



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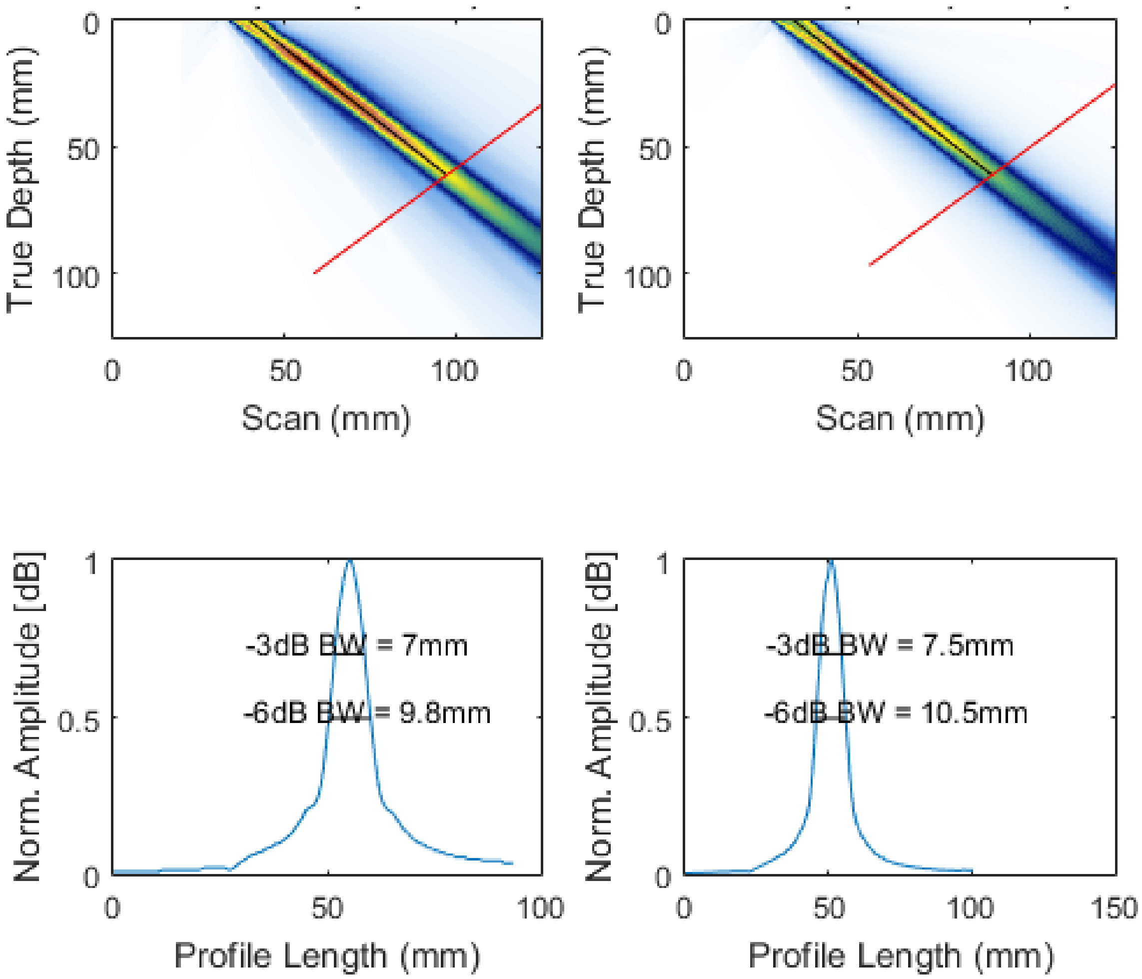
Simulation Data Analysis – 45° Insonified Face

- How the -3dB and -6dB beam widths were measured for each simulation package:
  - The same MATLAB[1] program as described earlier was used to measure the sound beam width for the 45° insonified face simulations.
  - Allowed for a consistent measurement technique between each UV and CIVA beam simulation images.

1: MATLAB is a computational software developed by MathWorks, Inc.

Simulation Data Analysis – 45° Insonified Face

- Red line is a slice through the image and it represents the 45° insonified face of the Mapping Block.
- Beam intensity, along the red line, is shown in lower images.
  – Normalized to its relative maximum
  – Beam widths are measured from these lines and compared to PAUT measurements.



1: MATLAB is a computational software developed by MathWorks, Inc.

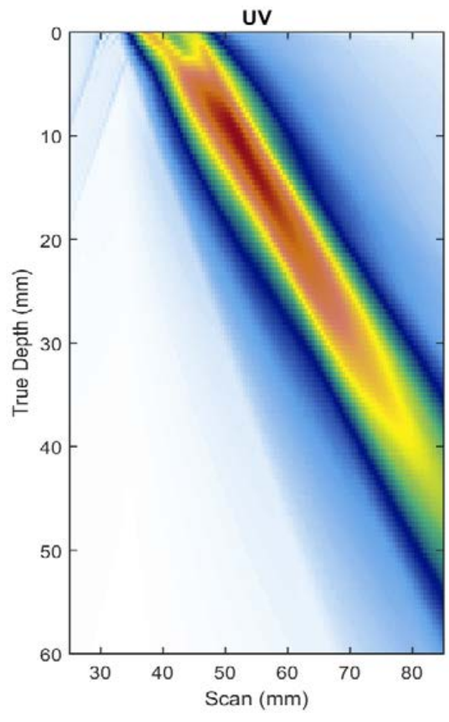
Test Cases

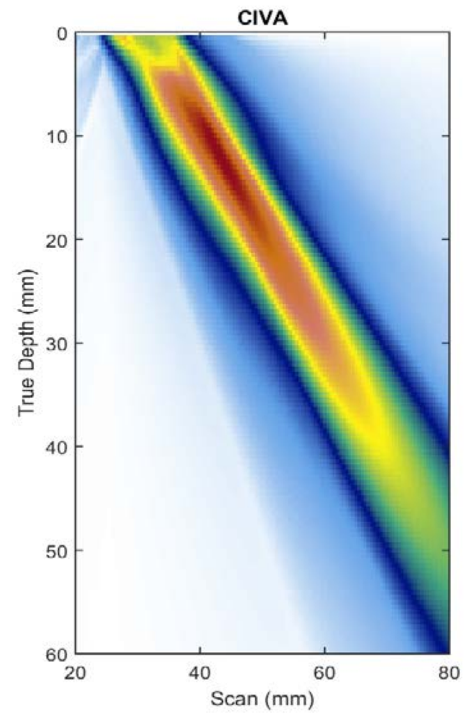
- Three test cases:
  - Test Cases 3-5 insonified the 45° face of the Mapping Block using 45° KBA wedges
    - Measured the beam width once it was maximized at the PAUT probe's center (element #30). This was equivalent to a sound half-path distance of approximately 84mm.
    - No experimental beam profile was recreated for the 45° SW cases.

Test Cases	Transmit Probe (Tx)	Receive Probe (Rx)	Mapping Face Angle/Wedge Angle
3	GEIT 1.5MHz, 1/2"Ø	60el, 2.25MHz Olympus PAUT Probe	45°/45° Wedge
4	GEIT 2.25MHz, 1/2"Ø	60el, 2.25MHz Olympus PAUT Probe	45°/45° Wedge
5	GEIT 5.0MHz, 3/8"Ø	60el, 5.0MHz Olympus PAUT Probe	45°/45° Wedge

Test Case 3 – Beam Simulation Results

- Tx: 1.5 MHz; ½" Ø; 45° SW with wedge & Rx: 2.25 MHz PAUT probe
- Simulation images for UV and CIVA





Half-Path Distance	Beam Width [mm]						Beam Width Error[mm]			
	Exp.		UV		CIVA		UV – Exp.		CIVA – Exp.	
	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB
84 mm	9.0	13.0	14.1	19.7	14.7	20.1	5.1	6.7	5.7	7.1

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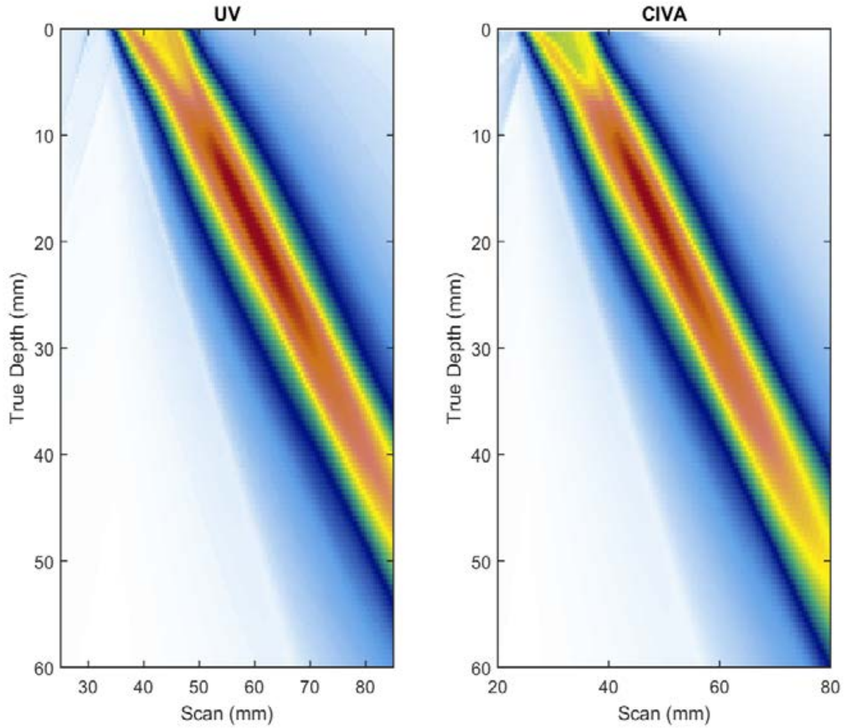
Test Case 4 – Beam Simulation Results

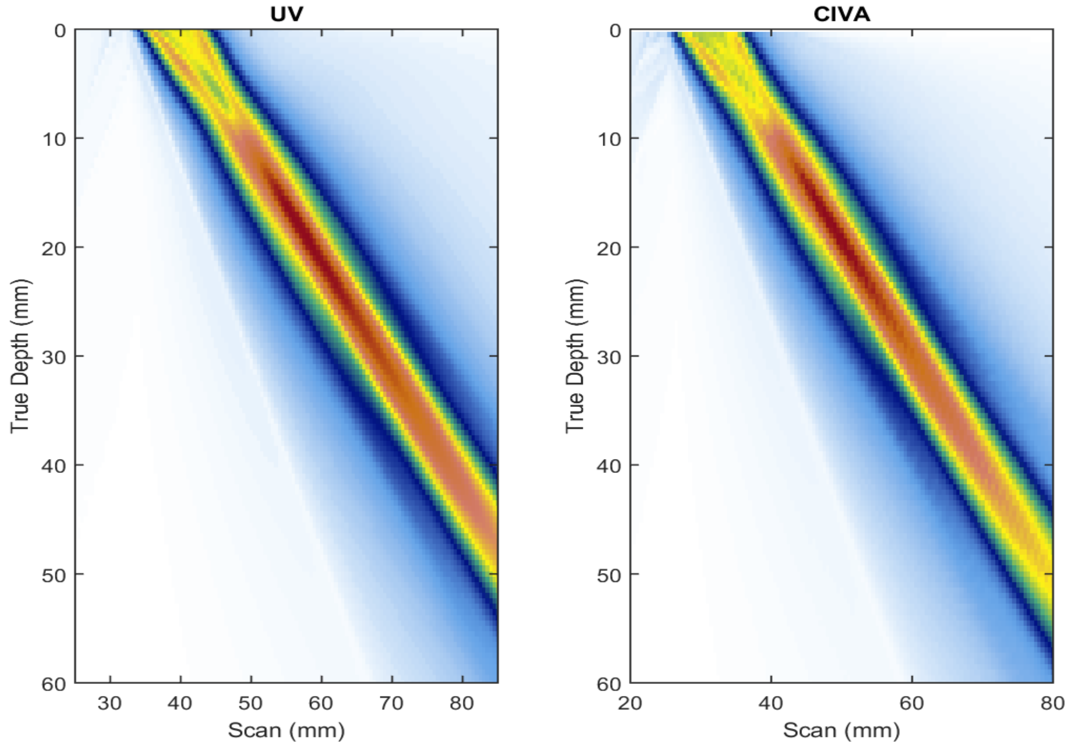
- Tx: 2.25MHZ; ½"Ø; 45°SW with wedge & Rx: 2.25MHz PAUT probe
- Simulation images for UV and CIVA



Half-Path Distance	Beam Width [mm]						Beam Width Error [mm]			
	Exp.		UV		CIVA		UV – Exp.		CIVA – Exp.	
	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB
84 mm	8.0	10.0	9.7	13.9	11.1	15.3	1.7	3.9	3.1	5.3

Test Case 5 – Beam Simulation Results

- Tx: 5.0MHZ; 3/8”Ø; 45°SW with wedge & Rx: 5.0MHz PAUT probe
- Simulation images for UV and CIVA



Half-Path Distance	Beam Width [mm]						Beam Width Error [mm]			
	Exp.		UV		CIVA		UV – Exp.		CIVA – Exp.	
	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB	-3dB	-6dB
84 mm	6.0	10.0	7.3	10.1	7.5	10.4	1.3	0.1	1.5	0.4

Results for All Test Cases

- For the 0°LW the following beam width observations were made:
  - UV and CIVA undersized experimental beam widths by -0.7mm and -0.3mm, respectively.
  - Average beam width errors differed by 0.4mm between CIVA and UV.

- For the 45°SW the following beam width observations were made:
  - UV and CIVA oversized experimental beam widths by 3.1mm and 3.9mm, respectively.
  - Average beam width errors differed by 0.8mm between CIVA and UV.

Category	Metric	UV – Exp.	CIVA – Exp.
		-3dB and -6dB	-3dB and -6dB
0° LW (Test Cases 1-2)	Mean	-0.7	-0.3
	RMSE	1.1	1.0
45° SW (Test Cases 3-5)	Mean	3.1	3.9
	RMSE	3.9	4.5
Note: -3dB and -6dB results are averaged in this table. Units are in mm.			

Conclusions

- For 0°LW measurements both UV and CIVA typically undersized the beam width in comparison to the experimental data.
  - On average each software undersized by less than 1mm.

- For 45°SW measurements both UV and CIVA oversized the beam width in comparison to the experimental data point.
  - UV and CIVA oversized experimental beam widths by 3.1mm and 3.9mm, respectively.
  - More experimental data points would be beneficial for angle beam measurements.

Conclusions

- Both programs performed similarly in producing beam maps, even though rectangular elements were simulated in UV.
- Opportunities for improving the experimental data:
  - For angle beam measurements, the Rx PAUT probe could be used to form an image of the experimental beam.
  - Beneficial to test other materials, probes, and wedges.
  - EPRI is seeking input from software developers regarding other methods for measuring the beam profile.
- The ability to make a determination about flaw detectability from beam profiles would be the ultimate next goal.

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