Regulatory Perspectives on Ultrasonic Modeling

EPRI Technology Week

June 21, 2016

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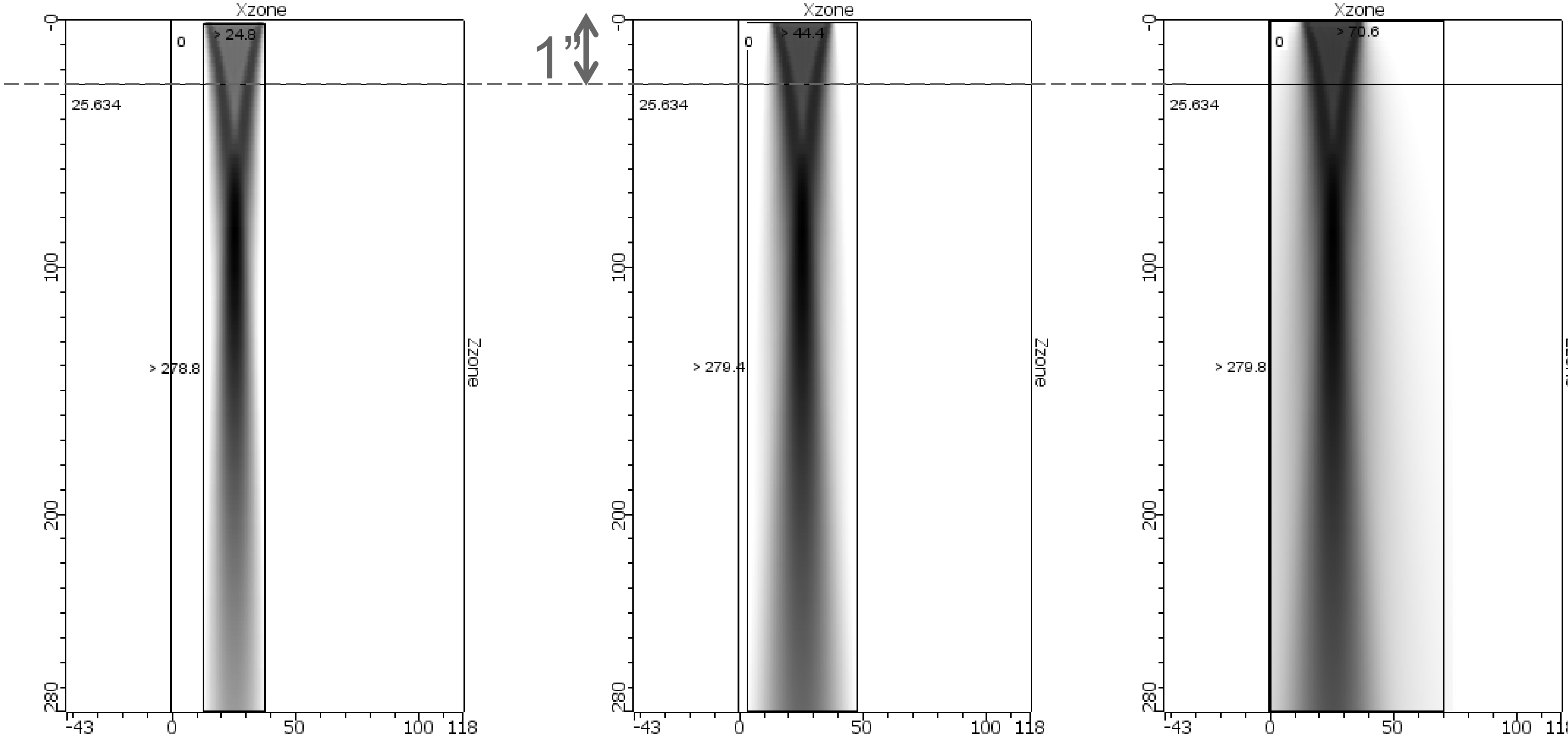
NRR Goals for UT Modeling

- Develop a technical basis to allow the NRC and industry to determine the effectiveness of an inspection using modeling
  - What do all of those colors mean, anyway?
- Coverage issues could be explored
- Challenging inspections could be tackled
- Hands-on practice could be done using modeled data

Intuition is not your Friend

-20 dB can work in some situations



-6 dB Focal Zone

-12 dB Focal Zone

-25 dB Focal Zone

Important Parameters

- When evaluating modeling results, what are the important parameters to consider?
  - Modeled flaw responses vs. modeled sound profile
  - Flaw response strength
  - Relative sound field strength
  - Absolute sound field strength
  - Width of sound field relative to flaw size
  - Appropriate noise levels for modeling
- What are the appropriate values for these parameters for an effective inspection?

Materials Issues

- Different materials will produce very different attenuation, beam redirection, and noise levels
- The required beam profile and/or flaw responses would be very different for ferritic, wrought austenitic, dissimilar metal welds, and cast austenitic inspections
- Some materials are extremely variable and change every inch around the weld and present challenges to modeling
- The required sound field properties for different materials is not known

System Noise

- In low-noise materials, the combined system noise may dominate
- The idea of turning up the gain on the receiver may help deal with low signal strength may fail if the system has issues
- Possible issues include
  - Overdriving probes
  - Poor transducer/wedge design
  - Cable issues
  - Electronic noise in pulser/receiver
- Including these effects in models will take careful work

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Coverage Questions

- The NRC and Industry have used modeling to address N-770-1 inspections where 100% inspection coverage was not possible
- Appropriate rules for beam spread and expanded coverage may be developed from effective modeling

Inspection Optimization

- While many inspection procedures have been shown to be good enough via performance demonstration, they can still be improved
- Transducer designs can be optimized via modeling and simulations as opposed to buying and trying probes
- Improved flaw detection and increased pass rates for Appendix VIII testing may be realized if procedures are highly optimized

Virtual Practice

- Many NDE inspectors spend months without access to flawed specimens
- Recorded realistic data with noise, geometry, and flaws could be used to allow people to practice on virtual welds
- “Classic” inspection problems could be modeled and presented to inspectors
- Skills could be maintained or improved during down time
- Inspectors could “warm up” prior to inspections

Issues with Modeling

- Modeling can be very complex and is open to interpretation and misinterpretation
- Modeling will require specialized training
- Some form of personnel certification or qualification for modeling may be useful
- Guidance on how to perform and interpret modeling will help prevent dueling conclusions
- A Regulatory Guide and possible industry guidance documents should be developed

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I know what you are thinking right now….

You are wondering what NRC's Office of Research is doing to address modeling?

User Need Request (UNR)

Program offices, such as Office of Nuclear Reactor Regulation (NRR), formally request assistance from RES via a User Need Request (UNR).

Research results are used to support regulatory decisions.

NDE-related UNRs

- UNR NRR-2013-009, "User Need Request for Evaluating the Reliability of Nondestructive Examinations (NDE) of Vessels and Piping"
  - Confirmatory research and analyses related to
    - Demonstration of NDE methods and techniques
    - Qualification of procedures, equipment, and personnel
    - Detection and characterization of flaws
- UNR NRR-2015-001, "Explore the Effects of Human Performance Issues on Nondestructive Examination Reliability"
    - Research to identify the human factors that are most likely to impact personnel performance during nondestructive examinations.

PNNL Modeling & Simulation Efforts

Phased Approach

•Phase 1
- Investigate simple geometrical reflectors and materials (machined notch defects in stainless steel plates)

•Phase 2
- Investigate more realistic reflectors (implanted/grown fatigue cracks) in stainless steel plates and welded specimens

•Phase 3
- Investigate realistic reflectors in coarse-grained, anisotropic materials (CASS)

Objectives (Focus on CIVA):

1. Investigate the importance of input parameters on the accuracy of output results,
2. Assess the reliability of modeling software by comparing simulated responses to experimental measurements,
3. Develop and implement a set of validation metrics/criteria for improving analyses and reducing subjectivity in image-based comparisons.

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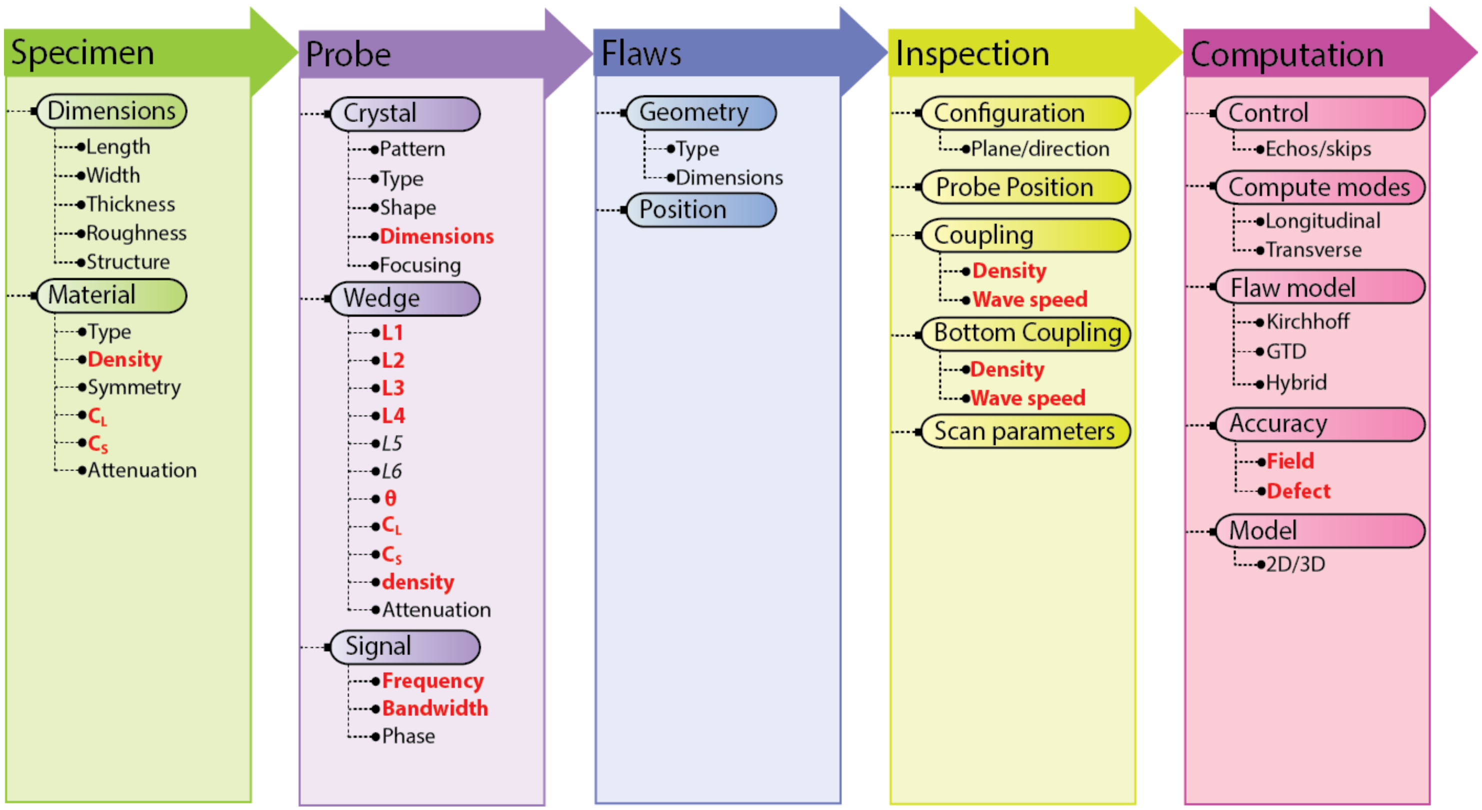
Activities

- Literature Review on NDE model validation
- Created an inventory of equipment for use under EPRI MOU
- Developed processes and guidelines for acquisition of key performance parameters for ultrasonic probe characterization
- Obtaining UT data on mockups with a variety of reflectors, probes, frequencies and modalities
- Conducted a comparative assessment of results from several models

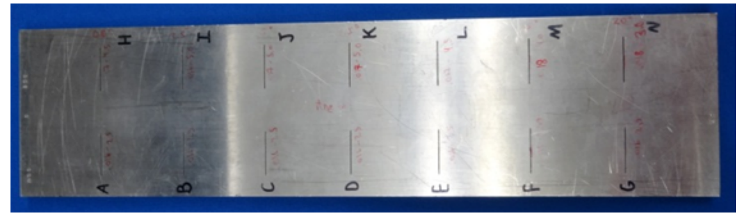
PNNL Modeling & Simulation Efforts

Parameter input for CIVA models

- Specifying parameters for a conventional UT scan in CIVA.
- For proper evaluation of CIVA computation:
  - Specimen, transducer and flaw parameters should match their experimental counterparts.



Targeted UT Inspection Parameters



- Stainless steel 304 plates with EDM notches.
- Measurements were conducted on 9 plates, but here we mention only 3 plates which are representative of the types of notches of interest:
  - Plate with 10 notches varying in depth
  - Plate with 5 notches varying in length and depth
  - Plate with 14 notches varying in both depth and tilt
- Various transducers are used to scan each plate:
  - 6.35 mm (¼”) diameter, 5 MHz, shear wave 45° beam angle
  - 12.7 mm (½”) diameter, 5 MHz, shear wave 45° beam angle
  - 12.7 mm (½”) diameter, 5 MHz, shear wave 60° beam angle
  - 6.35 mm (¼”) diameter, 2.25 MHz, shear wave 45° beam angle
  - 12.7 mm (½”) diameter, 1 MHz, L-wave 45° beam angle
  - Dual element TRL, 4 MHz, 60° beam angle

5 MHz, 45°, quarter inch

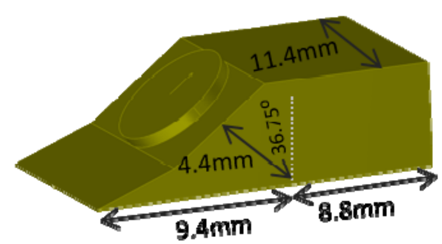
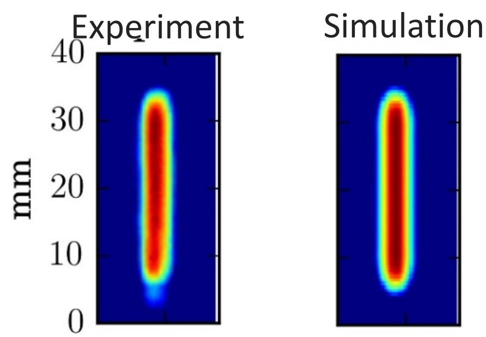


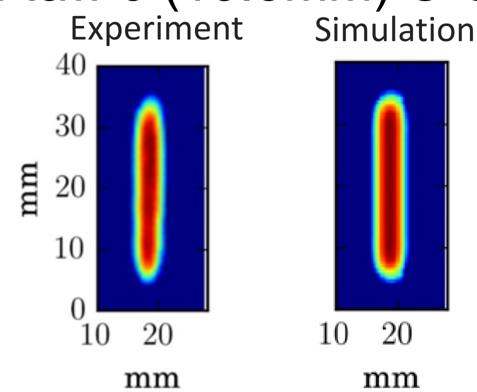
Plate with Defects Varying in Depth

- Scans using 5 MHz shear, 45° beam angle, 6.35 mm (¼”) diameter transducer shows good agreement between simulation and experiment.

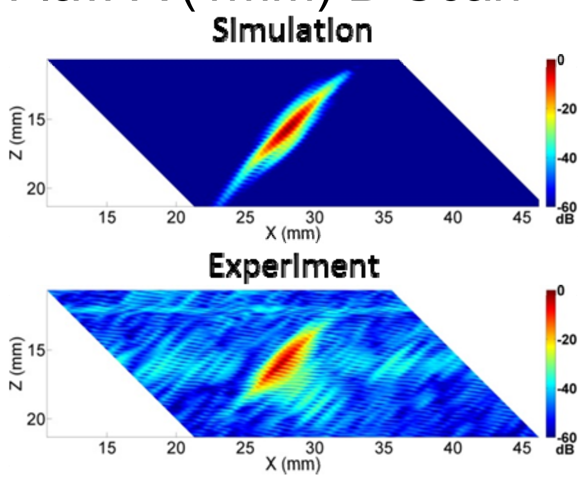
Flaw A (1mm) C-Scan



Flaw J (13.5mm) C-Scan



Flaw A (1mm) B-Scan



Flaw J (13.5mm) B-Scan

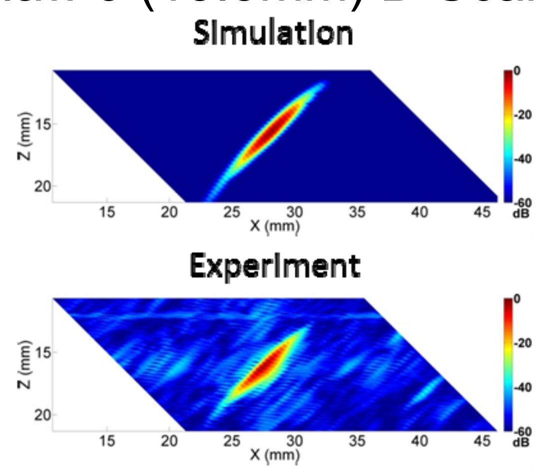
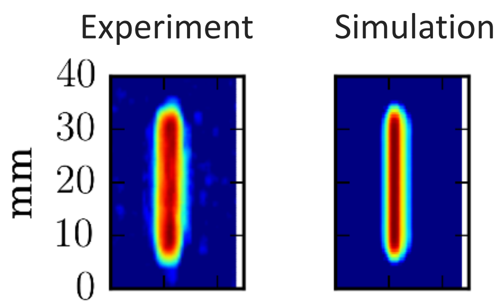


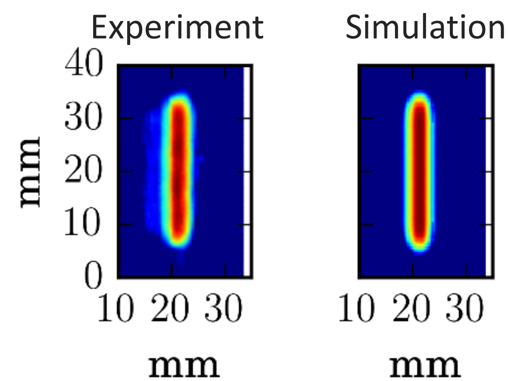
Plate with Defects Varying Orientation

- Scans using 5 MHz shear, 45° beam angle, 6.35 mm (¼”) diameter transducer. Some discrepancies can be seen.

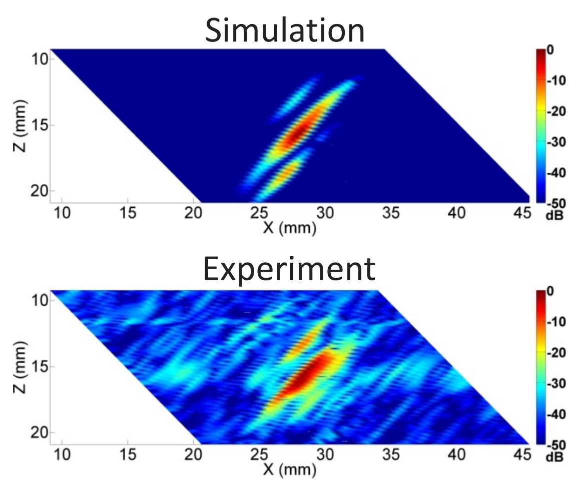
Flaw E (10°) C-Scan



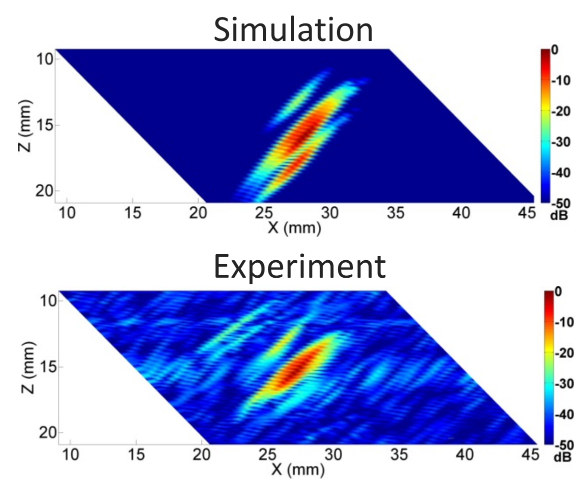
Flaw G (20°) C-Scan



Flaw E B-Scan



Flaw G B-Scan



PNNL Modeling & Simulation Efforts

Summary

- In general, CIVA results in Phase 1 match experiments well for the limited set of parameters evaluated
- Some discrepancies between experimental and simulated data still not understood:
  - What is the source? The inputs or computational algorithm accuracy?
- Data analysis has been completed for Phase 1; Phase 2 has been initiated
- More scrutiny to minimize the effects of experimental input parameters on output accuracy
- Parametric studies on some inputs were performed in Phase 1; however, more studies on the remaining model parameters are needed, including:
  - Specimen material attenuation
  - Transducer squint angle
  - Not perfectly rectangular notch defect shapes
- Expand the study to include more transducers and frequencies
- Simulated data need to be validated and metrics for quantifying differences between simulated and experimental data are evolving

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Questions