Virtual mockups – progress update

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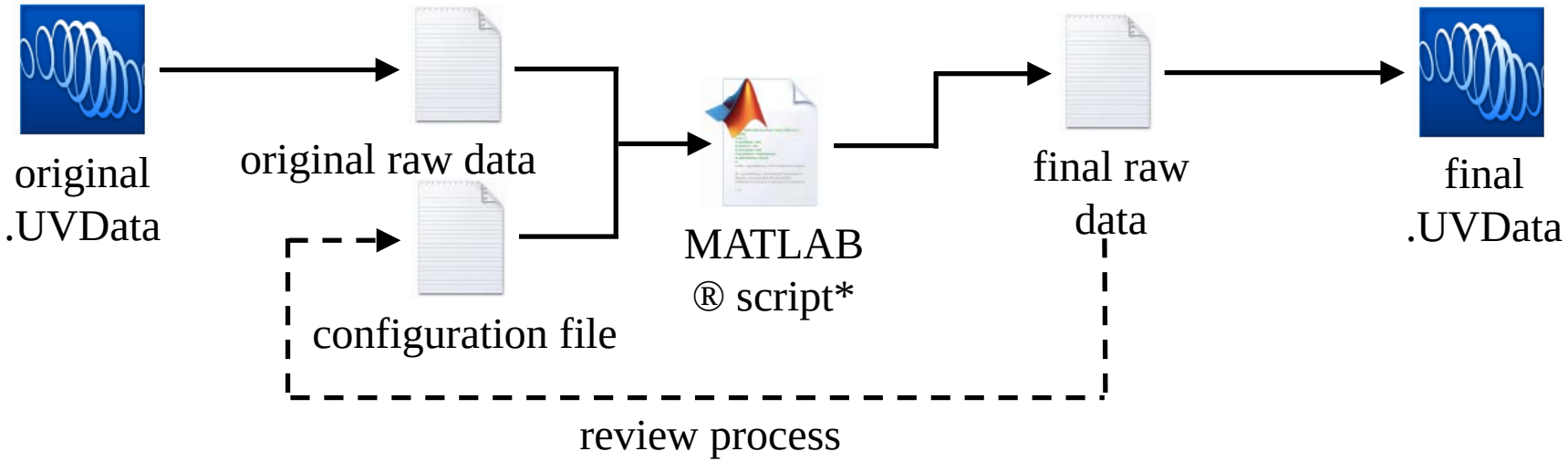
Past Research

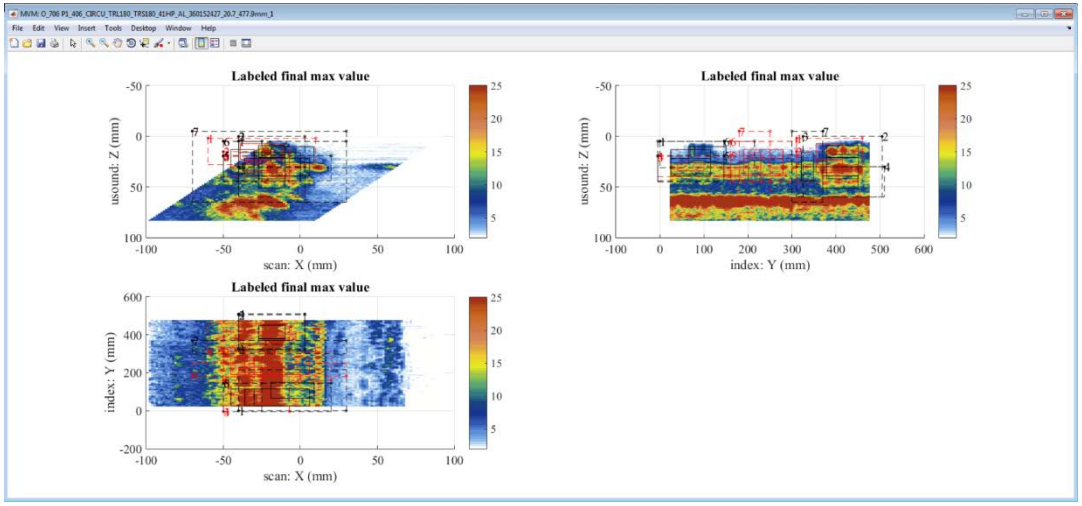
- Project work performed in the past
  - *Nondestructive Evaluation: Virtual Mockups – A Feasibility Study into Electronic Implantation of Flaw Responses into Previously Recorded Data.* EPRI, Palo Alto, CA: 2018. 3002013152.
    - Report detailing results of 2016 - 2018 phase of project
  - *NDE Training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

The Basics

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

Process for sourcing virtual flaws from existing data -





Current Capability for Creating Virtual Mockups

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

Industry Activities with Virtual Mockups

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

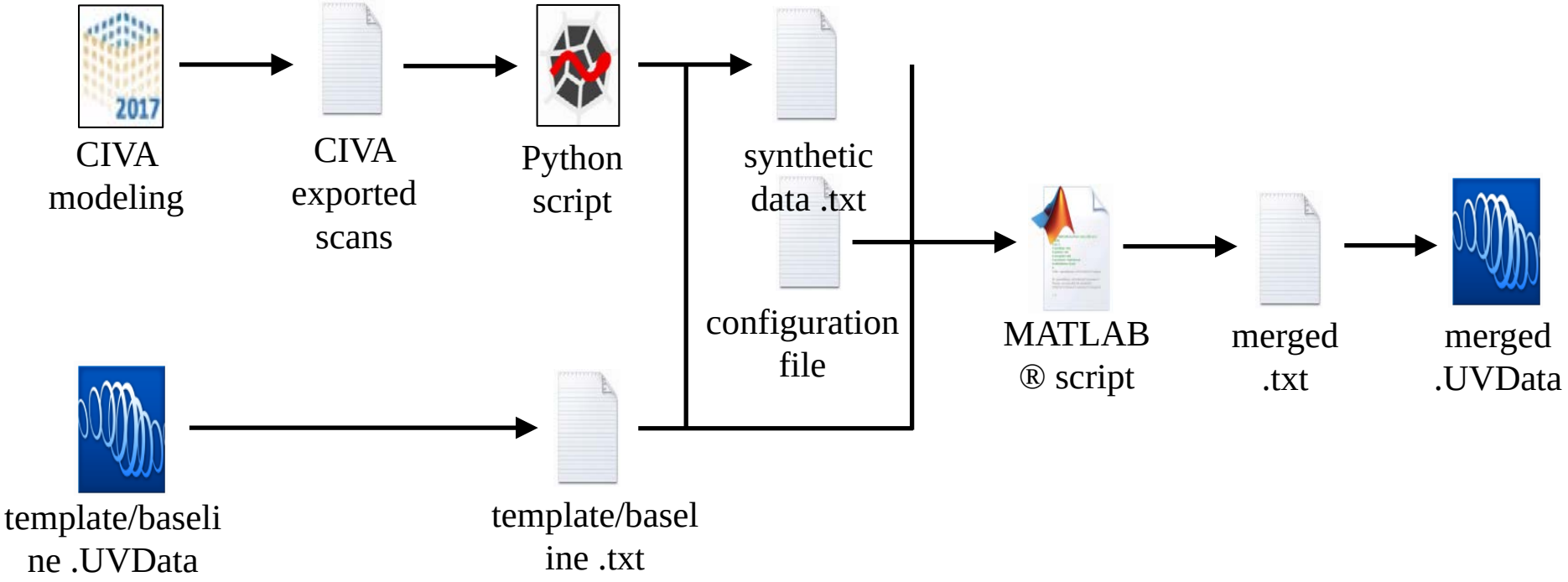
Industry Activities with Virtual Mockups

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

Future Research Areas

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

Process for creating synthetic flaws and injecting into previously collected data



Current Workscope

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

Supporting a Virtual Mockup Library

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

Summary

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

discussion

Together…Shaping the Future of Electricity

Update on Volumetric Examinations for BMNs

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Washington, DC
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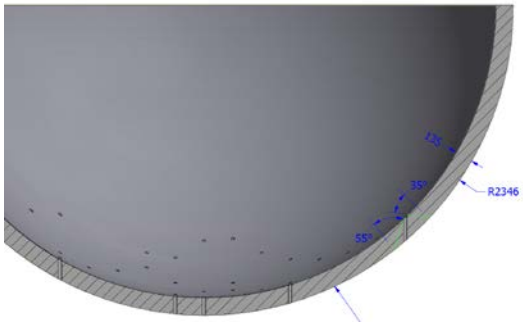
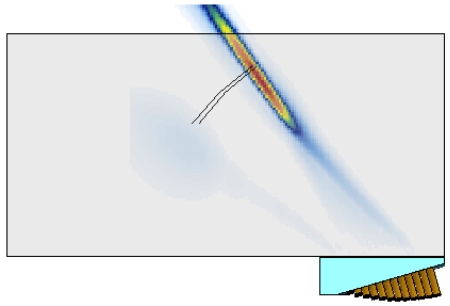
Phased Array UT of BMNs Feasibility Study

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

PAUT Study

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





Status

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

discussion

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Human Factors in NDE

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Outline

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

Introduction to Human Factors

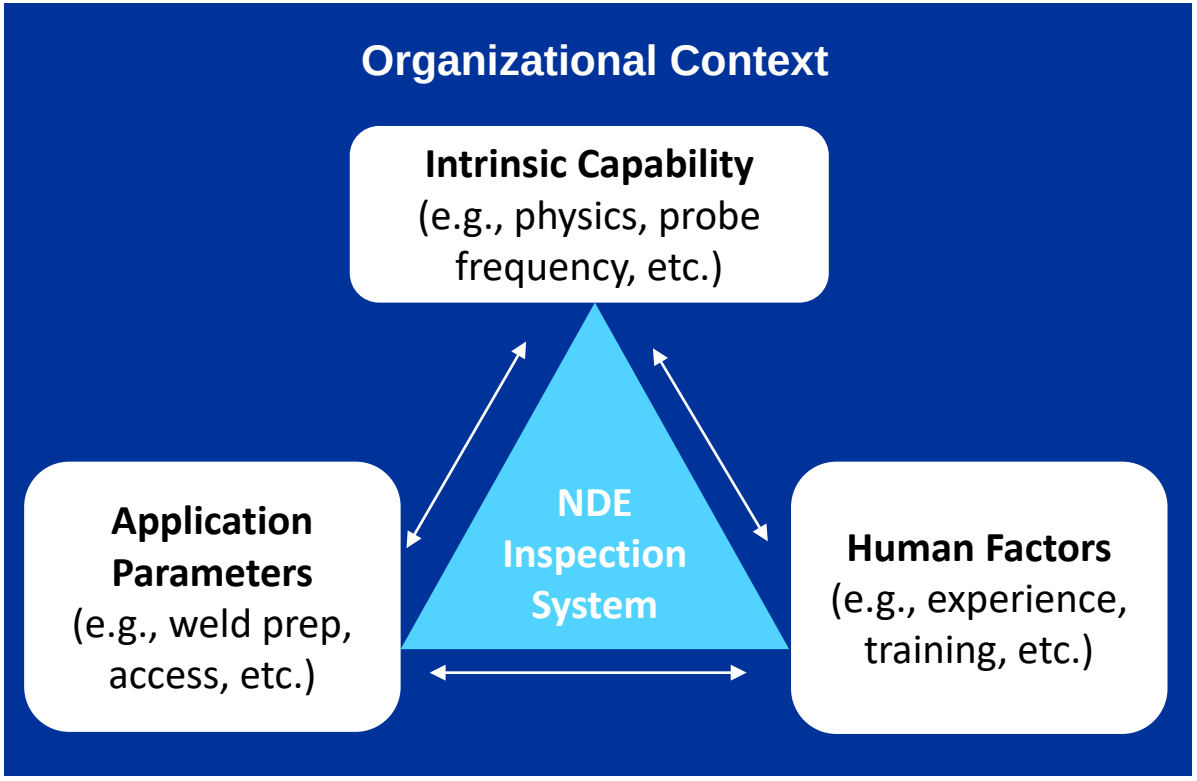
Human Factors (HF)

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

NDE Reliability – The Big Picture

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

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



Content sourced from 1, 2.

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

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

Human Factors in NDE Project

Project Focus and Objective

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

Laboratory

Field

MOU Tasks

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

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

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

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

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

Timeline of EPRI's Project

- The project timeline is 2016 – 2019:

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

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

Results and Applications

2017 – Domestic Examiner Interviews

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

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

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

Results from EPRI's Examiner Interviews 1 of 2

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

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

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

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

Results from EPRI's Examiner Interviews 2 of 2

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

2018 - Industry Feedback via Workshops

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

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

Results from 2018 Workshops 1 of 2

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

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

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

Results from 2018 Workshops 2 of 2

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

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

Meeting Examiner Requests with Human Factors

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

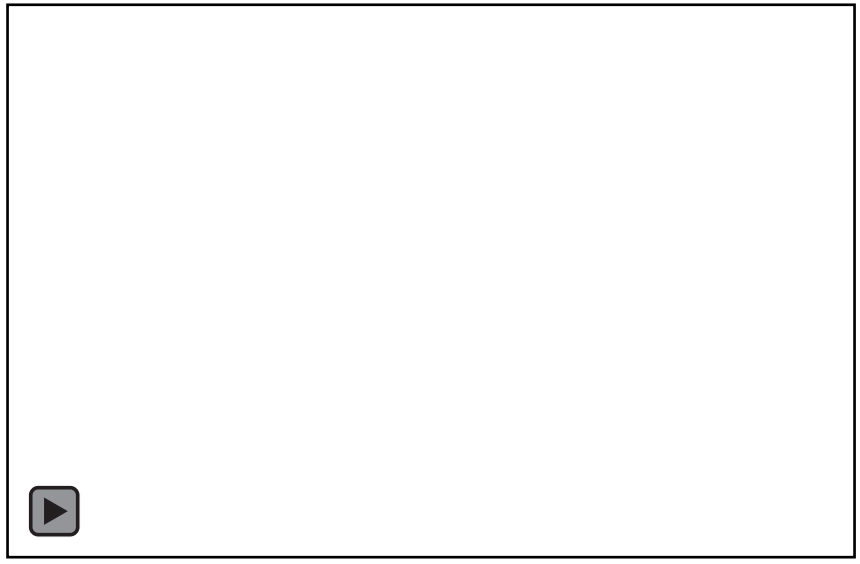
Question	UT Examiner Responses
What aspects of training could be improved and how?	"… look at more flawed samples." "Training needs to be on good mockups,…" "….just scanning samples is very valuable."
Opportunity – Examiners are requesting accessibility to practice samples	

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

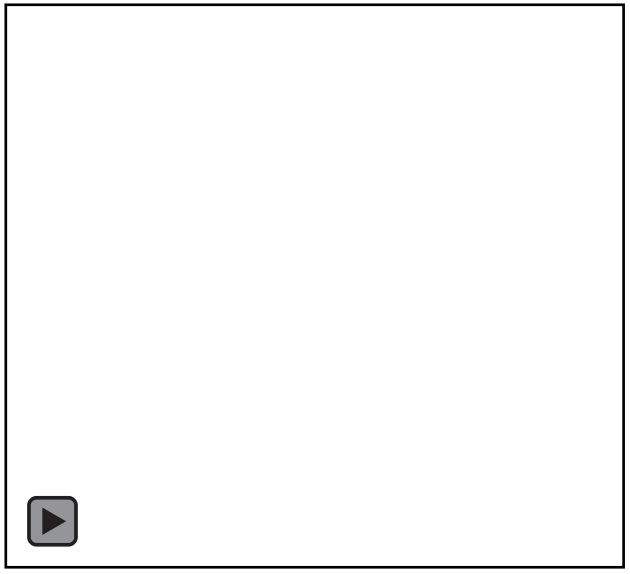
Virtual NDE (VNDE) 2.0 and Human Factors

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

Hardware Scan: Half Pipe



Hardware Scan: Rompas Block

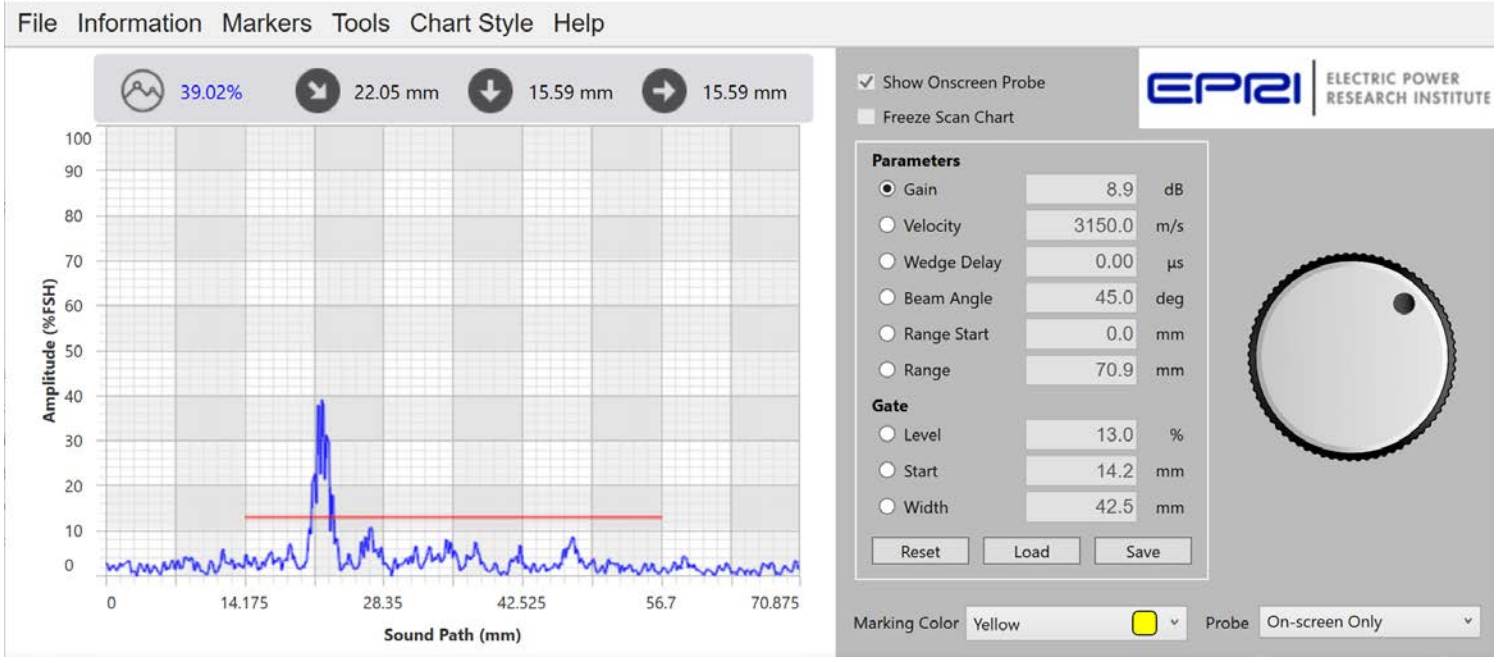


Product ID: 3002013243

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

Usability Testing

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



2019 Research

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

Conclusions and Takeaways

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

discussion

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