PNNL-SA-218184

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Virtual Flaw Technology

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U.S. DEPARTMENT of ENERGY BATTELLE

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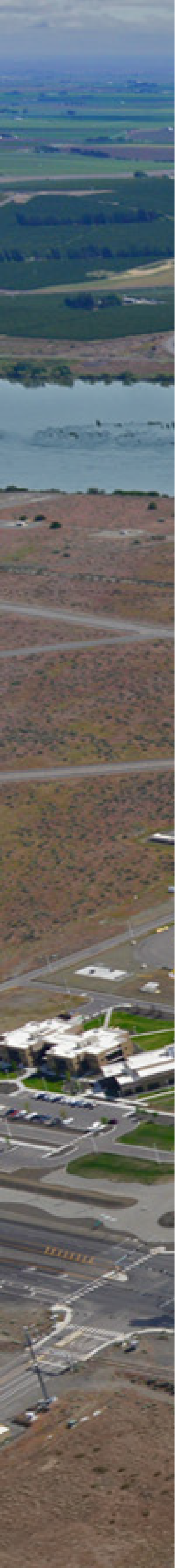
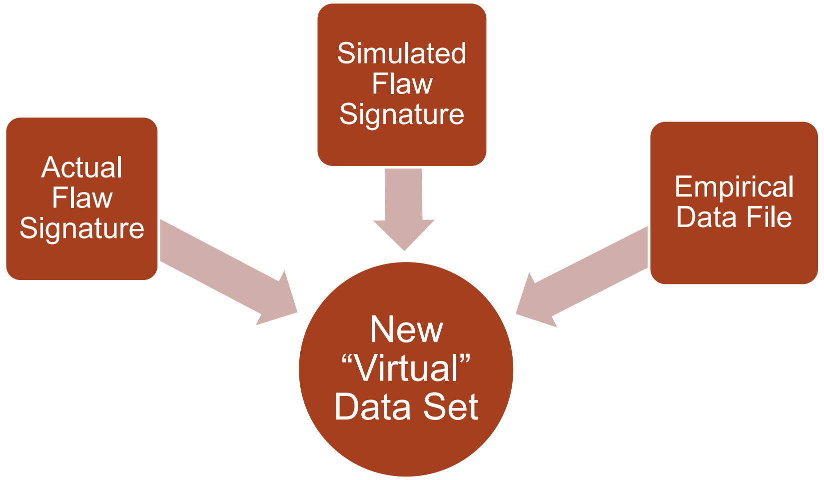


Presentation Overview

- PNNL's Collaboration with EPRI
- Industry Factors Driving PNNL's Research
- PNNL's Confirmatory Research Scope
- Flaw Modification Results
- Modification Errors
- Summary of Results

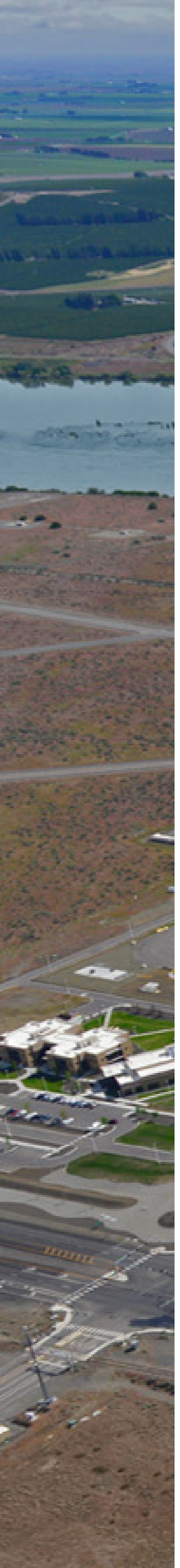
PNNL’s Virtual Flaw Definitions

- A “virtual flaw” is a digitized ultrasonic flaw signature that has been computationally modified by changing some aspect of the flaw signature, including location, size, orientation, and signal intensity
- A “synthetic flaw” is a digitized ultrasonic flaw signature that has been created from modeling and simulation software
- A virtual flaw may be created from empirical data or from synthetic flaw data
- An ideal virtual flaw will be indistinguishable from an inherent empirical flaw



PNNL's Collaboration with EPRI Initiative to Create Virtual Mockups

- Work began in late 2021 to review and assess EPRI's Modify Virtual Mockup (MVM) software
- Provided access to previous EPRI reports on flaw modification
  - 2018 Technical Report 3002013152
  - 2022 Technical Report 3002023719
- Provided Modify Virtual Mockup (MVM) software
- Initial meeting/workshop at EPRI
  - Review of EPRI work to date and information exchange on MVM software
- Continual interaction with EPRI responsible personnel



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Industry Factors Driving PNNL's Research

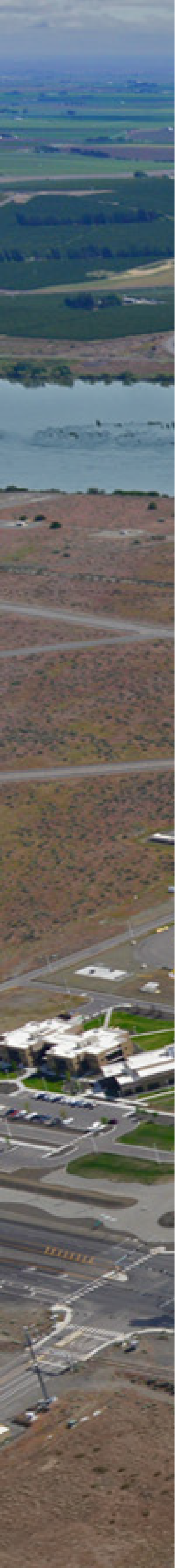
- Industry is working to improve training of personnel and qualification of personnel and equipment by expanding the existing flaw database

- There are two primary barriers that are driving industry to use virtual flaw technology:
  - Access to real flaws in components removed from service is extremely limited
  - Fabrication of flawed specimens is time consuming and expensive

- Improved training: adding virtual flaws to training data sets is expected to broaden the number and types of flaw signatures that analysts are exposed to

- More rigorous qualification: including virtual flaws in performance demonstration data sets is expected to further challenge analysts by testing them on realistic flaw signatures that may not be available in existing specimen sets

- In addition, industry requires extensive data sets to train machine learning (ML) models in their push for automated or assisted analysis and is exploring the use of virtual flaws

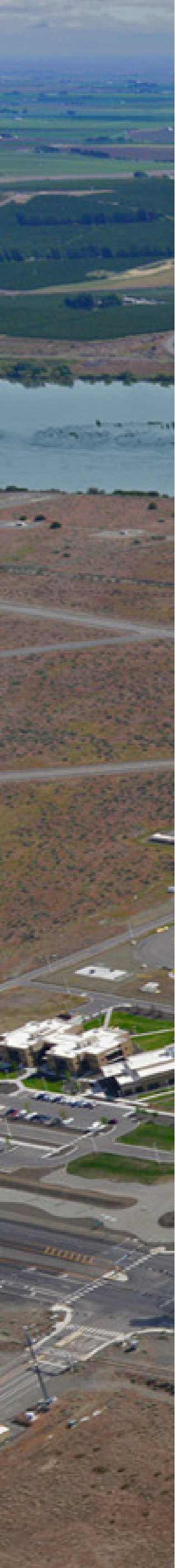


PNNL's Confirmatory Research Scope

- Provide the NRC with a technical basis for reviewing EPRI topical reports, licensee submittals, ASME Code actions, etc. where virtual flaws are used or proposed
- Identify areas of potential uses of virtual flaws within a regulatory environment, including the challenges of compliance of virtual flaws to the requirements of the ASME Code for training and qualification, such as Appendix VIII qualification
- Interact with virtual flaw software developers (EPRI, TrueFlaw) to provide insight to NRC on industry's evolution of the technology, planned uses and ASME Code revisions
- Create a set of virtual flaws from an empirical flaw database to verify the capability and limitation of existing flaw modification software
  - Round robin with qualified analysts to evaluate the effectiveness of virtual flaws
  - Training data for ML models
- Investigate if synthetic flaws can be used in place of empirical data for creating realistic virtual flaws
- Provide virtual flaws to augment training data for ML-based automated or assisted data analysis (in conjunction with other tasking on the project)

PNNL Work Completed to Date

- Evaluated the MVM software capabilities and usability
- Empirical flaw data from PNNL specimens was modified to create 25 virtual specimens containing virtual flaws
  - Performed on dissimilar metal (DM) weld data
    - ✓ DM welds is the primary use of encoded ultrasound exams and current industry focus for machine learning
  - Evaluated the impact that differences in data collection parameters and techniques have on the modification process
    - ✓ Different probes, probe frequency, scan parameters, and material thickness
- Developed technical basis for training and experience required for performing modifications



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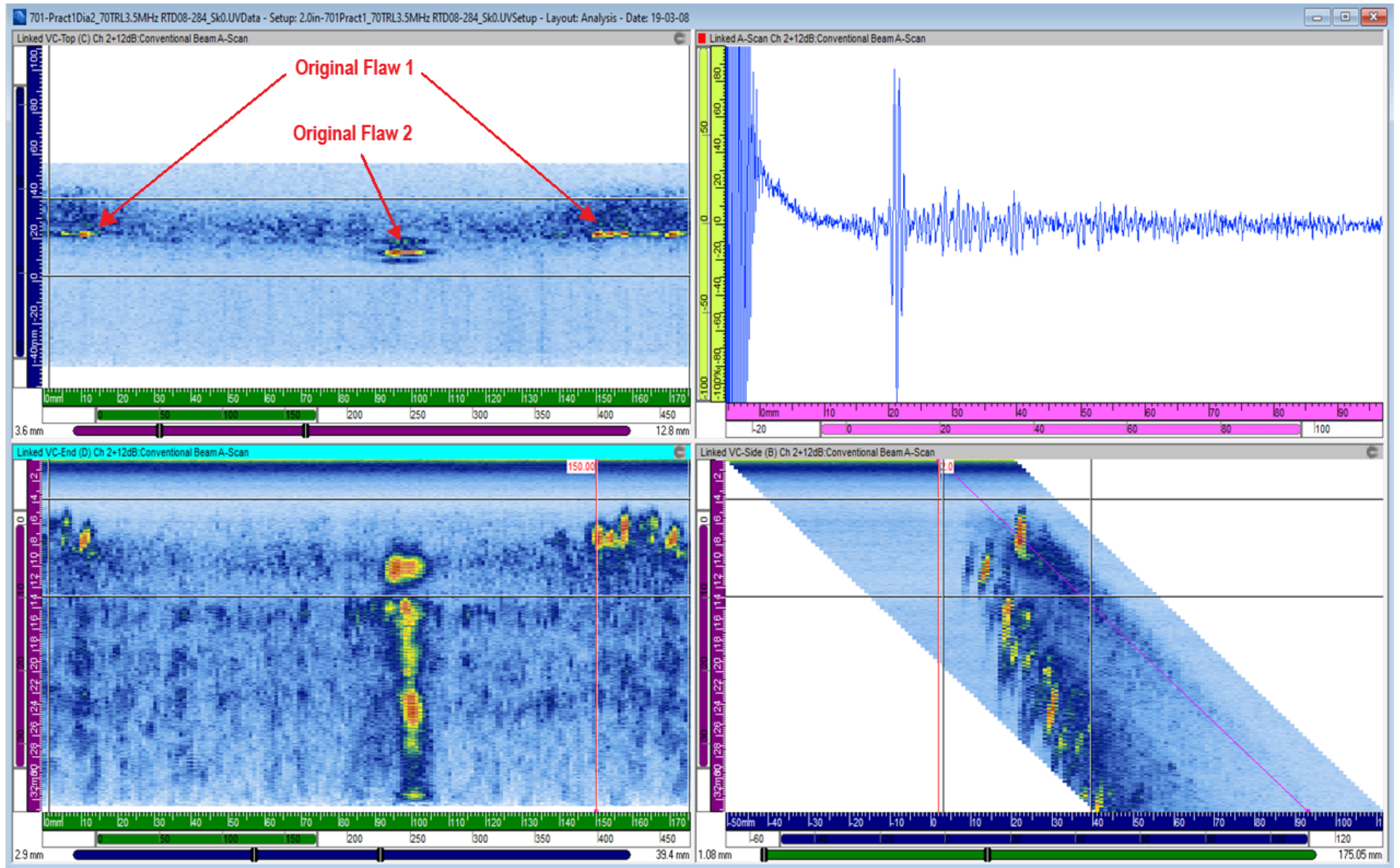
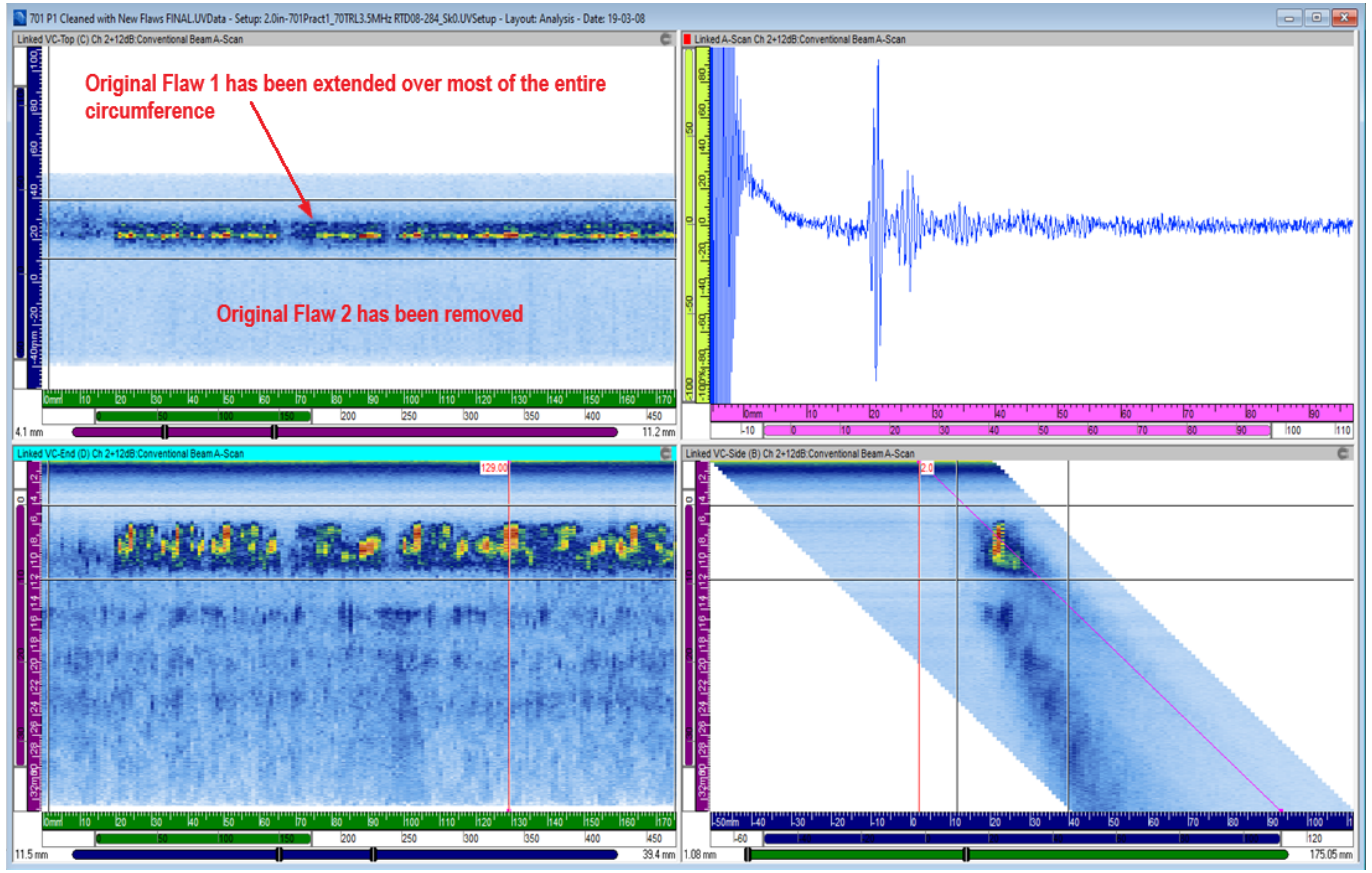
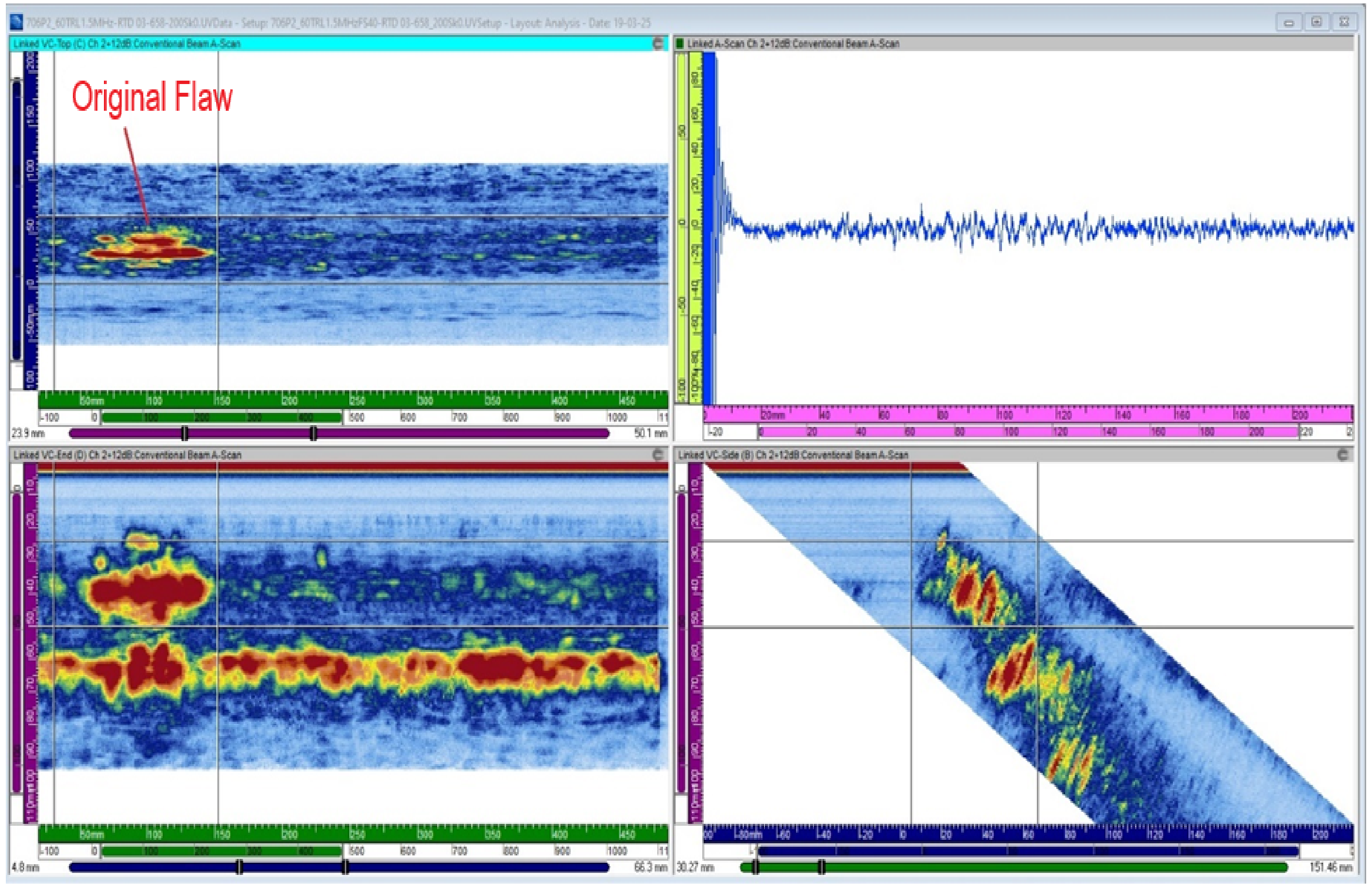
MVM Modified UT Data File - Example 1

Unmodified Data File	Modified Data File
	

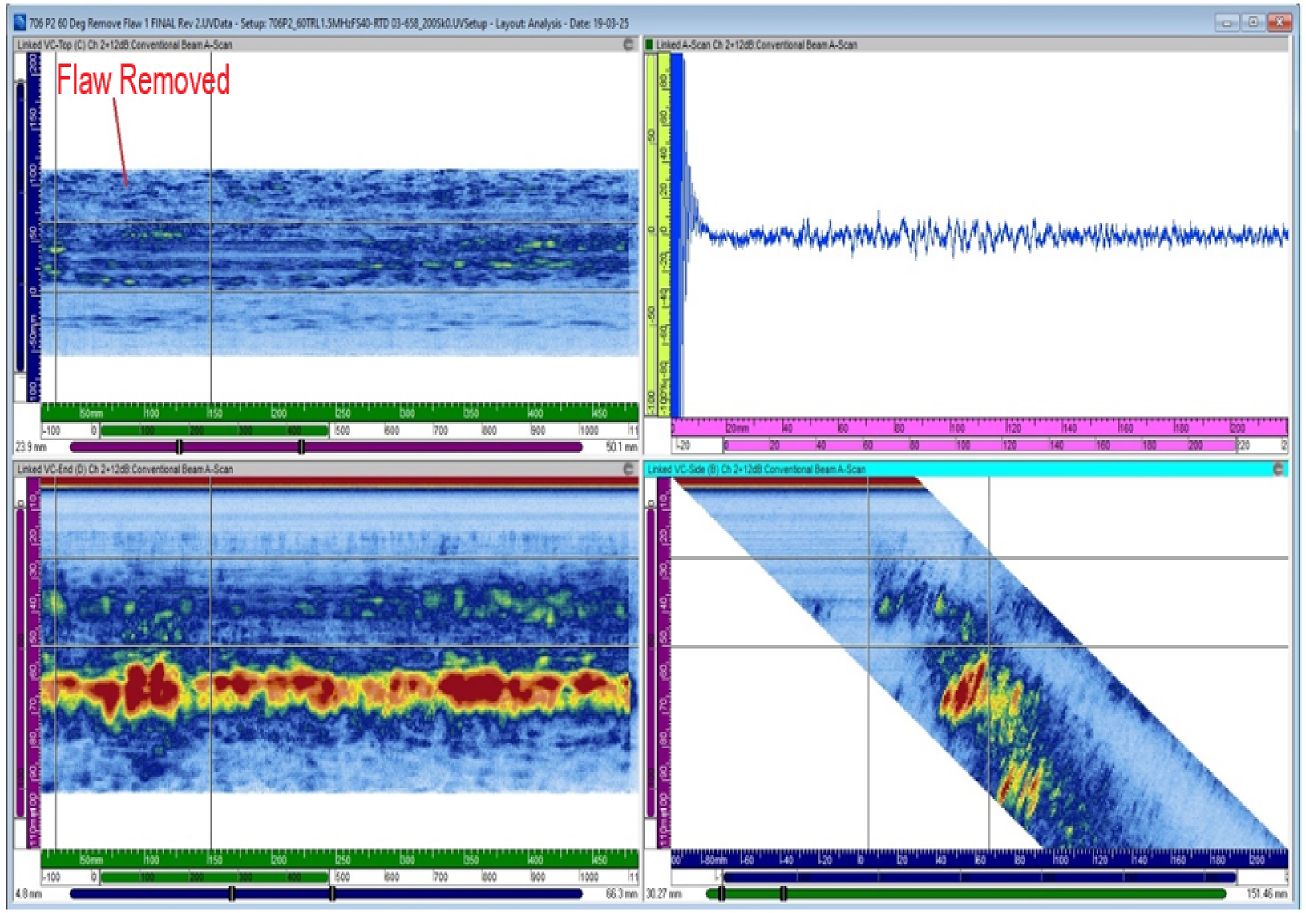
The modified flaw represents a flaw that extends over most of the entire circumference. These types of flaws are realistic in thin wall piping, such as this specimen, and can be challenging for a data analyst in discriminating between a response from a flaw versus a non-flawed weld root geometric condition.

MVM Modified UT Data File – Example 2

Unmodified Data File



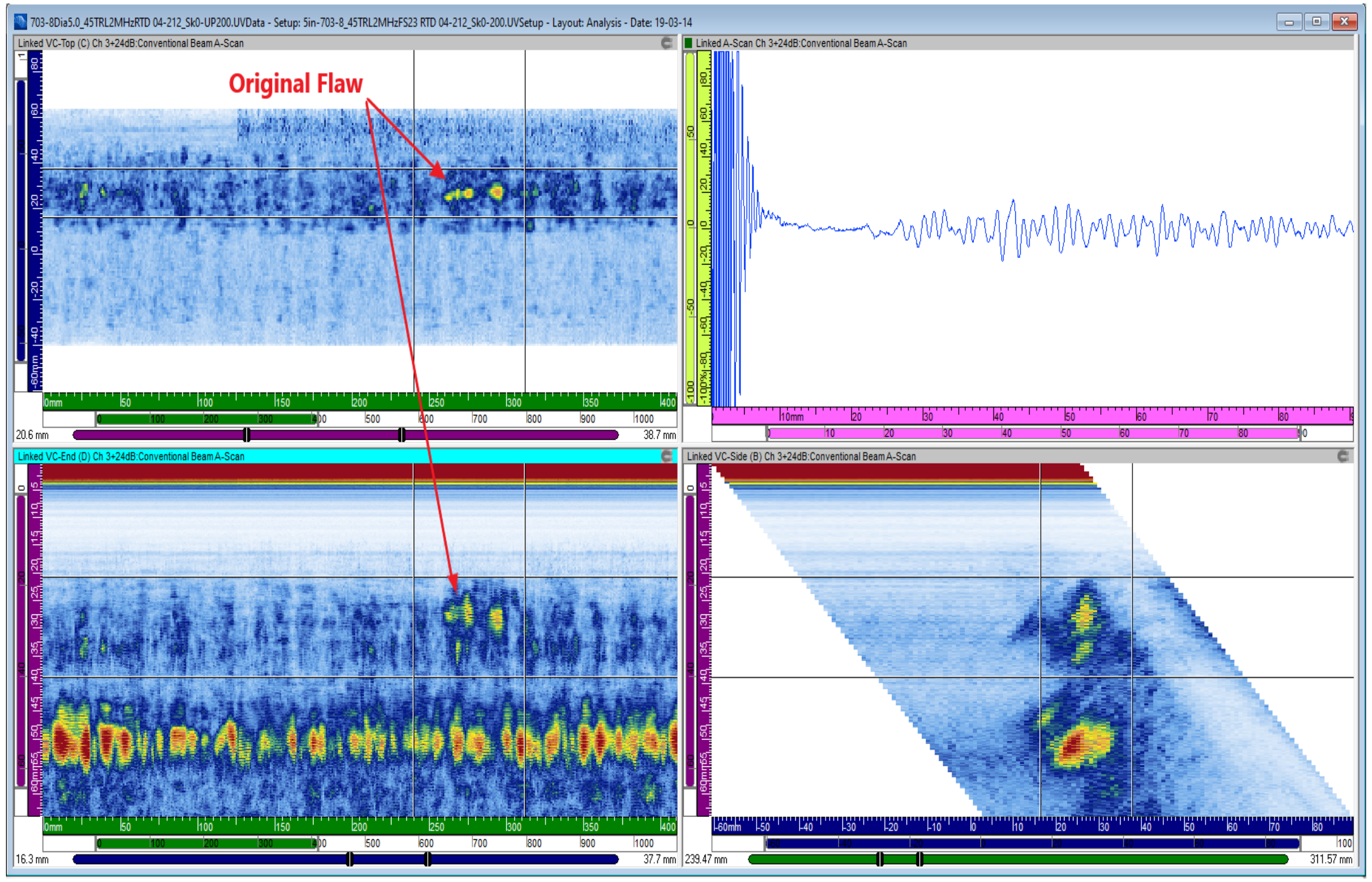
Modified Data File



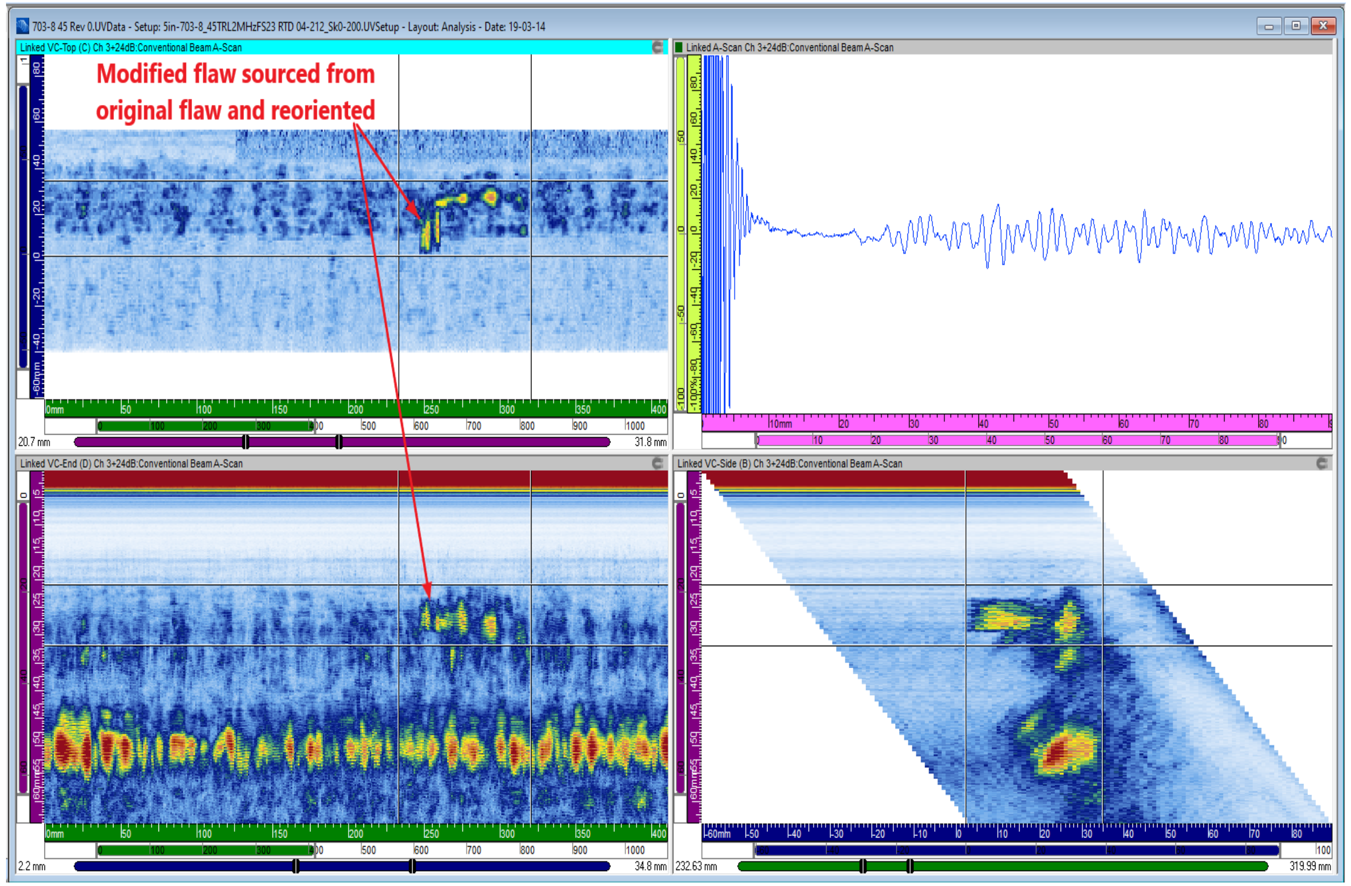
This modification was performed to evaluate the software's capability in removing a flaw. Once removed, this data file could now be used as a template for placing other flaws.

MVM Modified UT Data File – Example 3

Unmodified Data File



Modified Data File



This data was modified to source the original flaw, reoriented its shape, and place the modified flaw adjacent to the original flaw and the weld root. A modification of this type would challenge an analyst to discriminate the two responses as a flaw or geometric response.

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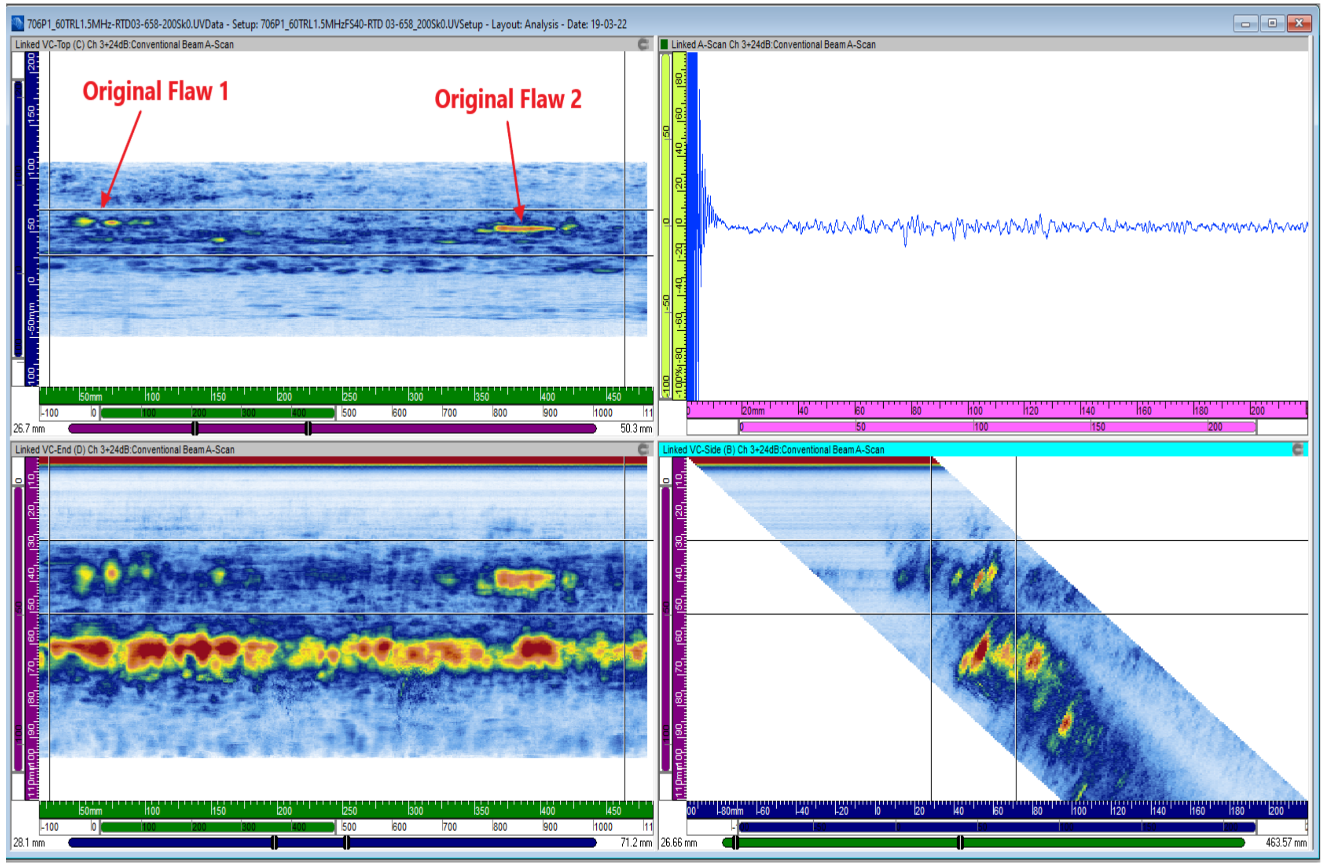
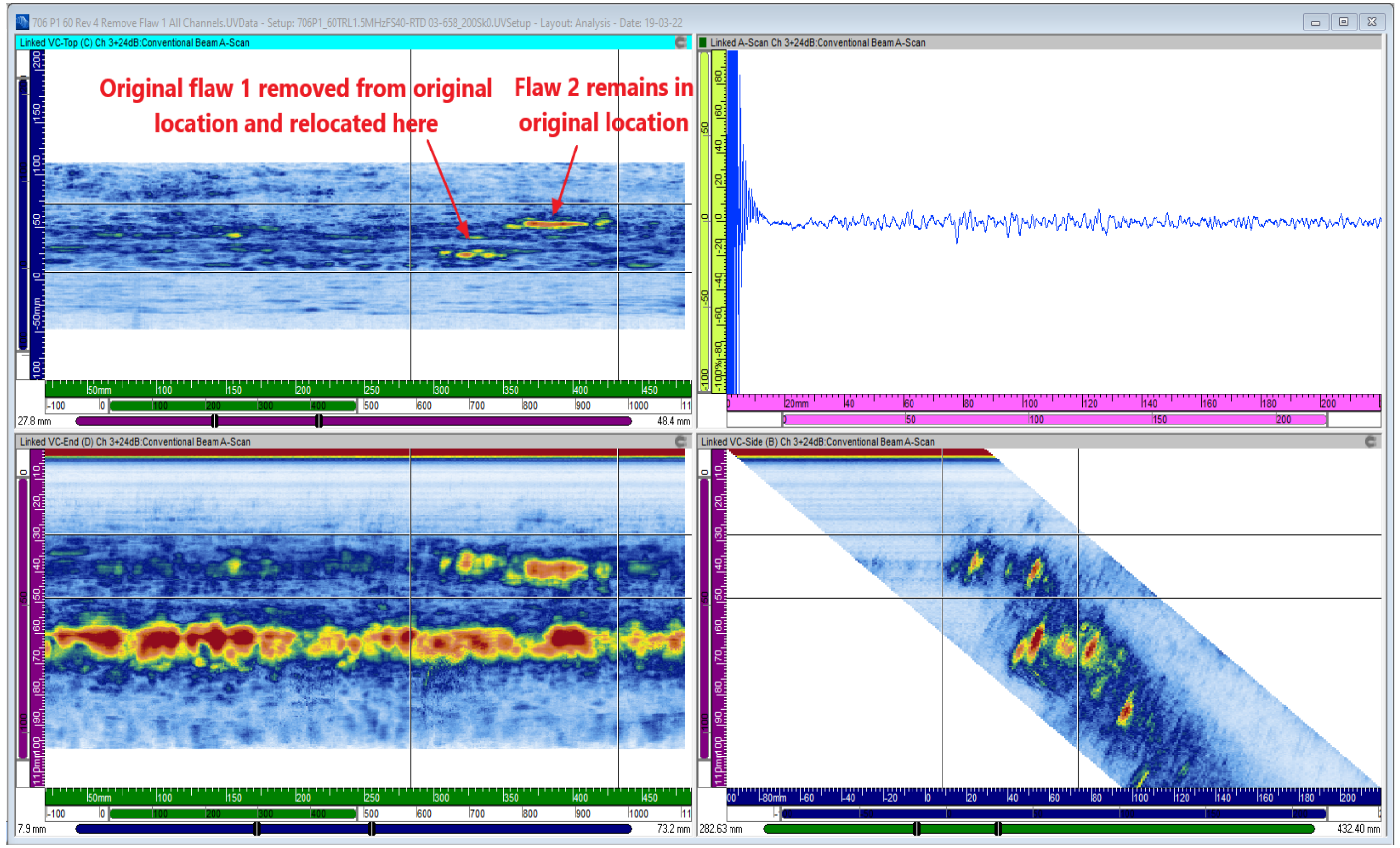
MVM Modified UT Data File – Example 4

Unmodified Data File



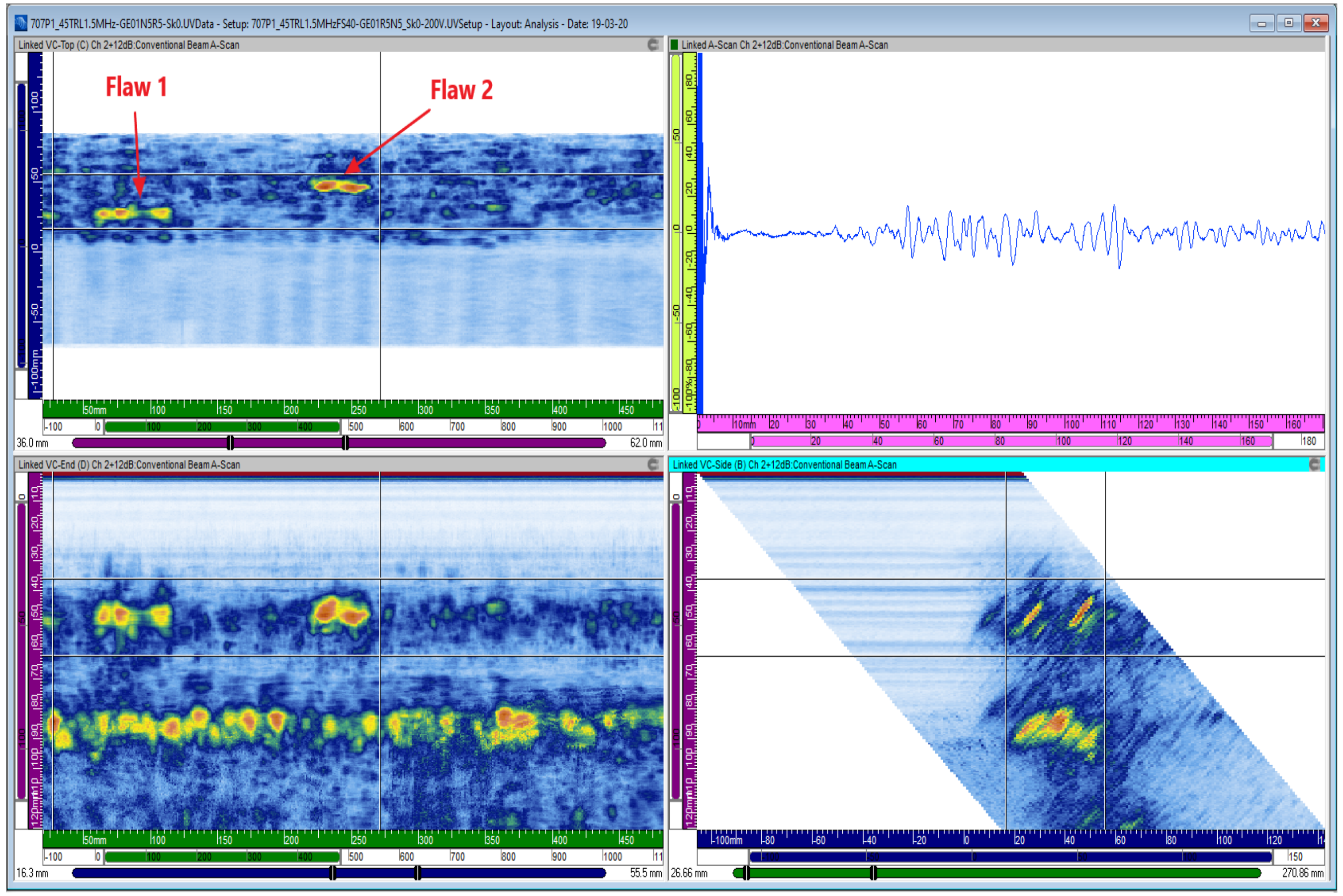
Modified Data File



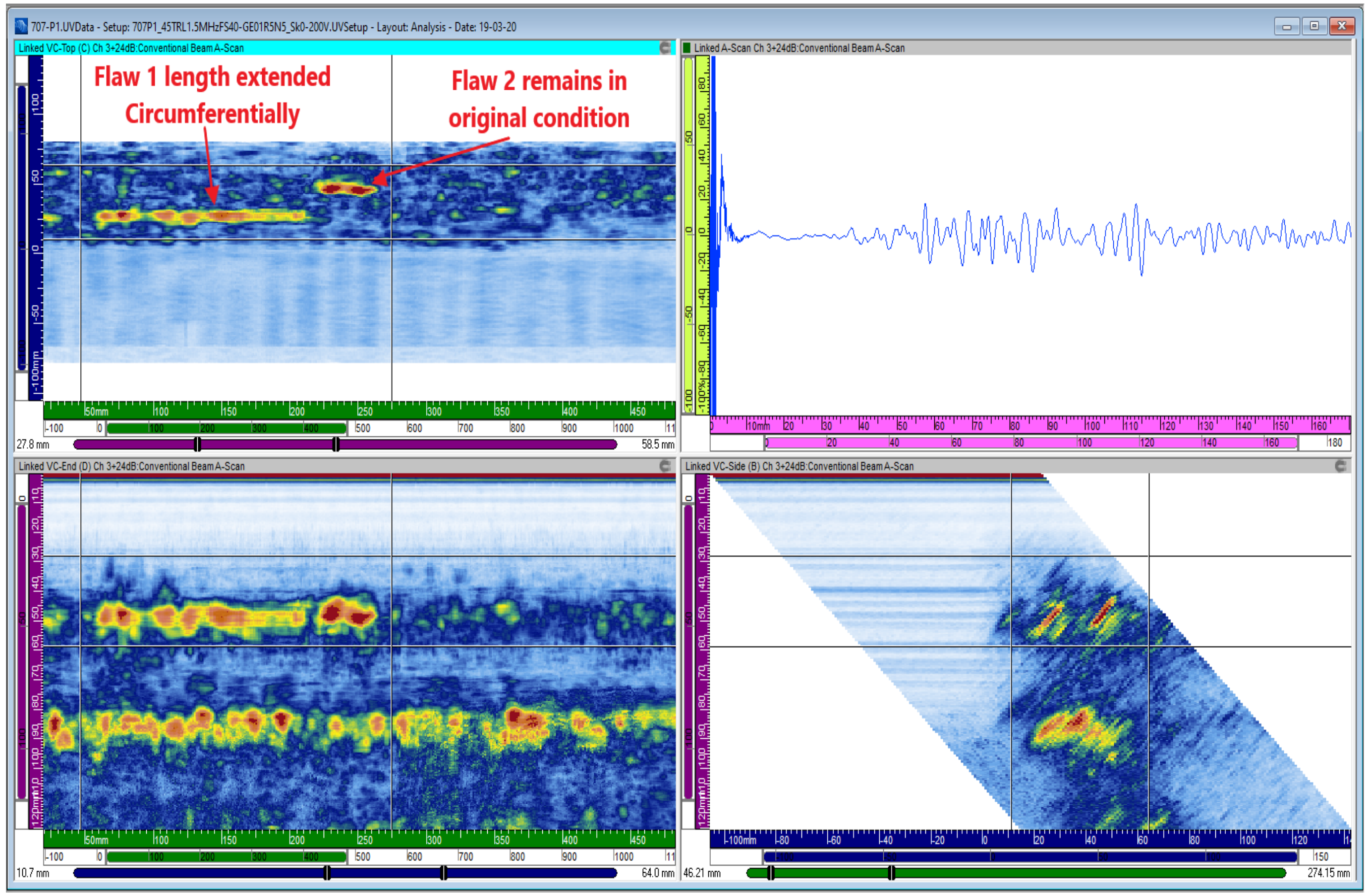
This modification sourced Flaw 1 and relocated it near Flaw 2 but closer to the weld root. The purpose would be to challenge an analyst to determine if both were flaws or the modified flaw was a geometric root response.

MVM Modified UT Data File – Example 5

Unmodified Data File



Modified Data File



This modification extended Flaw 1 in circumferential length. It appears closer to the weld root than Flaw 2 and its extended length would challenge an analyst to discriminate its response against a possible geometric condition.

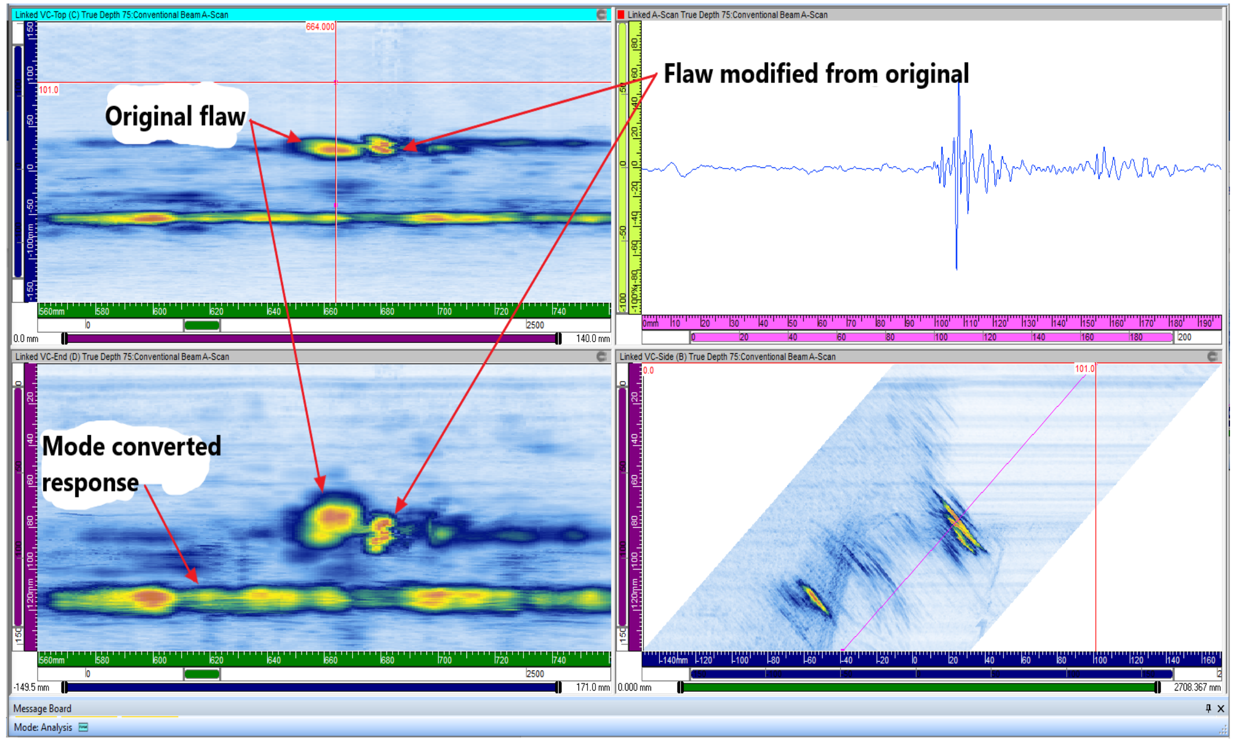
Errors in the Modification Process

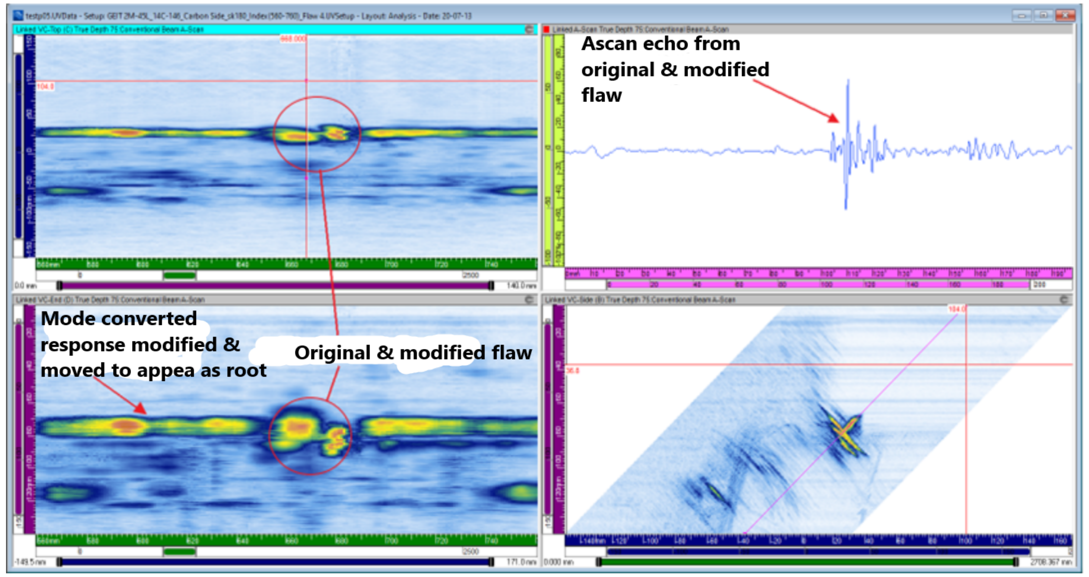
- Stalled processing with earlier version of MVM
  - I7 processor with 32 Gb RAM
  - Large files (~8 Gb) would stall the process
- Extracting a mode converted response appears acceptable in the image but not in the A-Scan
- Simulated flaws created in CIVA do not appear realistic
  - Not caused by the MVM modification process

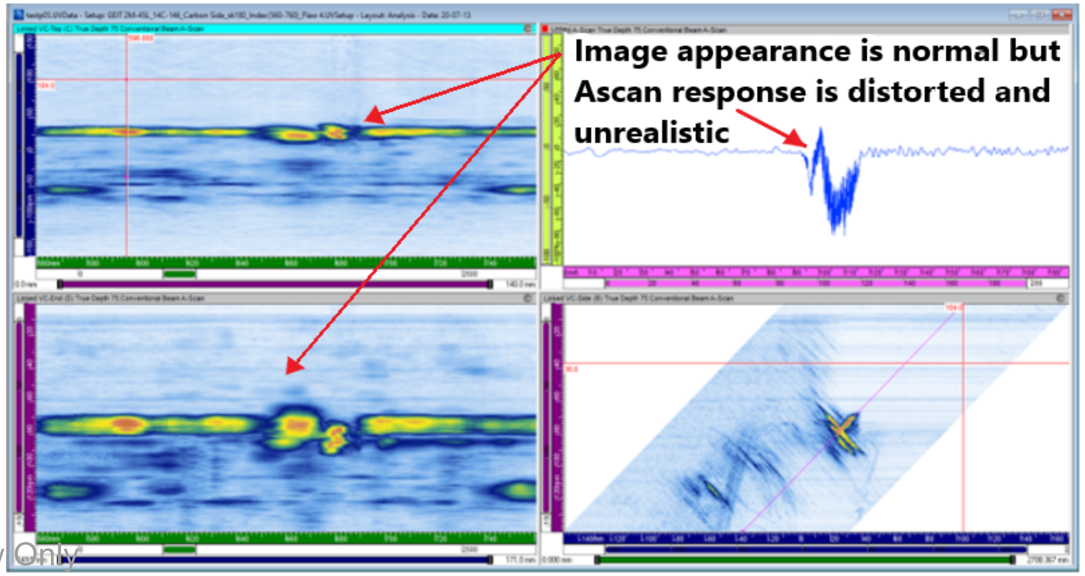
Errors Identified in the Modification Process

Original and modified flaw with accompanying original mode converted response

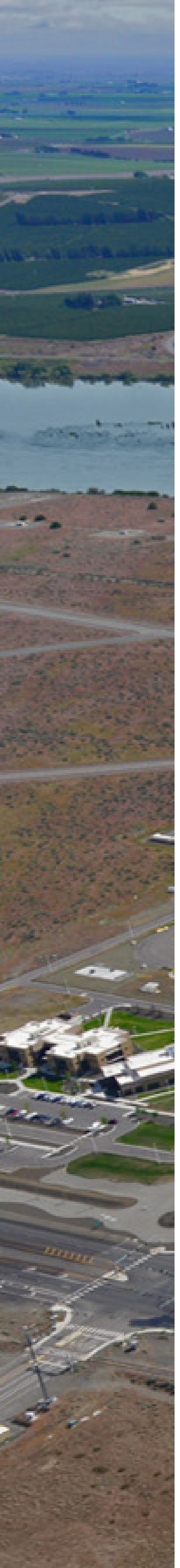
Original and modified flaw with accompanying mode converted response relocated to appear as root geometry. Raw A-scan data from flaw area appears realistic





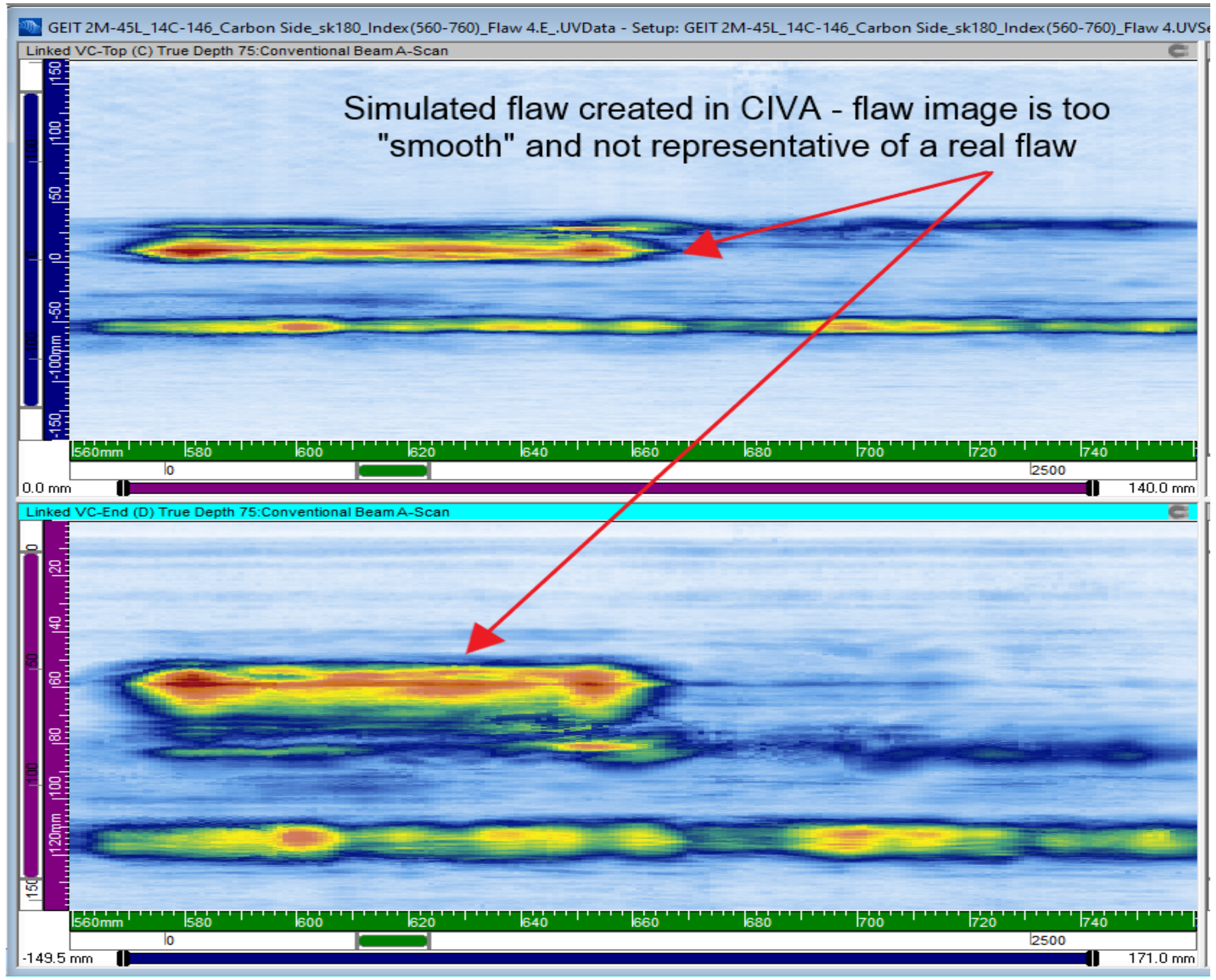


Raw A-scan data of modified mode converted response A-scan data is distorted and unrealistic

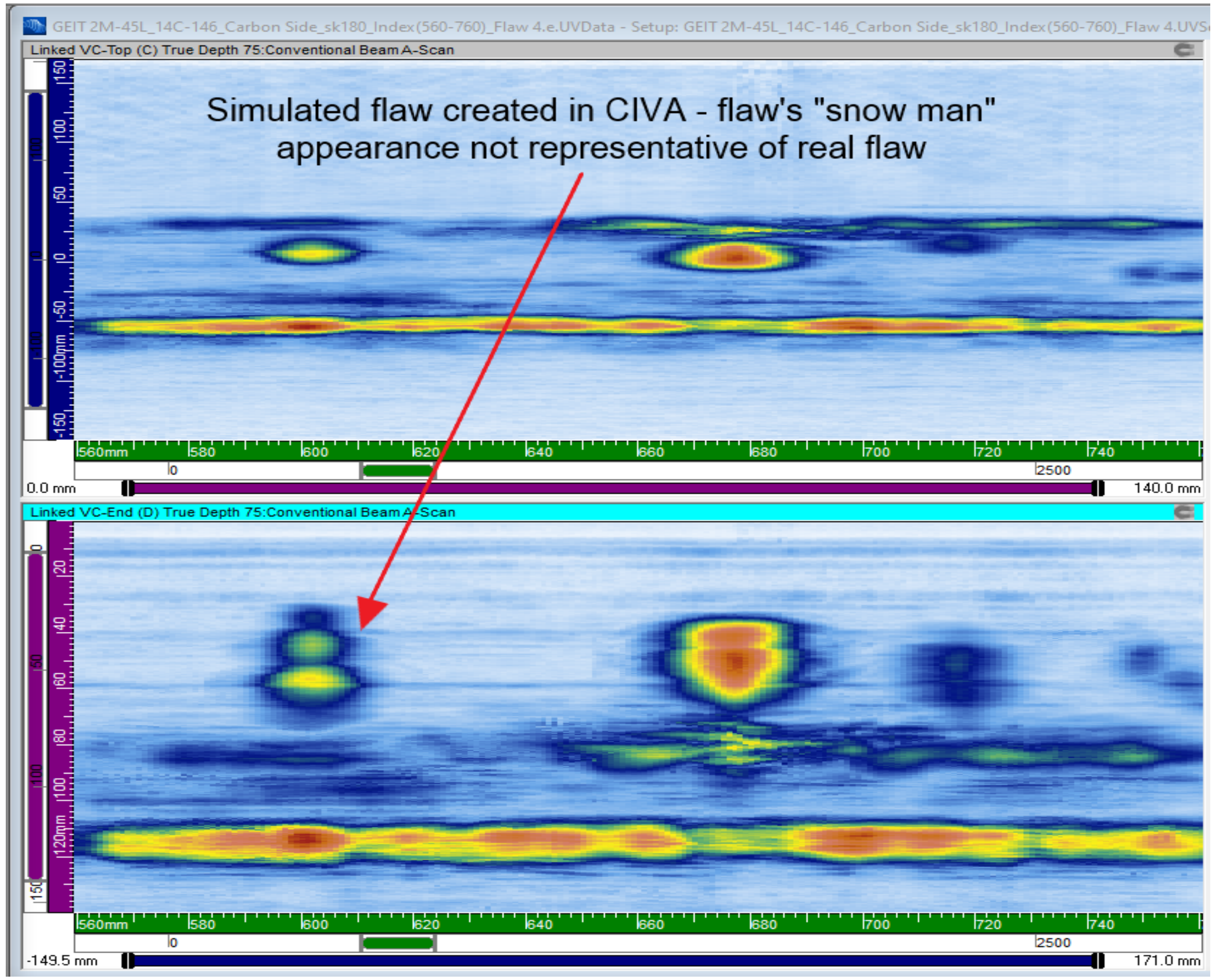


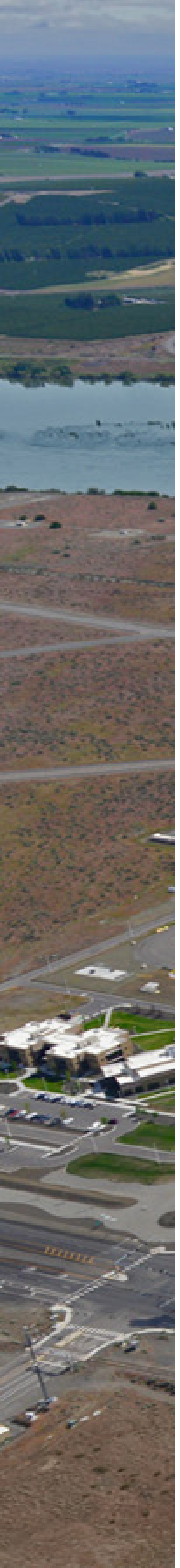
Errors Identified in the Creation of Synthetic Flaws

A synthetic flaw created in CIVA produced a relatively uniform intensity uncharacteristic of the “jagged” appearance of a real flaw



A synthetic flaw created in CIVA produced an unrealistic “snowman” appearance uncharacteristic of a real flaw





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Time Required for Data File Modification

- Not a fixed value – processing time is dependent upon:
  - Data size of the source file
  - Physical size of the image area to be modified
  - Number of specific modifications being performed
- Can range from 20 minutes to 1.5 hours
  - Only the processing time and dependent on file size and computer speed
  - Does not include time required to create the configuration file
  - This could take up to 4 hours depending on configuration complexity
- Once completed and viewed in UltraVision there may be additional adjustments required for the modification to appear as a real flaw
  - When adjustments are required, the entire process must start over beginning with revision of the configuration file
  - Results must be such that a trained analyst will not be able to tell the data set has been modified

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Summary & Flaw Modification Results

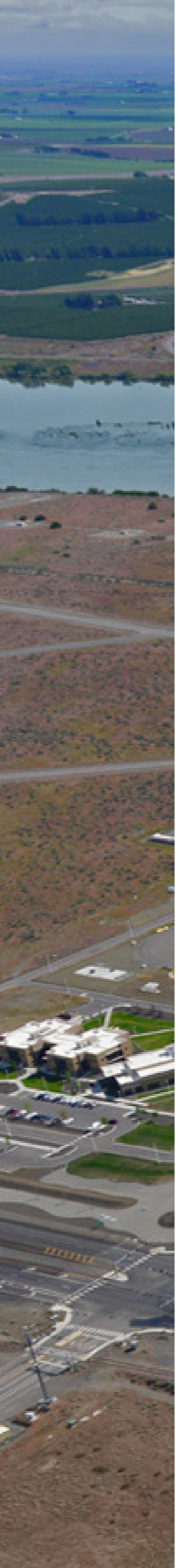
- Based on modification of conventional single probe data from 20 empirical source files containing flaws:
  - The MVM software can produce modified flaws that exhibit real flaw characteristics
  - The modification process can be time consuming, depending on the complexity of the modification, but is more cost effective compared to the fabrication of specimens containing flaws
  - A user’s manual or modification procedure does not currently exist for the software
    - ✓ A “Basic Operation Guide” was developed; however, it does not contain specific procedural steps to perform a modification
    - ✓ Training on software use must be provided to users or a modification service provided (EPRI)
  - Personnel performing flaw modifications must possess a level of knowledge in UT examinations and the UltraVision software
    - ✓ The specific competency level has not yet been defined

Pros & Cons of Virtual Flaw Technology

- Pros
  - Provide time and cost savings over the fabrication of test specimens containing flaws
  - A data analyst could create specimens with real world geometric conditions for training purposes
  - Virtual flaws could allow for an expanded test dataset
- Cons
  - Expertise required to assess the quality and realism of a virtual flaw
  - Virtual flaws may not be representative of real flaws
  - The essential parameters of existing software to produce valid results are unknown

Areas Requiring Industry Action

- Document the minimum required training and experience required for personnel performing flaw modification and how to determine if a flaw is acceptable for use
  - Identifying modifications to be performed
  - Performing the modifications
  - Assessing the modifications
  - Process required to revise or adjust a modification
- ASME Code action for acceptance of virtual flaws for training, certification, and qualification
  - Process would begin in ASME Section XI Working Groups
    - ✓ Working Group on Personnel Qualification, Visual, Surface, and Eddy Current Testing
    - ✓ Working Group on Procedure Qualification and Volumetric Examination



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Thank you