

Expansion and Refinement of EPRI Virtual Mockup Capabilities

Update: 2025 NRC-EPRI TIE

A graphic featuring a blue rounded rectangle with a white border. Inside, the text "Together... Shaping the Future of Energy®" is written in white. The background of the graphic shows a blurred image of two people wearing hard hats and safety vests, looking at a tablet.

Together...
Shaping the
Future of Energy®

George D. Connolly Engineer, EPRI, Inc.

J. Leif Esp Program Manager, EPRI, Inc.

Aroldo Claus Data Analyst, Nucleoeléctrica Argentina s. a.

22 January **2025**

Outline

- EPRI Virtual and Synthetic Flaw software suite:

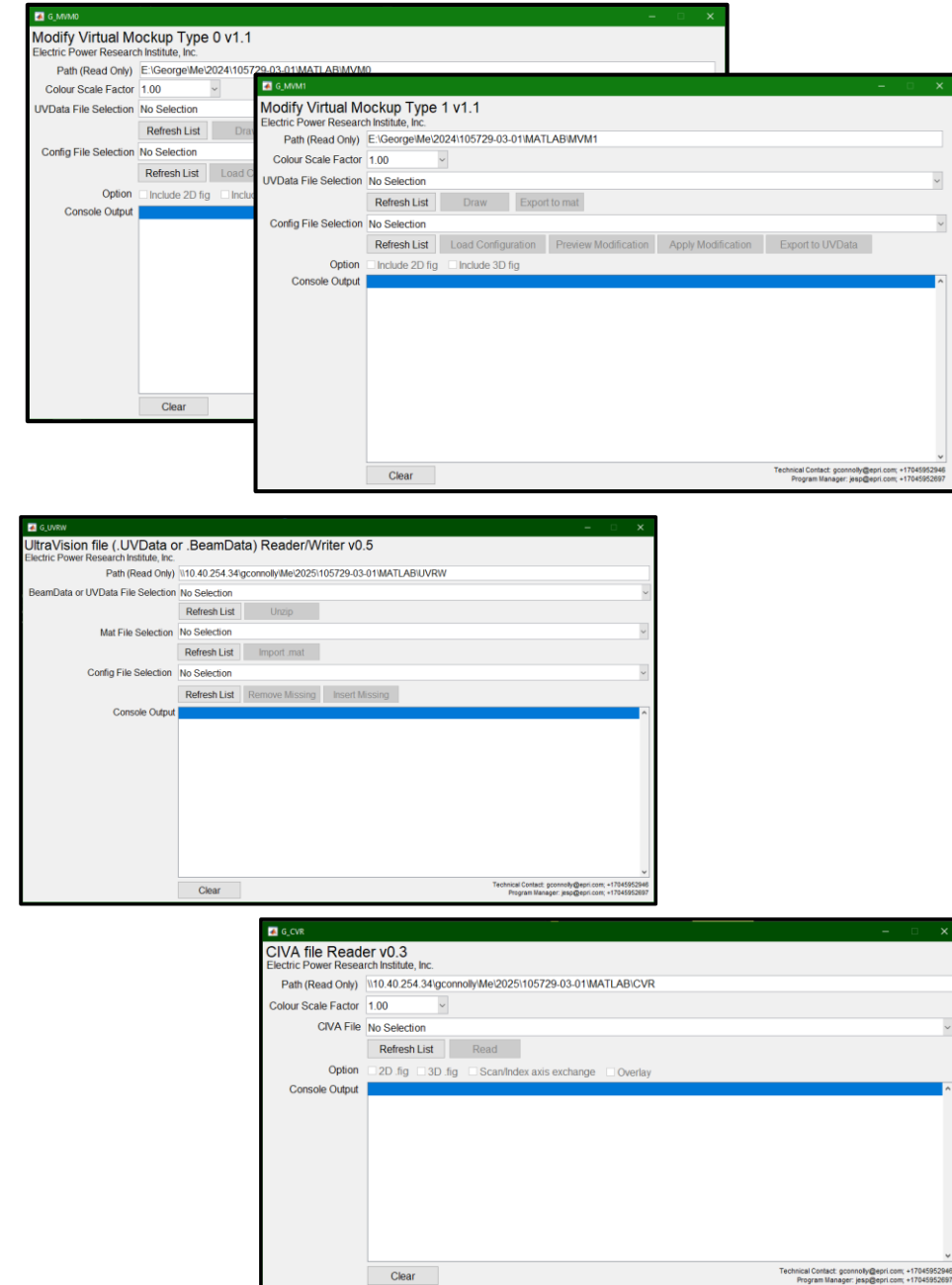
 **MVM0** “Modify Virtual Mockup Type Zero”

 **MVM1** “Modify Virtual Mockup Type Zero”

 **CVR** “CIVA Reader”

 **UVRW** “UltraVision Reader Writer”

- In this presentation:
 - Summary of recent improvements
 - Update on ongoing collaboration and industrial partnerships
 - New deliverable (November **2024**)
 - Perspectives: **2025** and beyond





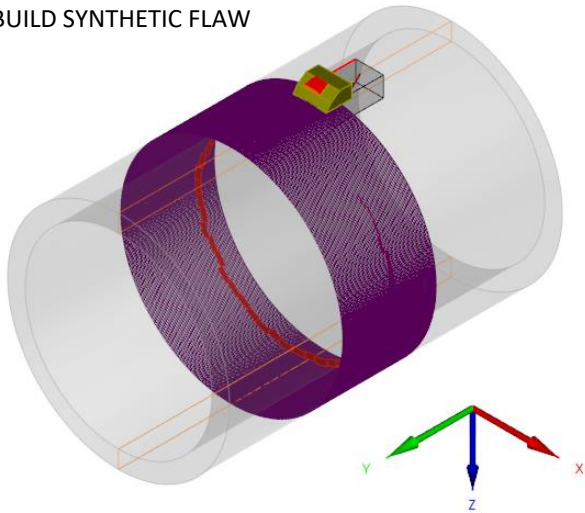
Summary of Recent Improvements

MVM in conjunction with CIVA

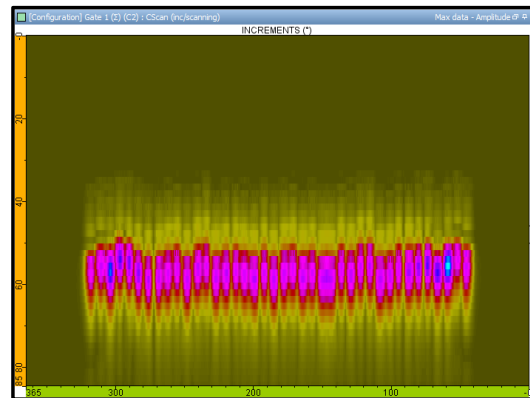
Summary of Recent Improvements

- Concept and workflow presented in §3 of the **2023** TR*; however, further improvements made during **2024**:
 - Multiple channels can be processed e.g., TFM with multiple modes
 - Scan/index axes can be manually exchanged
 - Overlays can be drawn in 2D and 3D for certain configurations: Plate, cylinder, certain types of weld and 2D CAD imports
 - Blending parameters now contained within the configuration file (improves auditability)
- Case study: Synthetic flaw insertion for AHC data file
 - In 2024, further data files with synthetic insertions were generated

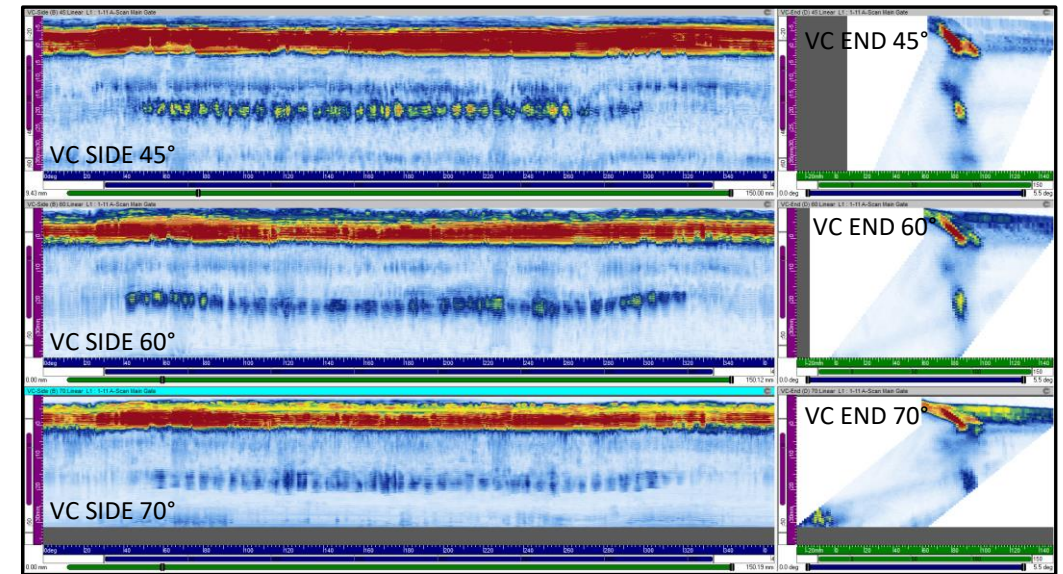
CIVA MODEL:
BUILD SYNTHETIC FLAW



CIVA RESULTS:
UNCORRECTED CSCAN (FOR 45° CHANNEL)



BUILD MOCKUP:
INSERT SIMULATED DATA TO DIFFERENT CHANNELS

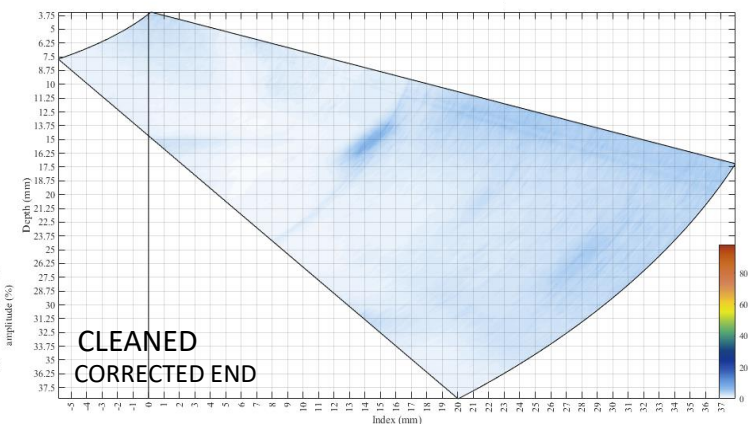
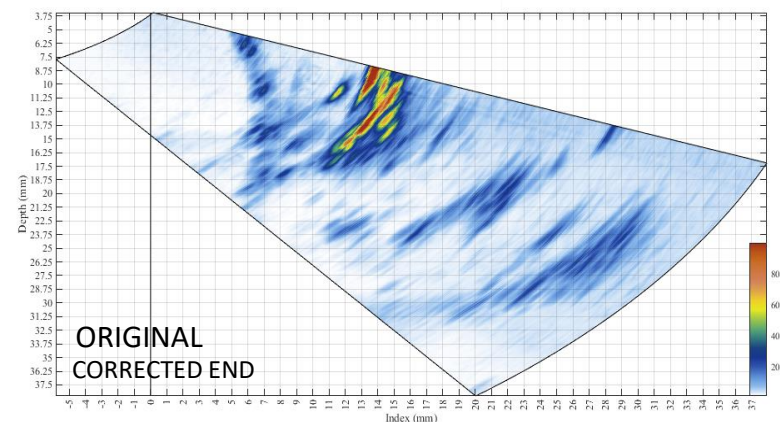
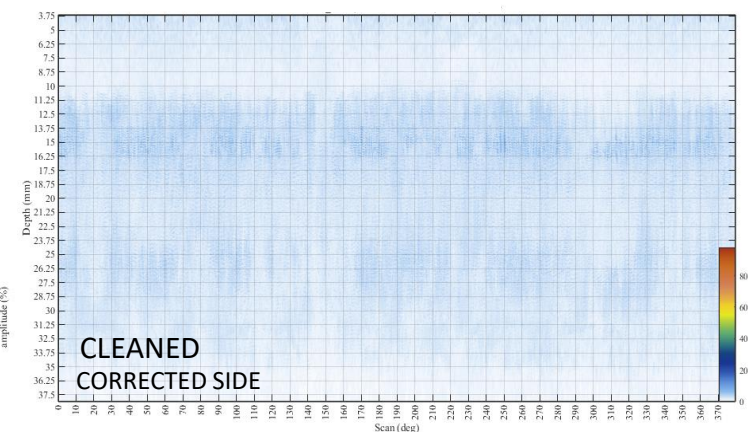
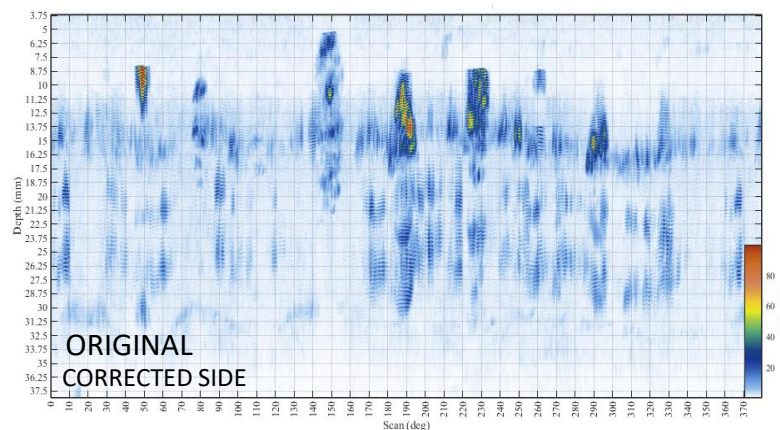


* Nondestructive Evaluation: Virtual and Synthetic Mockups—Electronic Implantation of Virtual and Synthetic Flaw Responses into Previously Recorded Data. EPRI, Palo Alto, CA: **2023**. 3002026416 (publicly available)

Mockup Cleaner

Summary of Recent Improvements

- Concept:
 - Prominent reflections that are limited along the rotation axis are suppressed closer to the level of the noise floor
 - Background noise left unaltered
 - Features that are consistent along the length of the rotation axis should be left unaltered
- The concept was illustrated in §2.3 of the **2023 TR***; however, further improvements made during **2024**:
 - Operation and associated threshold now integrated into the configuration file (improves auditability)
 - User specifies which channel and beam is to be cleaned
 - Region can be drawn to clean a specified part of the beam

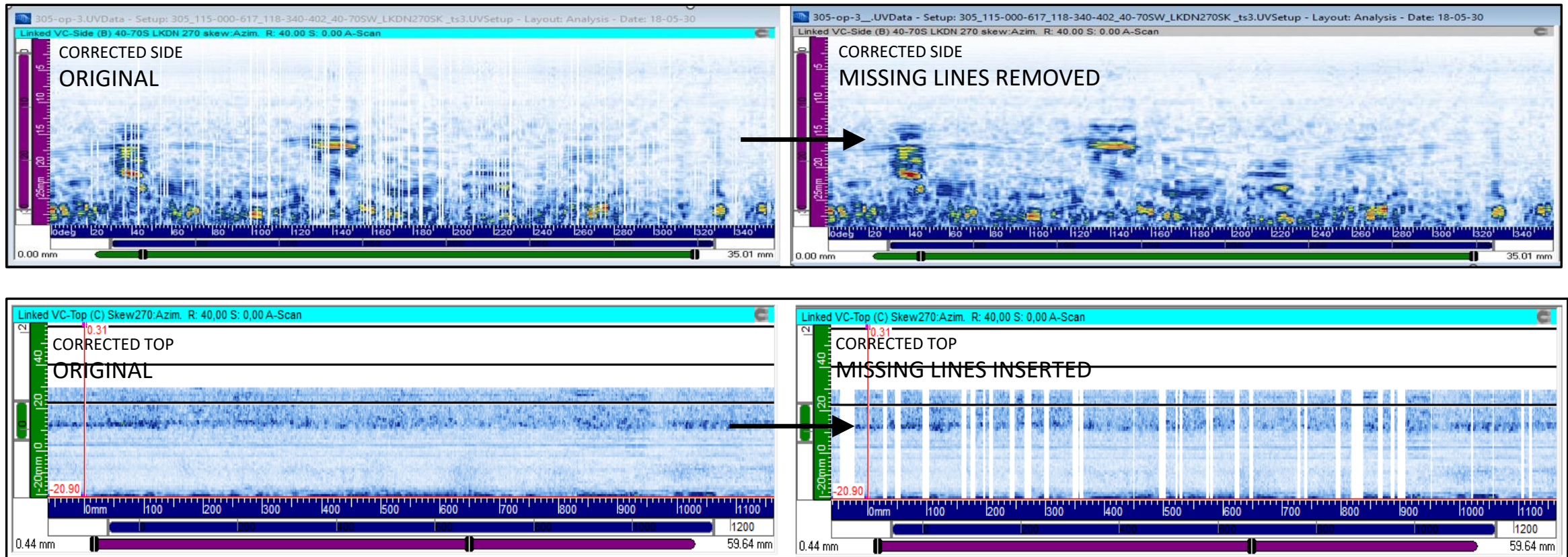


* Nondestructive Evaluation: Virtual and Synthetic Mockups—Electronic Implantation of Virtual and Synthetic Flaw Responses into Previously Recorded Data. EPRI, Palo Alto, CA: **2023**. 3002026416 (publicly available)

“Missing” Scan Lines

Summary of Recent Improvements

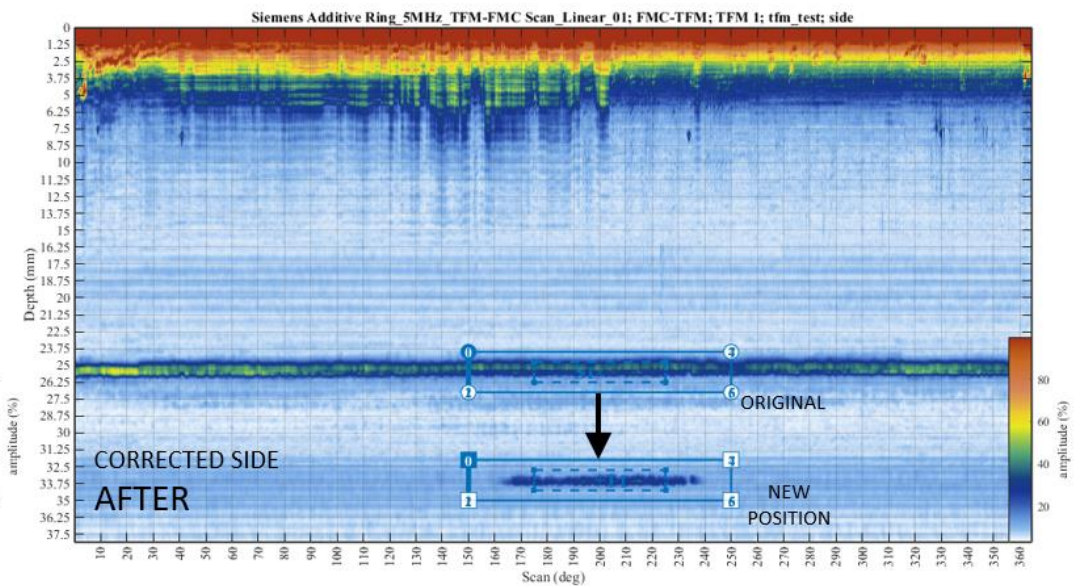
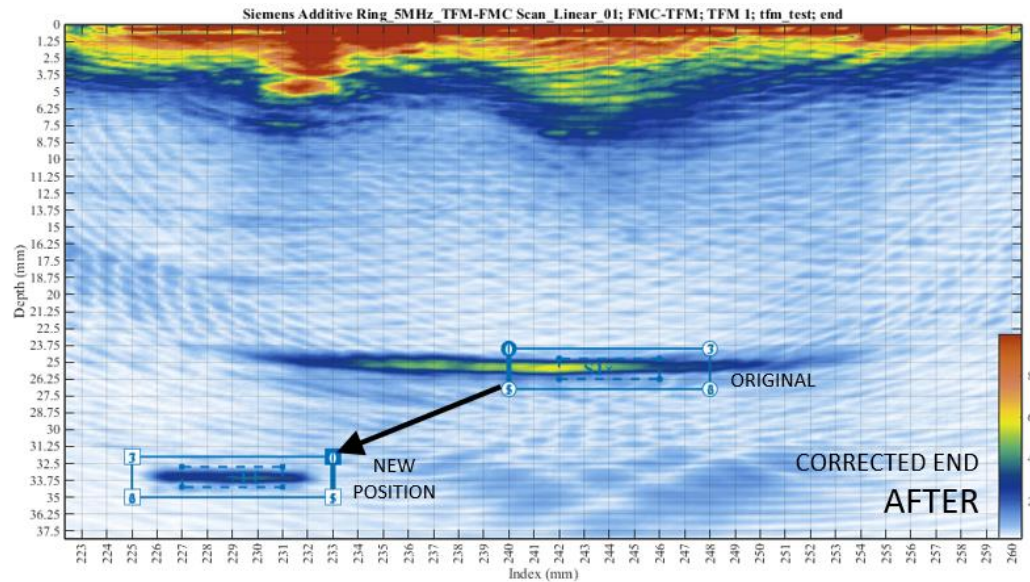
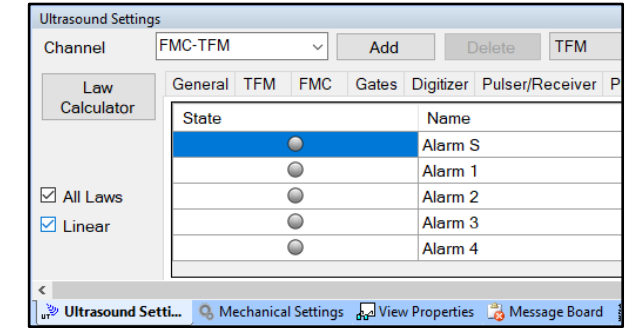
- “Missing” scan lines can be removed using the UVRW tool function “Fill Missing”
- Specified can lines can be rendered “missing” using the UVRW tool function “Insert Missing” which reads a configuration file



Files Containing TFM Channels

Summary of Recent Improvements

- MVM0 can modify data files containing TFM acquisitions
 - Requires “linear” option enabled to store TFM “beams” in the same channel
 - If not checked, MVM1 can be used to visualise the TFM but not yet to modify; simple workarounds can be implemented if necessary
- Configuration process is agnostic of acquisition type





Update on Industrial Partnerships

Overview

Update on Industrial Partnerships

- Five external collaborators past and present are involved in the EPRI virtual flaw and synthetic flaw project
 - EPRI project team provides worked examples, guidance, software improvements upon request
- Long-term aims:
 - Develop virtual flaw and synthetic flaw technology for the benefit of the NDE industry
 - Provide EPRI members and collaborators the ability to generate their own virtual mockups
 - Qualification of virtual flaw and synthetic flaw technology for all training, educational and demonstration purposes



Collaborative Activity with ÚJV Řež, a. s.

Update on Industrial Partnerships

■ Activities completed in **2024**:

- Versions of software callable from command line compiled and provided with documentation and worked example of batch script
 - Allows batch running
 - Application: Image augmentation for deep learning; development tool for random creation of virtual flaws
- At this collaborator's request, the following capabilities were added to the software suite:
 - Improved workflow to import simulated CIVA data
 - Controlled ability to insert and remove “missing” scan lines from data files by configuration file
 - File modification not directly involving the data e.g., adjusting a scan range

■ Perspectives for **2025**:

- Some visualisation issues to be fixed
- Ensure compatibility with Windows 11
- Aim for full regulatory acceptance for this technology in personnel qualification

December 2024: ÚJV delivered virtual mockups to ČEZ for personnel qualification

Collaborative Activity with Nucleoeléctrica Argentina s. a.

Update on Industrial Partnerships

- Activities completed in **2024**:
 - Manufacture of training sets for thermal sleeve inspection in conical DMW configuration
 - Manufacture of training sets for AQB (IRAM-MN-ISO 9712 training course)
 - Trained a NDE UT data analyst in a first-of-a-kind DMW inspection using virtual flaw technology
 - Implemented procedure: PDI EPRI-ENC-DMW-PA-1 at Atucha NPP
- WIP: Initiated a study on synthetic flaw generation (CIVA) in quantitative comparison against virtual flaws with EPRI collaboration
- Perspectives for **2025**:
 - Ability to export modified data to the OmniScan (X3+) format
 - Obtain approval for use in operator certification
 - UT Phased Array; IRAM-MN-ISO 9712 “Non-destructive testing; Qualification and certification of personnel”
 - Collaboration with EPRI to assemble a library or catalogue of standard and basic flaws

Training data sets built for AQB governing qualification and certification of personnel

Collaborative Activity with PNNL

Update on Industrial Partnerships

- WIP for **2024-2025** and beyond:
 - Technical assessment of digitally-modified and simulated flaw technology
 - Collaboration with EPRI project team:
 - Investigate appropriate use and limitation boundaries for the use of virtual flaw for personnel qualification
 - Consider requirements for incorporation into ASME code
 - Understanding of regulatory framework with NRC needed for such incorporation

2024 Deliverable

- Technical brief “EPRI Virtual Mockup and Synthetic Mockup Suite of Software Tools” November 2024 publicly available
 - In-depth overview of four tools in the suite
 - Worked examples of selected newer capabilities
 - Automated removal of indications in an acquisition but retaining geometric features e.g., weld root
 - Demonstrated manipulation of missing scan lines for sectorial data
 - Insertion and blending of CIVA simulated data into acquired data file*

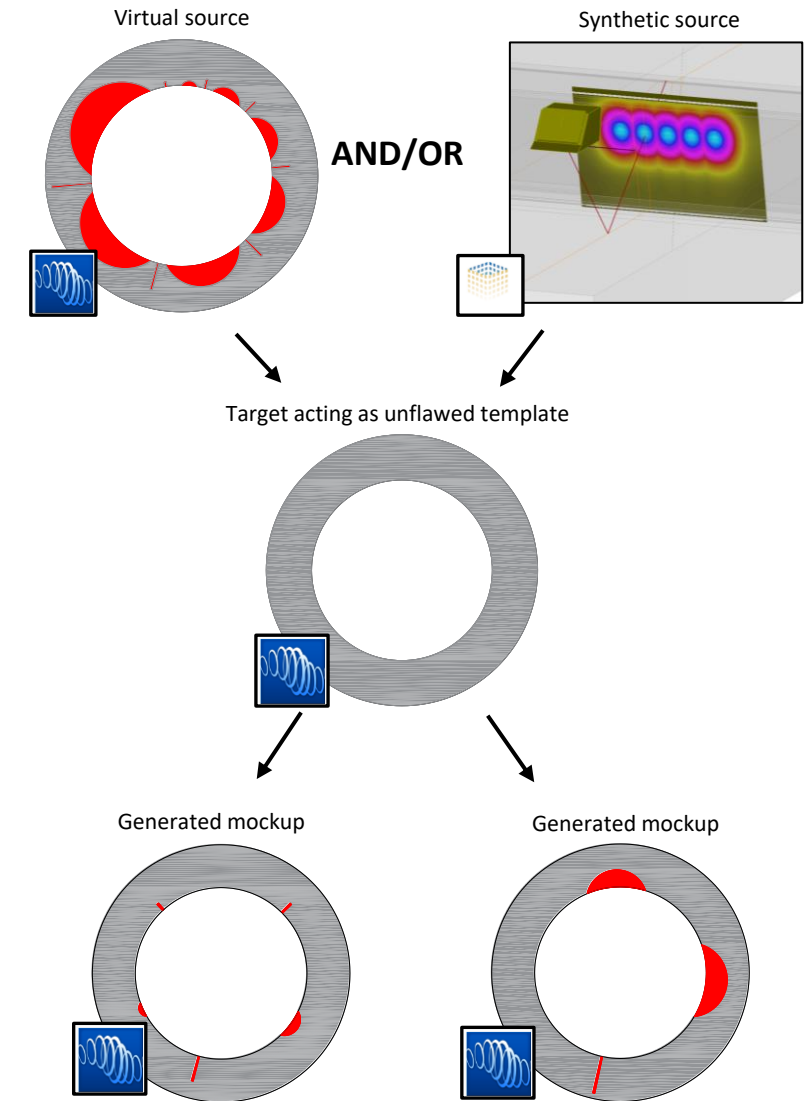


*Appears in other recent publications, also publicly available:

- Nondestructive Evaluation: Development of a Versatile and Efficient Virtual Mockup Modification System. EPRI, Palo Alto, CA: **2022**. 3002023719
- Nondestructive Evaluation: Virtual and Synthetic Mockups—Electronic Implantation of Virtual and Synthetic Flaw Responses into Previously Recorded Data. EPRI, Palo Alto, CA: **2023**. 3002026416

Perspectives: 2025 and beyond

- Encoded training and qualification sets (**2025+**):
 - Set of unflawed open samples procured (SMW and DMW of various thicknesses)
 - Used in conjunction with current inventory of PD samples; the number of virtual mockups that can be generated is multiples of the number of physical mockups
 - Can be used as training data for encoded analysis or added to UT simulator to increase population of available hands-on training data
 - Looking into potential future use for UT in lieu of RT qualification and training datasets
- Advanced methods involving synthetic flaw and data generation (**2026+**):
 - Virtual flaws to be complemented or supplemented using synthetic where virtual flaws are deficient or inadequate
 - Assemble library of known responses from given search units
 - Refine modelling techniques for flaw simulation



Technical report planned for Q4 of 2025; likely to be made publicly available



TOGETHER...SHAPING THE FUTURE OF ENERGY®