Expansion and Refinement of EPRI Virtual Mockup Capabilities

Update: 2026 NRC-EPRI TIE

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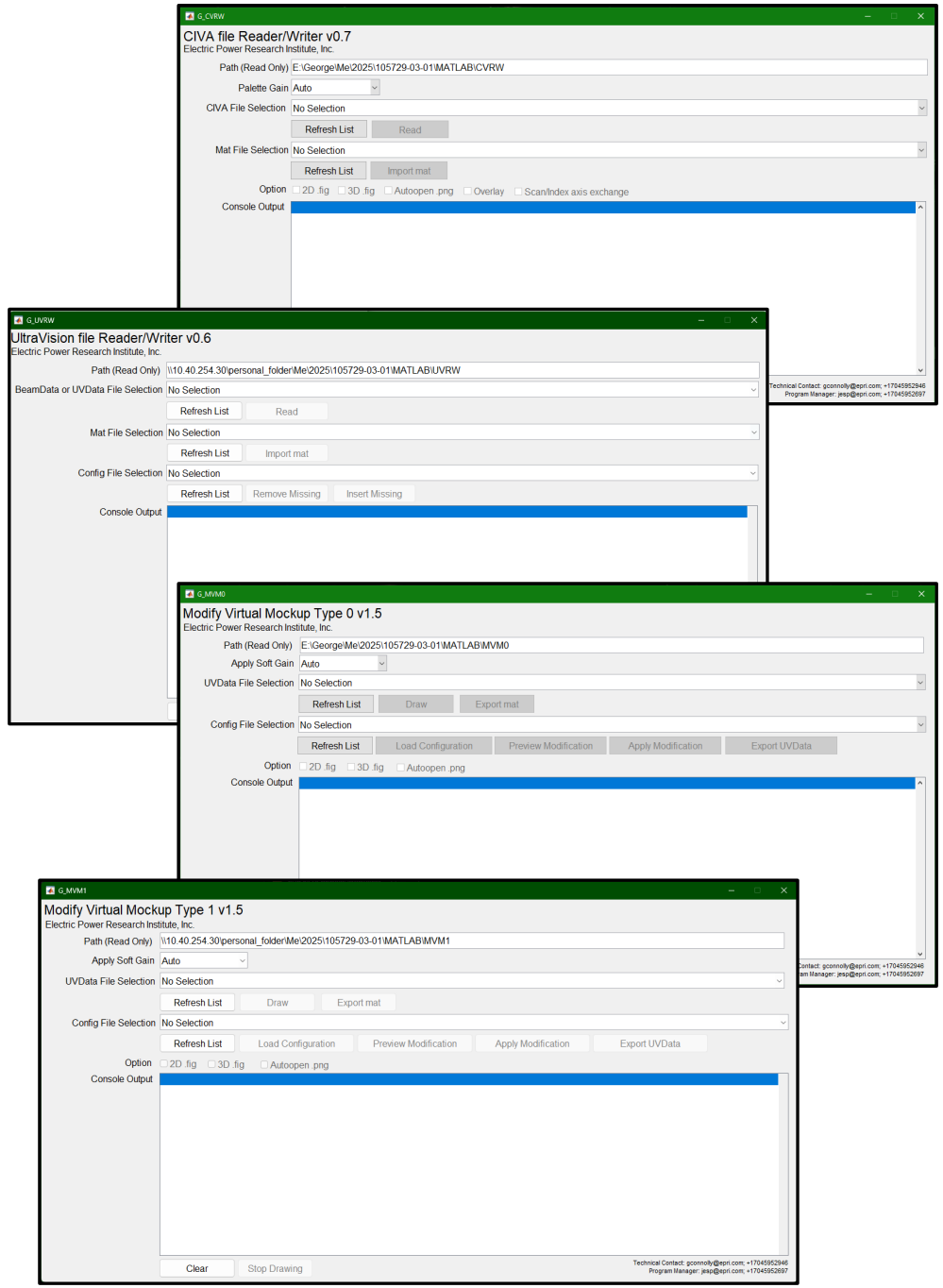
21 January **2026**

Outline

- EPRI Virtual and Synthetic Flaw software suite:
  - **CVRW** “CIVA Reader Writer”
  - **UVRW** “UltraVision Reader Writer”
  - **MVM0** “Modify Virtual Mockup Type Zero”
  - **MVM1** “Modify Virtual Mockup Type Zero”
- In this presentation:
  - Summary of recent improvements
  - Update on ongoing collaboration and industrial partnerships
  - **2025** Publications
  - Perspectives: **2026** and beyond

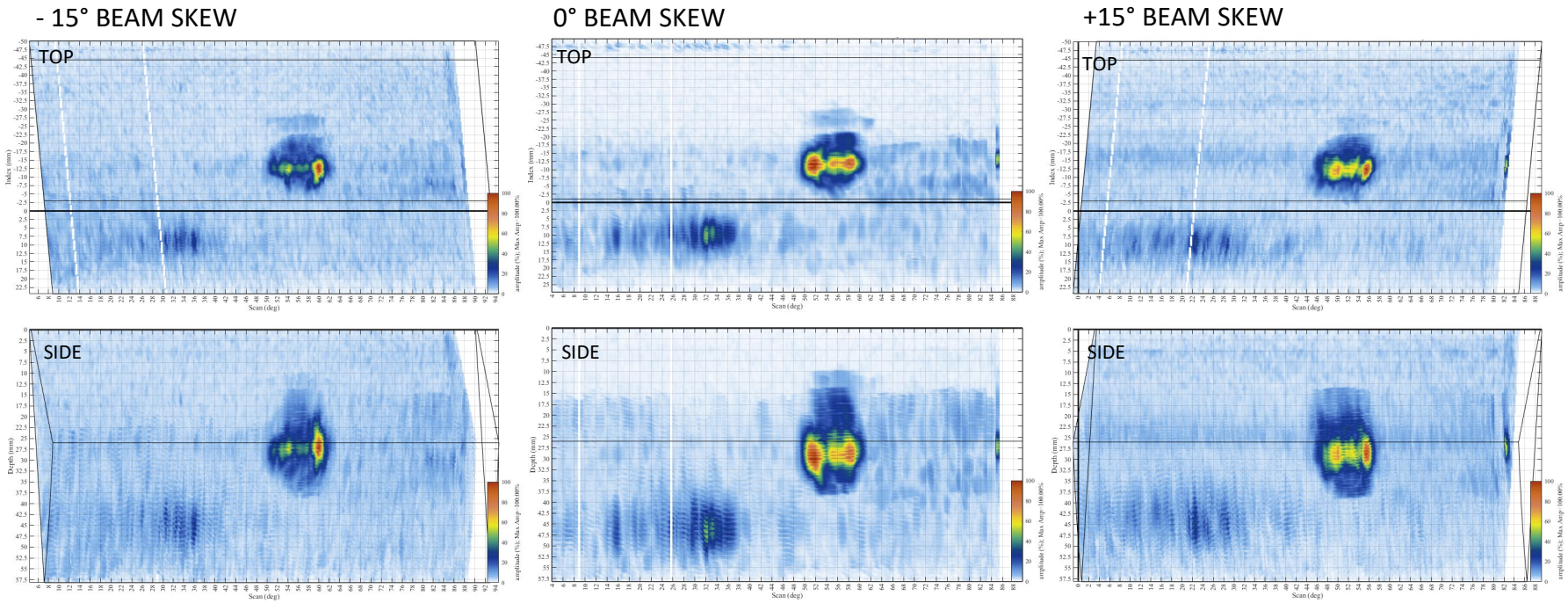


Summary of Recent Improvements

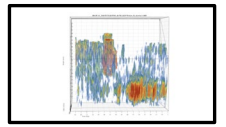
Skew Support

Summary of Recent Improvements

- Beam skew support in MVM and CVRW; the following account for beam skew:
  - Graphical output
  - Region positioning and modification
  - Example shown below with [-15,0,15]°
- Restrictions on probe skew removed from MVM and CVRW



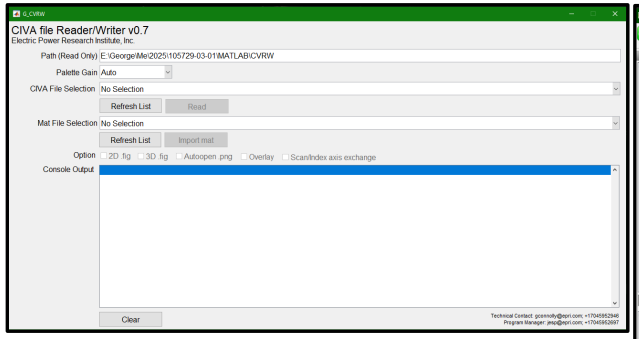
CLICK TO PLAY

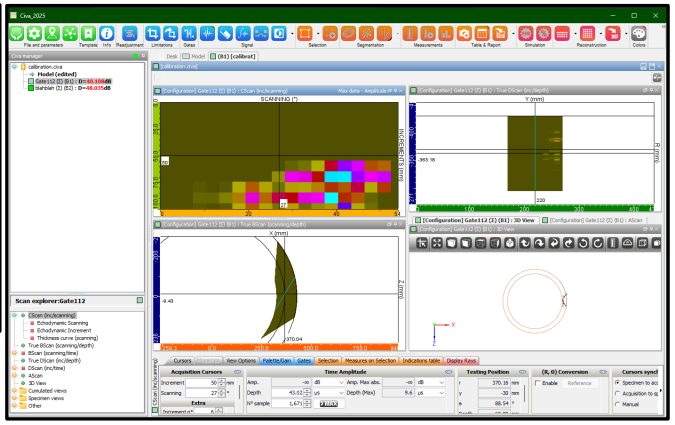


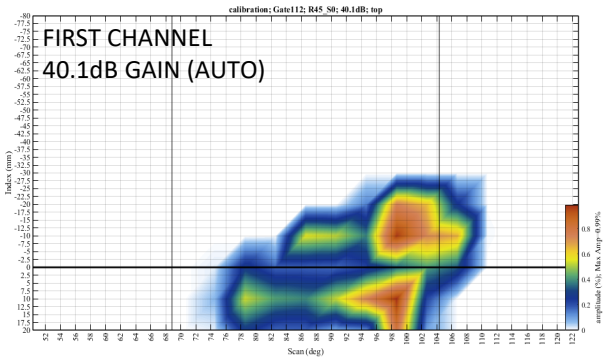
CIVA Reader/Writer

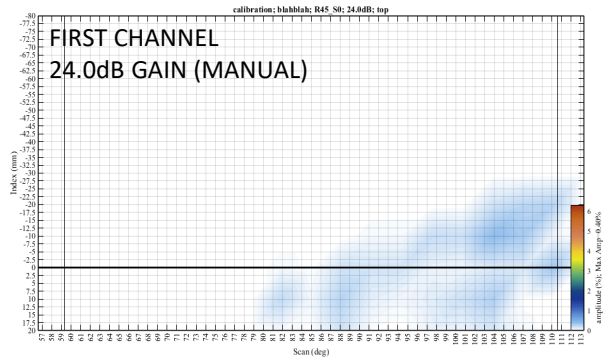
Summary of Recent Improvements

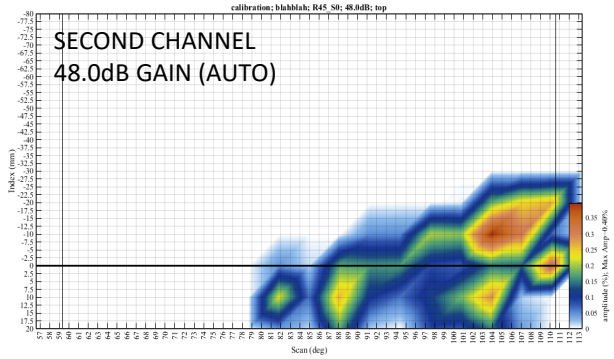
- Improvements to the CIVA reader:
  - No longer needs external tool to read compressed A-Scans
  - Supports arbitrary number of gates; channels named after gates
  - Improved channel and beam nomenclature for different UT types e.g., TFM
  - Supports reading of FMC data
  - Restrictions upon beam skew and probe skew have been eliminated
- A-Scan amplitude output:
  - Amplitude output changed from CIVA “points” to percentage
  - Supports applied calibration
  - Palette Gain mimics behaviour in the CIVA GUI (see right)

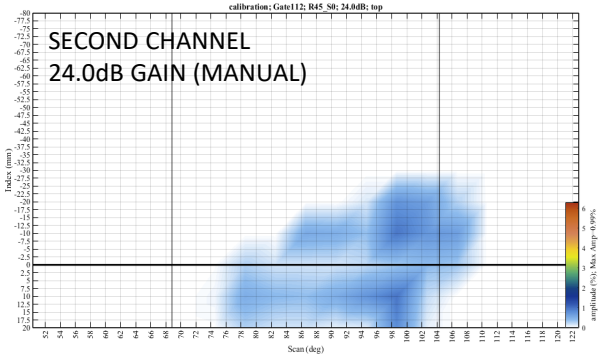








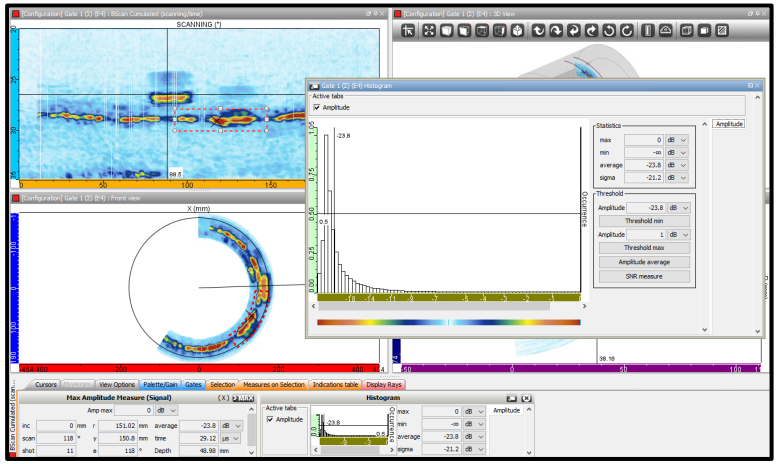




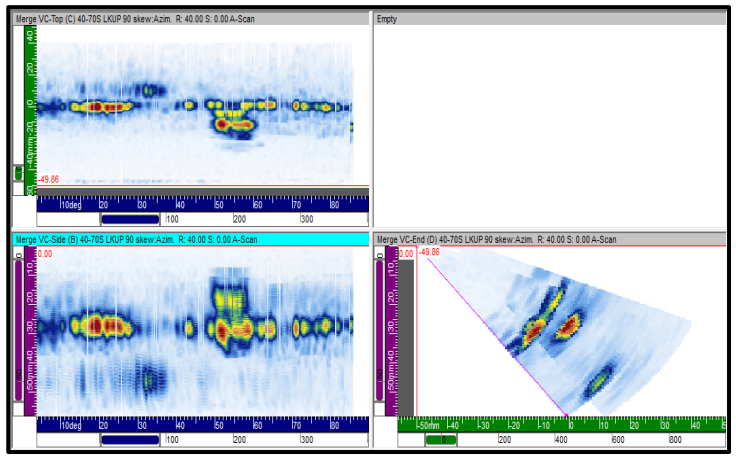
CIVA Reader/Writer (cont'd)

Summary of Recent Improvements

- CVRW tool importing data from the MVM intermediate file format to the .civa file; example workflow:
  - Establish CIVA model based upon data source, matching probe motion and A-Scan sample count
  - At least one flaw to be inserted to force CIVA generation of results files
  - Export from UltraVision using UVRW
  - Allow CIVA processing tools to be applied to imported data
  - Limitation: Non A-Scan data are not overwritten e.g., C-Scan data and modes identification



Original .UVData file as data source



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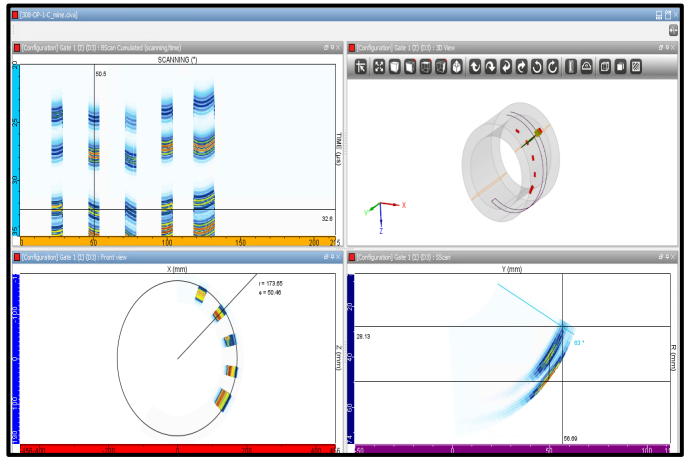
CIVA simulation as data target



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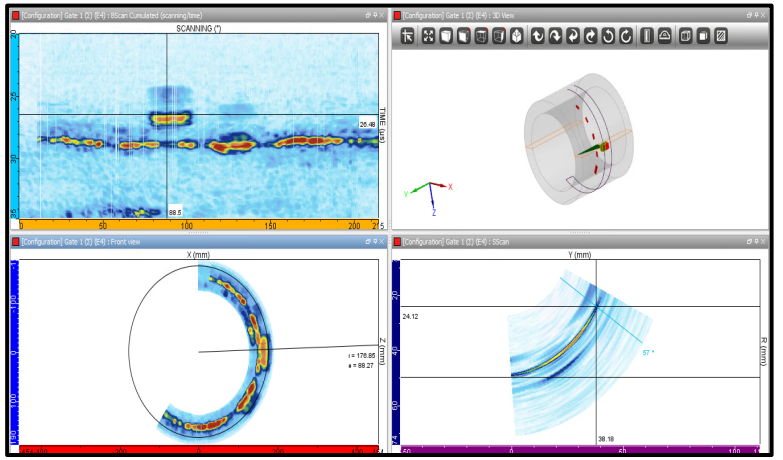
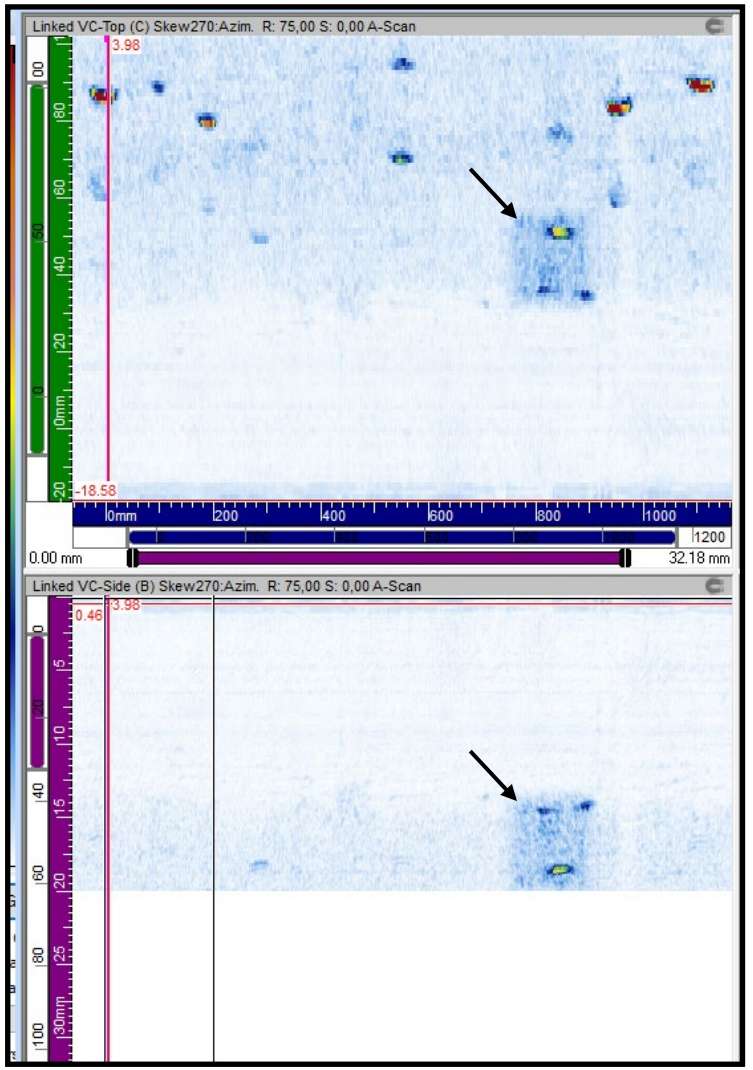
CIVA file with imported data allowing for use of CIVA processing tools



Digital Mockup Adjustment

Summary of Recent Developments

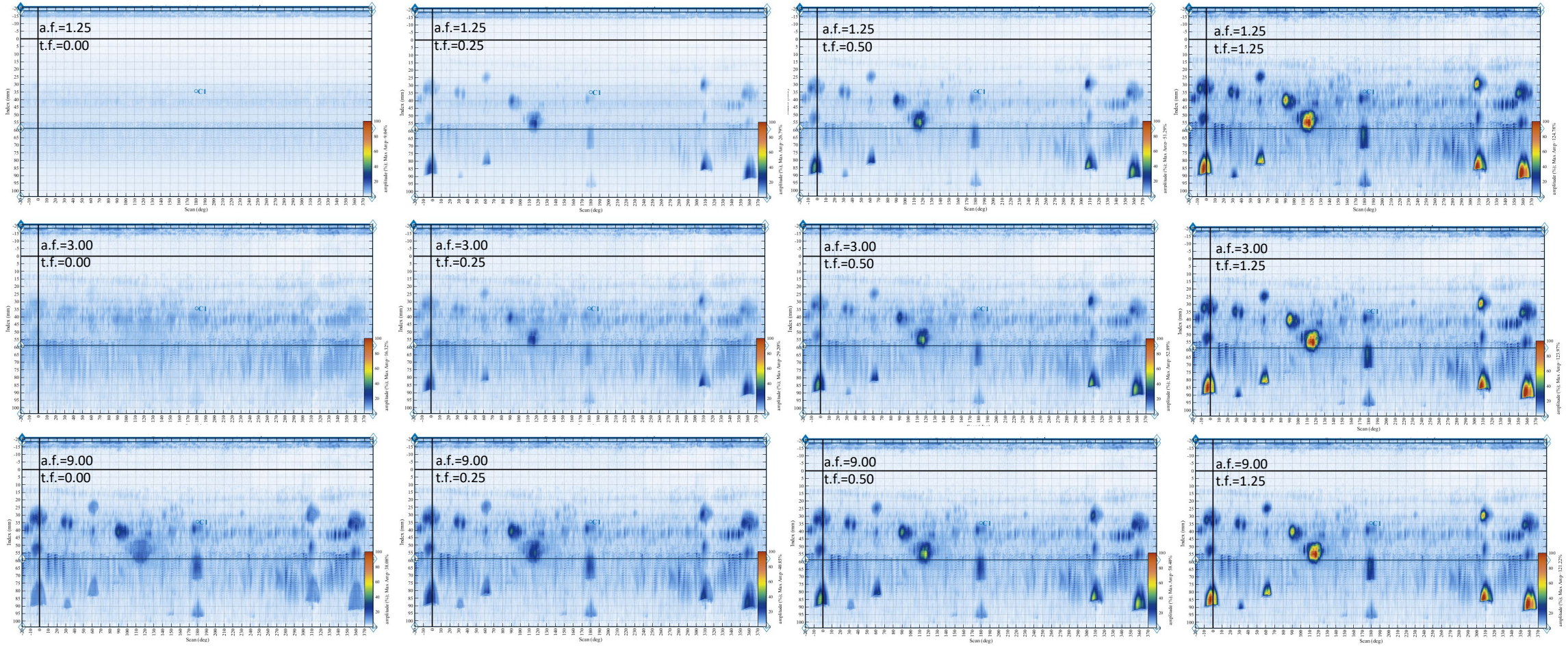
- Concept of mockup “cleaner” introduced in **2023**
  - Reduces prominent reflections above a user-defined threshold to the background noise level
- Concept is extended (**2025**) to give user:
  - Control of the adjustment of prominent reflectors
  - Ability to similarly modify the background noise in isolation
- Motivation: Copying signal from high noise region to low noise region (see right)
  - Problem: High noise is copied with the signal and matches the shape of the region; easily identifiable
  - Source factor was already reduced to zero; can’t reduce it any farther
  - Easiest solution is to reduce the target factor; however, what if I want to retain the max signal amplitude?



Digital Mockup Adjustment: Signal

Summary of Recent Developments

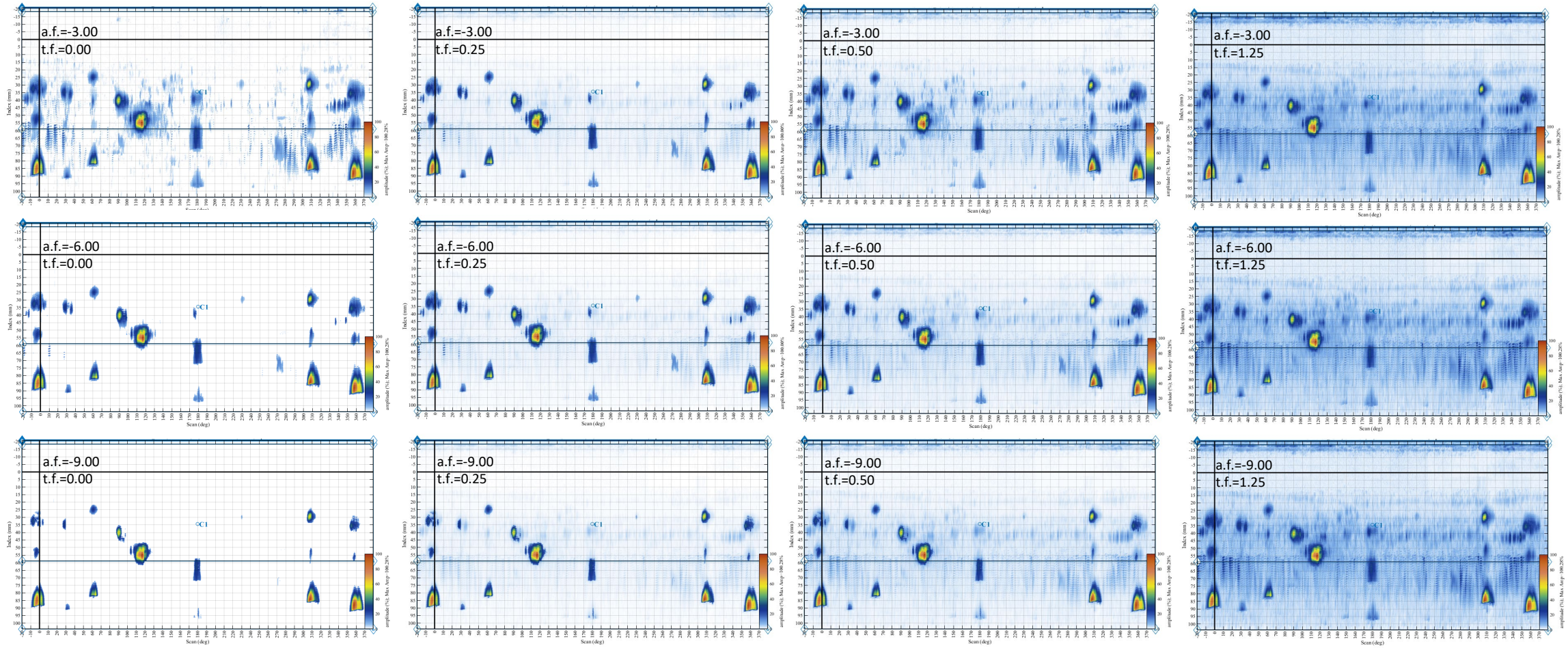
- Two parameters control signal adjustment: Amplitude factor (a.f.) and target factor (t.f.)
- Original mockup “cleaner” only supported equivalent of t.f.=0 (left column)
- Introduced new capability to amplify signals (right column)



Digital Mockup Adjustment: Noise

Summary of Recent Developments

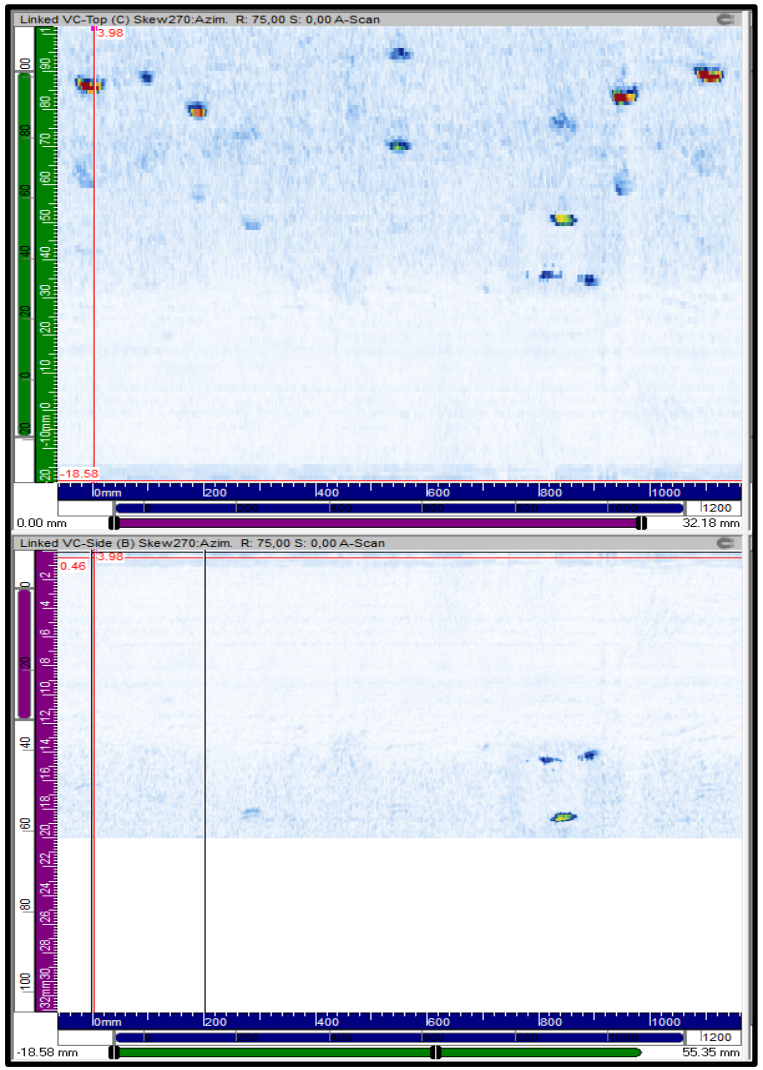
- Two parameters control signal adjustment: Amplitude factor (a.f.) and target factor (t.f.)
- Negative amplitude factor indicates adjustment to be made to noise (data beneath threshold) as opposed to signal (data above threshold)
- Possibility to amplify noise (right column) while leaving signals undisturbed



Digital Mockup Adjustment

Summary of Recent Developments

- Returning to the original problem:
  - Pre-treat the region to be copied by reducing the noise
  - Two possibilities:
    - Simplest: Modify but then adjust the target region afterwards to reduce the noise (shown on right)
    - If target noise texture is important, then pre-treat the source region prior to copying
      - *Drawbacks:* Will need a second, temporary file
    - Neither possibility was possible prior to this change



Update on Industrial Partnerships

Overview

Update on Industrial Partnerships

- Six 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 joint 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

Industrial Partner of the EPRI Virtual Flaw and Synthetic Flaw Project since **2025**

Pacific Northwest NATIONAL LABORATORY

Industrial Partner of the EPRI Virtual Flaw and Synthetic Flaw Project since **2022**

NUCLEOELECTRICA ARGENTINA S.A.

Ministerio de Economía Argentina

Industrial Partner of the EPRI Virtual Flaw and Synthetic Flaw Project since **2021**

ÚJV CEZ GROUP

Industrial Partner of the EPRI Virtual Flaw and Synthetic Flaw Project since **2020**

Activity with New Collaborator

Update on Industrial Partnerships

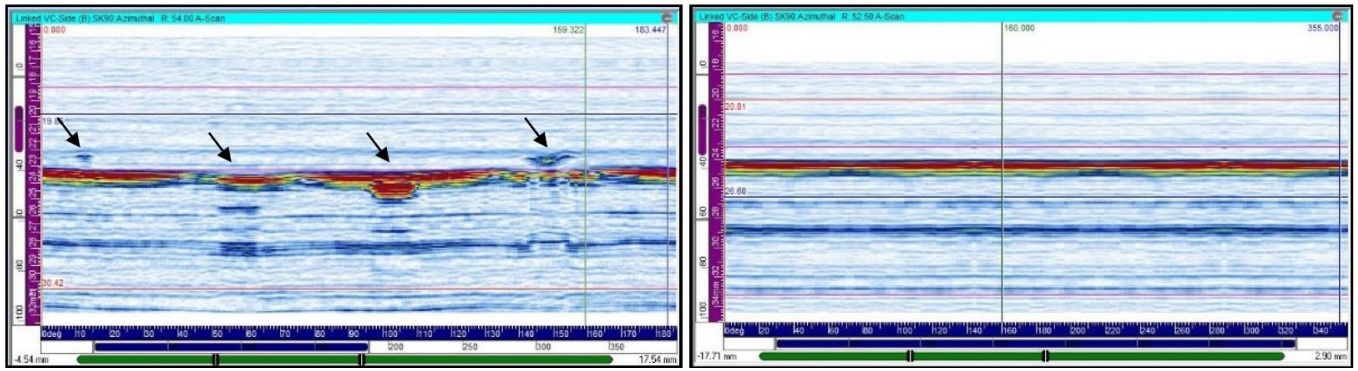
- Overall aims of interest: Evaluation of MVM capabilities in conjunction with CIVA to support:
  - Inspector training
  - Practice examinations
  - Performance demonstration examinations
  - Inspection procedure qualifications
- Specific tasks using MVM1:
  - Embed simulated CIVA flaw responses that are calibrated and benchmarked to physical notch data into UV data files
  - Copying physical flaw data to increase flaw sample set
    - This approach was recently used during a nozzle inspection procedure development and qualification effort
  - Flaw modification prior to implantation to unflawed dataset
- Development of internal standard practice to confirm that embedded simulated flaws would match a real counterpart to provide a technical basis for simulated flaw
- Simulated notch response should match characteristics of real flaws in the following ways:
  - The dominant modes that contribute to the presentation and characteristics of the notch response in the experimental data are captured in the simulated notch in the CIVA model
  - The amplitude of the notch responses of the simulated (% for CIVA) and experimental (%FSH UltraVision) notch are close to each other and change as expected for each small, medium and large sizes
  - The measured length and through-wall depth of the notch is comparable between the CIVA and experimental data of the same notch

Collaborative Activity with NA-SA

Update on Industrial Partnerships

- Activities of **2025**:
  - Virtual flaw technology approved for training purposes in NDE courses: In use at UTN Delta (National University of Argentina)
  - Supporting the use of virtual flaw technology in IRAM-MN-ISO-9712 NDE “Non-destructive testing; Qualification and certification of personnel”
  - Technical support involving MVM application to CIVA simulation datasets including extending scanning range

- Perspectives for **2026**:
  - Allow for modified data export to the OmniScan format
  - Seek approval for the of virtual flaw technology in personnel qualification
    - Via 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
  - Continue technical assessment of digitally-modified and simulated flaw technology



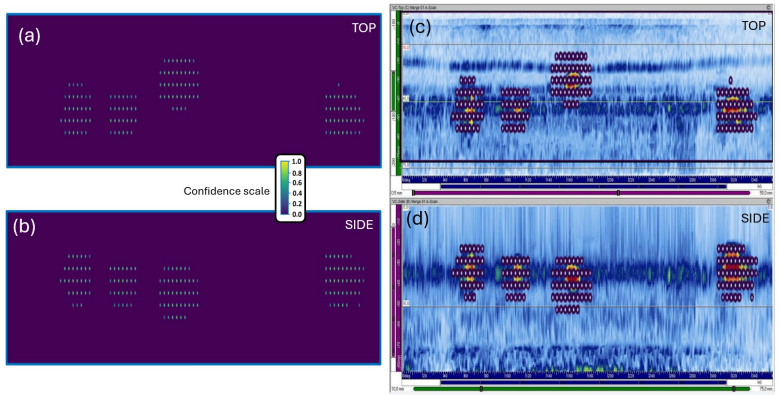
Original mockup (left) and virtual mockup (right), having been relieved of its flaws and with extension of its scanning range. Image provided by NA-SA staff

Collaborative Activity with ÚJV Řež, a. s.

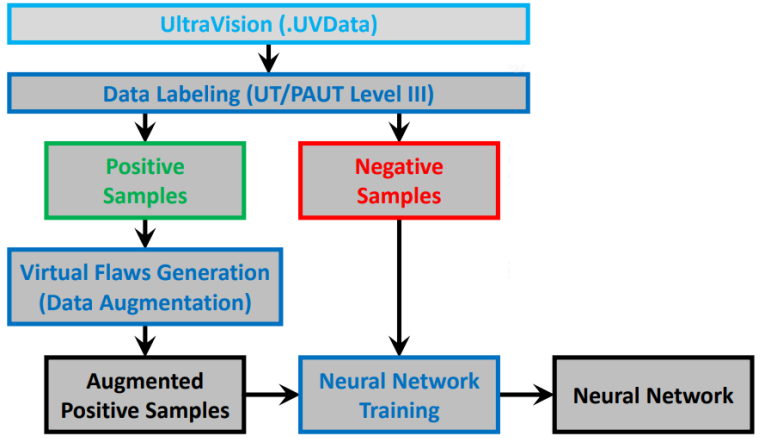
Update on Industrial Partnerships

- Activities completed in **2025**:
  - Applied gain in MVM graphical output mimics that of the UltraVision GUI, at this collaborator's suggestion
  - Improved workflow control and graphics handling
  - Established workflow to automatically generate many configuration files with variation in positioning, orientation and scaling of virtual flaws

- Perspectives for **2026**:
  - Conversion of software tool for improved portability and easier integration with other process
  - WIP to continue to pursue regulatory acceptance for personnel qualification with ENIQ Recommended Practice 10 considering the use of "virtual test specimens"



Example of neural network output to identify potential defect locations in data volume.
Image originally provided by ÚJV staff and taken from EPRI TR #3002033040



How virtual flaw technology is used to train neural networks in an integrated workflow.
Image originally provided by ÚJV staff and taken from EPRI TR #3002033040

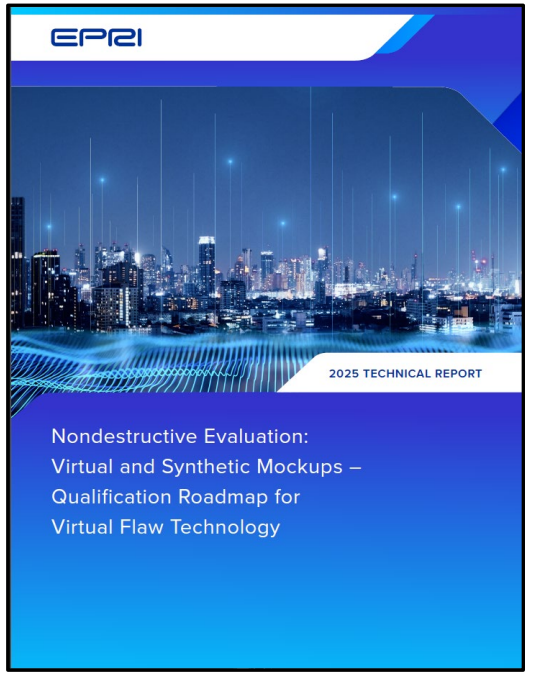
Summary and Perspectives

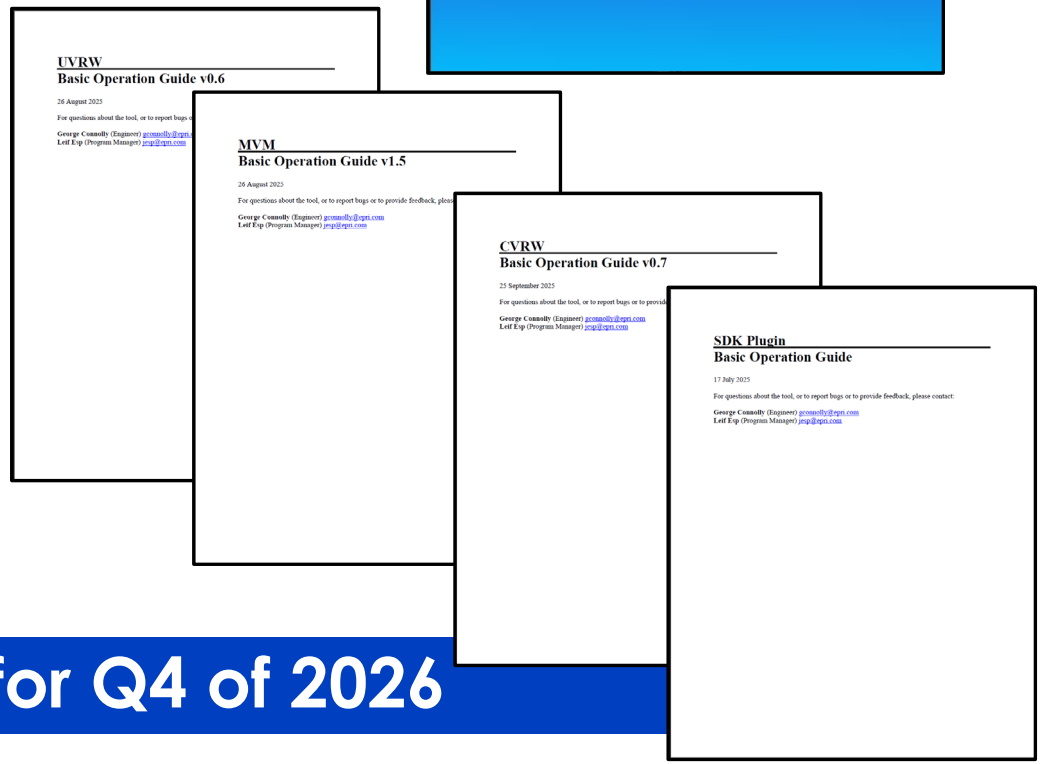
Recent Relevant Publications

- Already published:
  - Dopjera, D. *Divize Integrita a technický inženýring: Virtuálne skúšobné teleso* MVM1. ÚJV DITI/2311/11: **2023**
  - Claus, A., Connolly, G., Esp, J. *PDI EPRI-ENC-DMW-PA-1 Implementation Using EPRI Virtual Flaw Software - A Case of Successful Technology Transfer* **2025** url: https://www.ndt.net/article/NDE-Nuclear-2025/papers/3.5.4_Implementation_PDI%20EPRI-ENC-DMW-PA-1_Atucha_NPP_using_Virtual_Flaws_Technology.pdf
  - Dopjera, D. *Virtual Flaws Generation for Machine Learning* in: Proc. NDE in Nuclear **2025**
  - Harrison, J., Jacob, R. *Virtual Flaw Technology* **2025** url: https://www.nrc.gov/docs/ML2522/ML25224A192.pdf
- Under review:
  - Dopjera, D., Krňoul, Z., Connolly, G. *Machine Learning in NDT* (**2026**) submitted for review to the ASME J. Nuclear Engineering and Radiation Science

New Deliverable in 2025: TR #3002033040

- Technical report “Virtual and Synthetic Mockups – Qualification Roadmap for Virtual Flaw Technology” (top right) publicly available since November 2025
  - Illustration of new developments with worked examples
  - Proposed Qualification Roadmap
- New basic operation guides (bottom right) written and released for CVRW, UVRW and SDK plugin

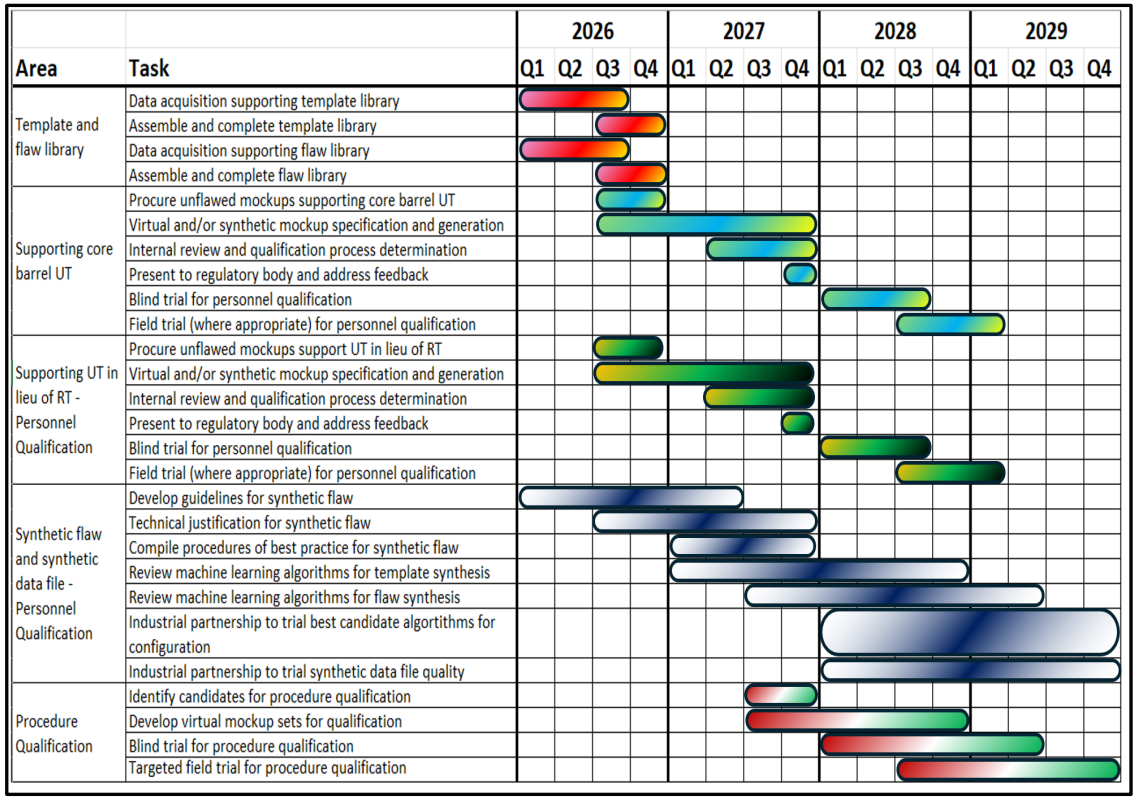




Technical update planned for Q4 of 2026

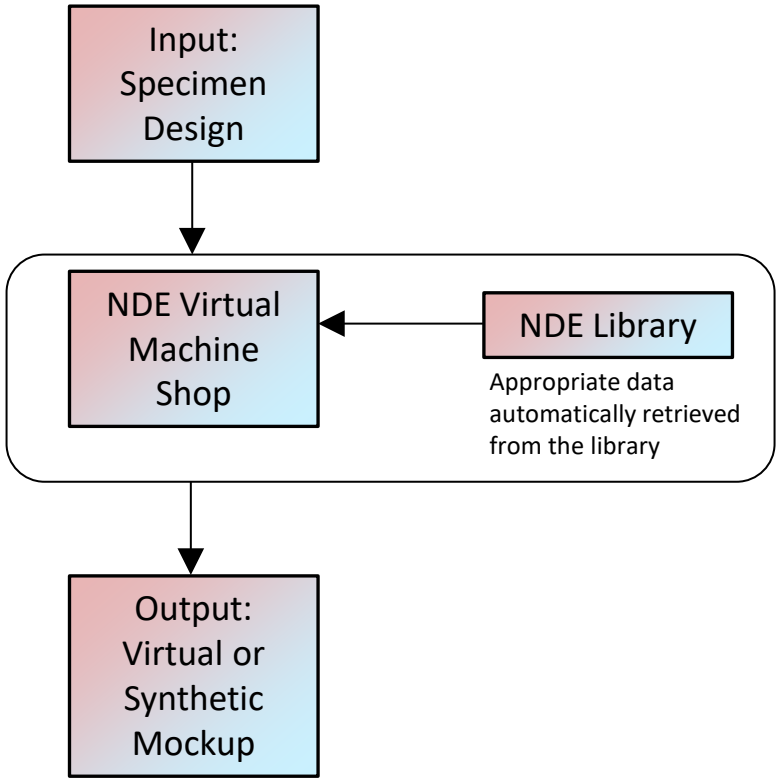
Proposed Qualification Roadmap

- Templates and Flaw Libraries:
  - Set of unflawed open samples to be 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
- Supporting UT in lieu of RT qualification and training datasets
- Advanced methods involving synthetic flaw and data generation using CIVA:
  - 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
  - Review and assessment of machine learning applications for template synthesis and flaw synthesis



Perspectives: Automating Virtual Mockup Fabrication

- Addresses some of the deficiencies with the current MVM tools
  - Learning curve with trial and error
  - Takes time and experience to be proficient in generating a configuration file that generates a high-quality mockup
  - Lack of specimen availability
- Proposal:
  - Fully automate the difficult processes leveraging simulation and ML approaches
  - Assemble NDE library: Comprises both canvasses and flaws
  - NDE Virtual Machine shop automatically converts user input to retrieve the most appropriate data from library
  - Assess different types of user input



Automates the specimen design process to realize the full value of this technology

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