

Automation for fuel inspection data processing

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1st International Conference on LWR Fuel Performance, Modelling, and Experimental Support

14 – 19.09.2025, Sol Nessebar Resort Hotel



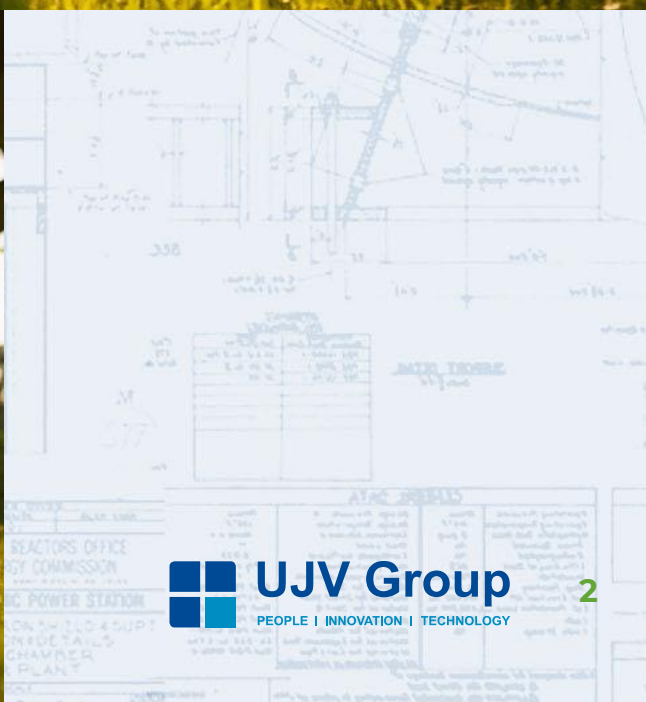
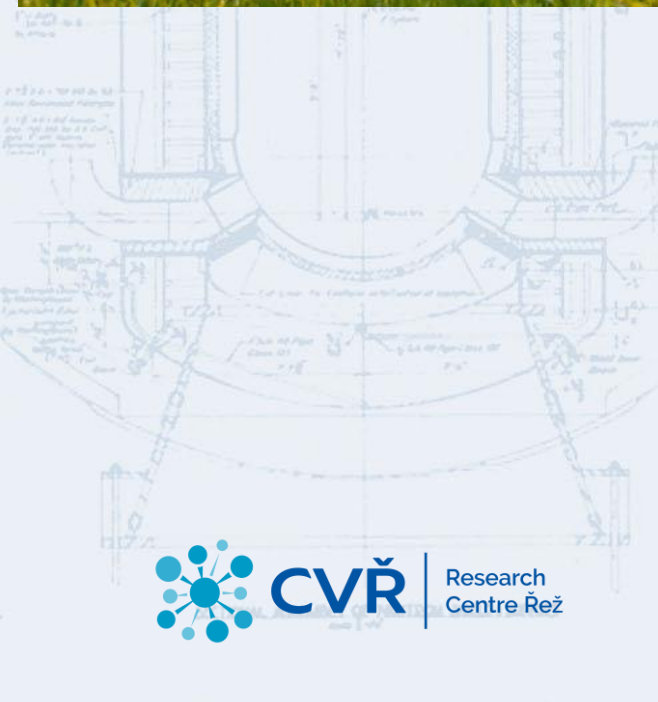
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Motivation & background

Length of typical fuel assembly ~ **4 meters**

Features of interest ~ **few millimeters**

Visual inspection of single fuel assembly ~ **tens minutes** of video recording

Image processing may help:

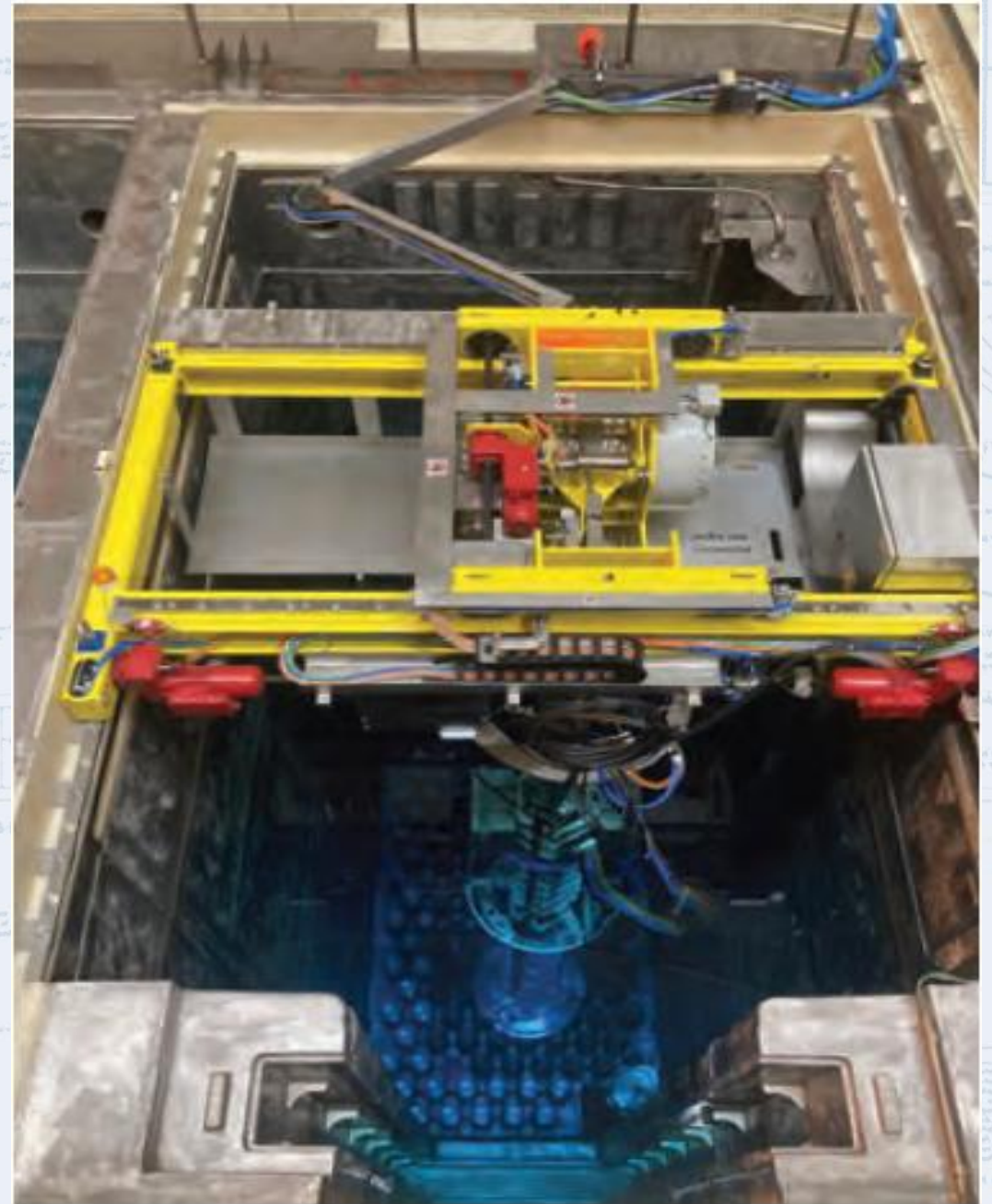
- Visualization and human readability
- Automation of routine tasks
- Anomaly detection assistance



www.kernbrennstoff.de

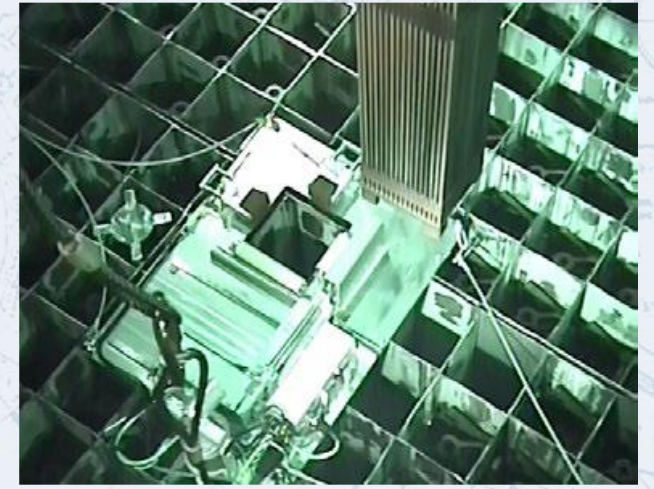
Motivation & background

- CVR performs the fuel inspection since 2011 for Temelin NPP (VVER-1000)
- Since 2023 CVR started the cooperation with vendors of square fuel type
- Implementation of new inspection equipment



Motivation and needs

The fuel can be inspected or screened during various activities at the NPP. A significant amount of data can be gathered and analyzed, especially during periodic inspections and refueling. A perfect example is a full-core offload and inspection carried out during this process or in the fuel building.



NUCLEAR FUEL INSPECTION, Tecnatom, Enusa

Fuel inspection provides information for:

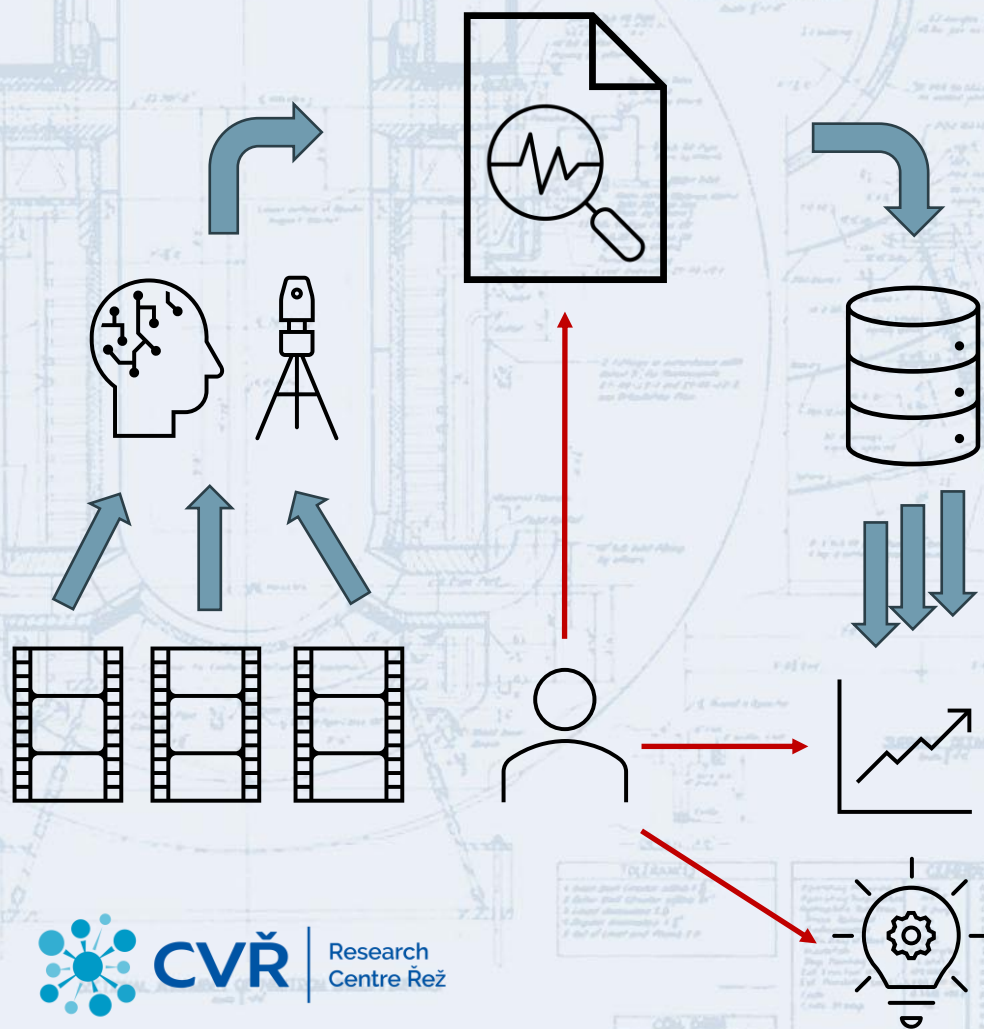
- Safety Assurance
- Performance Optimization
- Regulatory Compliance
- Minimizing Operational Risks & Costs
- Waste Management & Long-Term Sustainability

- Optimization of data analysis with the use of image processing, machine learning and AI provides

⇒ Decrease of the workload on critical path

⇒ increase of data flow

Fuel monitoring workflow SW

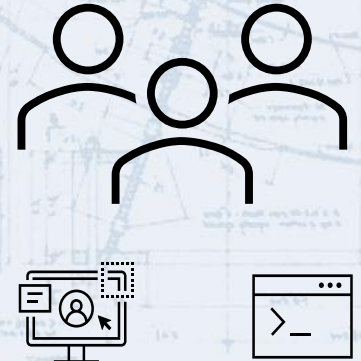
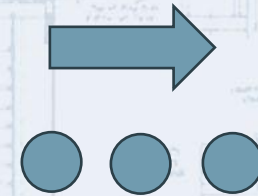
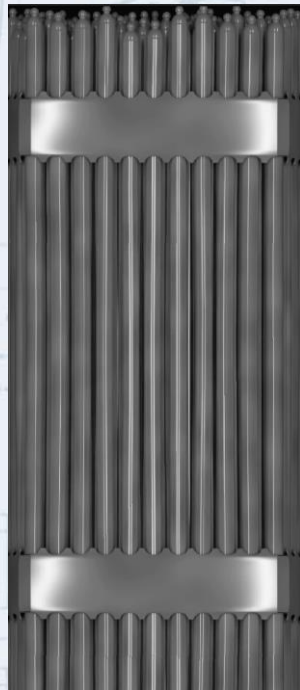
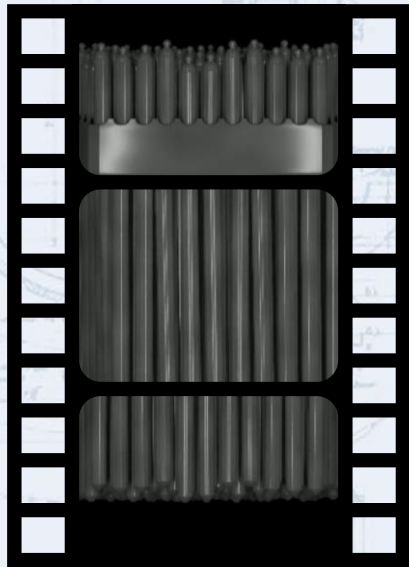


- Acquisition of numerous videos
- Automatic video processing
- Evaluation of parameters/features
- Automatic creation of reports
- Effective data store and retrieval
- Analysis of trends

=> **Knowledge**

One Image Overview – the key part of SW

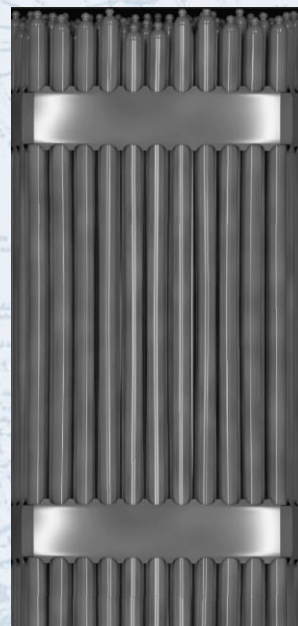
- **Fast overview**
- **Zoomable**
- **Effective comparison**
- **Easy reference (annotated images, GUI) and assessment**
- Conversion of videos (time domain) into images (spatial domain)

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Main features

Face 1



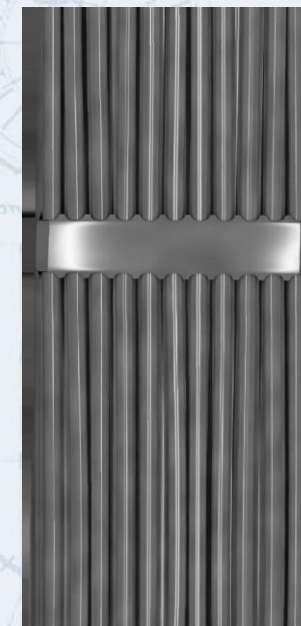
Face 2



Face 3



Face 4



The transition of multiple videos into photos that are stored in database for the operator.
No context loss.

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Main features – SW



Power plant: Power plant name Campaign: Campaign name Inspection device: Inspection device type

Campaign overview

All files	45	Without video	5	Failed	10	Status manually changed	2					
	☐	FA ID - FA FACE ↑	VIDEO FILE	STATUS	PROCESSING PROGRESS	FA AGE	ZONE POSITION	LEAKAGE	NOTES	SHOW LOG		
▼	☐	FA 10	5/6	Failed	2/6	2 yrs	Zone position L...	No	Some additional notes about FA			
	☐	FA 10 - F1	✓	Success	Processing runs: 2							
	☐	FA 10 - F2	✓	Success	Processing runs: 2							
	☐	FA 10 - F3	✓	In progress	Processing runs: 2							
	☐	FA 10 - F4	✓	Failed	Processing runs: 2							
	☐	FA 10 - F5	✓	Not started	Processing runs: 0							
	☐	FA 10 - F6	✗	No data	Processing runs: 0							
>	☐	FA 11	5/6	In progress	2/6	2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 12	6/6	Completed		2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 13	5/6	Failed	2/6	2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 14	5/6	Not started	2/6	2 yrs			Some additional notes about FA			
>	☐	FA 15	6/6	Completed		2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 16	5/6	Incomplete	4/6	2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 17	5/6	Failed	2/6	2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 18	6/6	Completed		2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 19	5/6	Failing	2/6	2 yrs	Zone position L...	No	Some additional notes about FA			
>	☐	FA 20	5/6	Failing	2/6	2 yrs	Zone position L...	No	Some additional notes about FA			

Processing setup

Configuration file: Config file name Configuration prepared by: Petr Novotný Video prepared by: Petr Novotný Metadata prepared by: Michal Procházka

Fuel assembly type: Fuel assembly type 2 Inspection scope: ☒ OIO ☐ Output type ☐ Output type ☐ Output type ☐ Output type ☐ Output type ☐ Output type ☐ Output type ☐ Output type

+ Add processing note

Files to be processed 5					+ Add files	
☐	FA ID - FA FACE ↑	FA AGE	ZONE POSITION	LEAKAGE	NOTES	REMOVE FROM PROCESSING
▼	☐ FA 10	2 yrs	Zone position info..		Some additional notes about FA	
	☐ FA 10 - F1	SCAN DIRECTION: Top - down	SCANS TO BE PROCESSED: ☐ Scan 1 ☐ Scan 2			
	☒ FA 10 - F2	SCAN DIRECTION: Top - down	SCANS TO BE PROCESSED: ☐ Scan 1 ☒ Scan 2			
	☐ FA 10 - F3	SCAN DIRECTION: Top - down	SCANS TO BE PROCESSED: ☐ Scan 1			
	☒ FA 10 - F4	SCAN DIRECTION: Top - down	SCANS TO BE PROCESSED: ☐ Scan 1 ☒ Scan 2 ☒ Scan 3			
	☒ FA 10 - F5	SCAN DIRECTION: Top - down	SCANS TO BE PROCESSED: ☐ Scan 1 ☒ Scan 2			
	☐ FA 10 - F6	SCAN DIRECTION: Top - down	SCANS TO BE PROCESSED: ☐ Scan 1 ☐ Scan 2 ☐ Scan 3			
▼	☐ FA 11	2 yrs	Zone position info..	Some leakage info	Some additional notes about FA	
	☐ FA 11 - F1	SCAN DIRECTION: Top - down	SCANS TO BE PROCESSED: ☐ Scan 1 ☐ Scan 2			

Cancel processing

Start processing

Processing run overview

Configuration file

Fuel assembly type

Inspection scope

Configuration file name

Fuel assembly type 2

OIO

Configuration prepared

Video uploaded

Metadata prepared

Petr Novotný

Petr Novotný

Michal Procházka

Processing note

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam sodales eleifend metus in maximus. Donec condimentum nisi nec justo elementum, ac egestas felis rhoncus. Etiam placerat iaculis luctus.

All processed files

5

Failed

2

FA ID - FA FACE	SCAN	STATUS	PROCESSING PROGRESS	SENT FOR PROCESSING	SHOW OUTPUTS	STOP PROCESSING
FA 10		Failed	2/6	25/02/2025 10:35		
FA 10 - F1	Scan 1	Failed		25/02/2025 10:35		
Subprocess name Subprocess name Subprocess name Subprocess name Subprocess name						
FA 10 - F2	Scan 1	Success		25/02/2025 10:35		
FA 10 - F3	Scan 1	In progress		25/02/2025 10:35		
FA 10 - F4	Scan 1	Failed		25/02/2025 10:35		
FA 10 - F5	Scan 1	Not started		25/02/2025 10:35		
FA 10 - F6	Scan 1	Not started		25/02/2025 10:35		
FA 11		In progress	2/6	25/02/2025 10:35		
FA 12		Completed		25/02/2025 10:35		
FA 13		Completed		25/02/2025 10:35		
FA 14		Completed		25/02/2025 10:35		

Log detail

FA 10 - F1 - Subprocess name

All

Debug

Error

Warning

Event title comes here

2022-08-31 10:21:58

Event title comes here

2022-08-31 10:21:58

Event title comes here

2022-08-31 10:21:58

Event title comes here

2022-08-31 10:21:58

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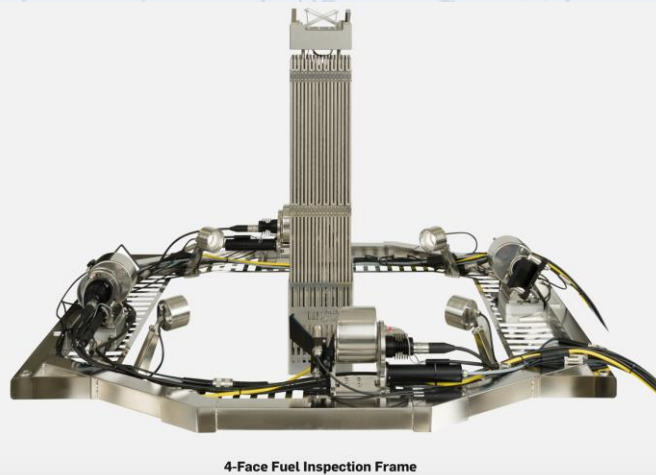
Stop processing run

Go to campaign overview

Stop processing run

Go to campaign overview

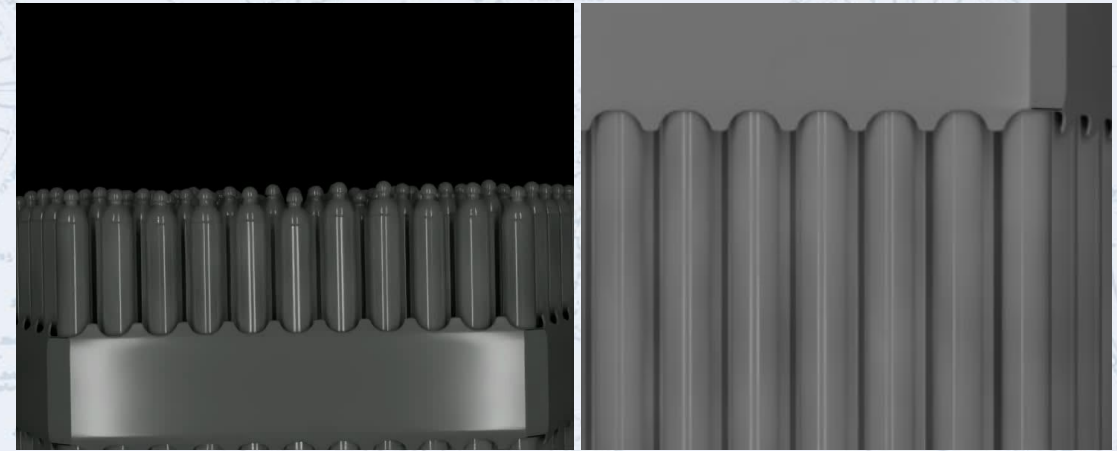
Output photo quality



Ahlberg Cameras <https://www.ahlbergcameras.com/products/systems/4-face-fuel-inspection/>

The processing deals with:

- Bow & twist of the FA
- Oxidation map and exposition
- Refueling machine specifics
- FA speed and movement



The transition from time to spatial domain assures:

- Whole video context packed up into the image
- Pixel perfect overlapping between frames
- Full refactoring of oxide layer boundaries
- Full transition of FA geometry projection
- Metadata incorporation into the processing of the video

back debug

Fuel Assembly Viewer v2

synth ST02

dif top mid bot

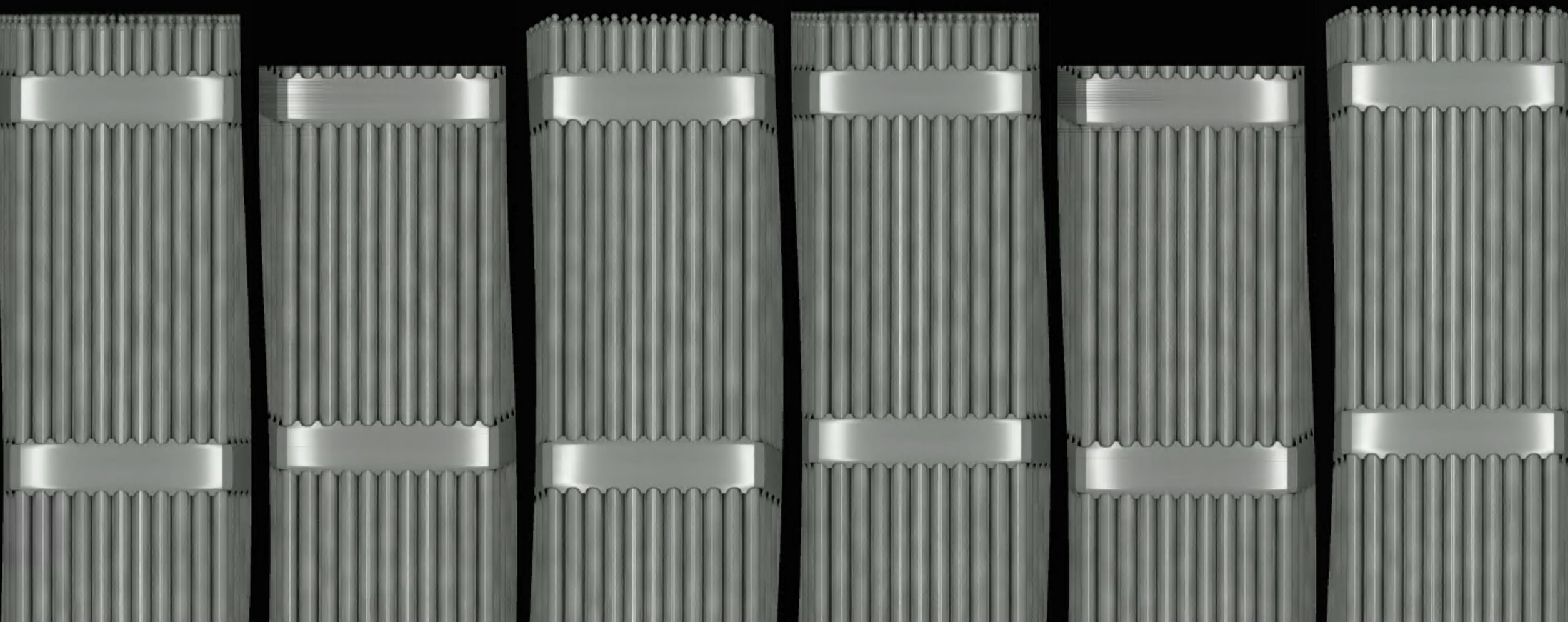
dif top mid bot

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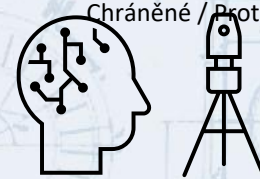
dif top mid bot



Required Process Normalization Steps

- On-site computation
- Camera
- Video encoder
- Manipulators
- Lights
- Speed



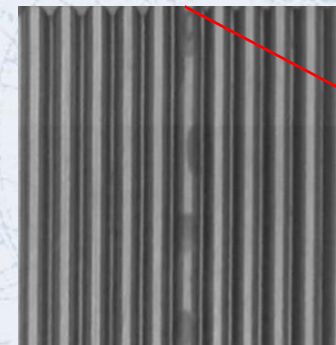


OIO follow up potentials

Outputs

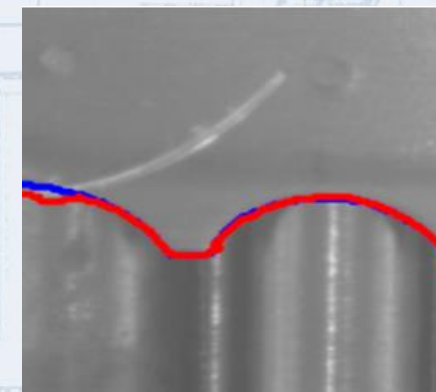
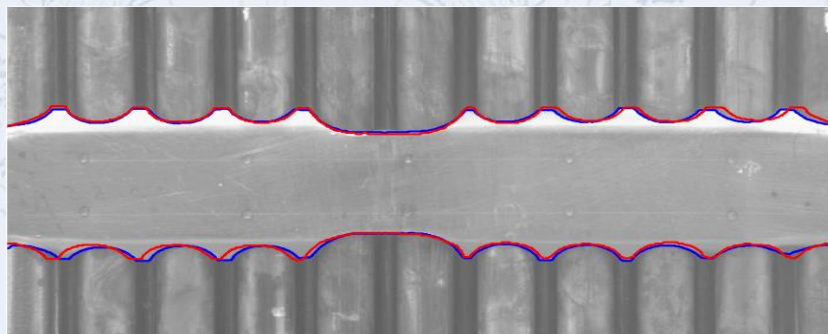
BASIC:

- Fuel geometry
- Rod geometry
- Rod surface
- Whatever unusual
- Reports



EXTENSION:

- Foreign objects recognition
- Automatic video cut
- Rod growth measurement
- Oxidation map
- Skeleton growth
- Segmentation
 - Oxides
 - Spacer grids
- Reports/charts/previews

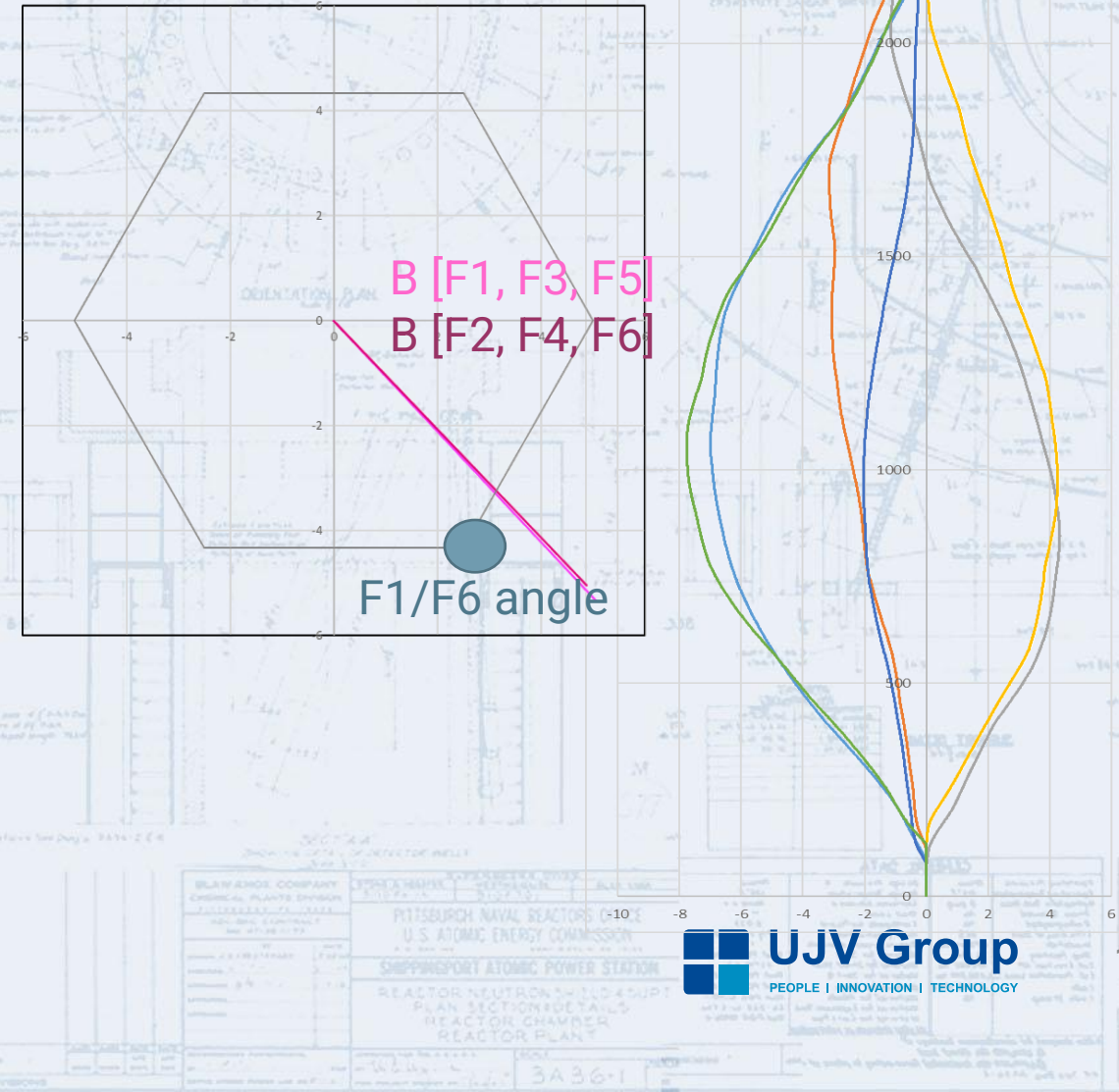


Fuel assembly bow

Combined deflection from 3 (or 2) sides define 3D position of FA center

$$\Delta X_i = \sum_{j=0}^i \sin(\alpha_j) \cdot d_j$$

Because we have 6 (or 4) sides, the error can be estimated from the second triplet.



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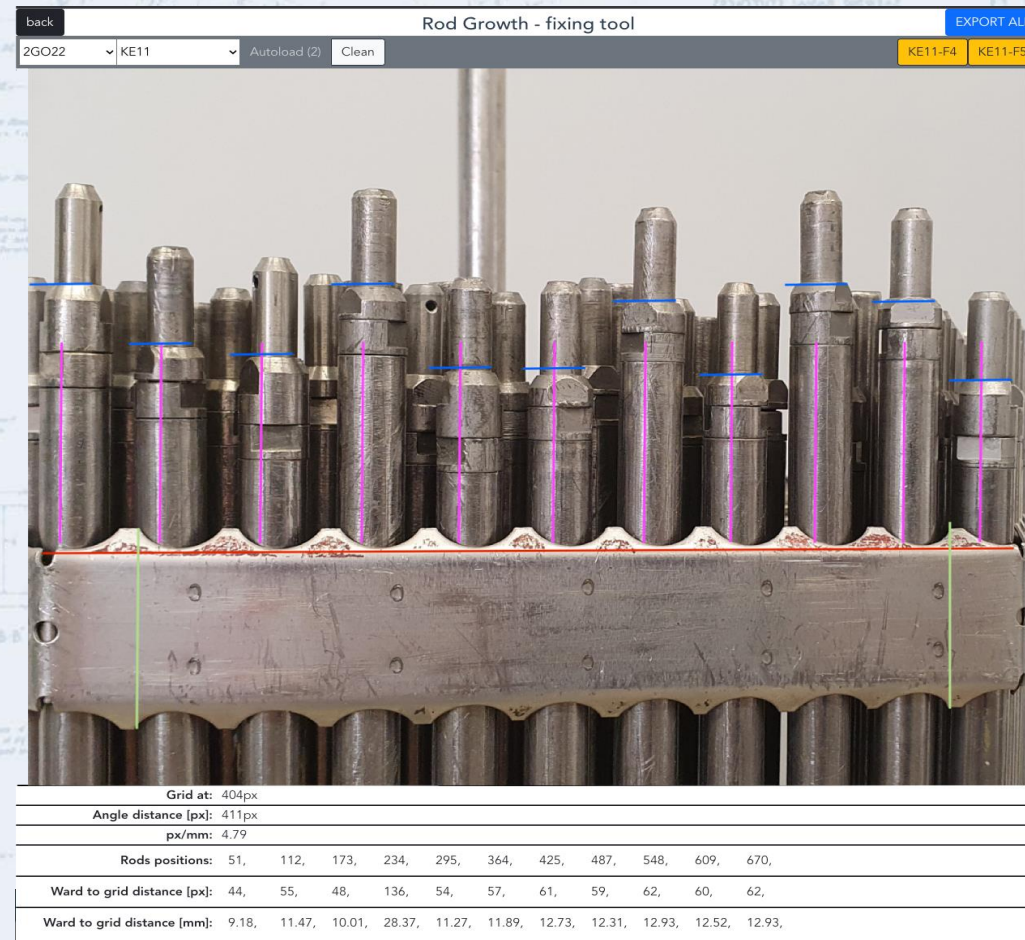
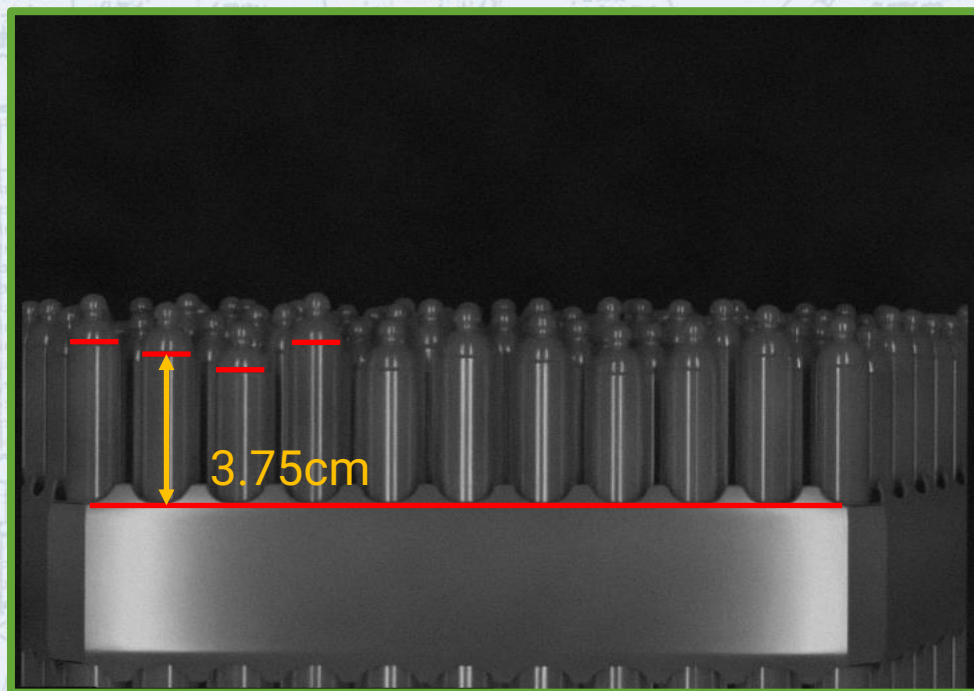


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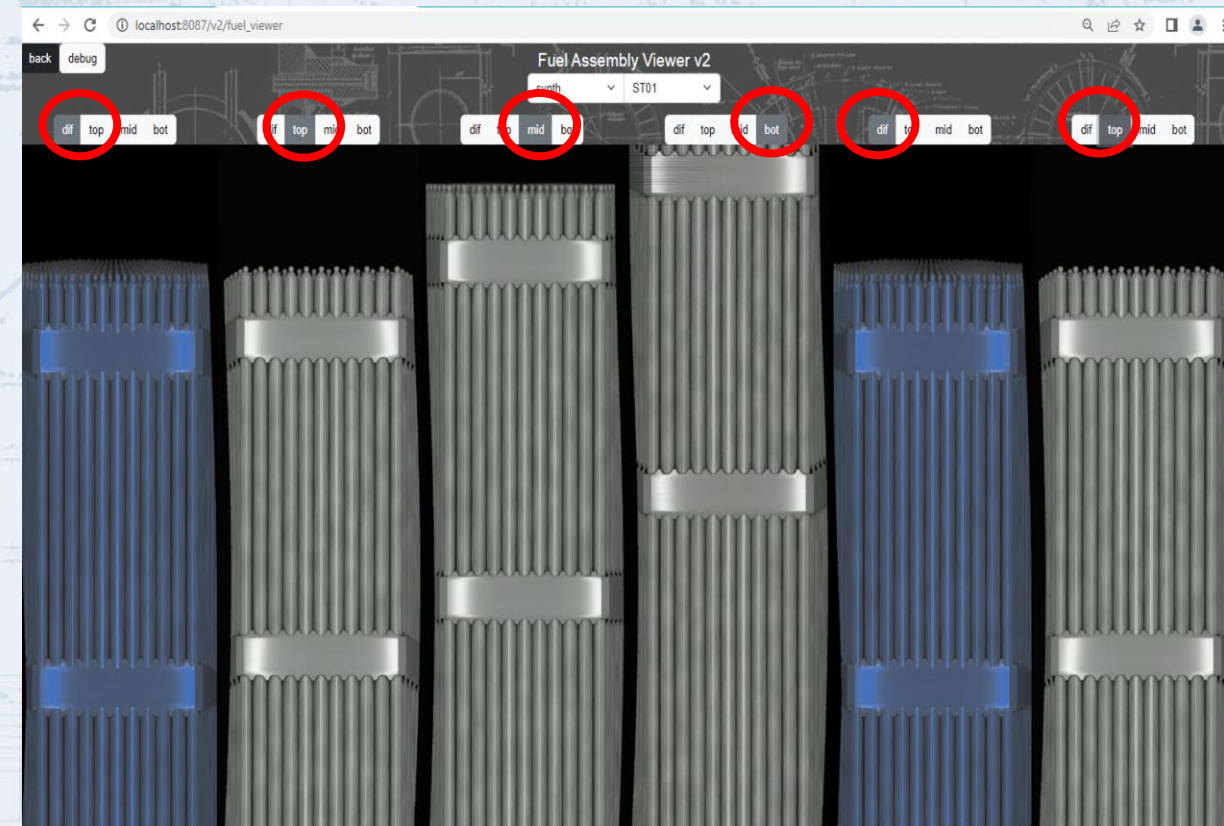
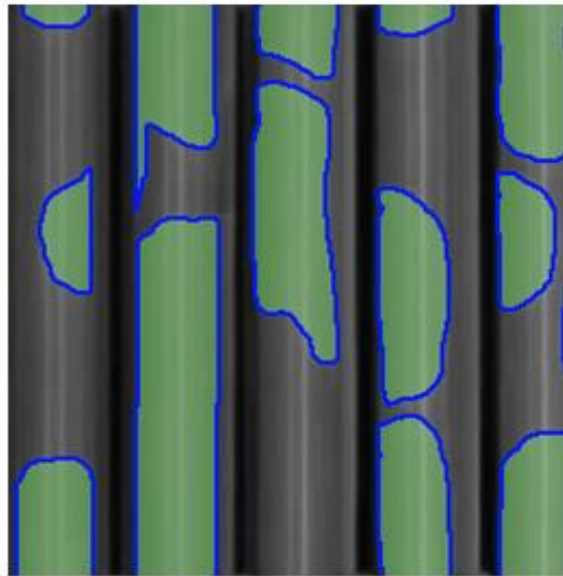
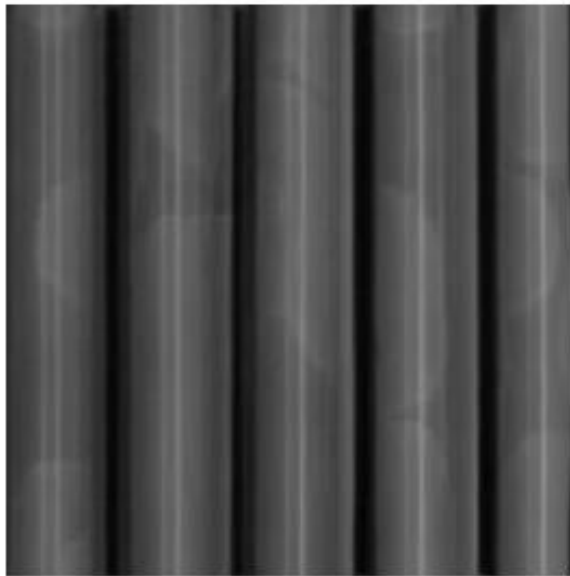
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Rod Bow

Overall accuracy of automated detection > 98%, 2% in GUI for operator check.



Main followup features

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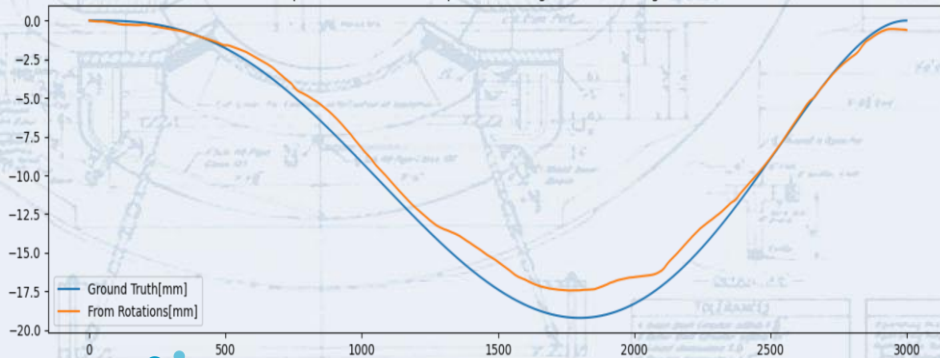
16

CVR's solution possibilities - summary

Summary

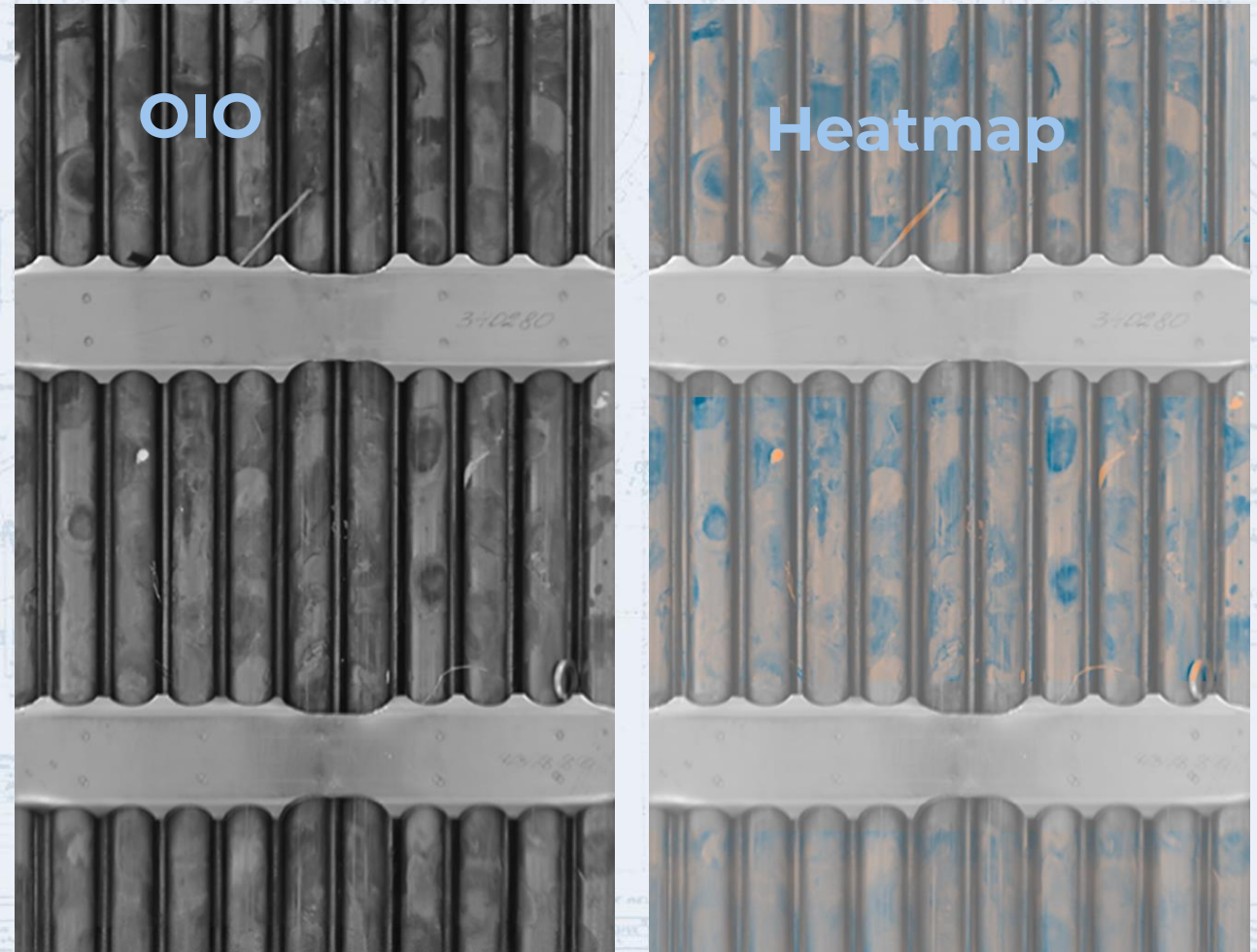
- Faster data processing
- Metadata in normalized form
- Homogenous databasis for AI tools
- Higher output quality
- Reproducibility

Comparison of fuel bow computed from angle rotations and ground truth



CVR

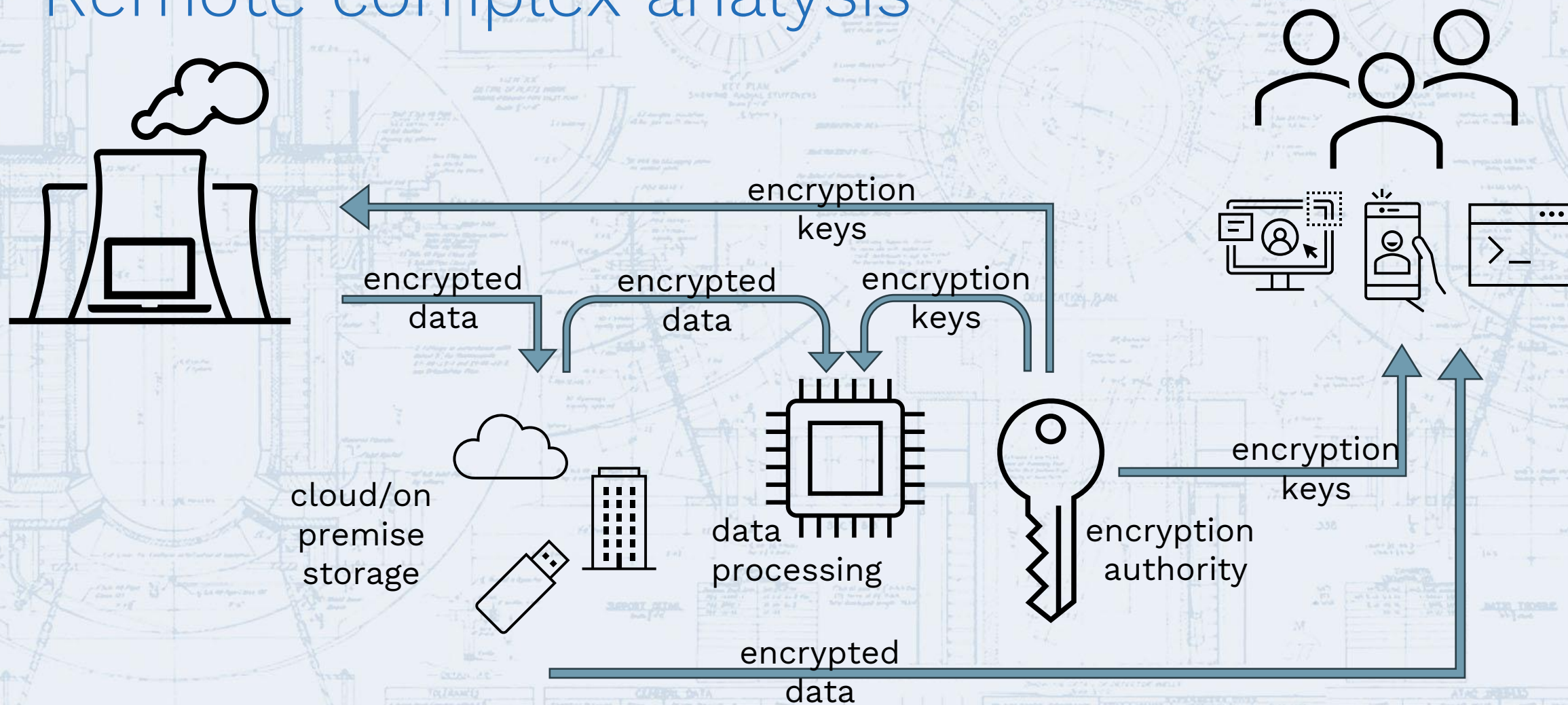
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Remote complex analysis



References – Onsite use

FIRE WEC inspection equipment

- Temelín NPP, 2018 U1+U2 – postprocessing
- Temelín NPP, 2019 U1+U2 – postprocessing + OIO
- Temelín NPP, 2020 U1+U2 – onsite: OIO + postprocessing

SIPS ŠJS inspection equipment

- Temelín NPP, 2021 U1+U2 - onsite: OIO + postprocessing
- Temelín NPP, 2022 U1+U2 - onsite: OIO + postprocessing to fullscope
- Temelín NPP, 2023 U1+U2 - onsite: fullscope

Different inspection equipment

- Square fuel inspection, 2023, 2024,...

References – Publication

- Knotek, J., Blažek, J., Kopeć, M., Simulating Nuclear Fuel Inspections: Enhancing Reliability through Synthetic Data, Nuclear Engineering and Technology, 2025
- Plašienka, D., Knotek, J., Blažek, J., Kopeć, M., Malá, M., Measurement of nuclear fuel assembly's bow from visual inspection's video record, Nuclear Engineering and Technology, 2023

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- Bin Yang, Yu-qi Cheng, Rui Chen, Li Li, Ran Guo, He-hui Geng, Tao Liu, Wen-long Li, A panoramic image stitching method for nuclear fuel assemblies, Measurement Science and Technology, 2023
- Chuncheng Feng, Congzheng Wang, Lingyi Zhang, Wanqi Gong, Lei Liu, Baihao Peng, Chang Feng, Underwater 3D measurement using sheet of light system with multi-layer refractive interface, Measurement, Volume 244, 2025,
- Rui Chen, Yu-qi Cheng, Wentao Yang, Bin Yang and Wenlong Li, An illumination-robust edge detection method for nuclear fuel assembly deformation measurement, Journal of Physics, 2024
- V. Zeman, Z. Hlaváč, Š. Dyk, Contact phenomena between load-bearing skeletons of bowed fuel assemblies in PWRs with mixed cores, Progress in Nuclear Energy, Volume 178, 2025

Thank you!

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