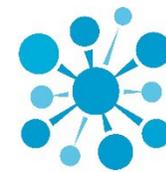


Fuel on nuclear power plants

Marcin Kopeć, Research Centre Řež

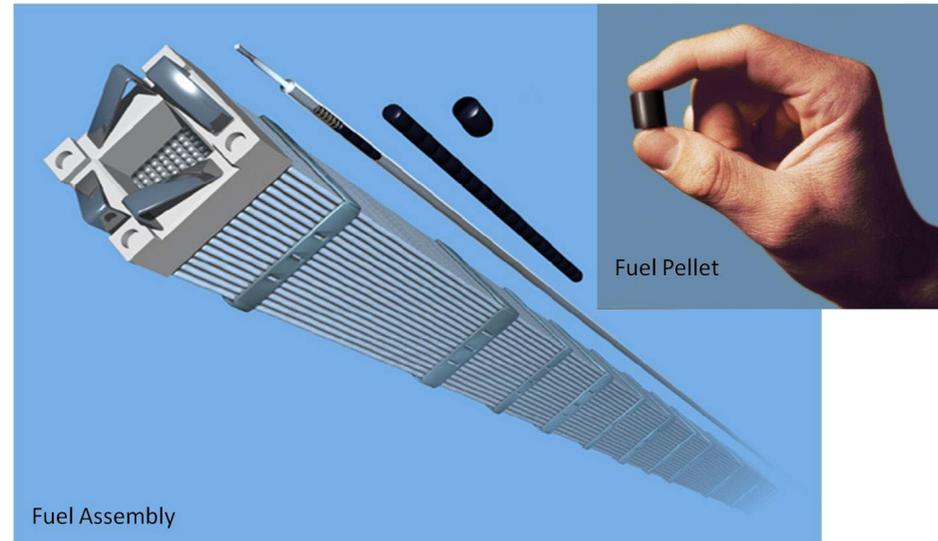
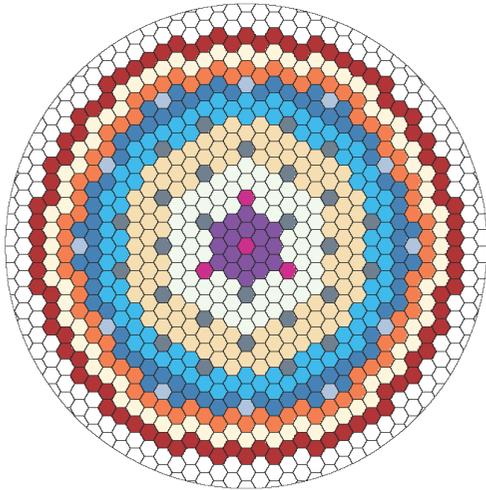
Image Analysis in Nuclear Research
Workshop
9-11.9.2024



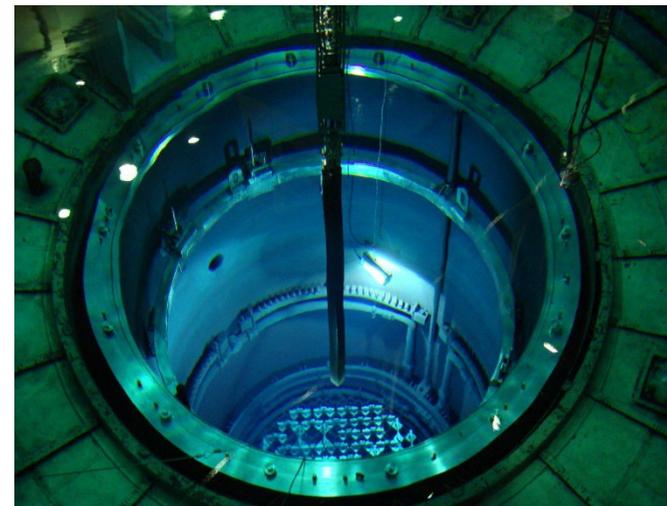
What is nuclear fuel?



Fuel pellet (UO_2) → fuel rod → fuel assembly



core → reactor

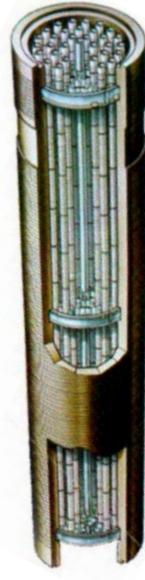


Nuclear fuel



CVŘ

Centrum
výzkumu Řež



PELLETS:

■ Geometrical changes

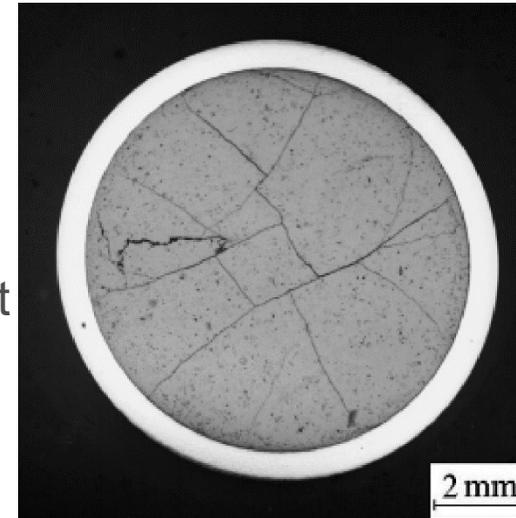
- Creep
- Swelling
- Cracking, defragmentation into pieces and dust

■ Microstructure changes

- Burnup
- Fission products release
- Cracking along the grain's boundaries

■ Parameters' change

- Neutronics – fission material transmutation (Pu), (n capture)
- Thermomechanics – heat transfer \neq const. (with burnup the HTC decreases; pellet-cladding gap \neq const...)



Cladding:

■ Oxidation

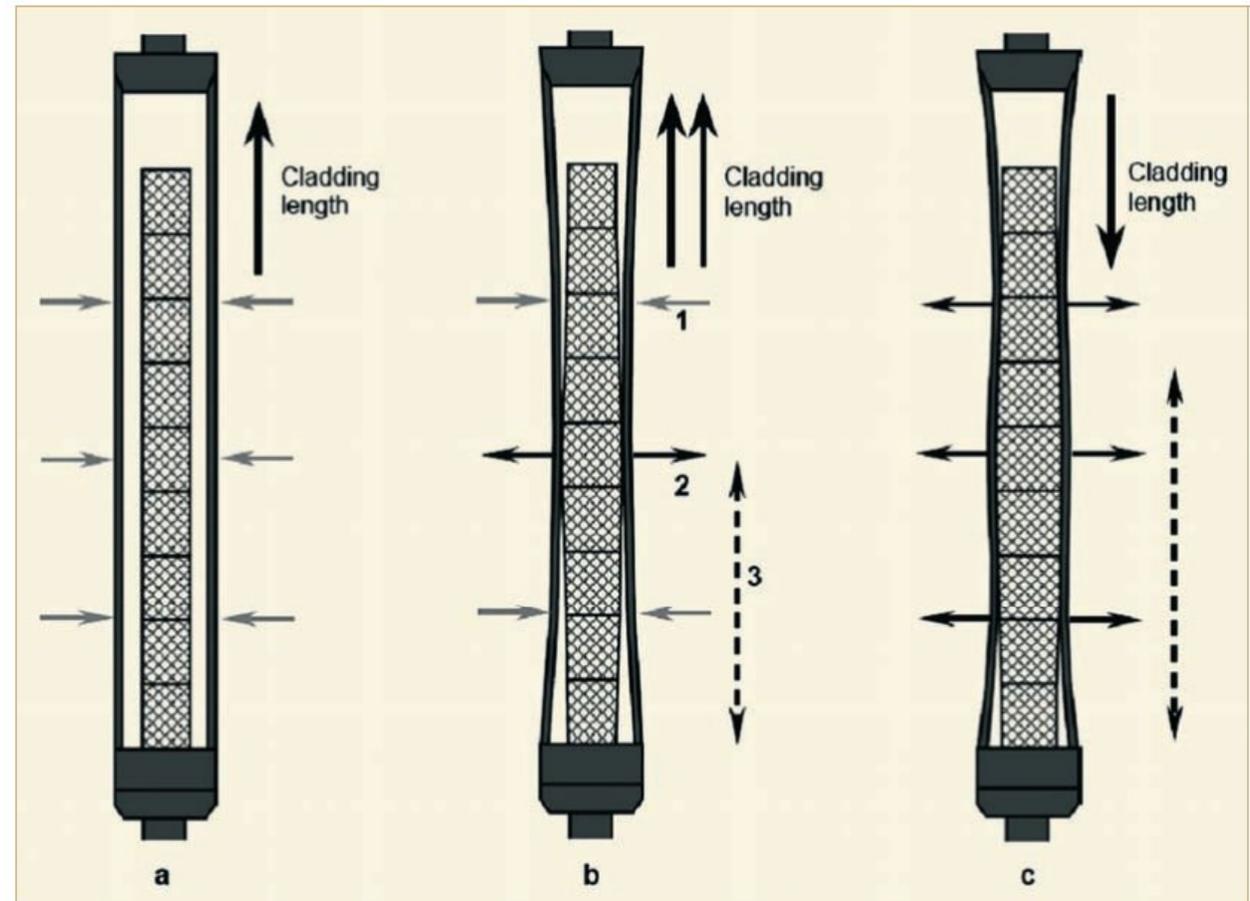
- Zr oxide generation

■ Hydridation

- Zr hydrides → embrittlement

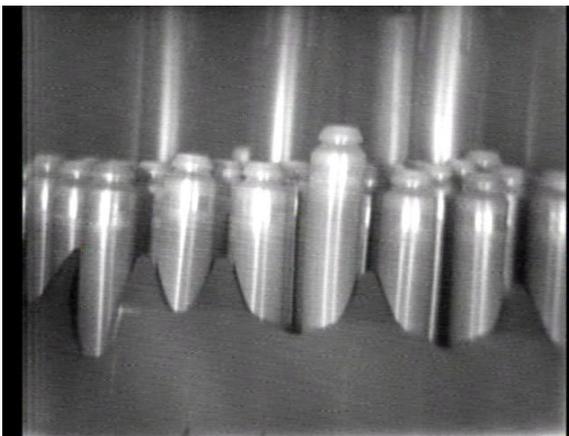
■ Geometrical changes

- Due to damage
- Creep
- Radiation growth
- Bow
- Bamboo effect



Palivo VVER: a) před PCI; b) během PCI; c) PCI po většině délky palivového sloupce;
1) vliv chladiva; 2) vliv průměru paliv. sloupce; 3) vliv délky paliv. sloupce

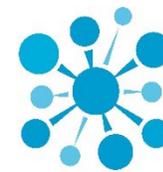
http://dev.antinternational.com/wp-content/uploads/ZIRAT14_IZNA9_STR_In-Reactor_Creep_sample.pdf



FA skeleton:

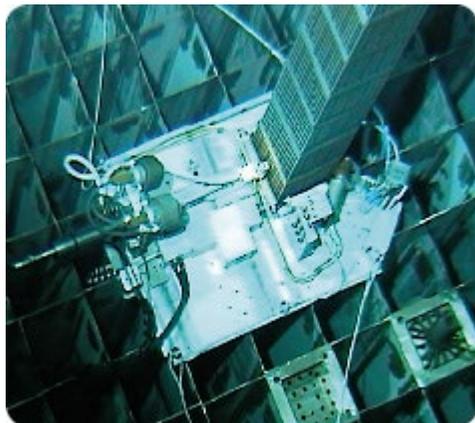
- **Twist**
- **Bow**
- **Radiation growth**
 - Lower than FR
- **Construction damage**
 - SG damage
 - Scratches on head/bottom piece
 - others





CVŘ

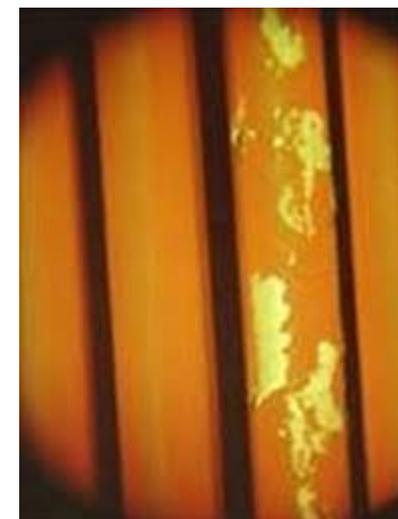
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Why to do fuel inspections?



Takto je vidieť poškodenie gasovej palivovej sústavy v sústavke M-100, ki je ta točen dvigajila volik na preha.
(Foto: Daniel A)



- **Safety**

- Fuel behavior: Y/N – anomalies in behavior, weak design features of FA

- **Hot Cells' data complementation**

- **Economics of fuel cycle**

- FA repair and reload
- Spent fuel pool optimization

Scope of the fuel inspection (currently)

- **Visual inspection**

- **Measurements:**

- Leakage detection
- FR/FA geometry measurements
- Oxide layer measurements

- **Measures:**

- Cameras
- UT(Leaking rod detection; crud cleaning), EC, laser





How to do the inspections?

■ Fuel vendors, utilities and service companies

- Fuel behaviour guaranties
- R&D to improve fuel design, performance, and utilization

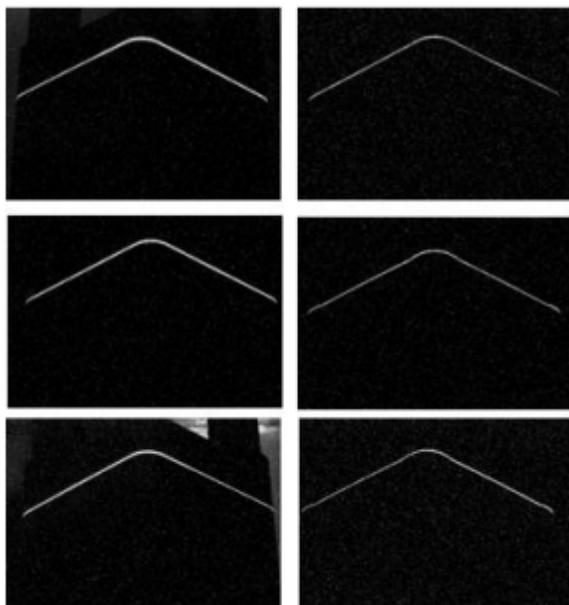
Framatome (EDF,AREVA)

- Visual inspections
- Mast (β -effic. 7%, γ -effic. <1%, background 10-20 cps) , incore, single rod sipping
- Measurements: FA, FCH, RCCA – growth and FA/FR length
- Oxide layer thickness measurements
- Debris removal
- Peripheral rod crud removal, sampling
- Deflection measurements over entire FA
- Burn-up mapping over FA (gamma scanning)
- Ultrasonic Fuel Cleaning
- FA repair and reconstruction
- FR Opening and Cladding segment removal system – fission gas analysis
- Ultrasonic leaker localization

Rolls-Royce

- Visual inspection – fully rotating (355°) camera system providing 100% view coverage
- Magnetic particle testing
- Dye penetrant inspection
- Phased array UT inspection, UT, eddy currents
- Digital radiography
- Surface defect inspection and metallurgical replication (also underwater)
- Electromagnetic interference monitoring
- Irradiation damage analysis (#D atom probe)
- Noise and vibration background examination
- Composite inspection
- Crud and material sampling
- Radiation resistant camera wit 72x zoom

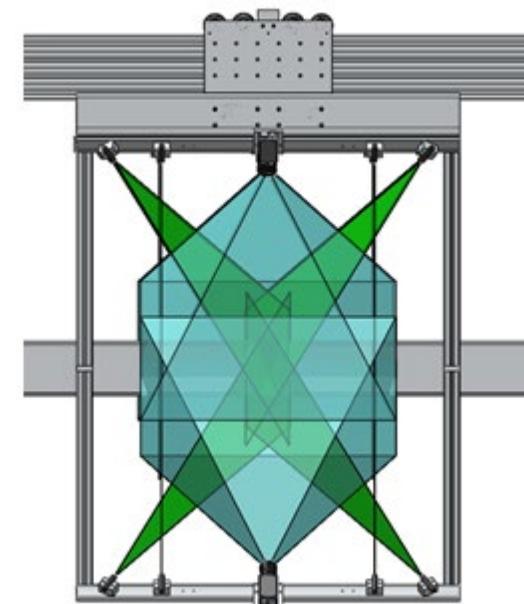
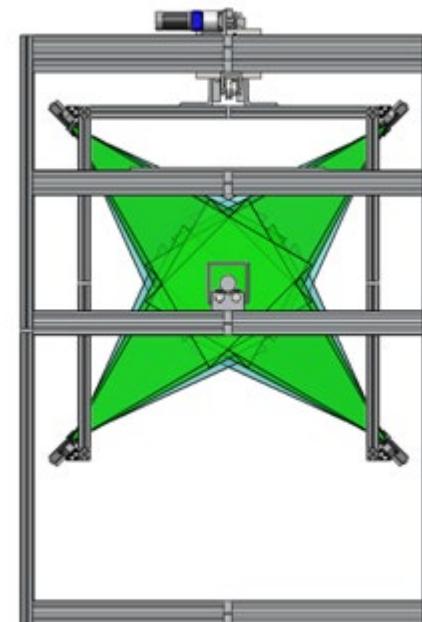
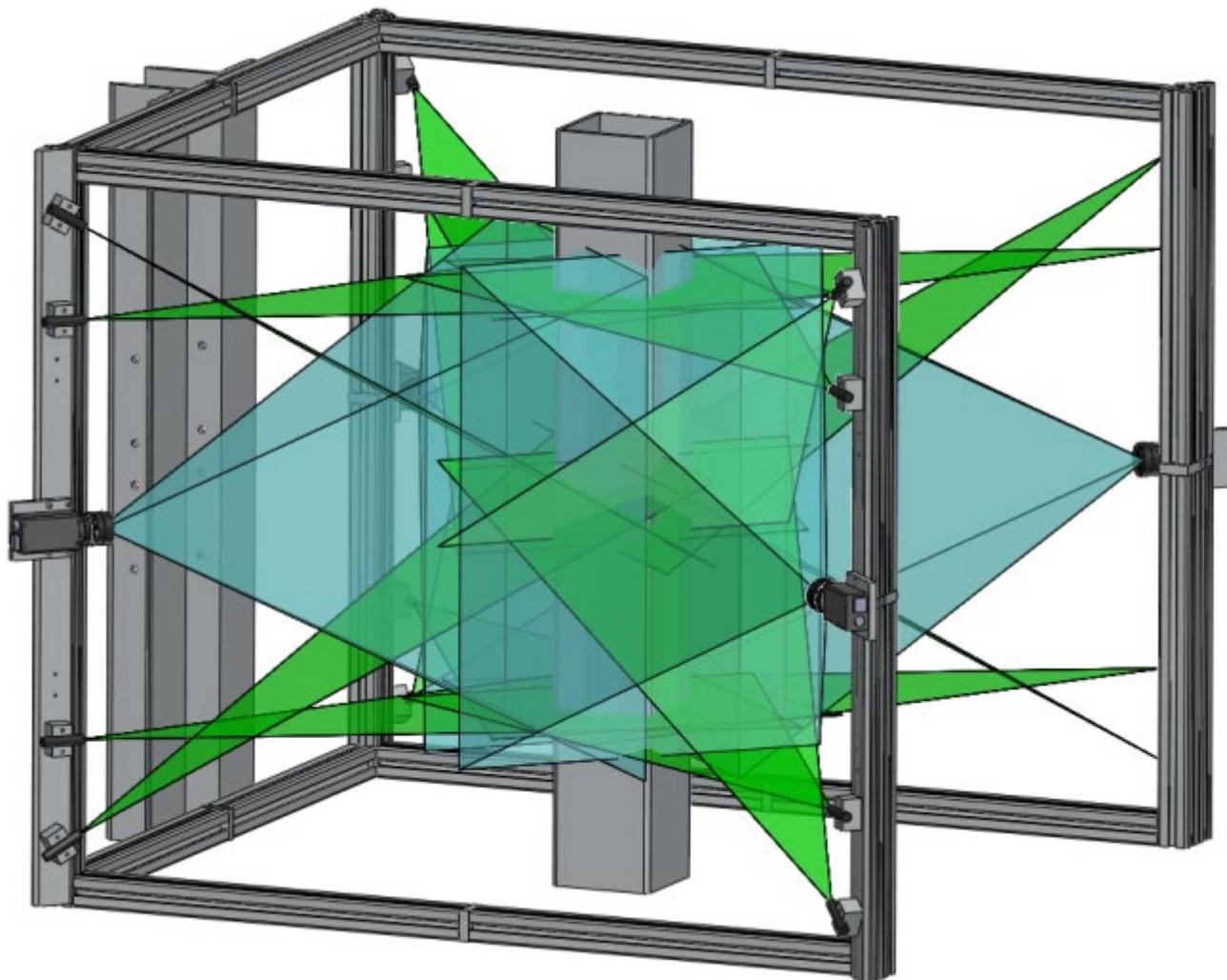
Mabema 3D Laser Scanning - Vattenfall

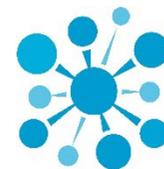


Accuracy	Length +/- 0.5 mm Bulge +/- 0.2 mm Bow +/- 0.2 mm Twist +/- 0.1 degree
Time	0,5 s
Dimensions	Length 4650 mm Width 2400 mm Weight 300 kg
Material	Fixture: stainless steel Housings: stainless steel Brackets: alloy



Newton Labs QUAD400UW





Ahlberg Cameras

4-FACE FUEL INSPECTION SYSTEM

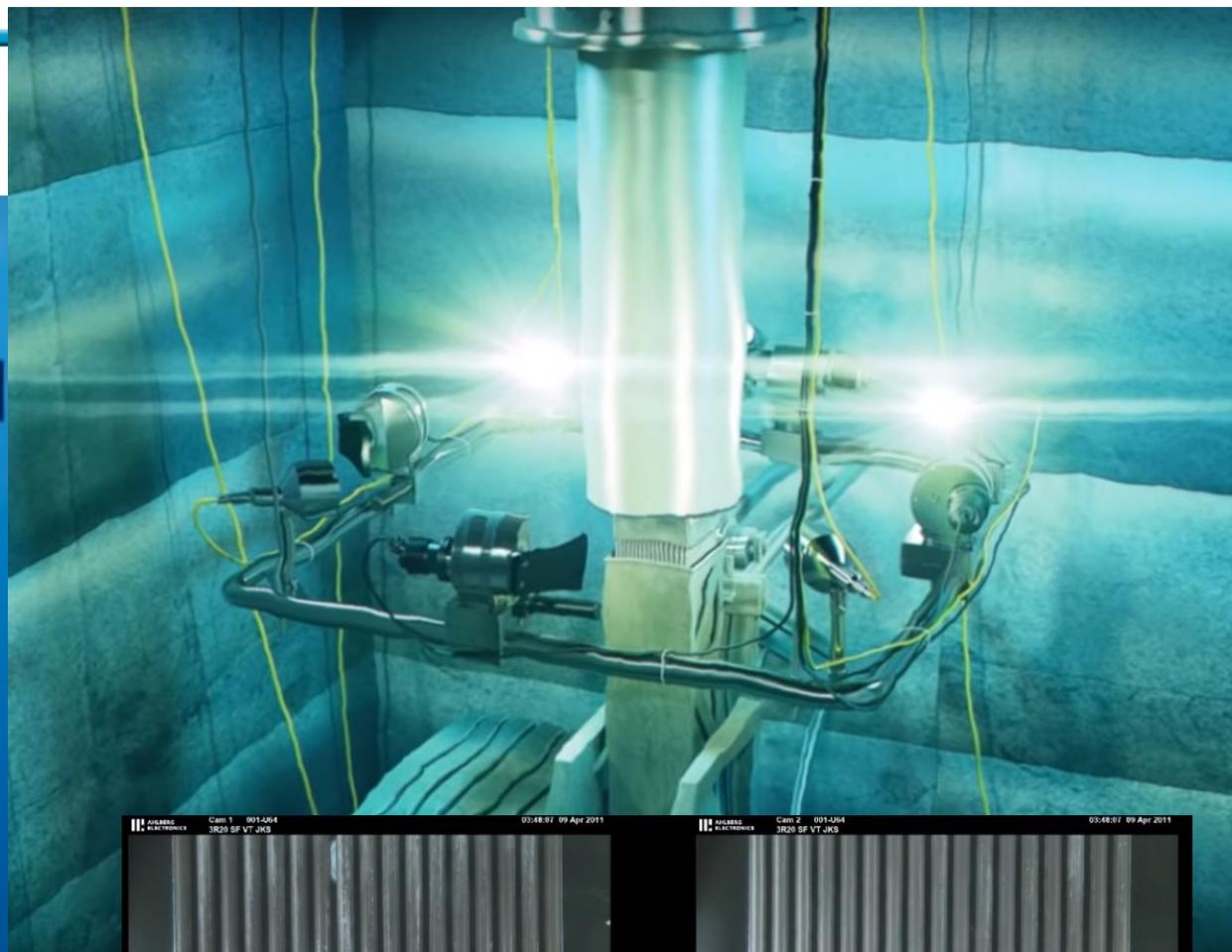
No addition
to critical path

720p HD
color image

Records with
lifting speeds up to 15m/min

Image analysis software with
bow measurement functions

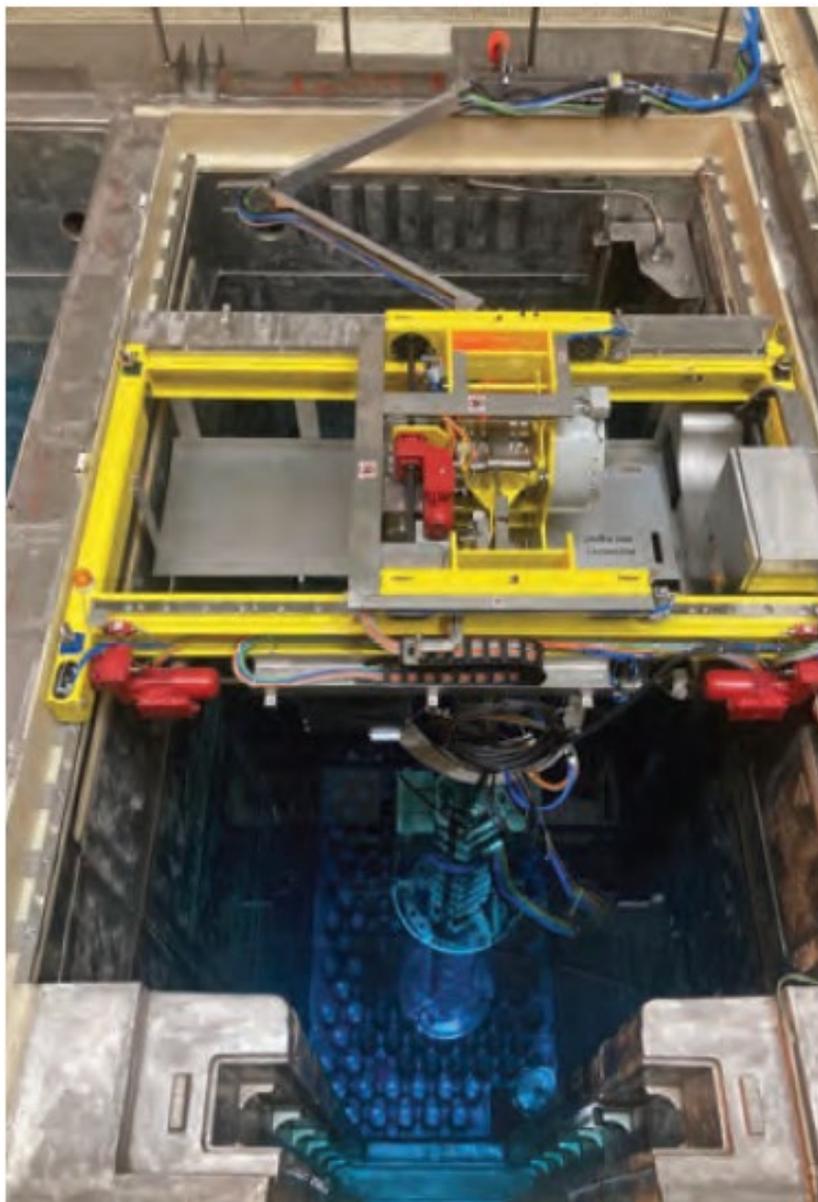
Cameras with
cooling system





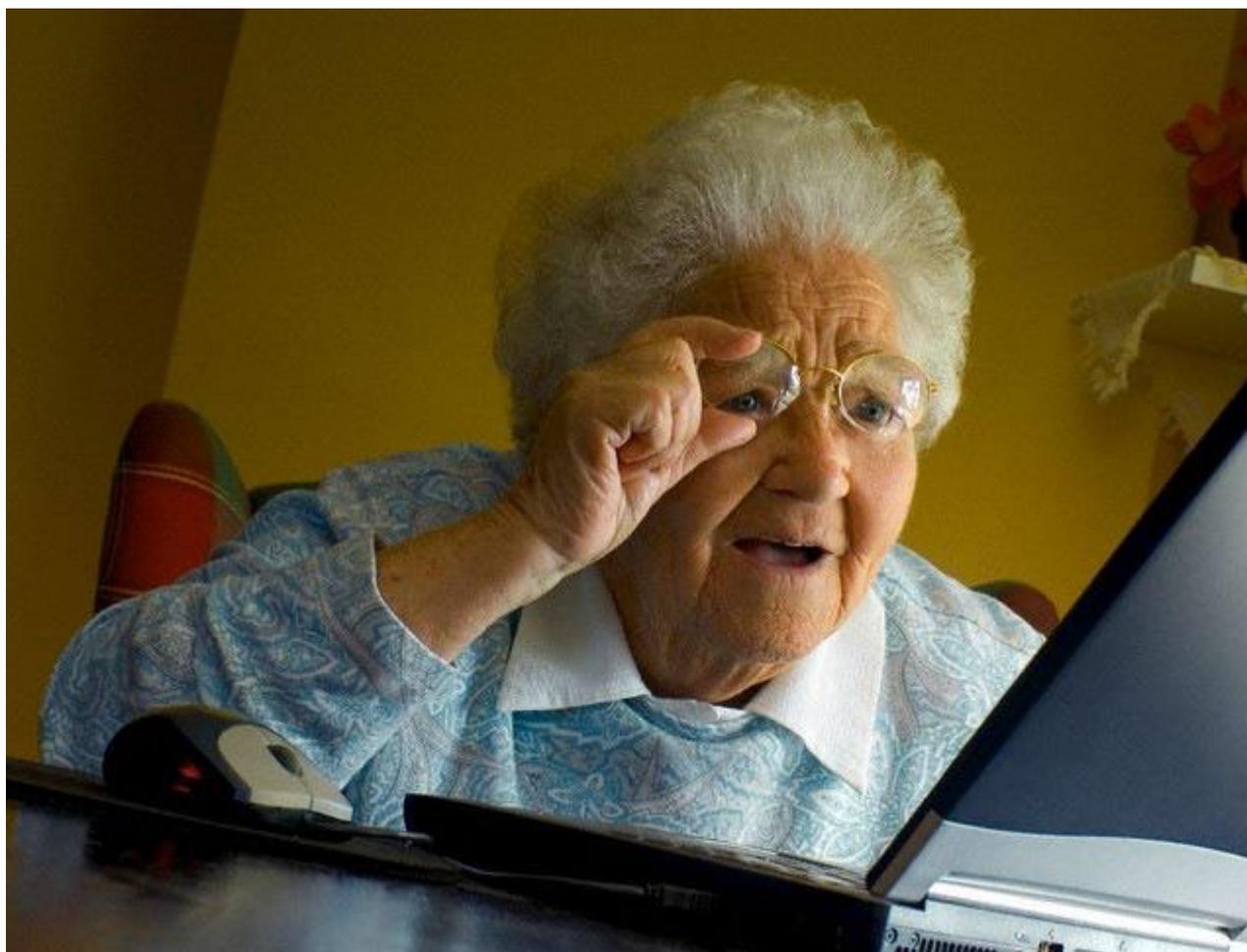
How we process the outputs?

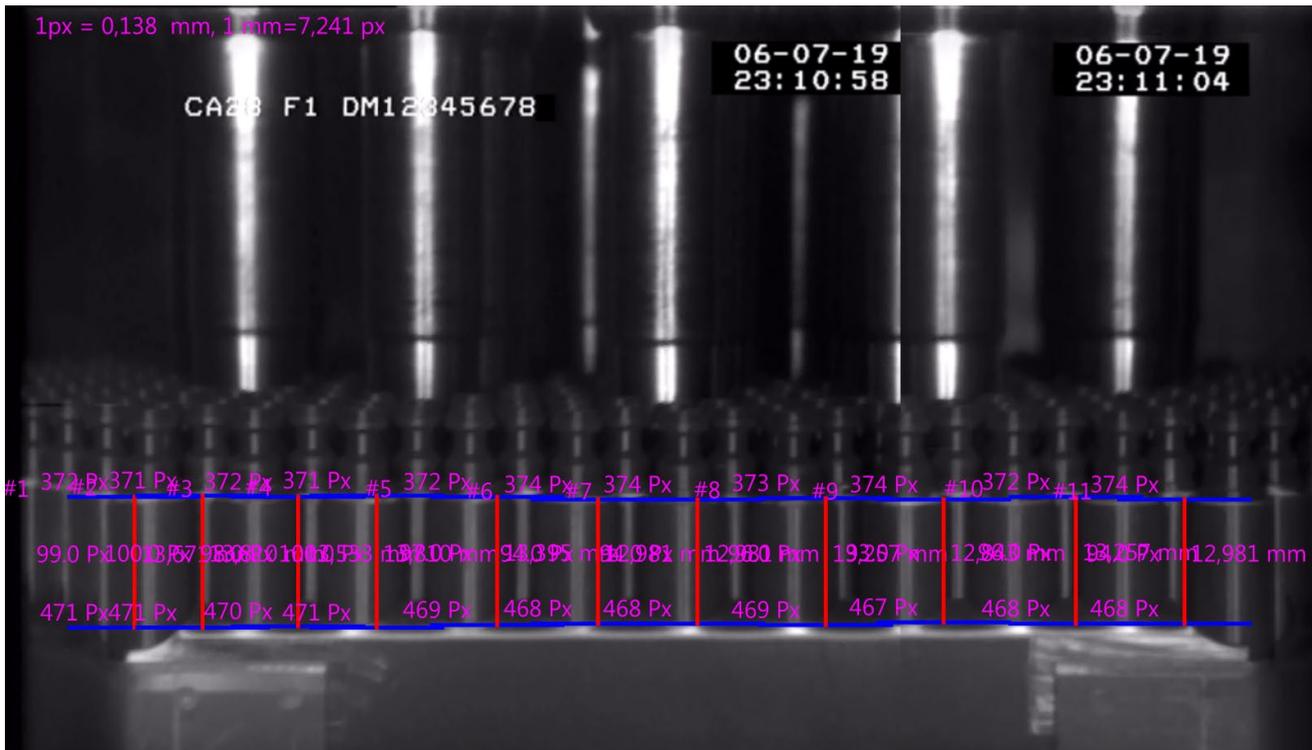
SIPS – JE Temelín



*M. Ruchař, M. Štípek. Stend inspekci palivových souborů.
Článek v Jaderná energetika, redakce_04_2022, strana 16,
listopad 2022.*

Old „analogue“ approach

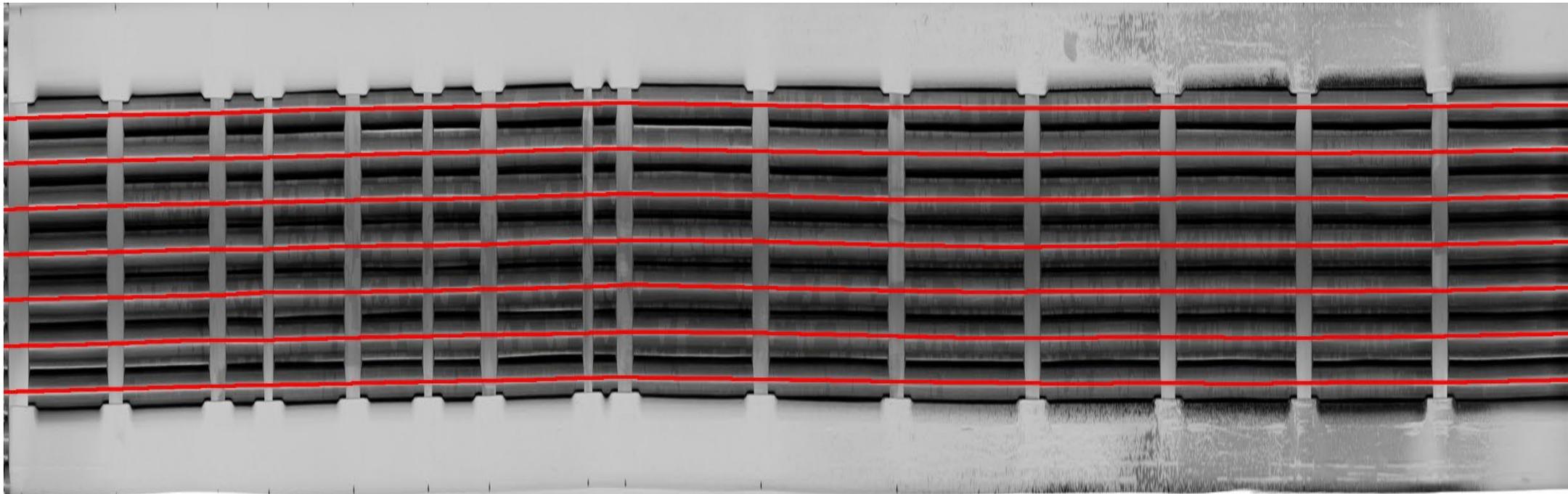




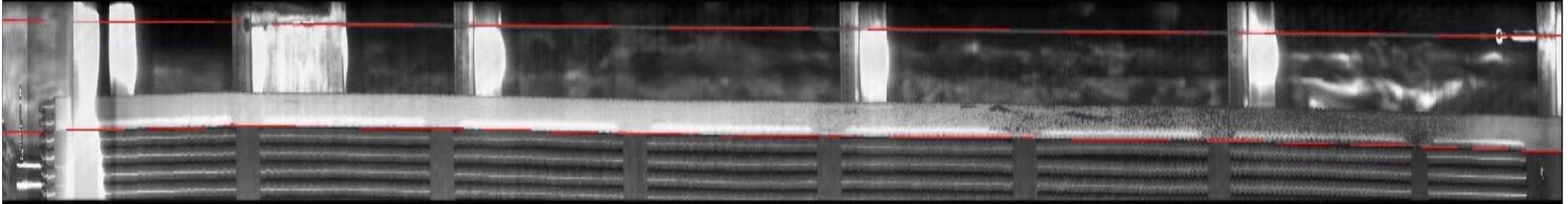
Rod Growth

Pos [px]	K #1[mm]	K #1 [px]	K #2 [mm]	K #2 [px]	vzdalenost [mm]	vzdalenost [px]
99.0	51.371428571428574	372	65.04285714285714	471	13.67142857142857	99
151.0	51.233333333333334	371	65.04285714285714	471	13.80952380952381	100
224.0	51.371428571428574	372	64.90476190476191	470	13.533333333333339	98
284.0	51.233333333333334	371	65.04285714285714	471	13.80952380952381	100
376.0	51.371428571428574	372	64.76666666666667	469	13.395238095238092	97
453.0	51.64761904761905	374	64.62857142857143	468	12.980952380952381	94
529.0	51.64761904761905	374	64.62857142857143	468	12.980952380952381	94
627.0	51.50952380952381	373	64.76666666666667	469	13.257142857142853	96
717.0	51.64761904761905	374	64.4904761904762	467	12.842857142857149	93
818.0	51.371428571428574	372	64.62857142857143	468	13.25714285714286	96
901.0	51.64761904761905	374	64.62857142857143	468	12.980952380952381	94

FR bow



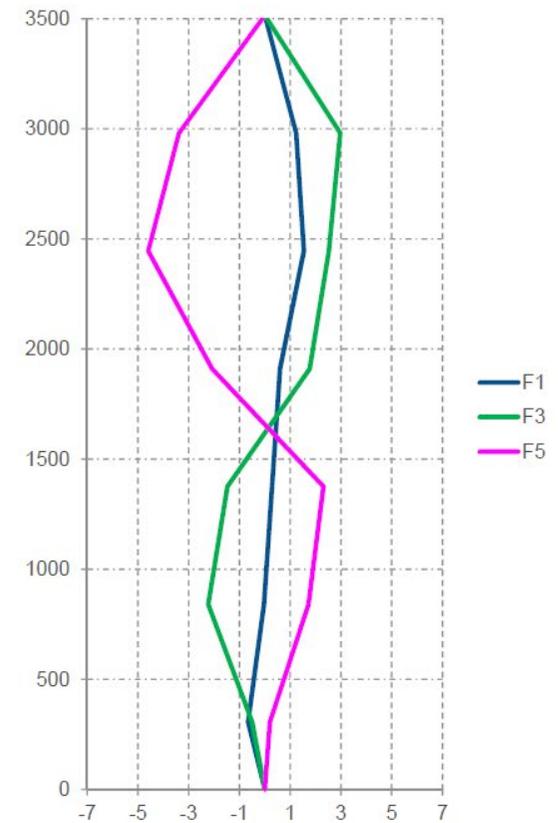
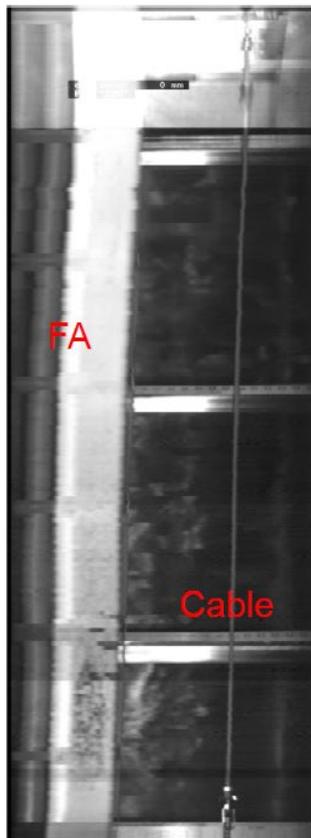
FA Bow

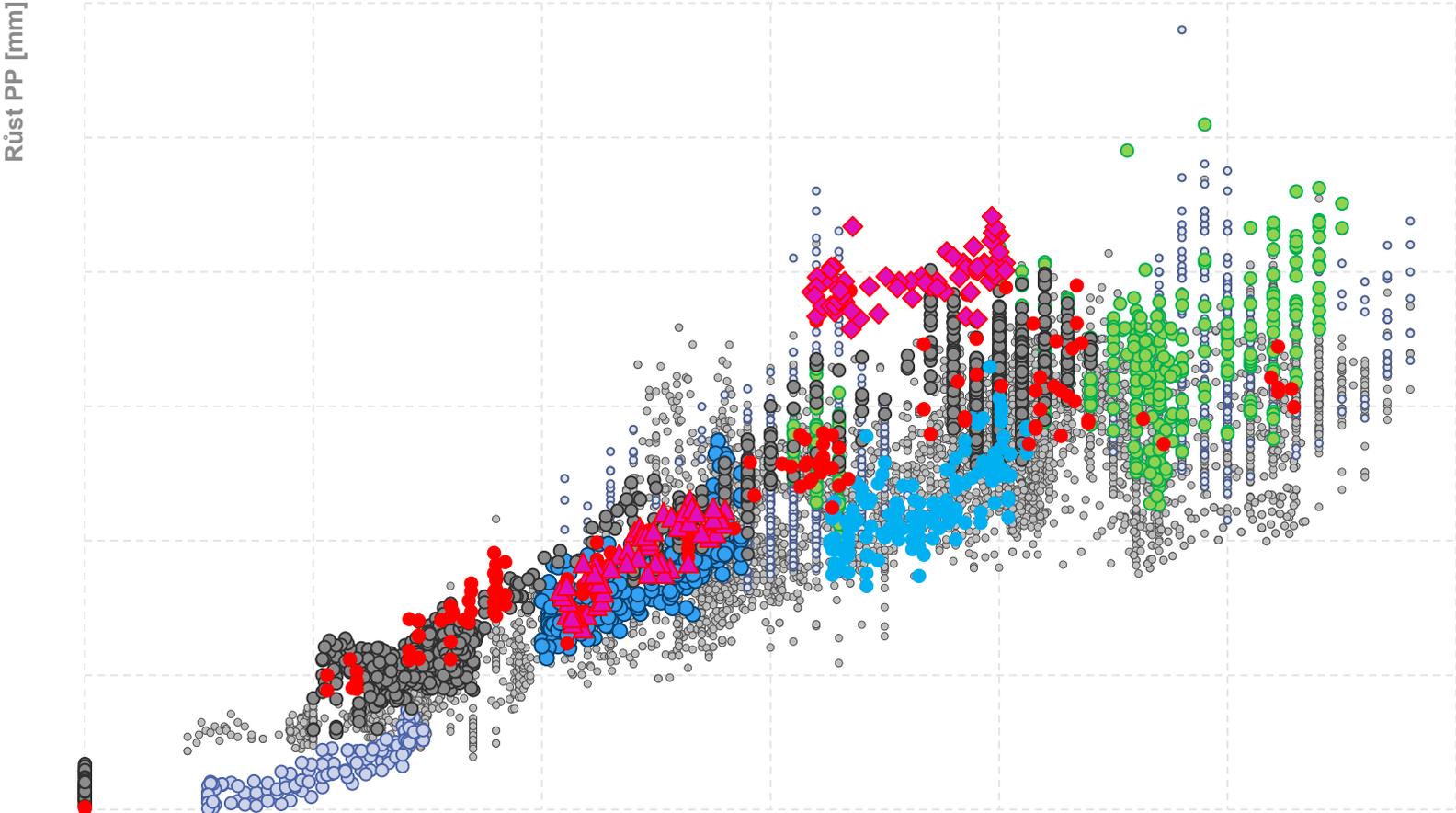


Face 1

Face 3

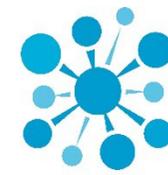
Face 5





Vyhoření PP [MWd/kgU]

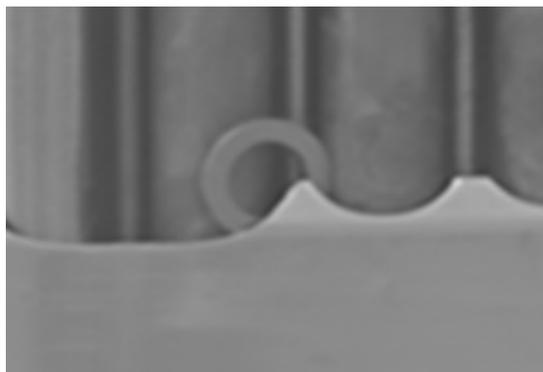
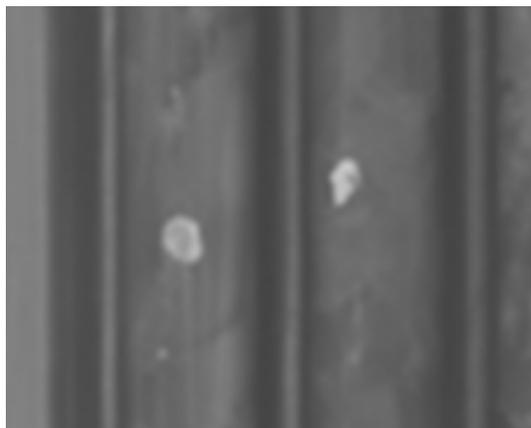
Outputs aggregation



New age of DIP

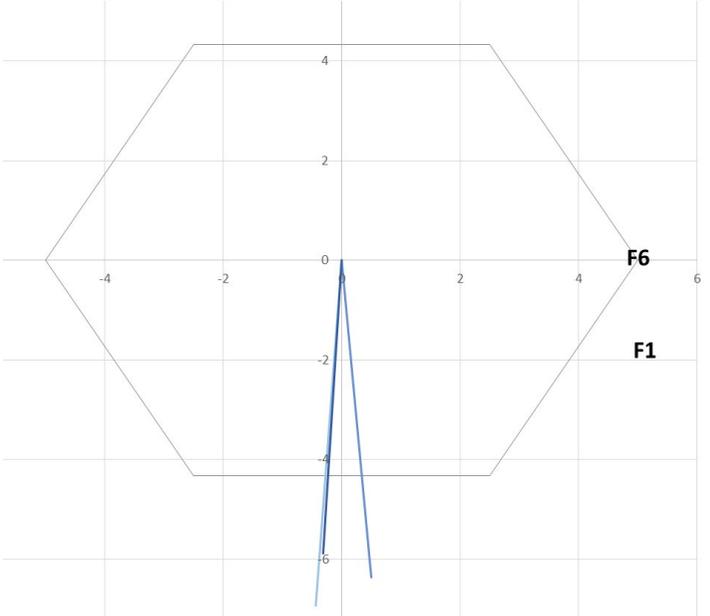
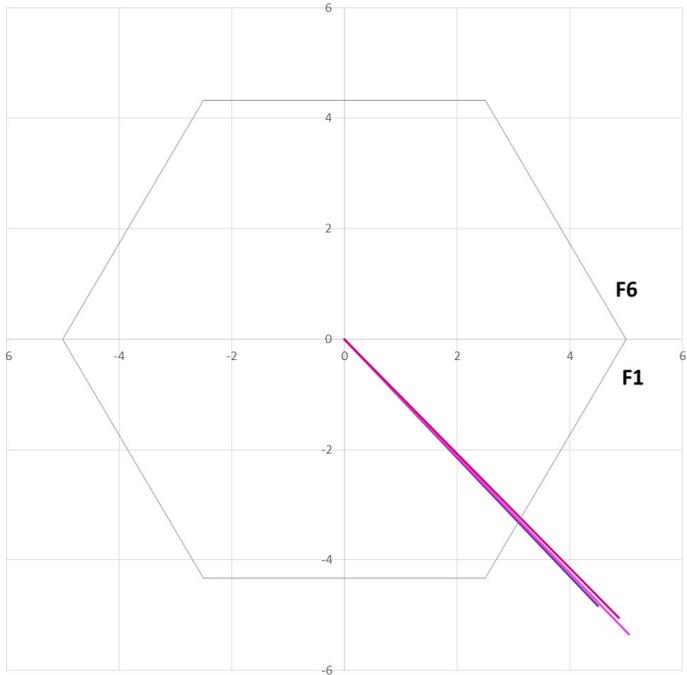
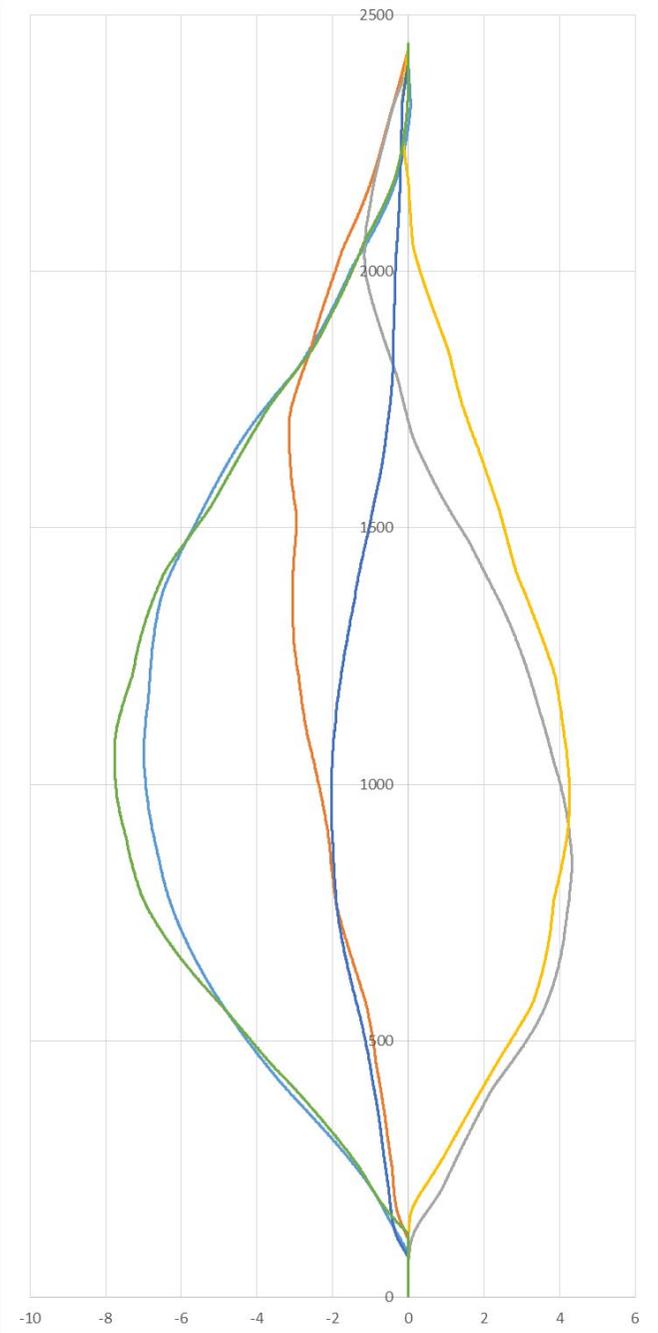


DIP



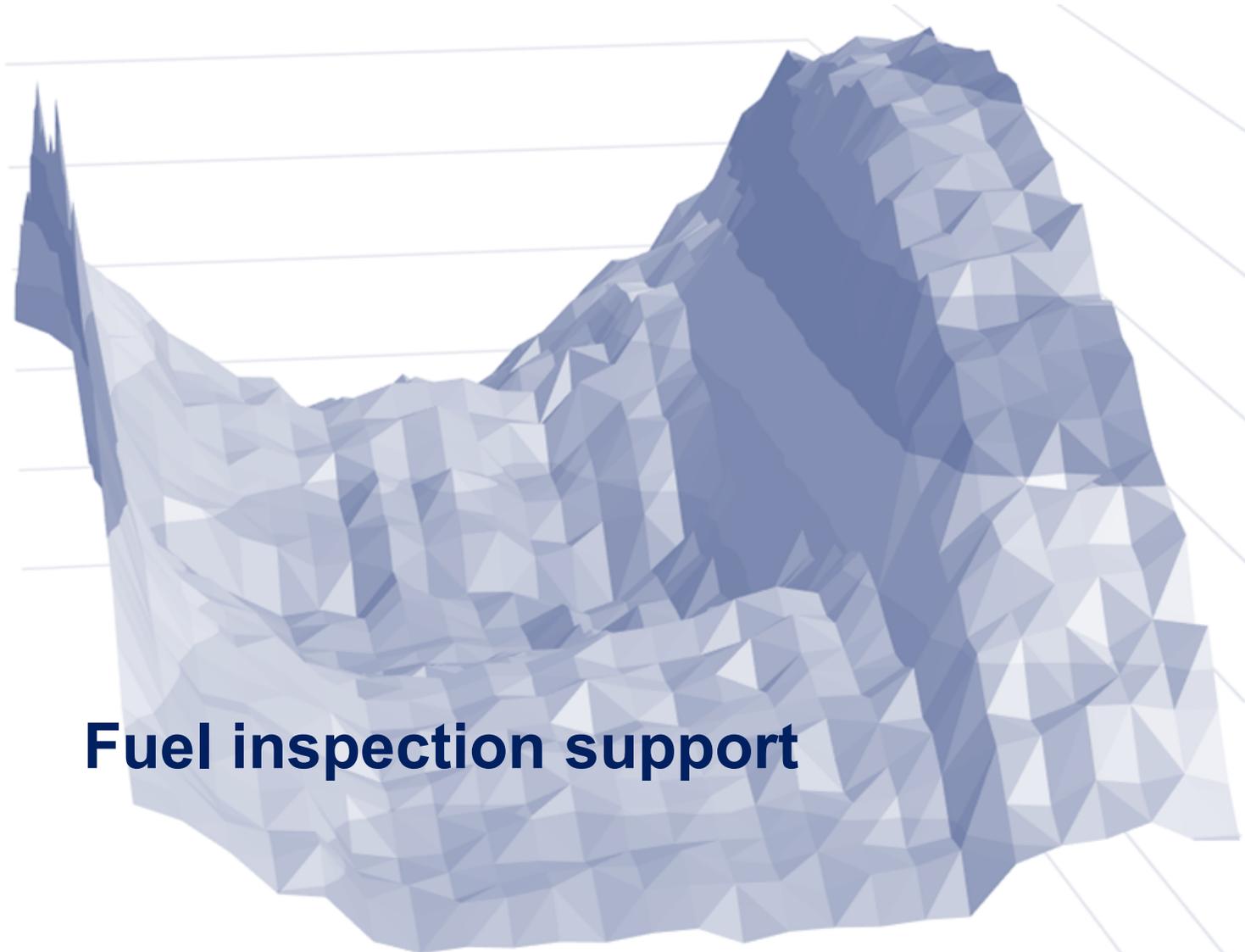
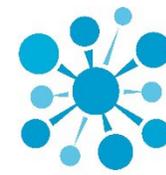


Dlp



Thank you for your attention

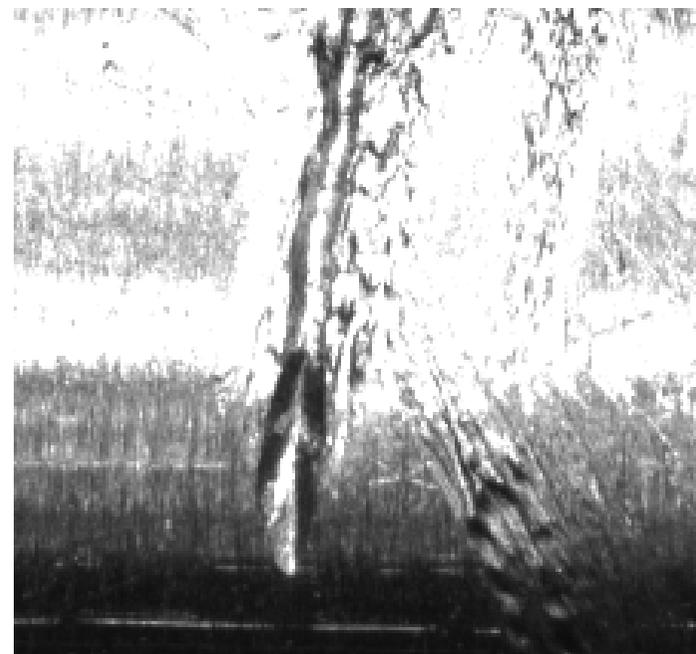
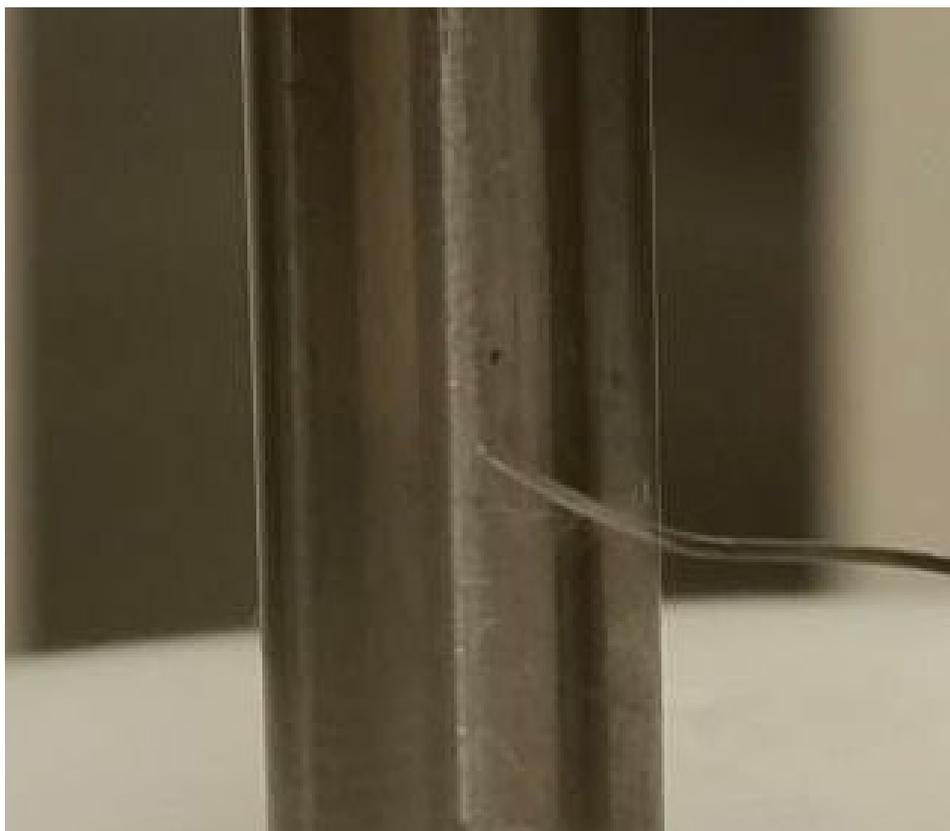
marcin.kopec@cvrez.cz



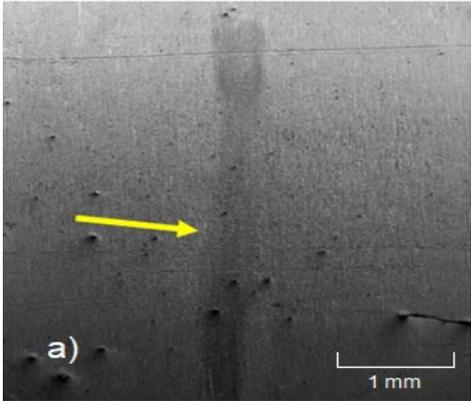
Fuel inspection support

■ -0.15--0.1 ■ -0.1--0.05 ■ -0.05-0 ■ 0-0.05 ■ 0.05-0.1 ■ 0.1-0.15 ■ 0.15-0.2

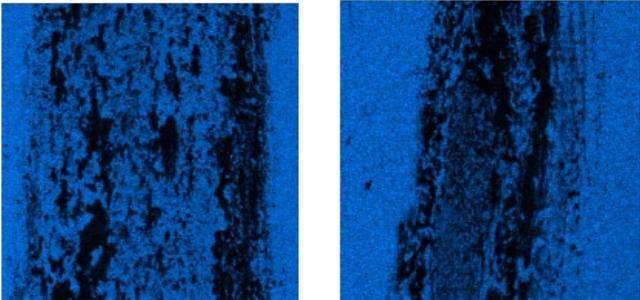
Debris Fretting



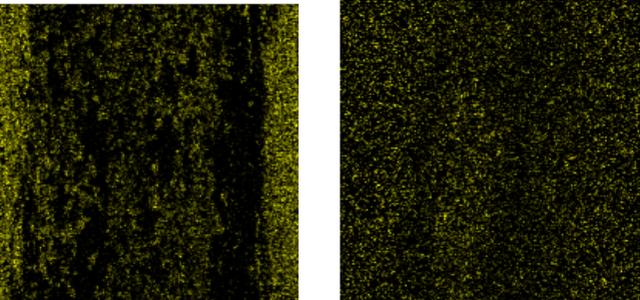
Debris Fretting



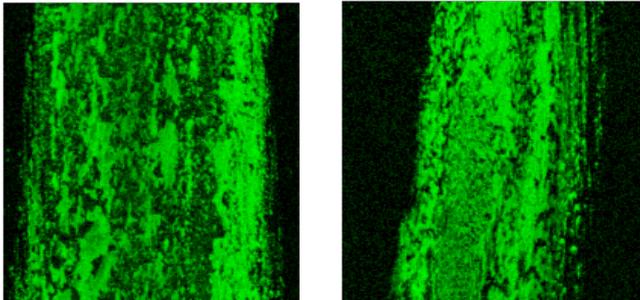
Cr K series



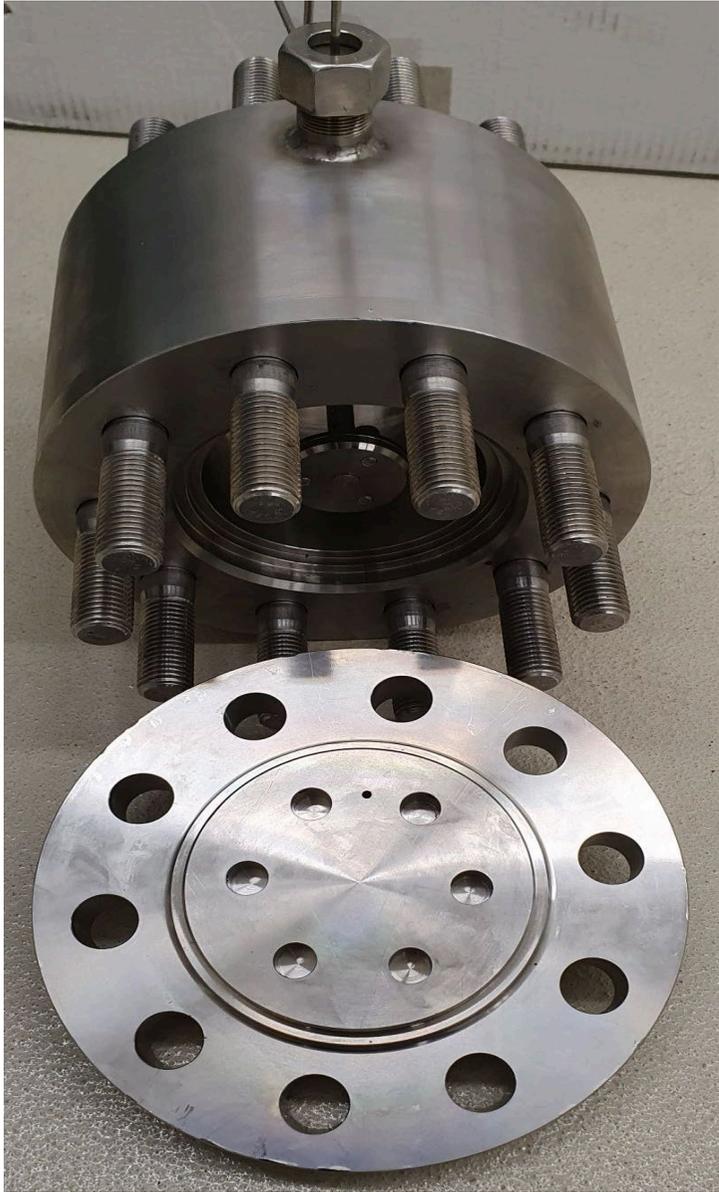
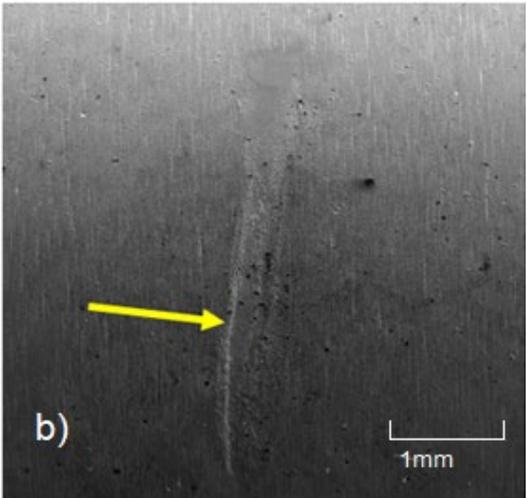
N K series



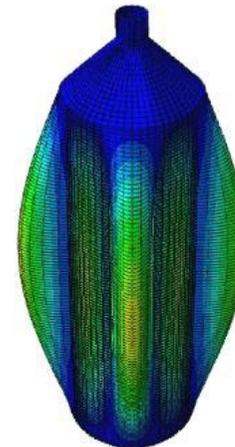
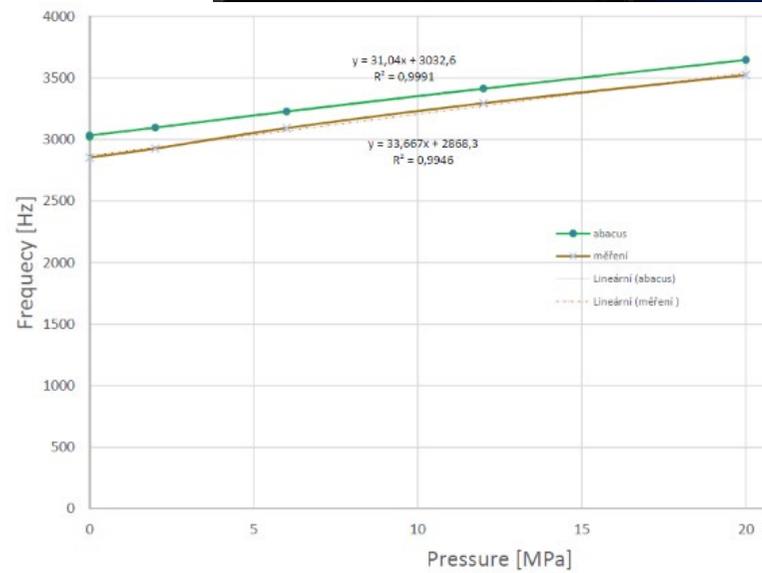
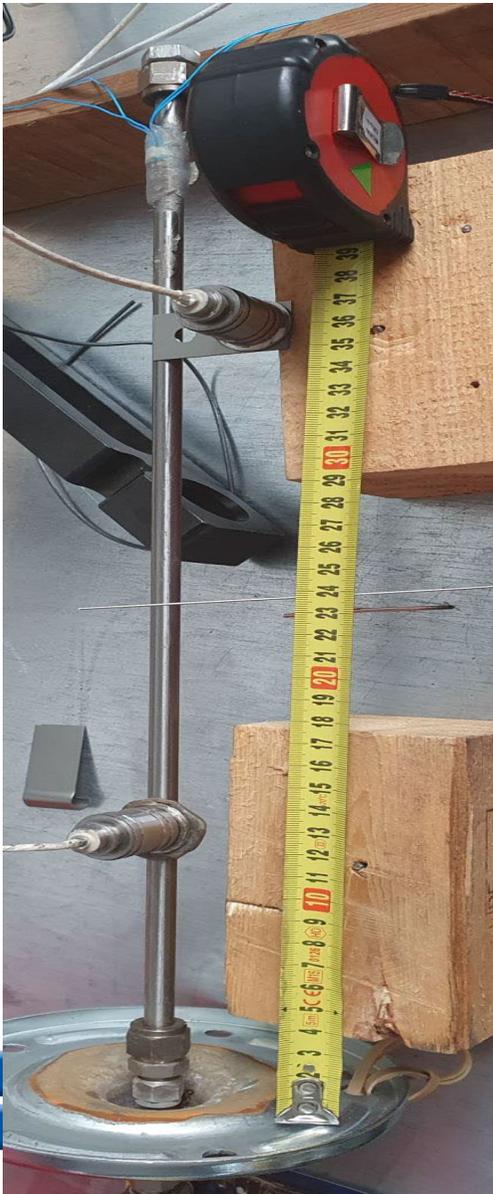
Zr L series



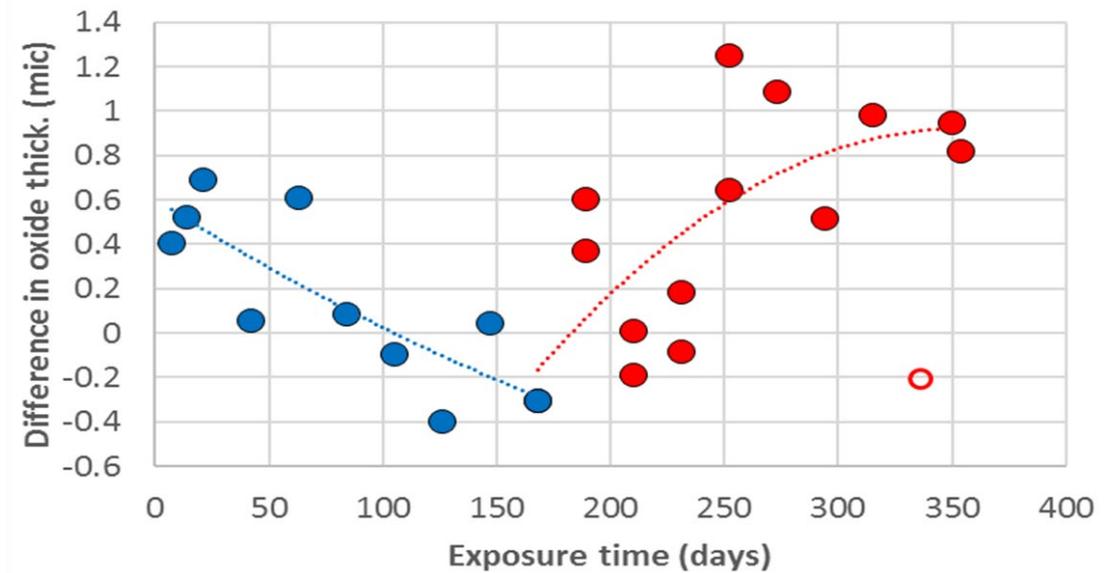
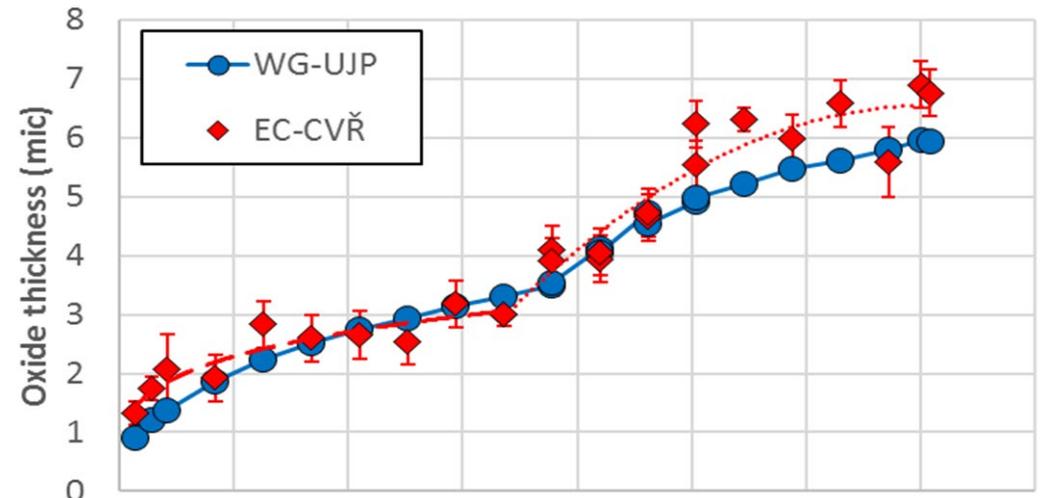
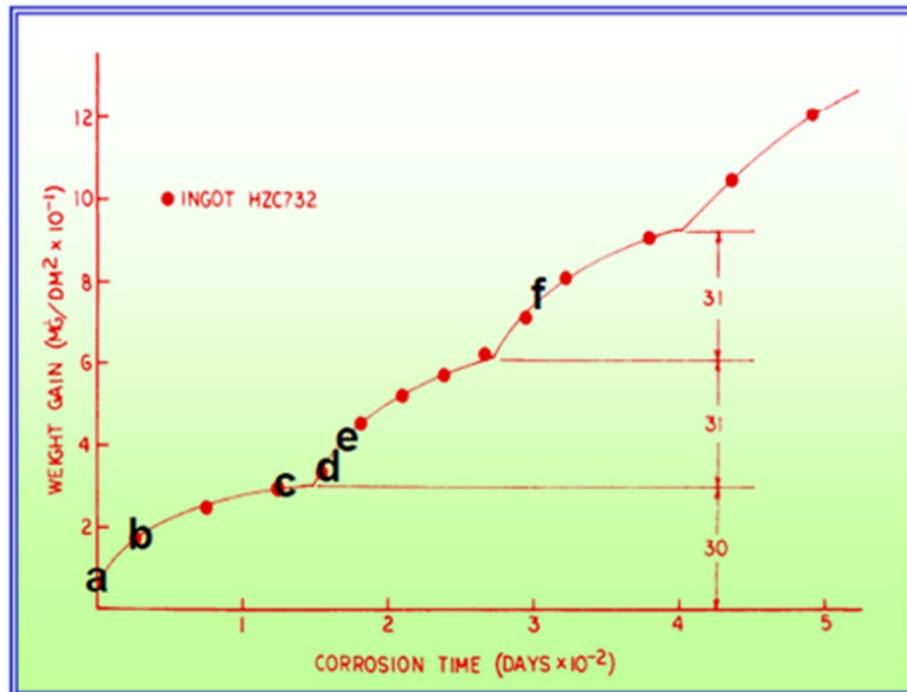
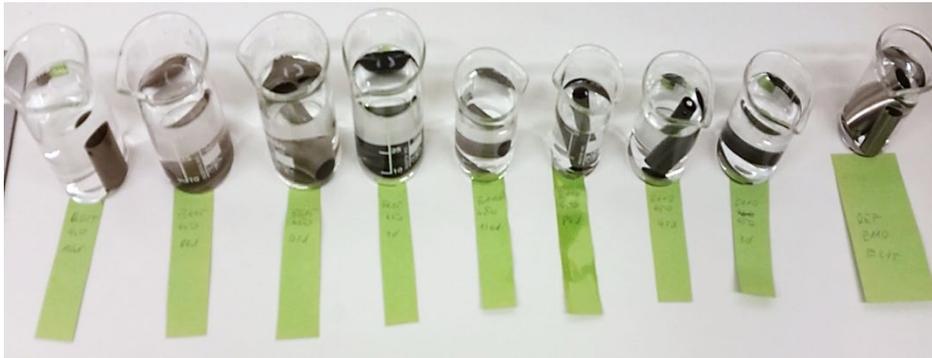
SEM analysis of fretting marks: a) CrN; b) CrN₂+Cr



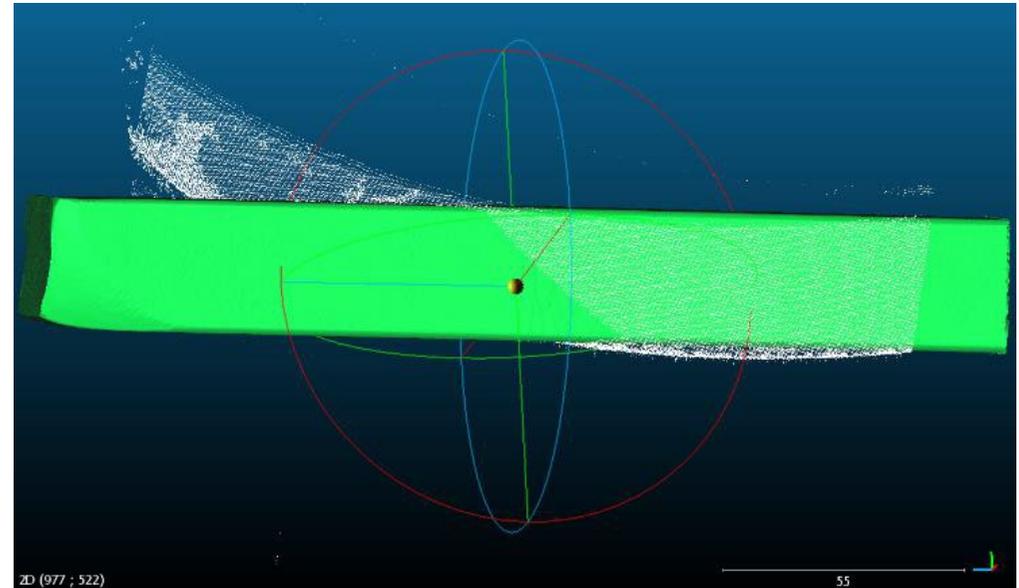
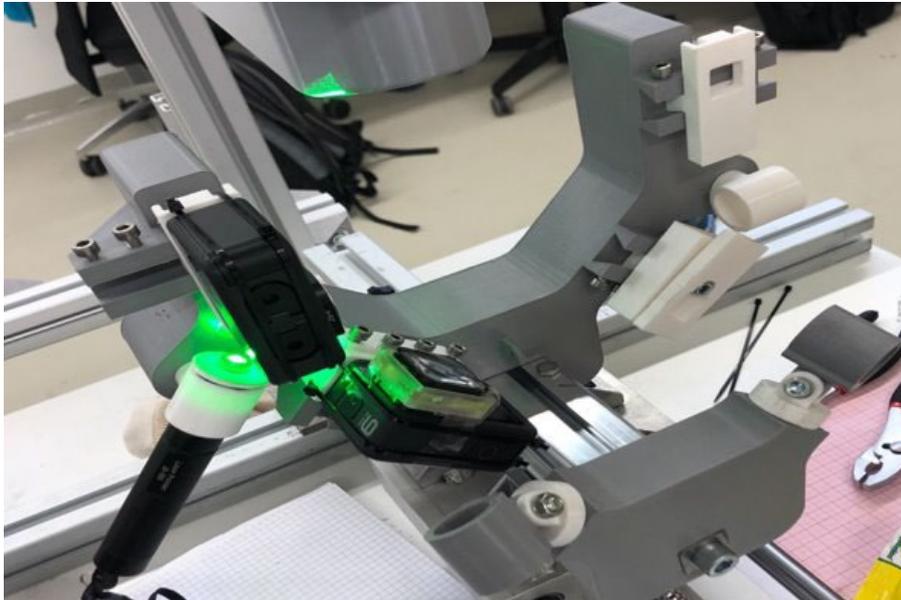
FR internal pressure measurements



Oxide layer measurements



NPP components measurements



Wings and dumps measurements (core basket support) – accuracy: 12,5 μm .

