CORTEX

Core monitoring techniques and experimental validation and demonstration

Neutron noise experiments in the AKR-2 and CROCUS reactors for the CORTEX European project

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The CORTEX project

First AKR-2 campaign

- The AKR-2 reactor
- Perturbation systems
- Detection instrumentation
- Measurements performed

First CROCUS campaign

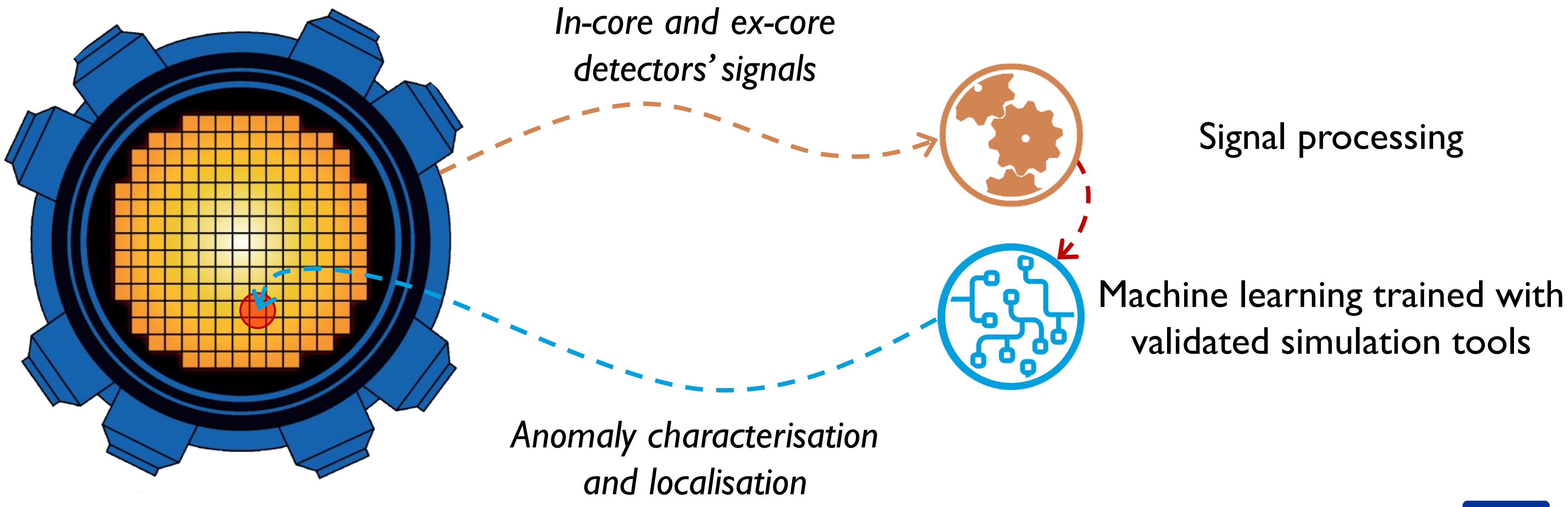
- The CROCUS reactor
- Fuel rods oscillator
- Detection instrumentation
- Measurements performed

Conclusions & outlook

The Horizon 2020 CORTEX project[1]

CORe monitoring Techniques and EXperimental validation & demonstration

↳ develop a core monitoring technique for the early detection, characterization, and localization of anomalies using neutron noise



[1] Demazière C., Vinai P., Hursin M., Kollias S., and Herb J., Overview of the CORTEX project, Proc. Int. Conf. Physics of Reactors – Reactor Physics paving the way towards more efficient systems (PHYSOR2018), Cancun, Mexico, April 22-26, 2018 (2018)

The Horizon 2020 CORTEX project

20 partners for 5 work packages

- WP1 – Development of modelling capabilities for reactor noise analysis:
- Task 1.1 – Modelling of fluid-structure interactions
- Task 1.2 – Modelling of the effect of fuel assembly vibrations
- Task 1.3 – Generic modelling of reactor transfer function
- Task 1.4 – Methodology for uncertainty and sensitivity analysis applied to reactor noise simulations

- WP2 – Validation of the modelling tools against experiments in research reactors
- Task 2.1 – Generation of high quality experimental data for code validation
- Task 2.2 – Validation of the computational tools

- WP3 – Development of advanced signal processing and machine learning methodologies for analysis of plant data
- Task 3.1 – Generation of basic scenarios and simulated data
- Task 3.2 – Advanced data processing in the time- and frequency-domains
- Task 3.3 – Data analysis using machine learning techniques and deep neural networks

- WP4 – Application and demonstration of the developed modelling tools and signal processing techniques against plant data
- Task 4.1 – Preparation of available measurements and core data; performance of additional measurements; packaging and distribution of tools to project partners
- Task 4.2 – Demonstration of the computational tools and methodologies developed in WP1 and WP3
- Task 4.3 – Recommendations on in-core and out-of-core instrumentations

- WP5 – Knowledge dissemination and education
- Task 5.1 – Education in reactor dynamics, neutron noise and diagnostics
- Task 5.2 – Knowledge dissemination
- Task 5.3 – Communication

Experimental campaigns for CORTEX

20 partners for 5 work packages

- WP1 – Development of modelling capabilities for reactor noise analysis:
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- Task 5.3 – Communication

TUD EPFL ISTec

4 acquisition systems

1st AKR-2 campaign in March 2018
- rotating neutron absorber
- vibrating absorber

1st CROCUS campaign in Sep. 2018
- fuel rods oscillator

Data acquisition systems (DAQ)

TUD Pulse-mode DAQ (1 channel): ORTEC Easy-MCS multichannel scaler and MAESTRO software

EPFL Pulse- (4 ch.) and current-mode (4 ch.) DAQ:

- ORTEC PCI-based multichannel scalers and LabVIEW routines
- Lecroy Wavesurfer 10 oscilloscope

ISTec SIGMA industry-grade current-mode system (16 ch.), used with Robotron 20046 frequency to voltage converters for pulse-mode.

[1] A. Rais et al., "Towards the validation of neutron noise simulators: comparative assessment of data acquisition systems", M&C 2019, Portland (USA), 25-29 August 2019

First AKR-2 campaign

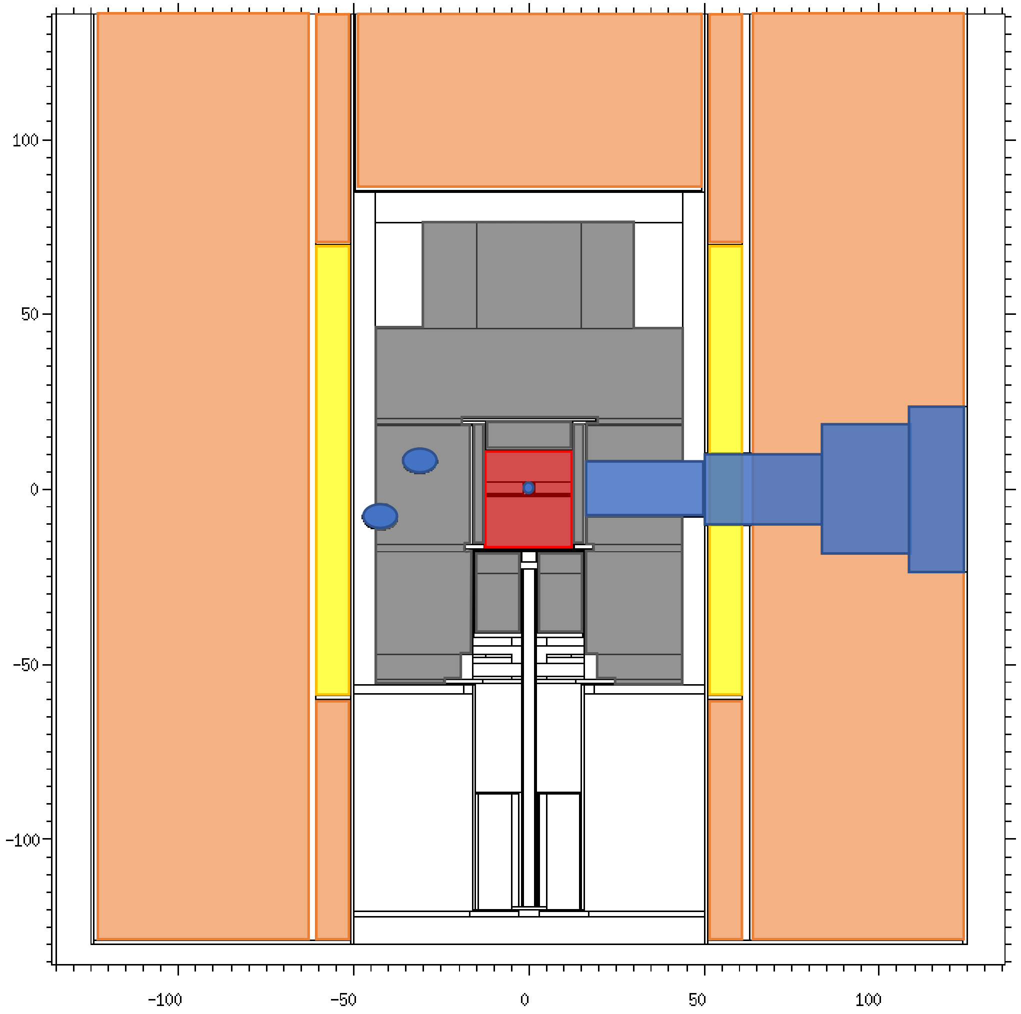
6-15 March 2018

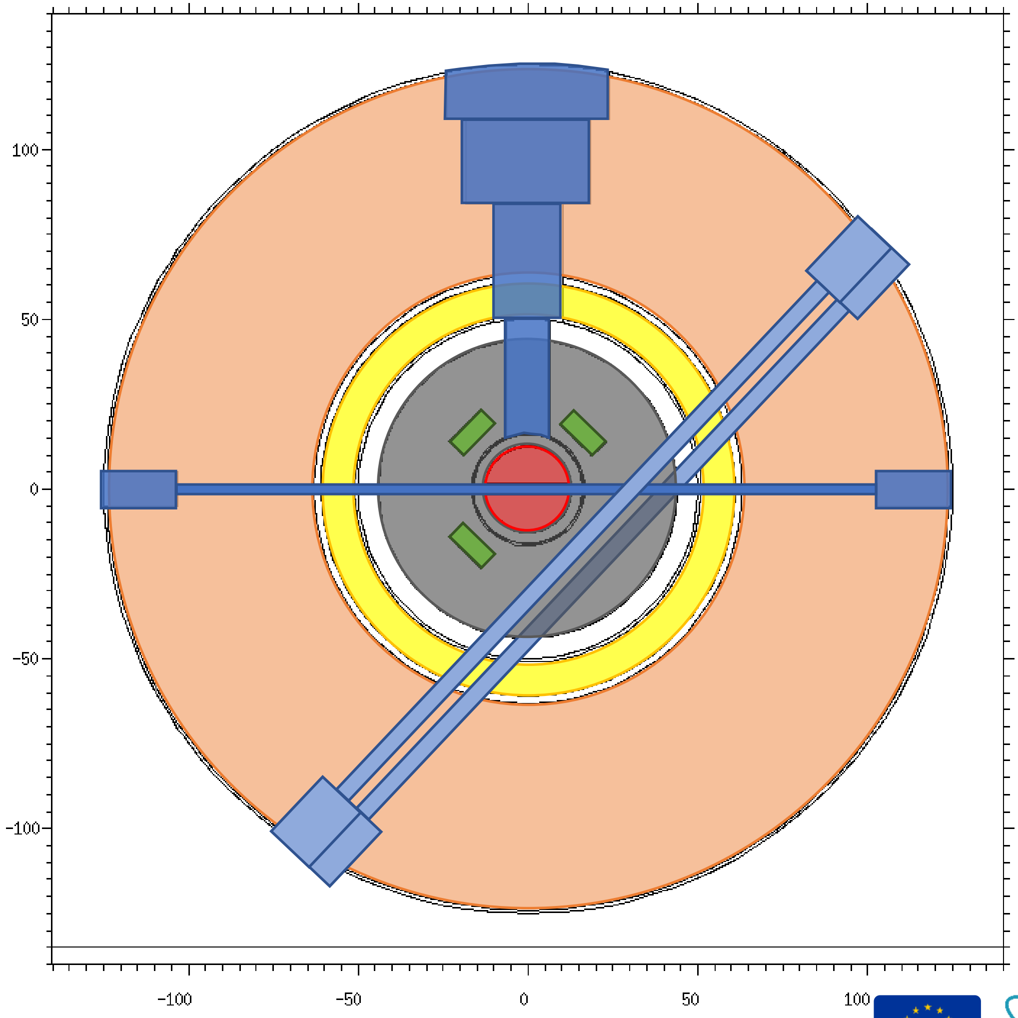
AKR-2 Characteristics

- Thermal, zero-power reactor
- Homogeneous uranium-oxide, polyethylene core
- U-235 enrichment of 19.8 % (ca. 790 g)
- Graphite reflector
- Φ_{max}= 2.7 · 10^7 $cm^{-2}.s^{-1}$
- $P_{therm,max}$ = 1.4 W (2W)

AKR-2 Components

Fuel | Reflector | Control- and Safety rods | Experimental Channels | Shielding



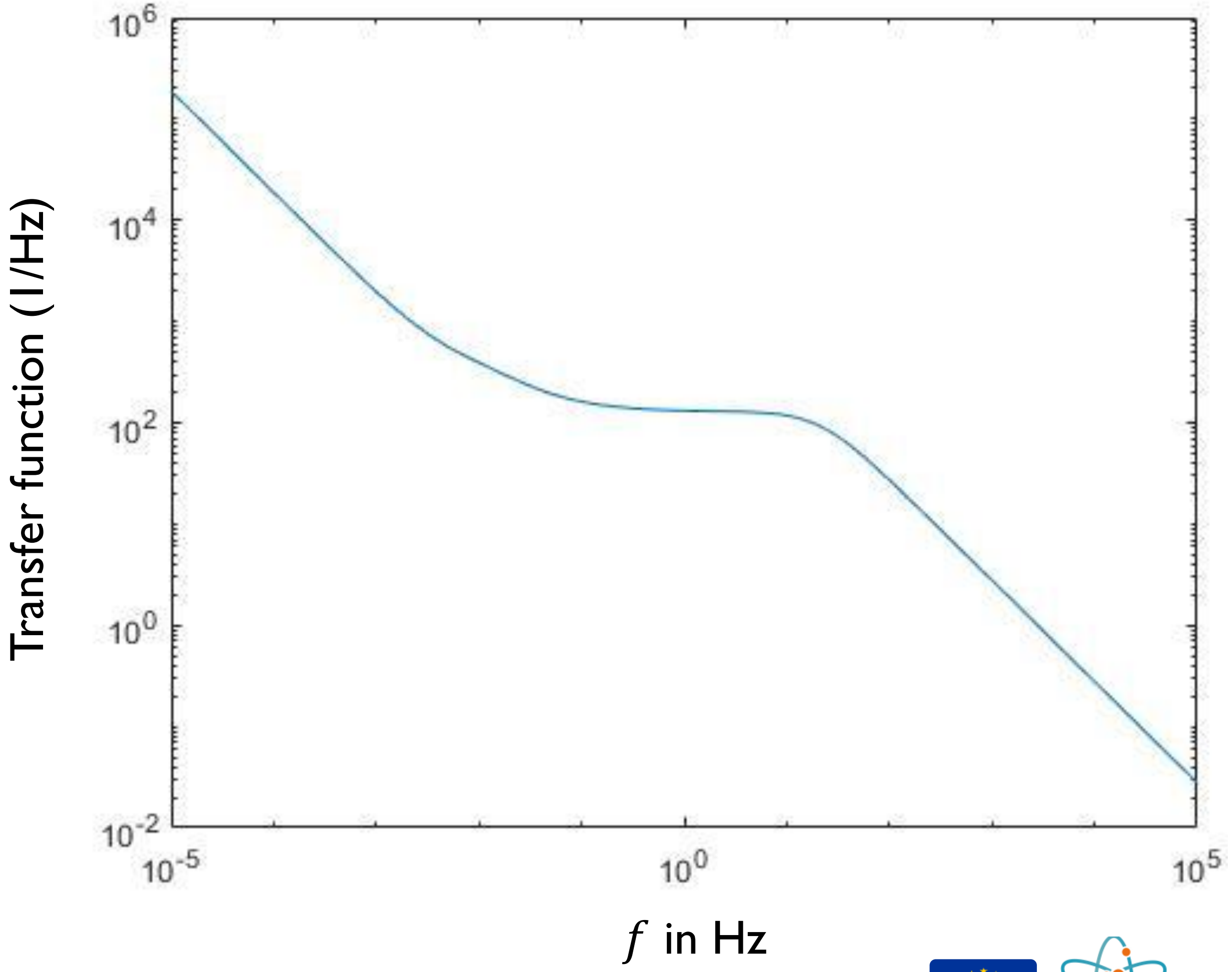


AKR-2 Kinetic Parameters & ZPTF

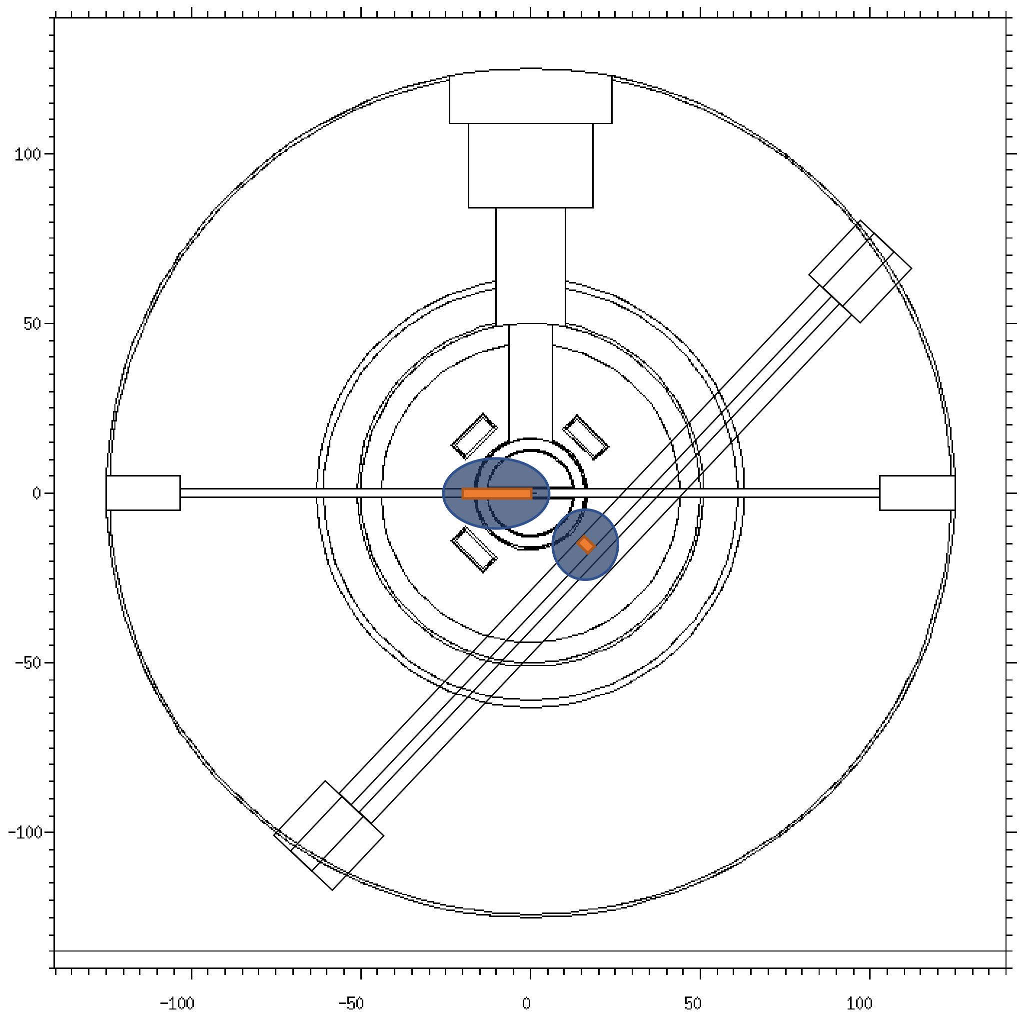
MCNP 6.0
ENDF/B-VIII.0

		Estimate
Generation time	Λ	57.29561 x 10^{-6} s
Beta effective	β_{eff}	0.00766

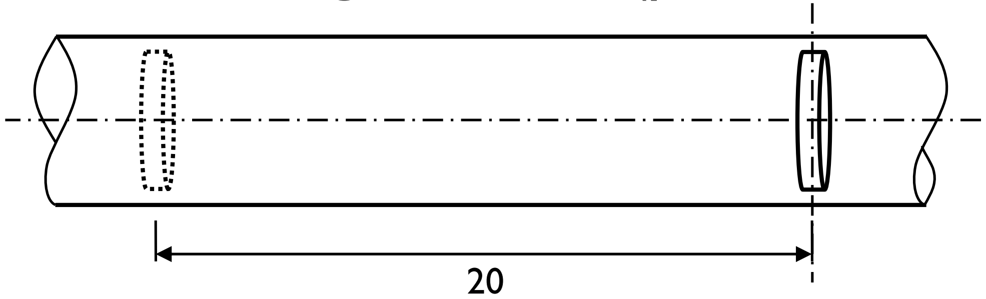
Precursor	$\boldsymbol{\beta}_{\text{eff}}$	$\boldsymbol{\lambda_i}$ **(s^{-1})**
1	0.00027	0.01334
2	0.00137	0.03273
3	0.00133	0.12079
4	0.00296	0.30293
5	0.00123	0.85011
6	0.00050	2.85508



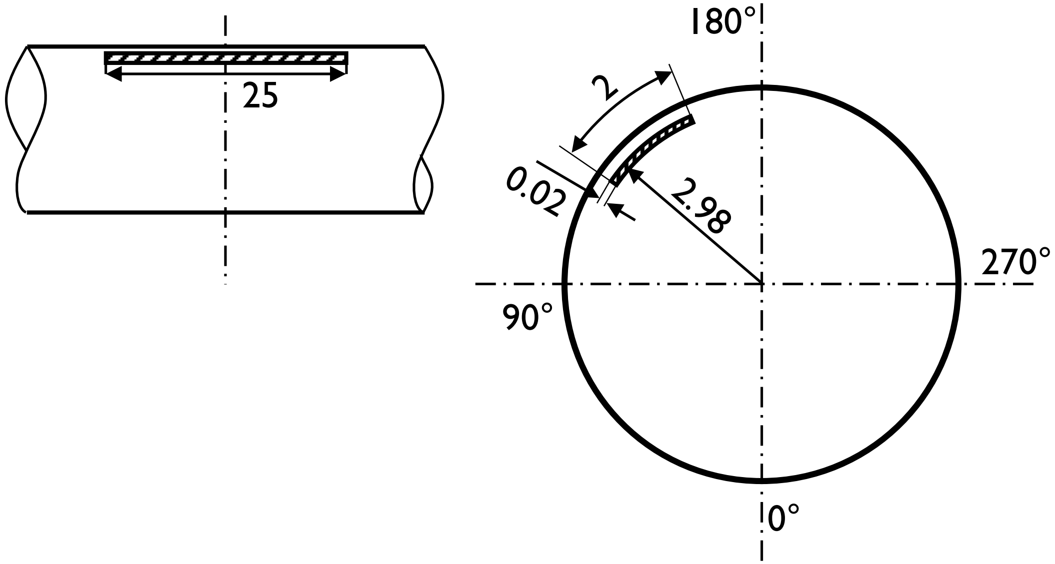
AKR-2 Locality of Perturbations



Linear moving absorber (pile oscillator)



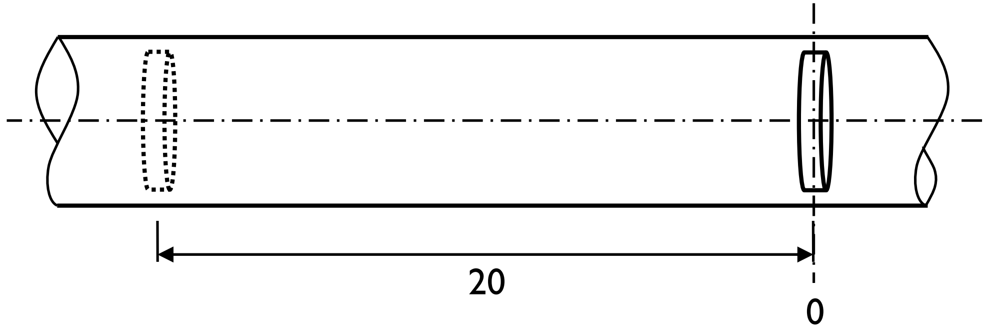
Rotating absorber

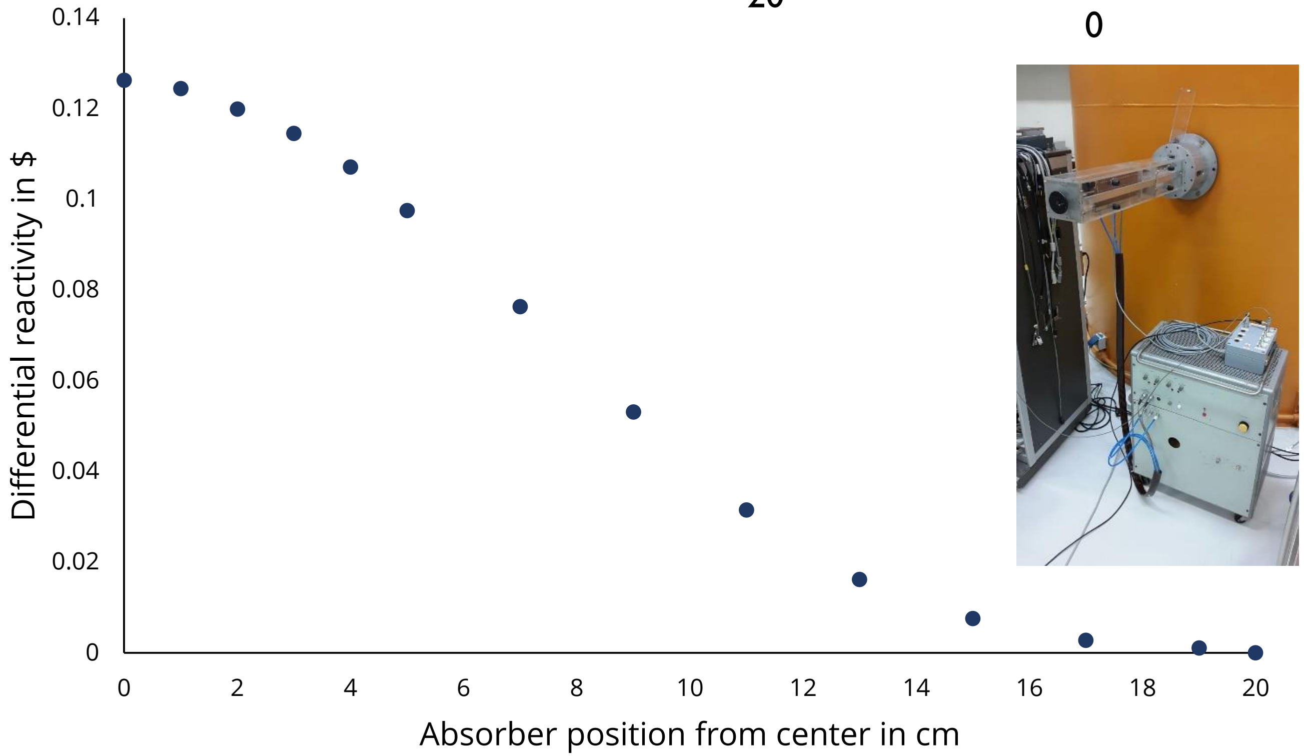


AKR-2 Perturbation systems

Linear moving absorber

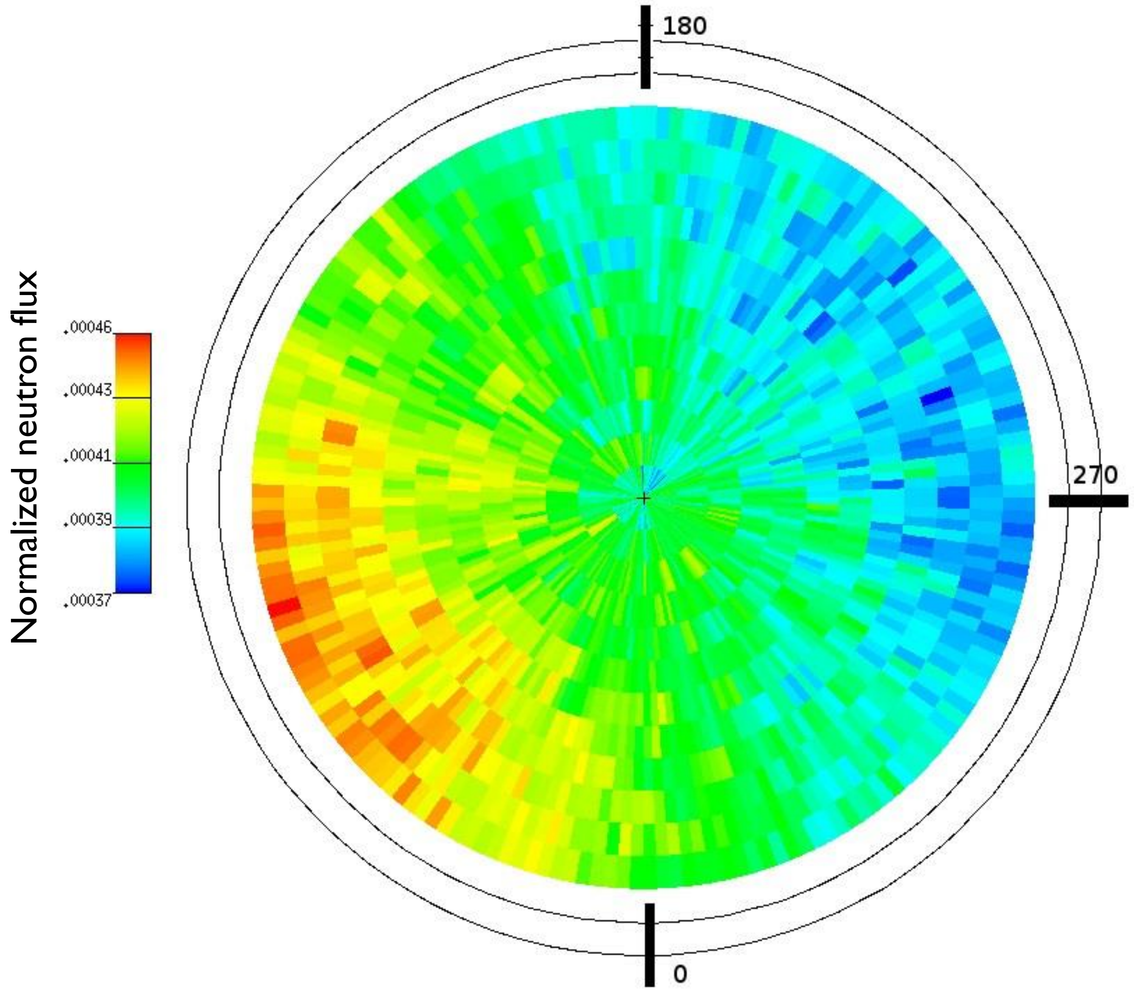
- Drive: pneumatic
- Distance: fixed, 20 cm
- Frequency: 0.08 to 0.71 Hz
- Motion profile: fixed, trapeze (jump)
- Total reactivity: ρ'_t=0.0126 $





AKR-2 Perturbation systems

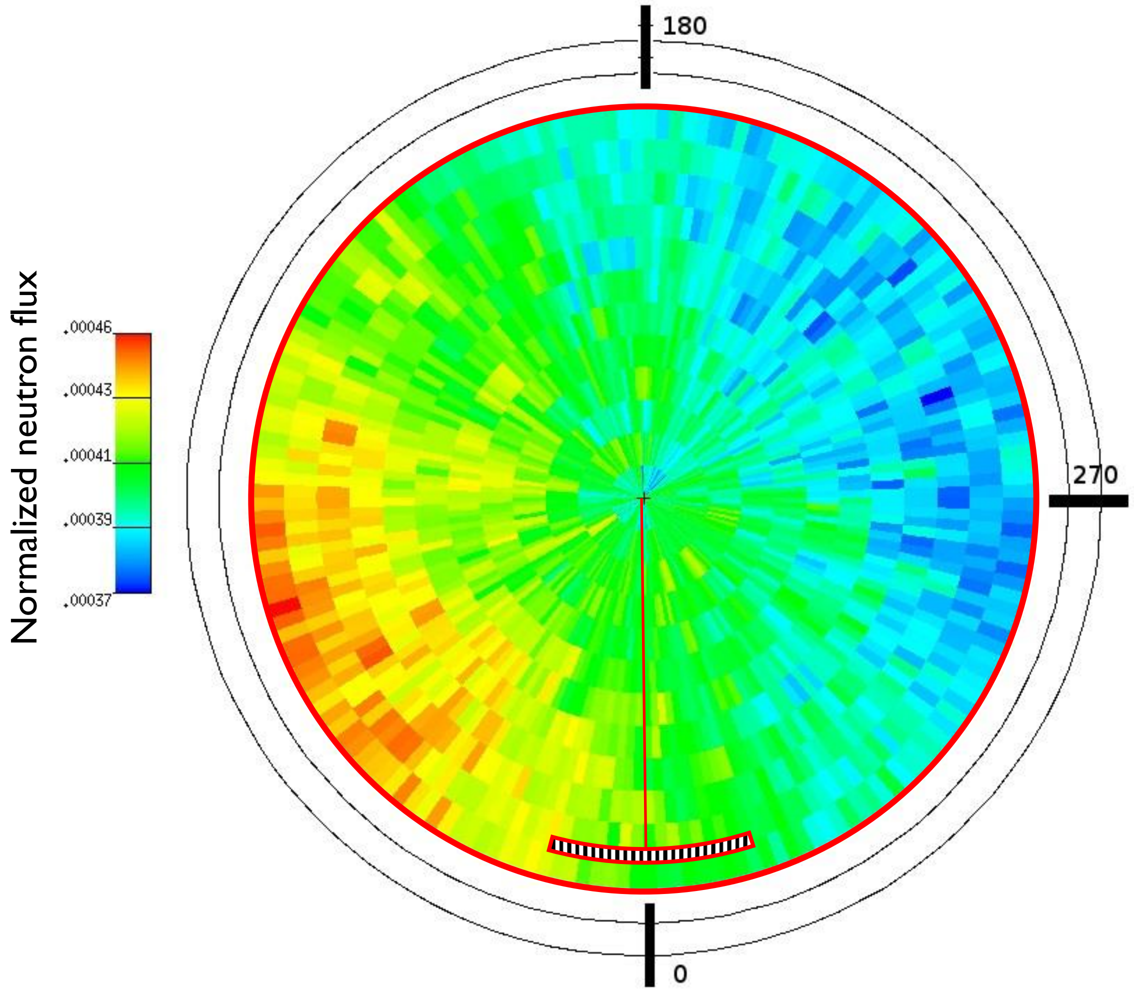
Rotating absorber



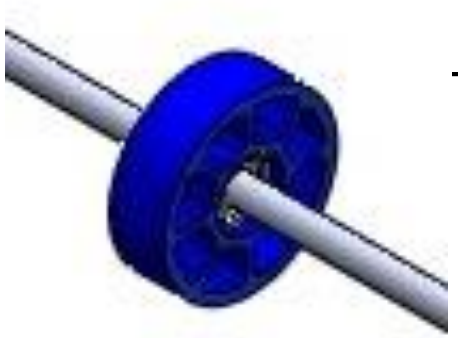
MCNP simulation of the flux in the tangential channel 3-4

AKR-2 Perturbation systems

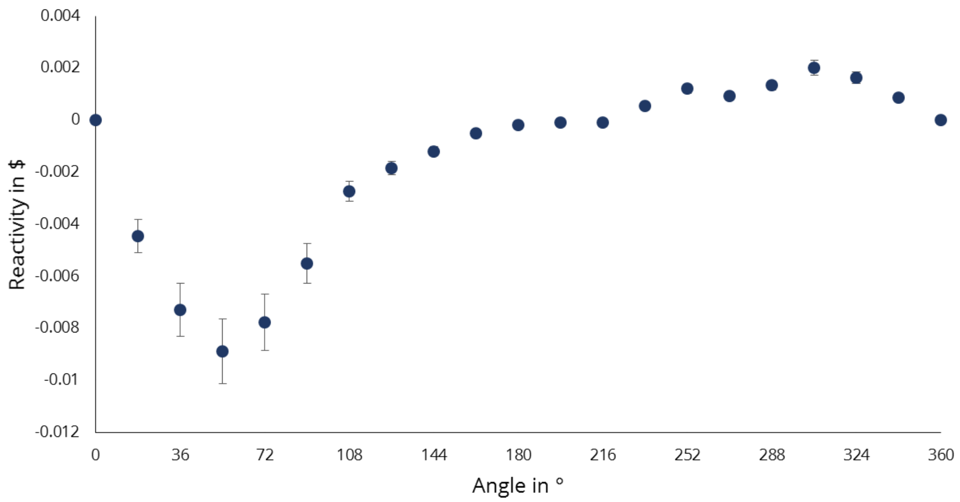
Rotating absorber



MCNP simulation of the flux in the tangential channel 3-4

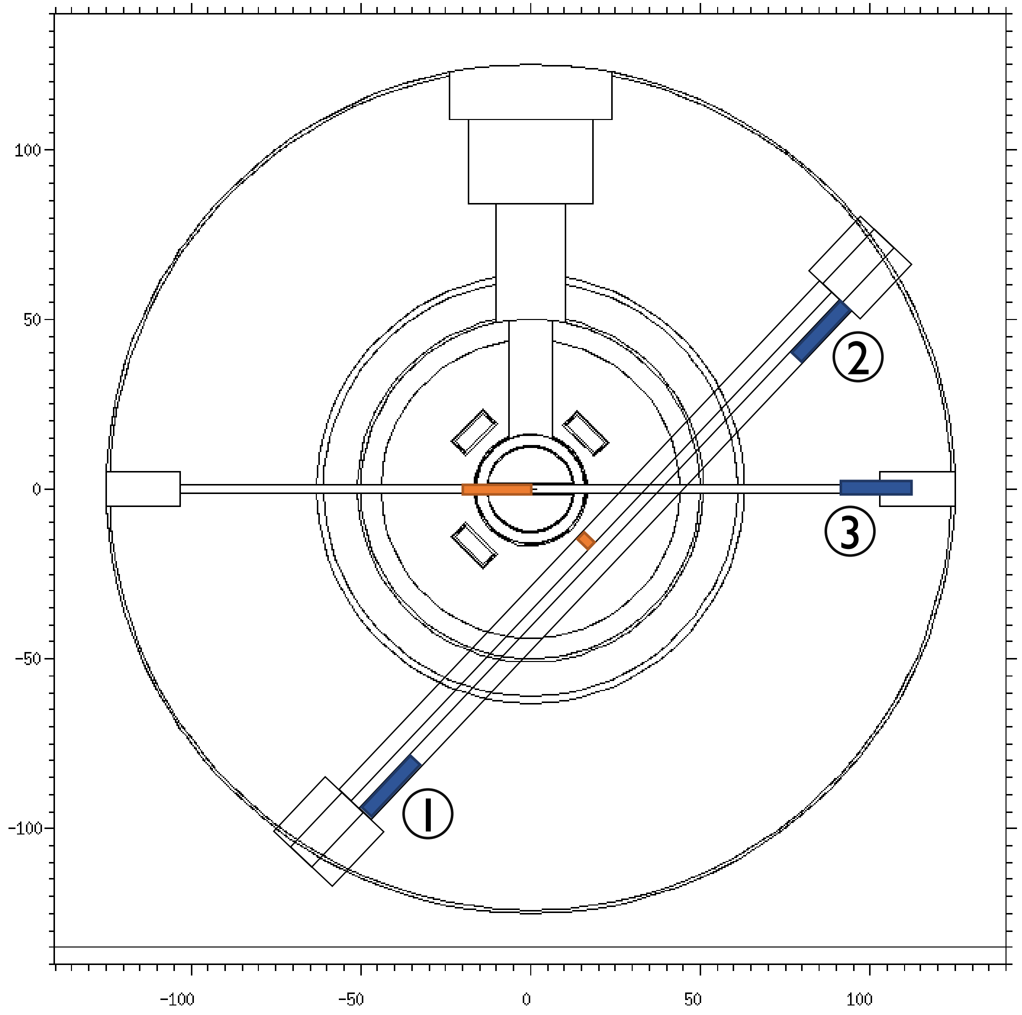


Total reactivity: ρ'_t=0.0109 $

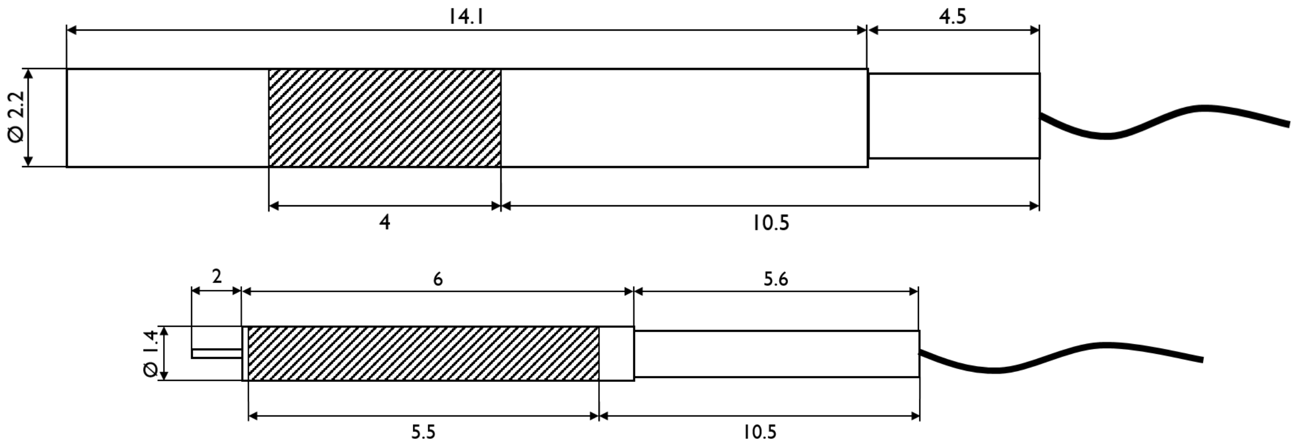


Measured reactivity of the rotating absorber

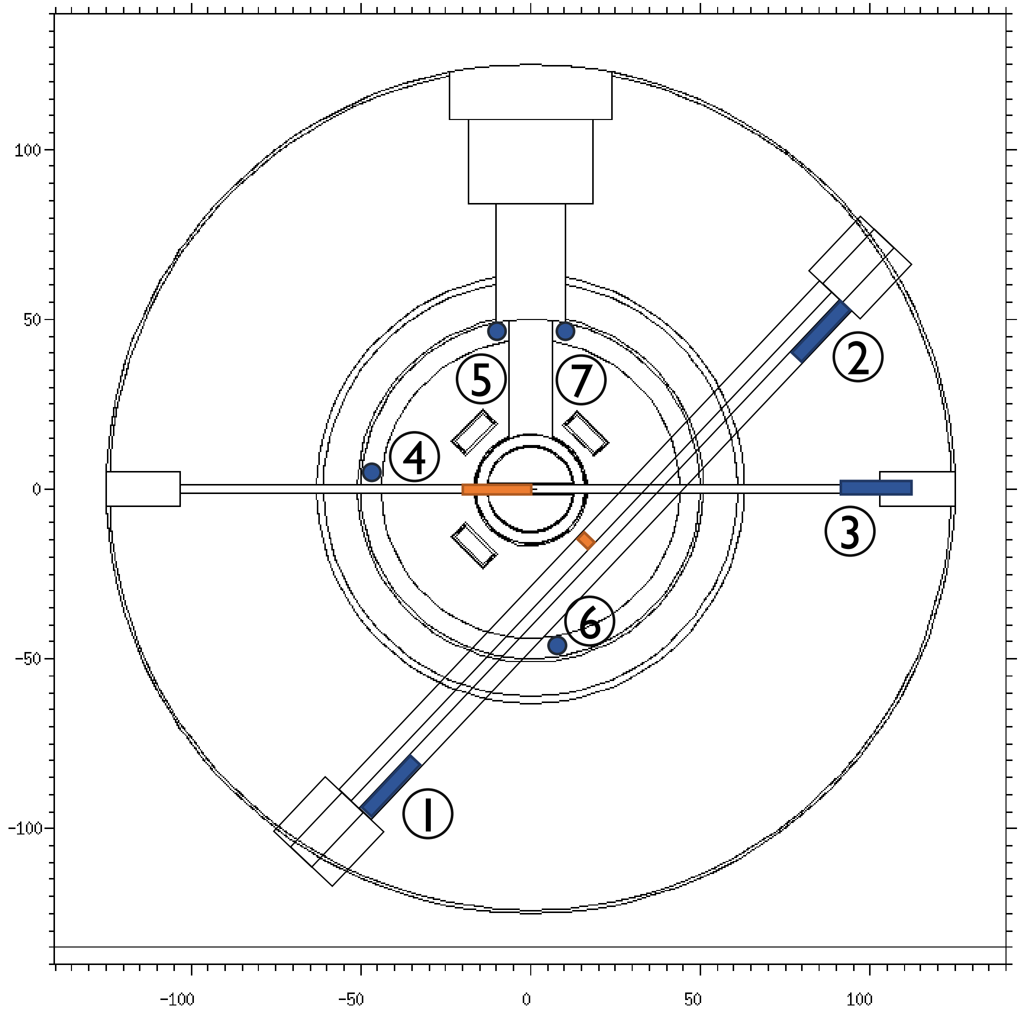
AKR-2 Position of detectors



① to ③ He-3 proportional counter

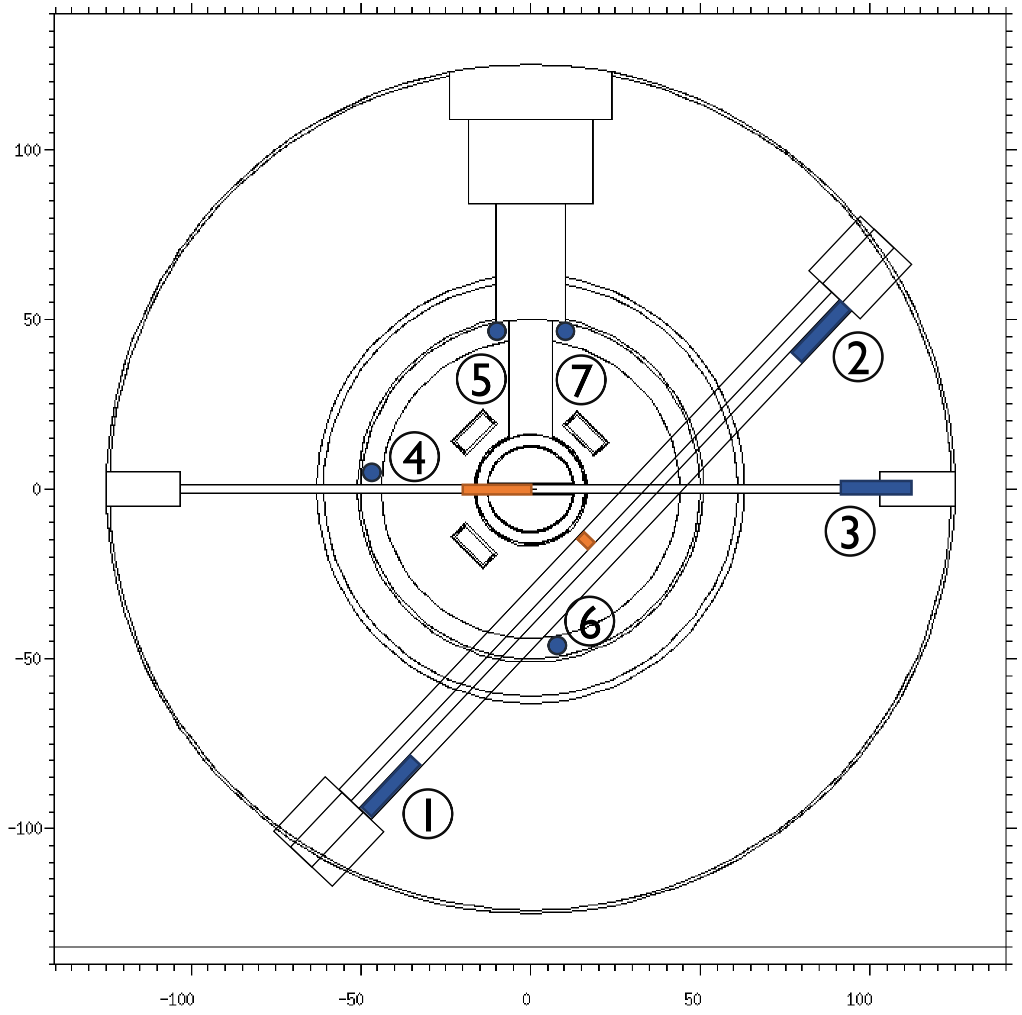


AKR-2 Position of detectors



① to ③	He-3 proportional counter
④	Fission chamber
⑤ & ⑥	Fission chamber, wide range
⑦	γ- compensated ion chamber, power range

AKR-2 Position of detectors



TUD EPFL ISTec

① to ③ He-3 proportional counter

④ Fission chamber

⑤ & ⑥ Fission chamber, wide range

⑦ γ- compensated ion chamber, power range

AKR-2 Measurement Campaign

Linear Moving Absorber (Pile Oscillator)

IsTec	EPFL	TUD	Comparable
18	17	16	15 (17)

Reactor Power: 0.8 to 2.0 W; Perturbation frequency: 0.08 to 0.71 Hz

Rotating Absorber

IsTec	EPFL	TUD	Comparable
23	10	4	4 (10)

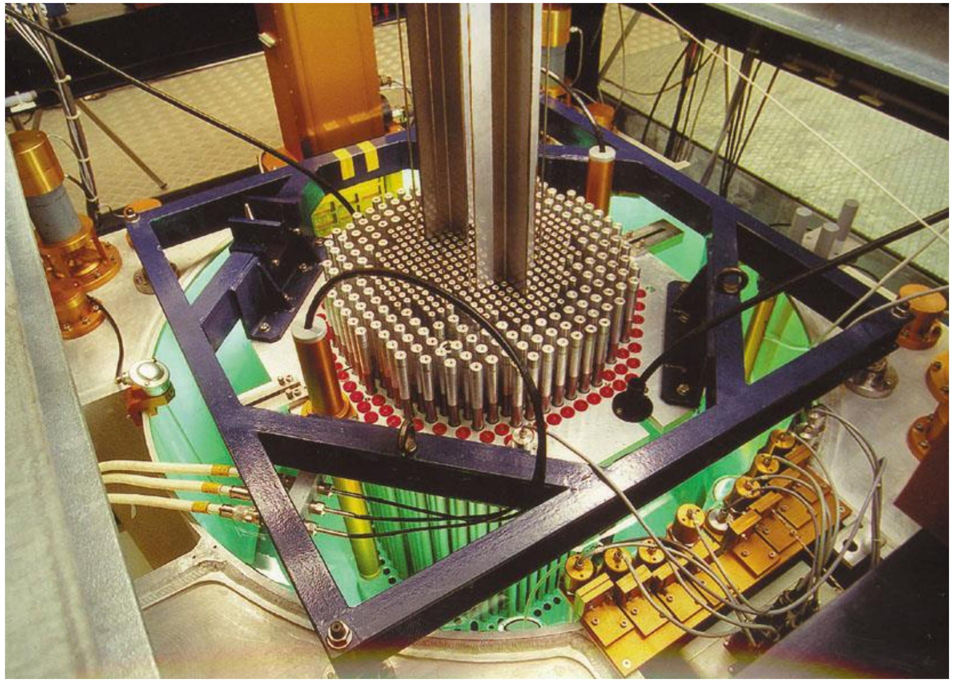
Reactor Power: 0.2 to 2.0 W; Perturbation frequency: 0.2 to 2.0 Hz

Static measurements of ISTec (and TUD) at different power levels

First CROCUS campaign

17-21 September 2018

The CROCUS reactor



- Reactor type
  - LWR with partially submerged core
  - Room T (controlled) and atmospheric P
  - Forced water flow (160 l.min-1)

- Operation
  - 100 W (zero-power reactor)
  - i.e. maximum 2.5×10^{9} $cm^{-2}.s^{-1}$
  - Control: B_4C rods and spillway

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  LWR with partially submerged core
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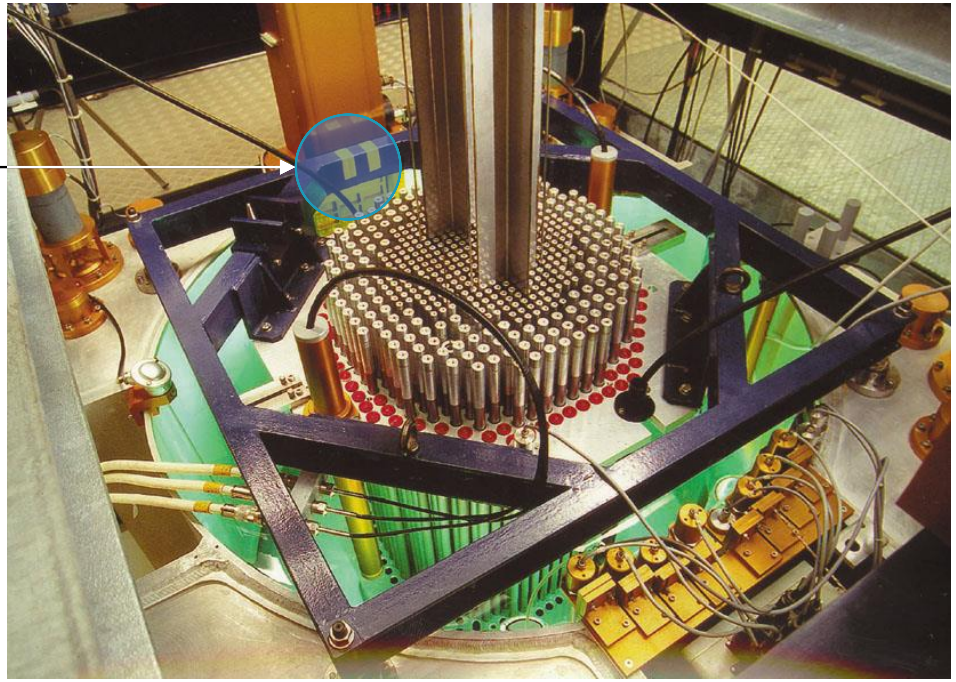

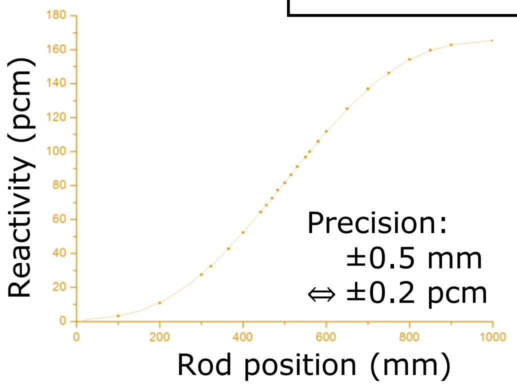

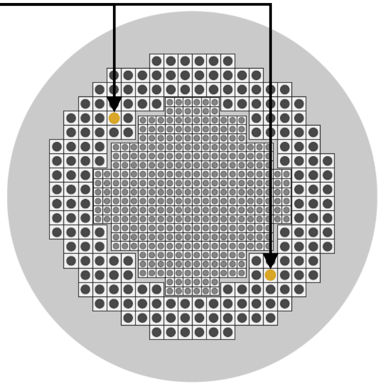

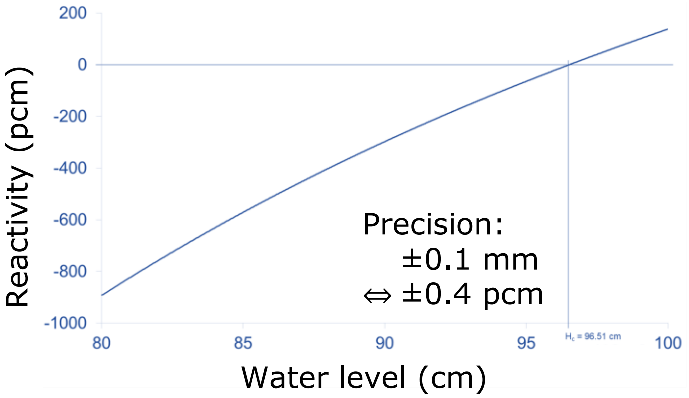

The CROCUS reactor

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  LWR with partially submerged core
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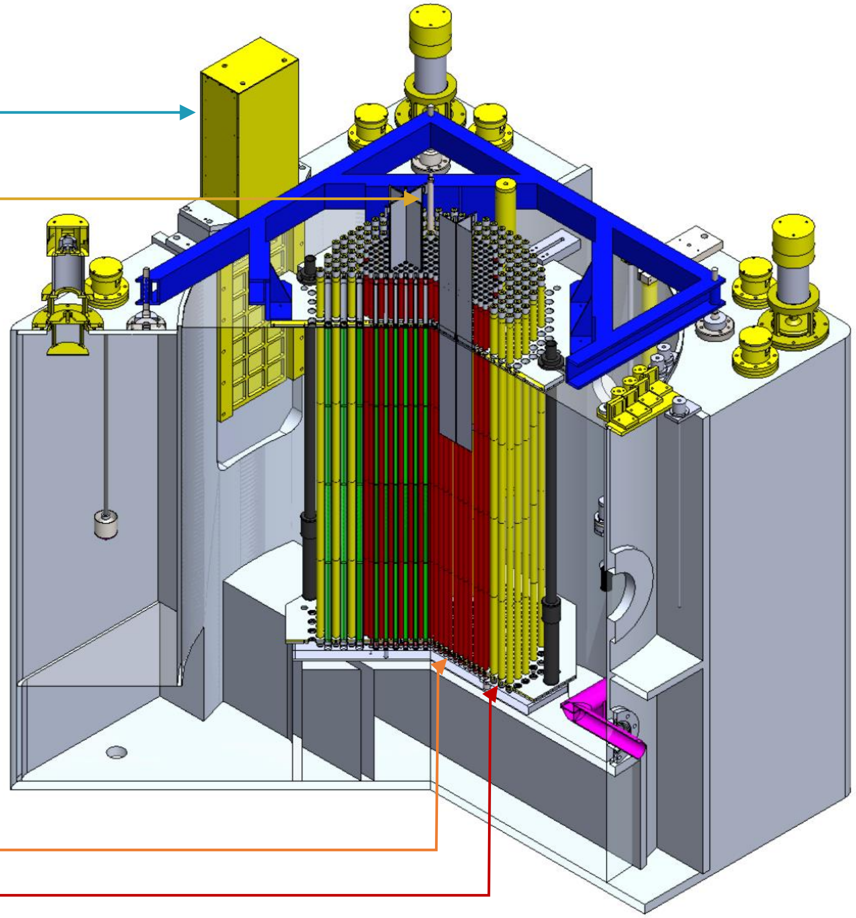
- Operation
  100 W (zero-power reactor)
  i.e. maximum 2.5×10^{9} $cm^{-2}.s^{-1}$
  Control: B_4C rods and spillway

- Core dimensions
  ⌀60 cm/100 cm

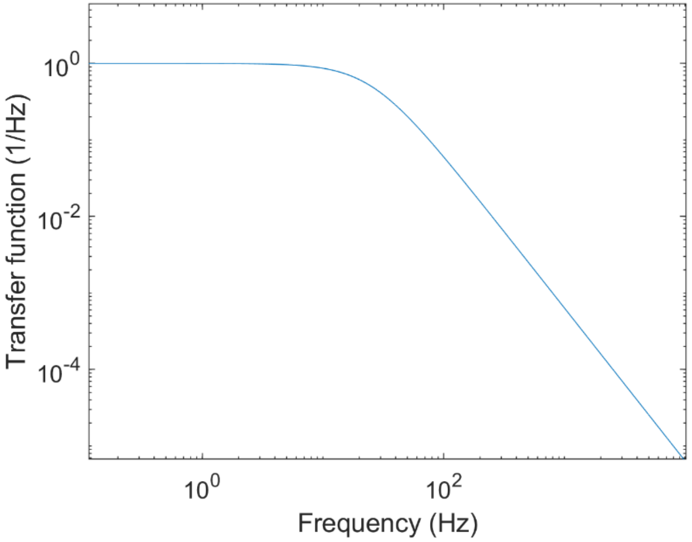
- Fuel lattices
  2-zone: 336/176 rods actually
  Inner: UO_2 1.806 wt% 1.837 cm
  Outer: U_{met} 0.947 wt% 2.917 cm



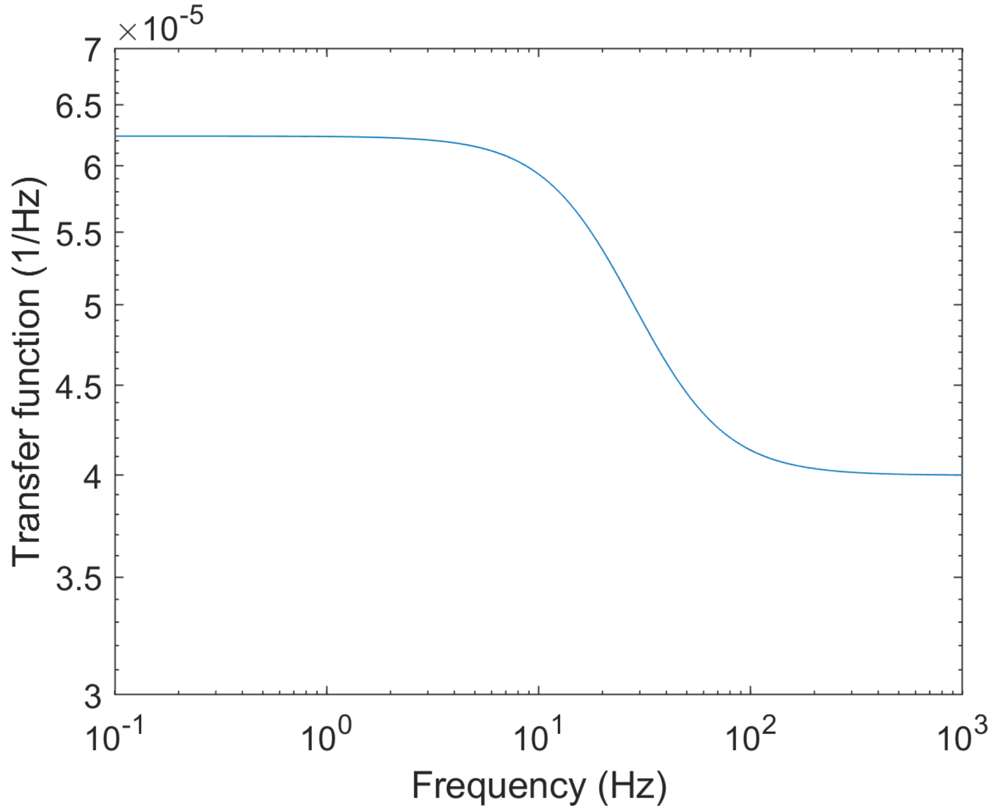
CROCUS Kinetic Parameters & ZPTF

MCNPv5-1.6
JEFF 3.1.1

		Estimate
Generation time	Λ	47.82 ± 0.05 μs
Beta effective	β_{eff}	759 ± 7 pcm



ZPTF

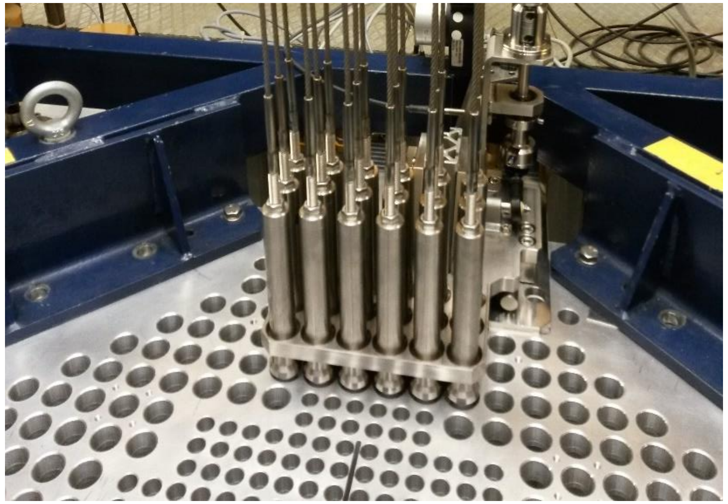


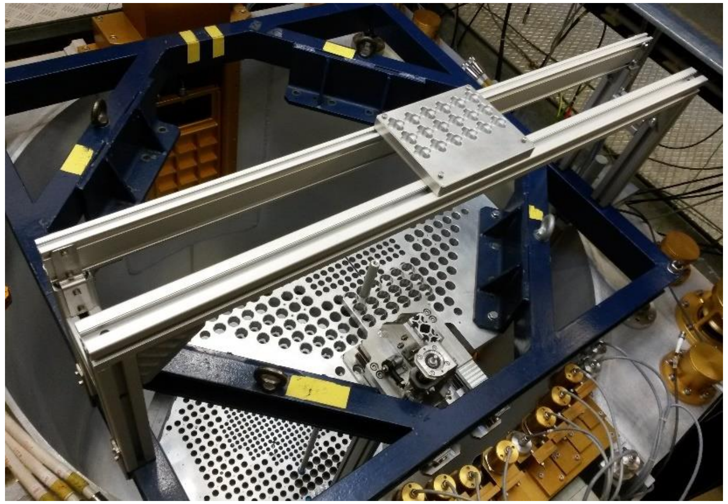
Estimated APSD from an efficient detector (10^{-5})

Fuel rods oscillator

Design for investigating power fluctuations induced by fuel oscillations

- COLIBRI experimental program in CROCUS
- Up to 18 U_m rods, ±2.5 mm (i.e. 8 pcm), 2 Hz
- Authorization in July 2018 for step-by-step loading and testing procedure, from in-air out of the vessel to critical operation[1]





View of the oscillation device for testing in the vessel

[1] V. Lamirand et al., "The COLIBRI experimental programme in the CROCUS reactor: development and licensing of a fuel rods oscillator," RRFM/IGORR 2019, Swemieh (Jordan), 24-28 March 2019

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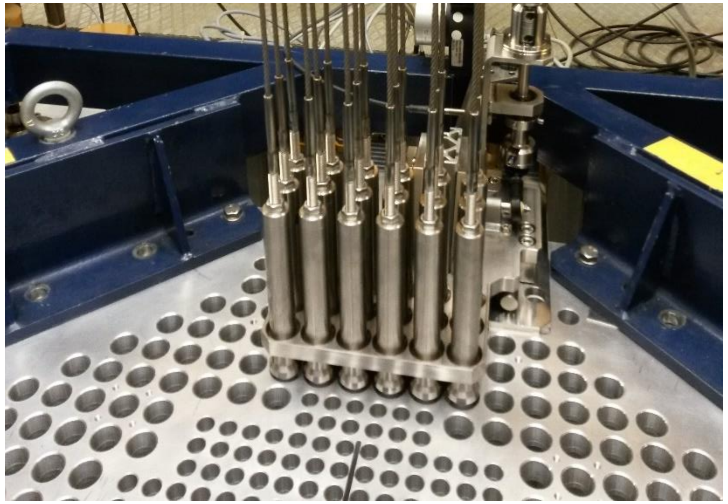
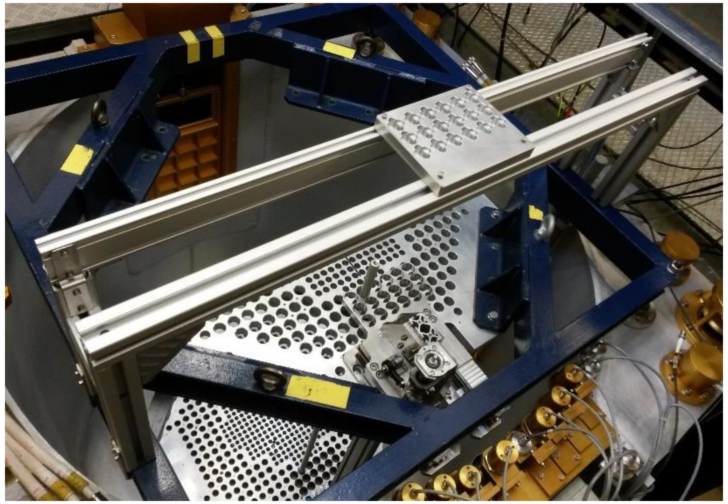
Presentation on
Thursday at 14:40
(Europa)





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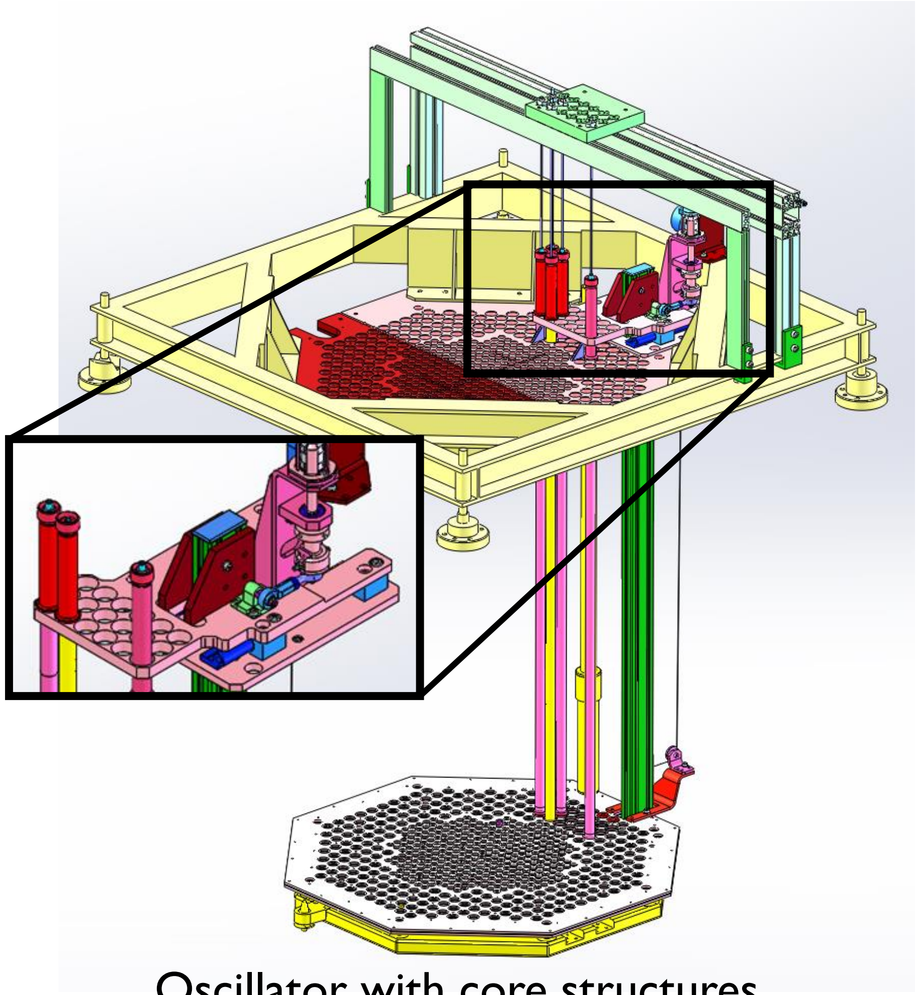
Fuel rods oscillator

Specifications

- No elements in the active zone
- Rigid transmission top to bottom, with Al beam
- Fuel rods lifted for oscillation: 10 mm



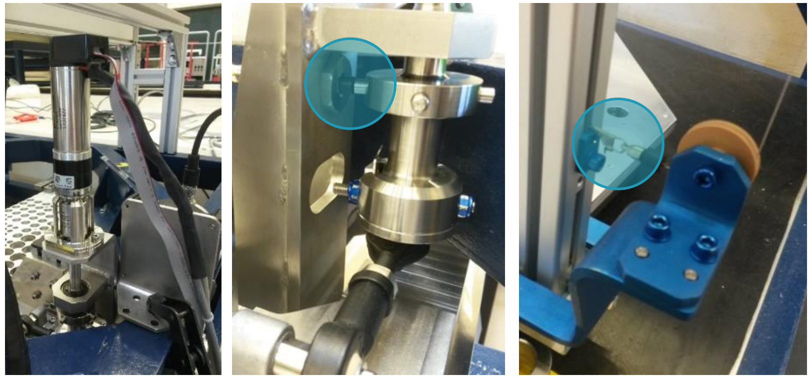
Oscillator with core structures,
and few pins inserted in the device

Fuel rods oscillator

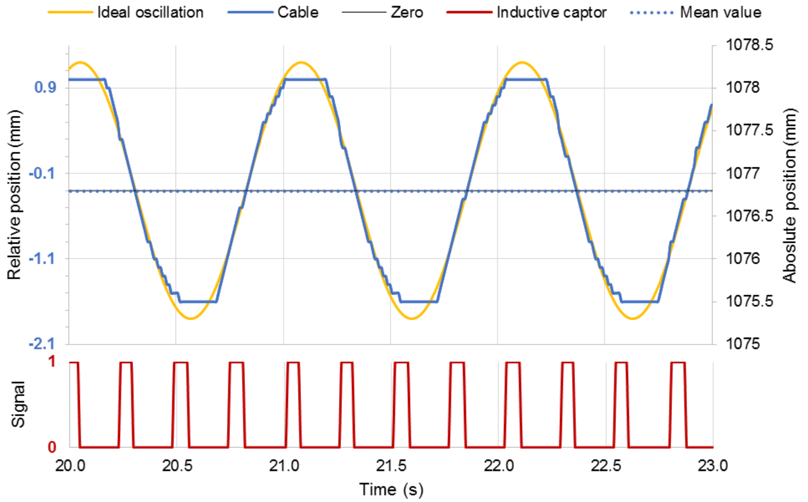
Specifications

- No elements in the active zone
- Rigid transmission top to bottom, with Al beam
- Fuel rods lifted for oscillation: 10 mm
- Signal outputs
  - Motor's position from control
  - Motor's rotation via inductive captor
  - Position at device bottom via cable sensor

  All signals collected by the operation software,
  + extraction of the inductive captor's output.

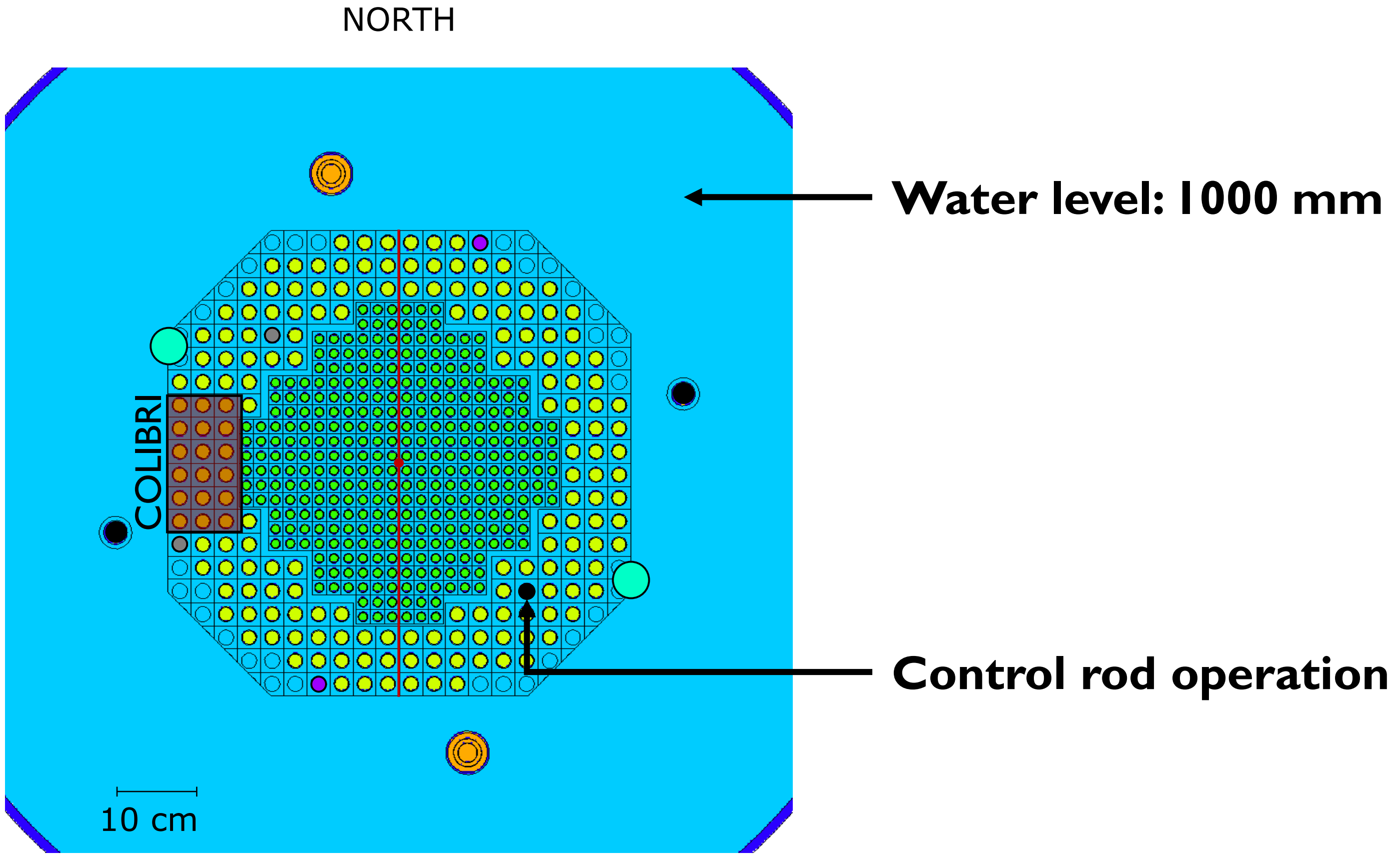


Motor, inductive captor and pins, and measuring cable



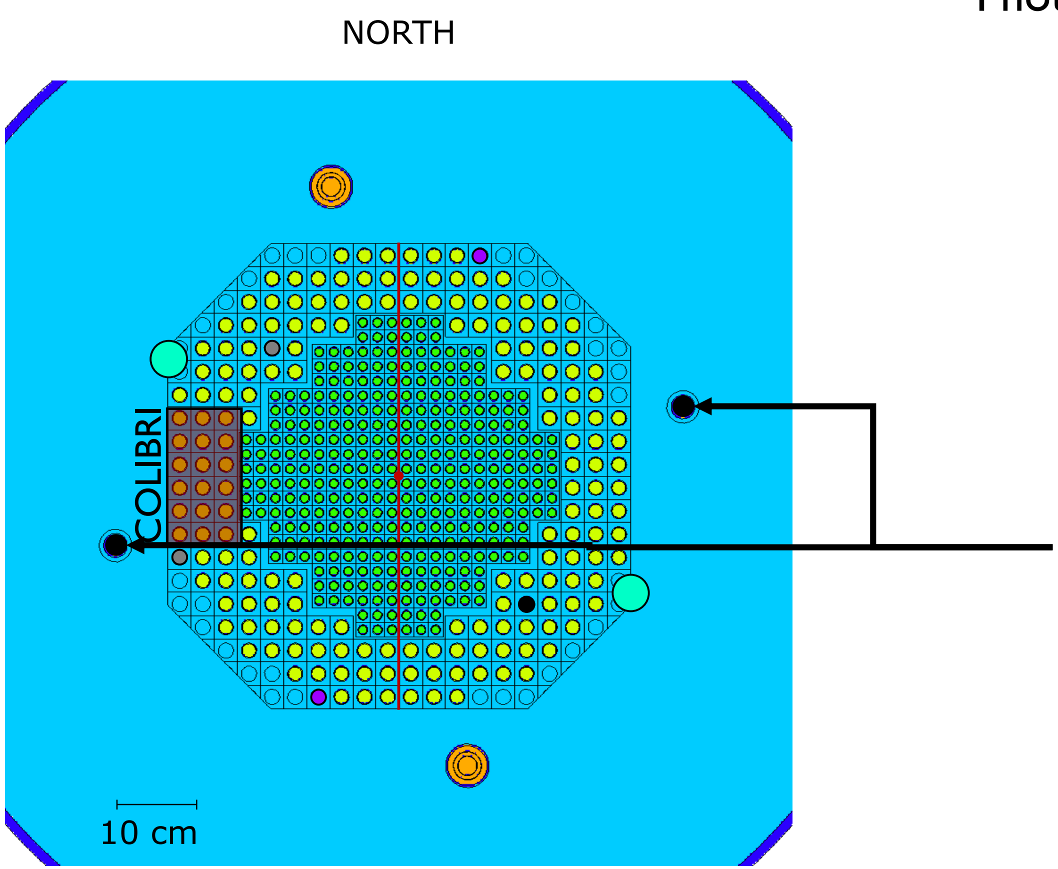
Cable (blue) and inductive captor (bottom, red) signals provided by the control (1 rod in air, ±1.5 mm and 1 Hz)

Configuration



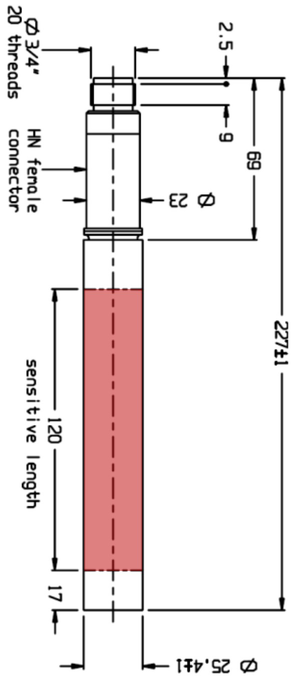
Experimental locations and associated detectors

Detection instrumentation



Experimental locations and associated detectors

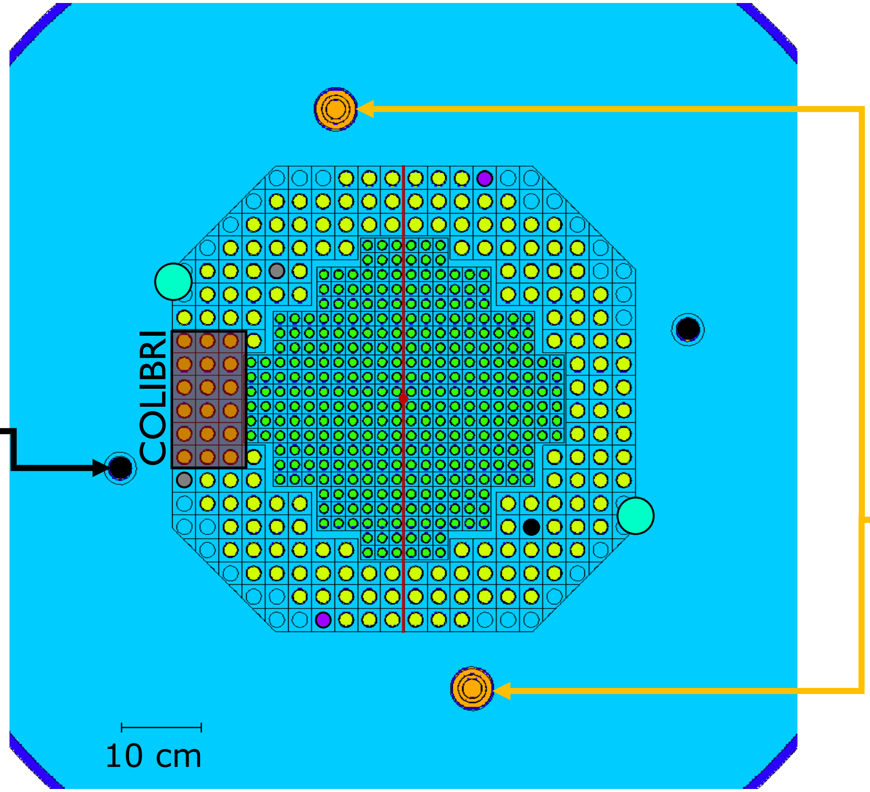
Safety Monitor
Photonis CFUM21 ^{235}U FC
⌀25.4 x 120 mm
$10^{-2}\ n_{th}^{-1}$



Detection instrumentation

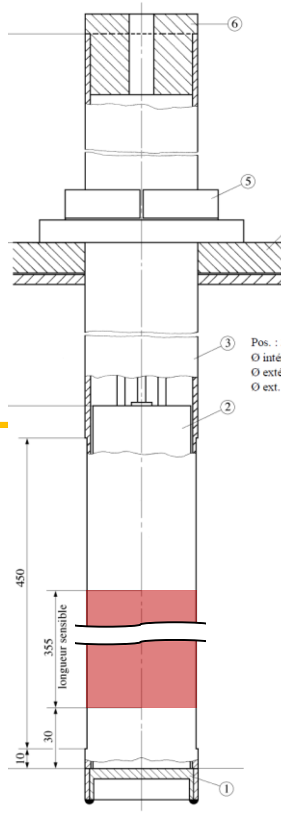
Monitor CFUM21 ^{235}U FC (W)

NORTH

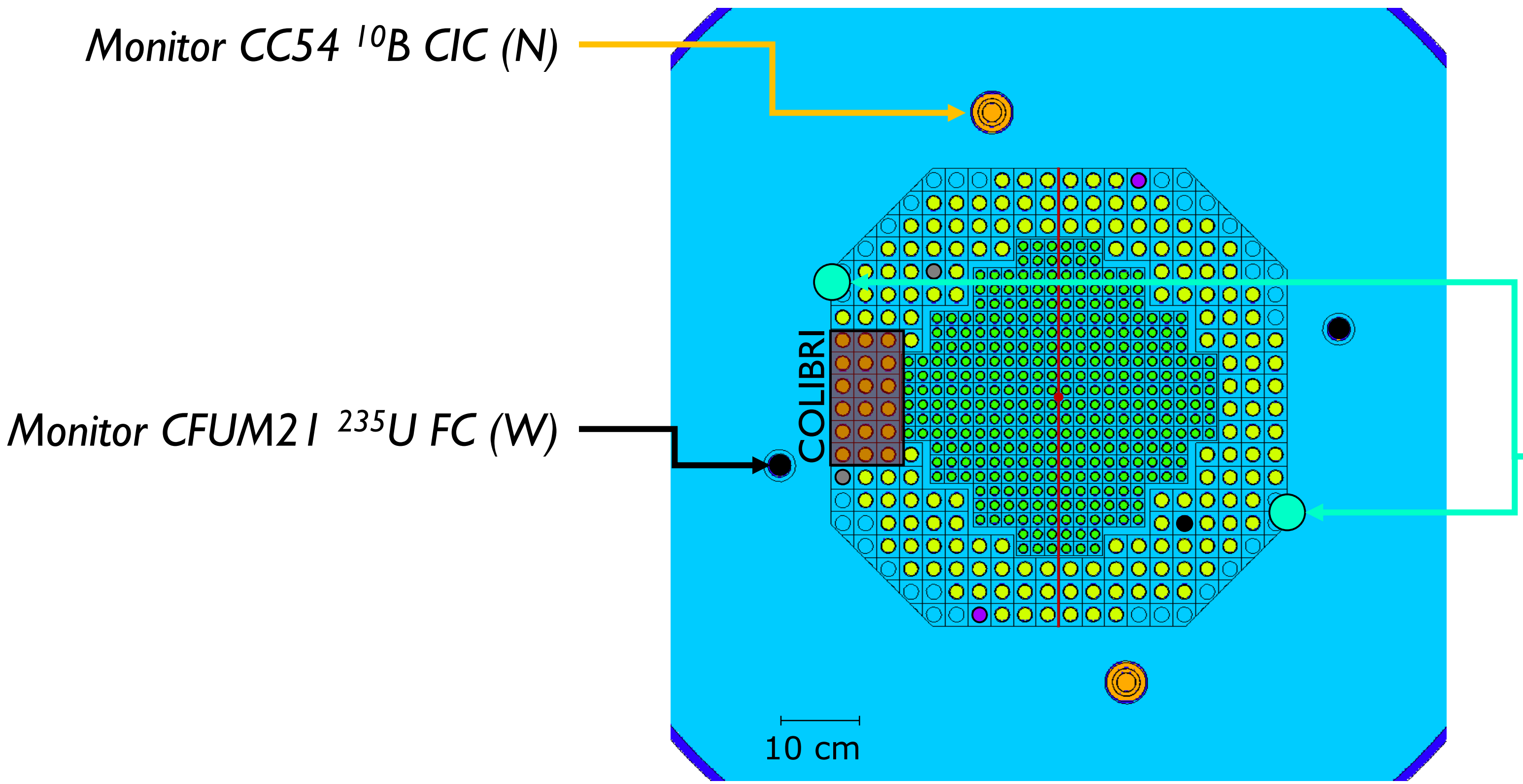


Experimental locations and associated detectors

Monitor
Merlin Gerin CC54 ^{10}B CIC
⌀50 x 355 mm
3×10^{-14} $A.n_{th}^{-1}$

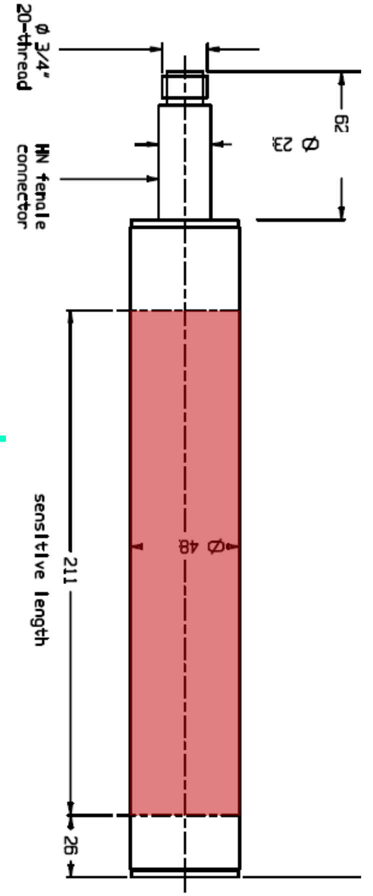


Detection instrumentation



Experimental locations and associated detectors

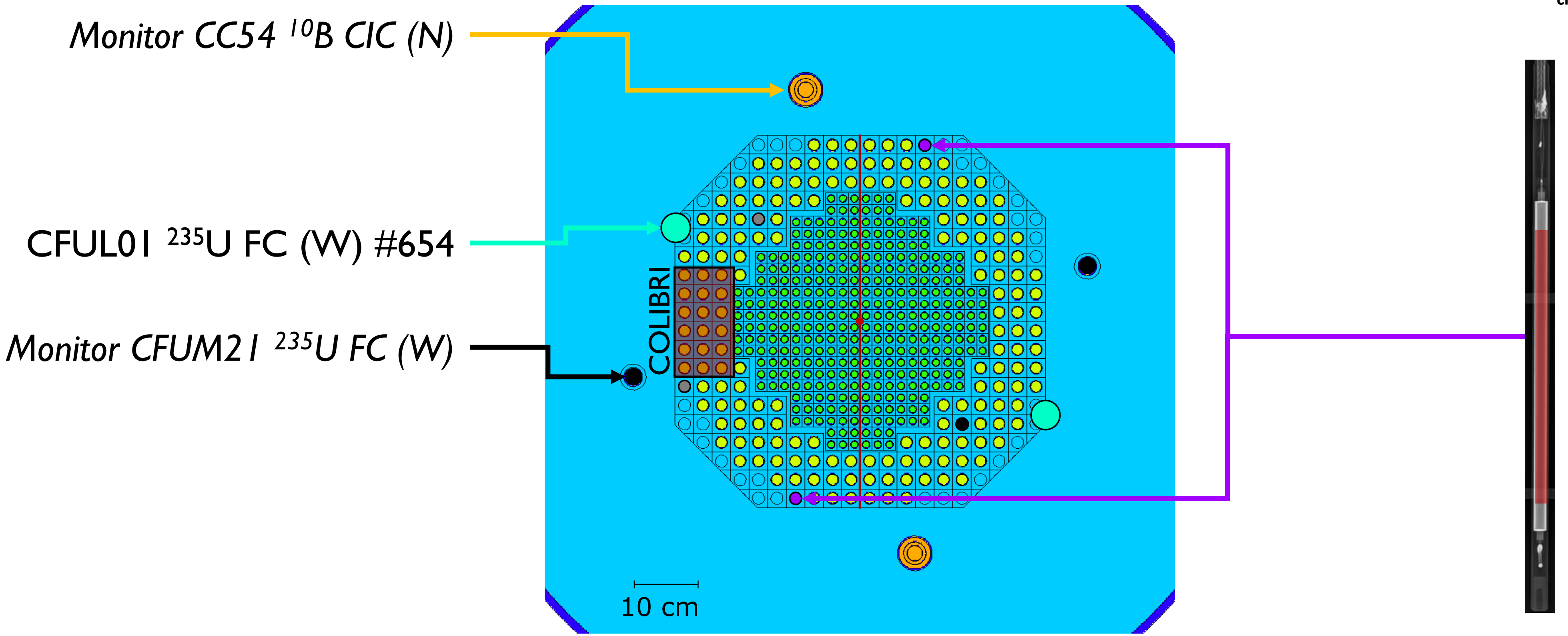
Photonis CFUL01 ^{235}U FC
⌀48 x 211 mm
1 n_{th}^{-1}



Detection instrumentation

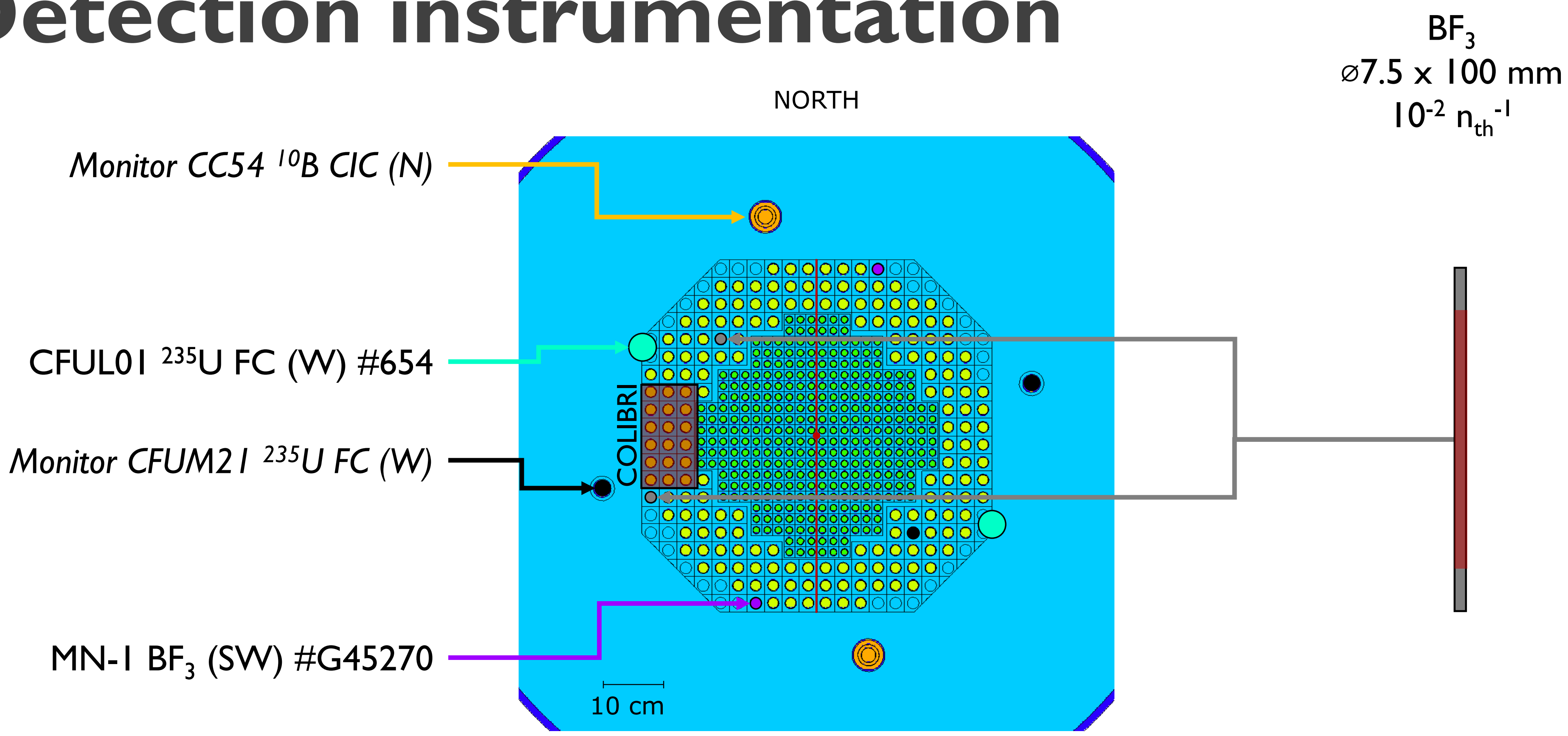
Transcommerce Int. MN-1 BF_3
⌀7.5 x 100 mm
10^{-2} n_{th}^{-1}

NORTH



Experimental locations and associated detectors

Detection instrumentation



Experimental locations and associated detectors

Detection instrumentation

Monitor CC54 ^{10}B CIC (N)

BF_3 (NW) #G20056

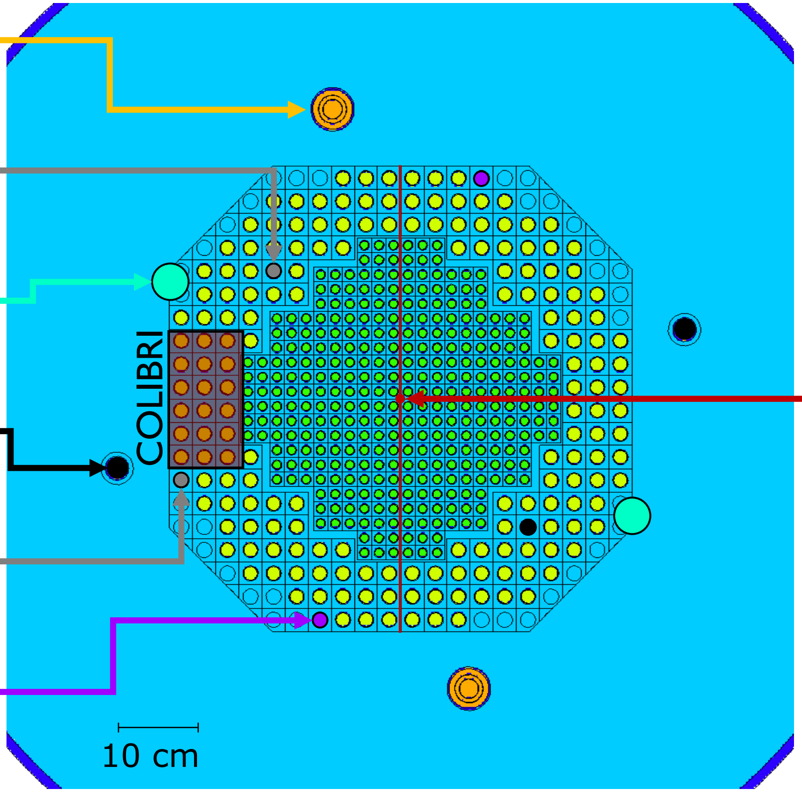
CFUL01 ^{235}U FC (W) #654

Monitor CFUM21 ^{235}U FC (W)

BF_3(COLIBRI) #G20055

MN-1 BF_3 (SW) #G45270

NORTH

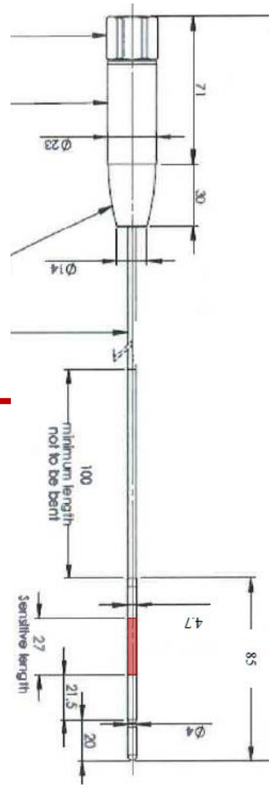


Experimental locations and associated detectors

Photonis CFUF34 FC

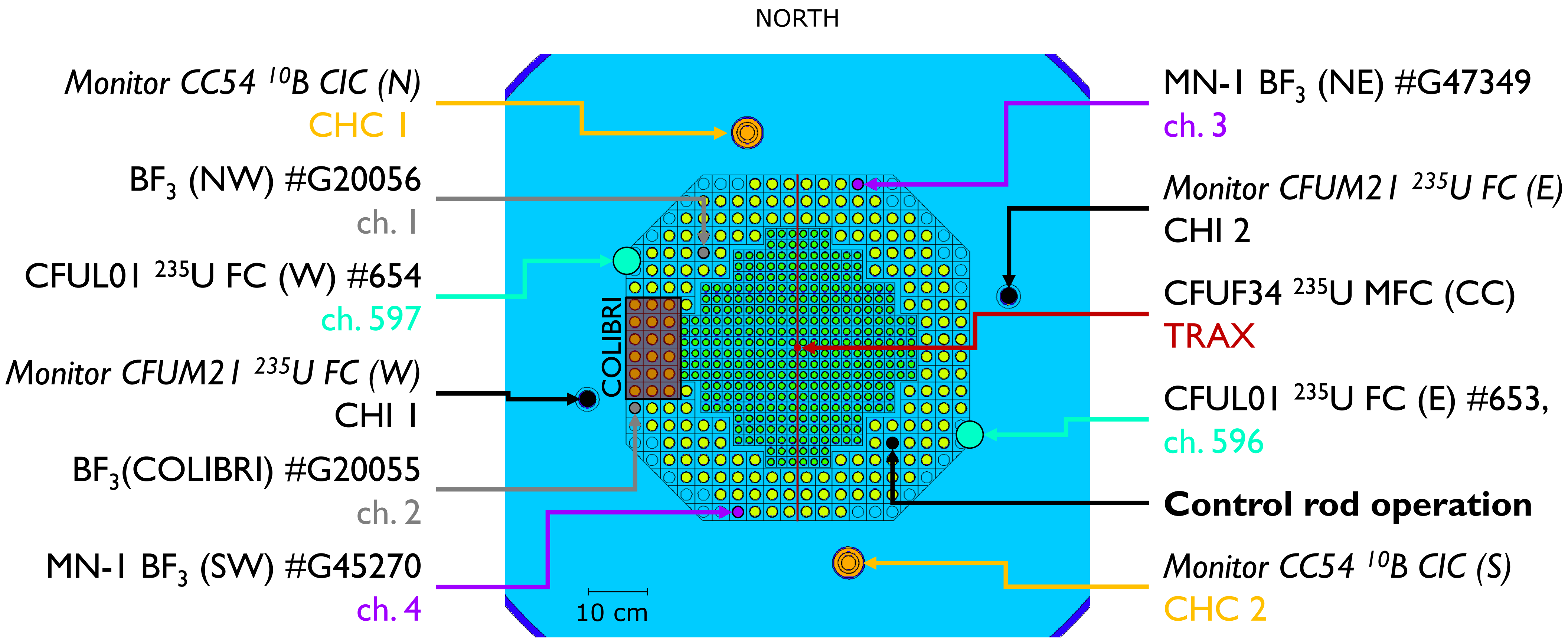
⌀4.7 x 27 mm

$10^{-3}\ n_{th}^{-1}$



Experimental setup

In addition from COLIBRI:
- Inductive captor
- Cable coder } *via* software output only
- Motor position } *via* software output only



Experimental locations and associated detectors

Acquisition

In addition from COLIBRI:
- Inductive captor
- Cable coder } *via* software
- Motor position } output only

NORTH

Monitor CC54 ^{10}B CIC (N)
CHC 1

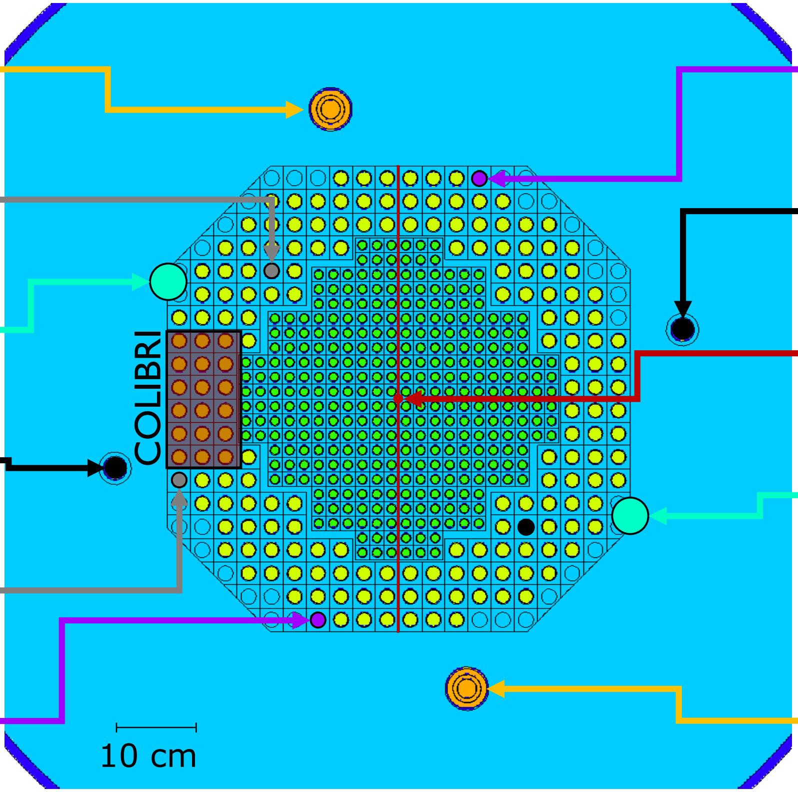
BF_3 (NW) #G20056
ch. 1

CFUL01 ^{235}U FC (W) #654
ch. 597

Monitor CFUM21 ^{235}U FC (W)
CHI 1

BF_3(COLIBRI) #G20055
ch. 2

MN-1 BF_3 (SW) #G45270
ch. 4



Experimental locations and associated detectors

MN-1 BF_3 (NE) #G47349
ch. 3

Monitor CFUM21 ^{235}U FC (E)
CHI 2

CFUF34 ^{235}U MFC (CC)
TRAX

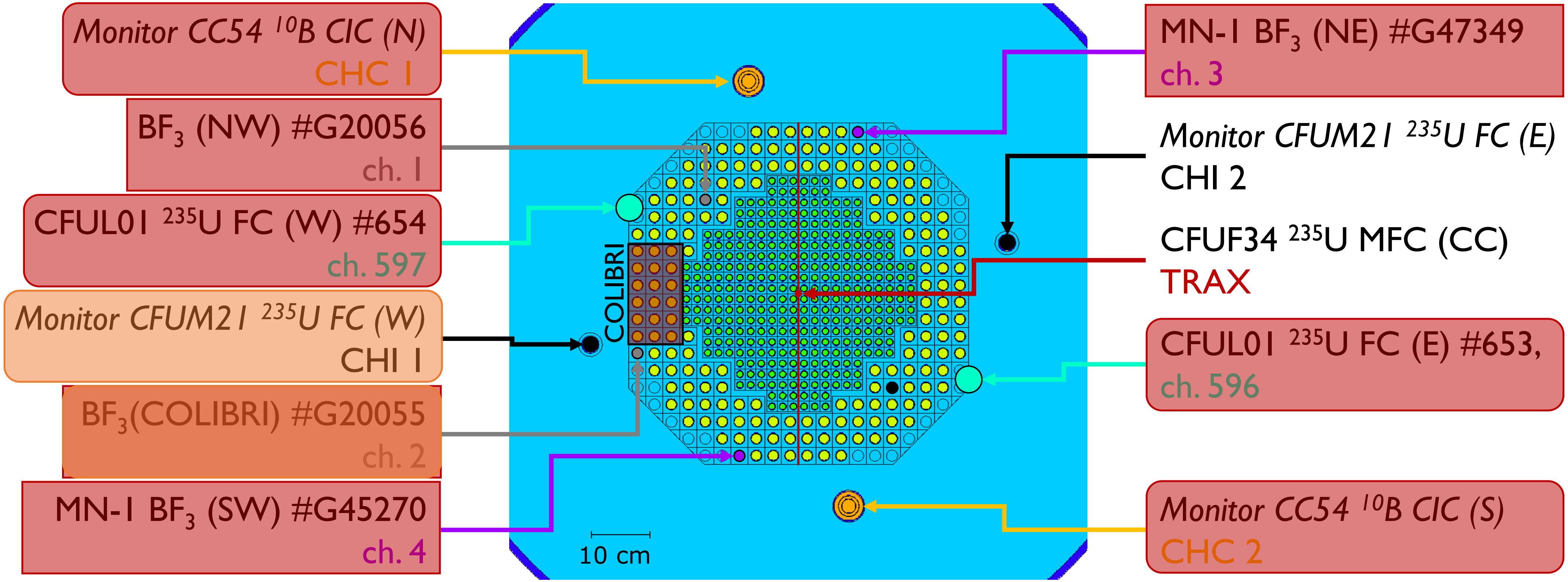
CFUL01 ^{235}U FC (E) #653,
ch. 596

Monitor CC54 ^{10}B CIC (S)
CHC 2

TUD

Acquisition

In addition from COLIBRI:
- Inductive captor
- Cable coder } *via* software output only
- Motor position } *via* software output only



Experimental locations and associated detectors

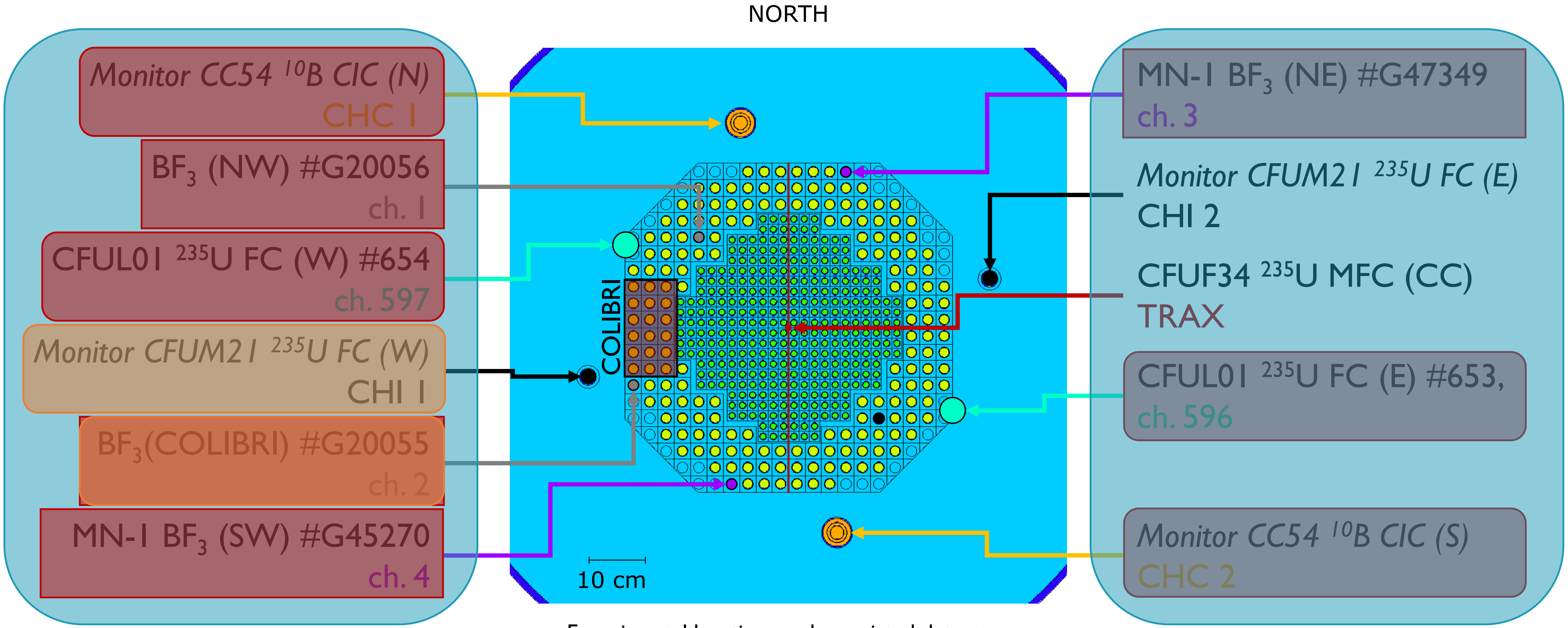
TUD EPFL

In addition from COLIBRI:

- Inductive captor
- Cable coder
- Motor position

via software output only

Acquisition



Experimental locations and associated detectors

TUD EPFL ISTec

Measurements

Static measurements

Reactor: 100 mW stable power, 20°C, 1000 mm water level, control rod operation

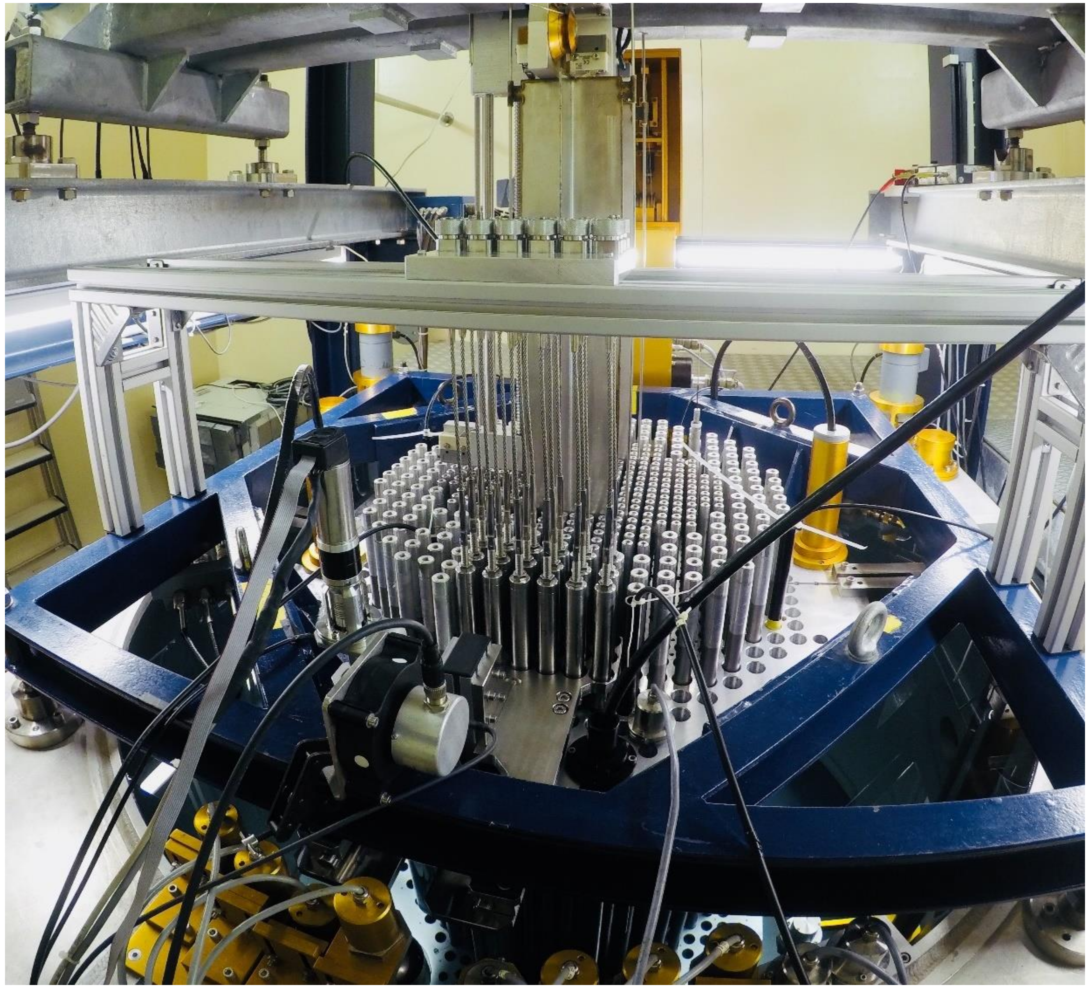
COLIBRI measurements

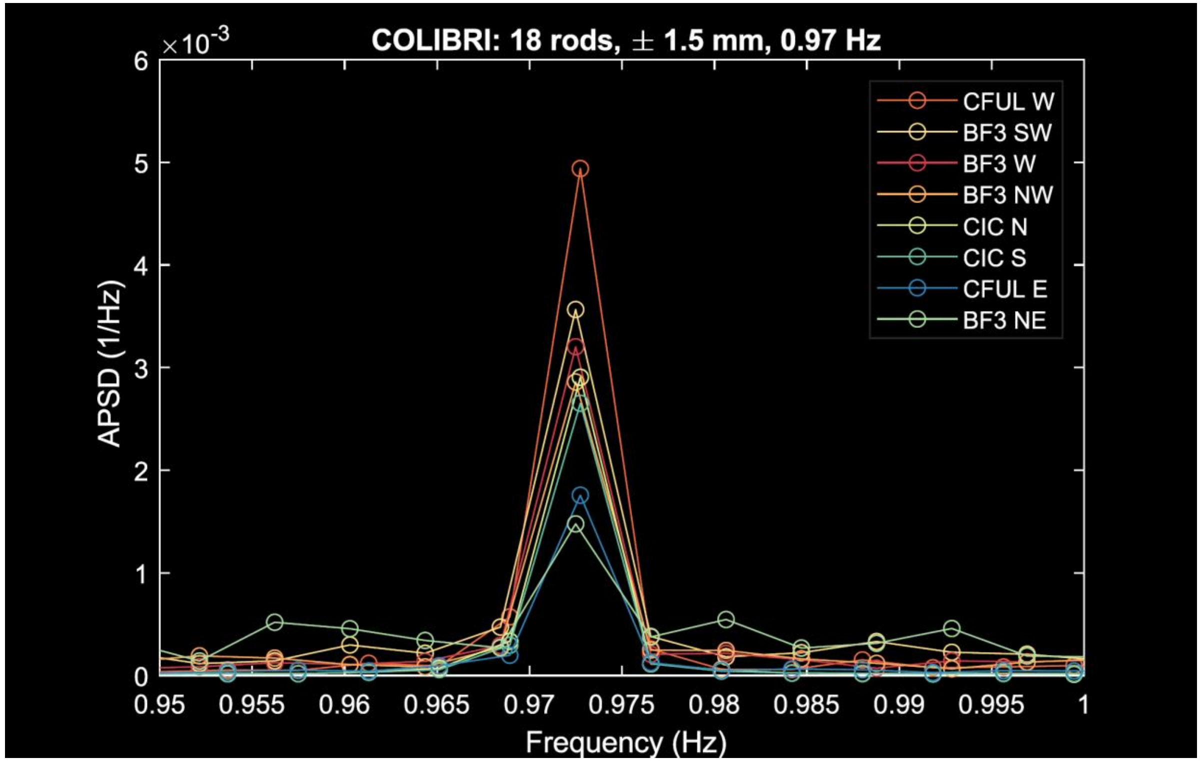
Reactor: same, but variable control rod insertion

Setup: 18 rods oscillation, 30 min to 2 h measurements

Amplitude (mm)	Frequency (Hz)				
	0.1	0.5	1	1.5	2
±0.5	✓	✓	✓		
±1.0	✓	✓	✓	✓	✓
±1.5	✓	✓	✓	✓	✓
±2.0	✓	✓	✓		

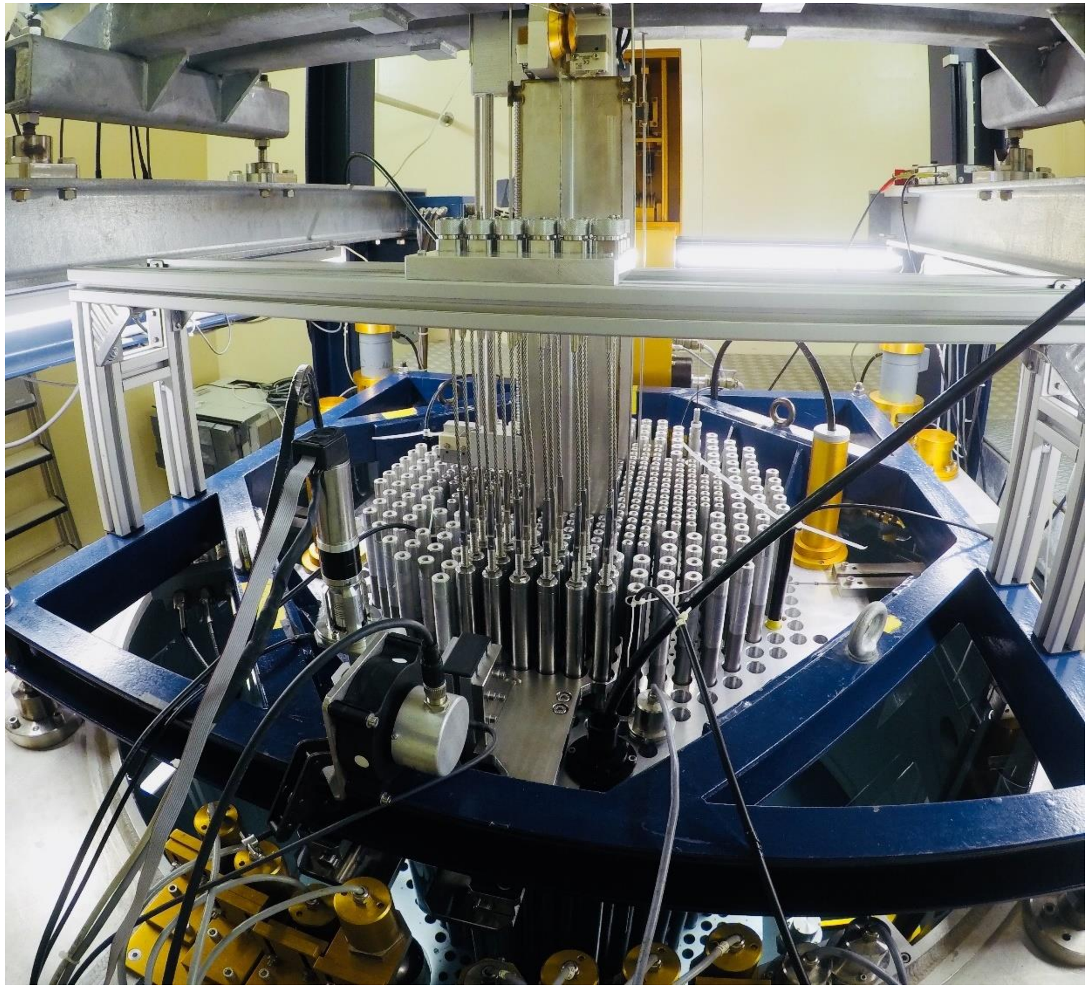
Measurements

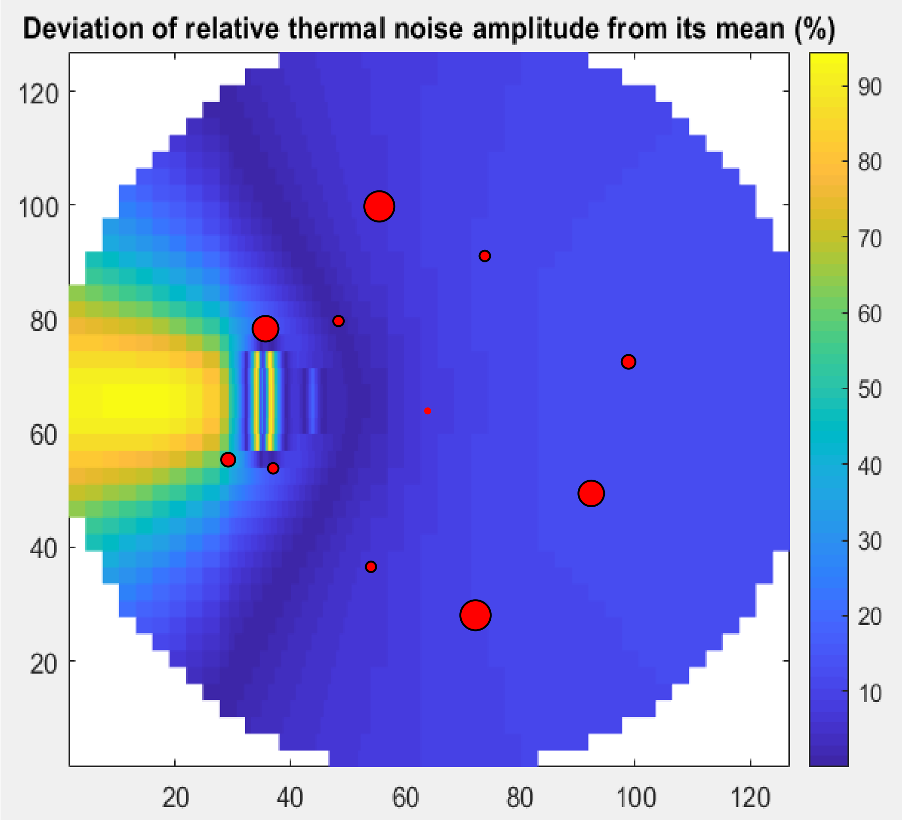




18 rods at ±1.5 mm and 1 Hz

Measurements





Preliminary results for COLIBRI with 18 rods at ±2 mm and 1 Hz modelled with CORE SIM (courtesy DREAM, Chalmers University)

Conclusions and outlook

CORTEX: an H2020 collaborative project for innovative core monitoring techniques

- The two first campaigns in AKR-2 and CROCUS were carried out successfully
- Data processed and distributed along a technical report to the Consortium
- Qualification study of TUD and EPFL acquisition systems with respect to ISTec
- On-going analysis of the experimental data, with uncertainty quantification
- Iteration with the modellers for the design and preparation of the next campaigns:
    - October 2019 for COLIBRI in CROCUS
    - Spring 2020 for AKR-2
- Upgrades of the perturbation devices and instrumentations
- Development of miniature fiber-coupled scintillators for core-mapping

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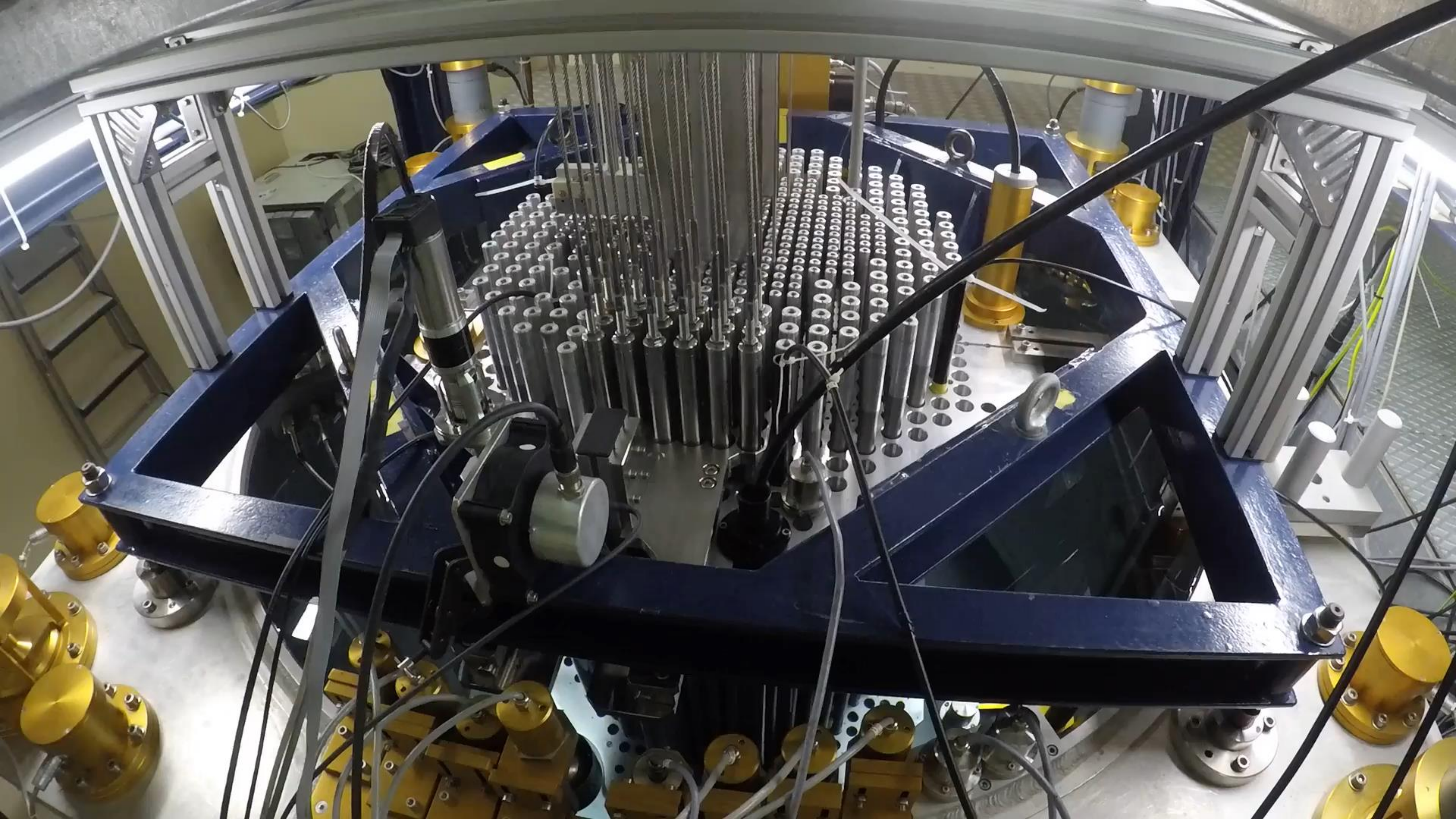
Presentation on Thursday by F. Vitullo at 15:20 (#04-1456, Europa)



Thank you!