KompOst doctoral seminars Zittau, December 13th, 2018
East German Centre of Competence in Nuclear Technology

Generation of high precise data for the verification of computational tools for reactor signal analysis

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This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754316.

[1]

The AKR-2

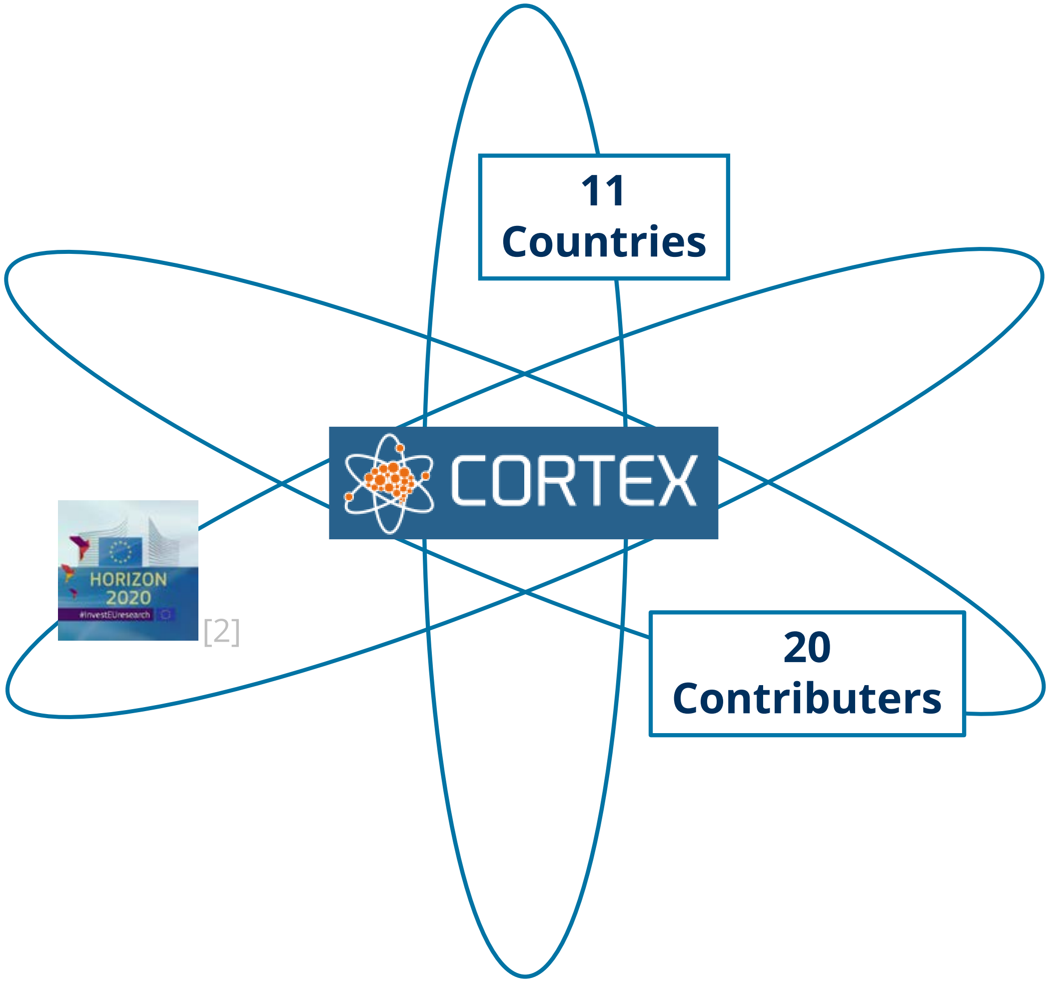
Training Reactor of the TU Dresden

Homogenouse, zero-power reactor with a maximum power of 2 $W_{thermal}$

Outline

- Embedding in the European project CORTEX
- Experimental setup
  - Design of the pertubation systems
  - Detector positions
- Comparison of signals
- Applications beyond CORTEX
- Future sight

Embedding in the European project CORTEX



Embedding in the European project CORTEX

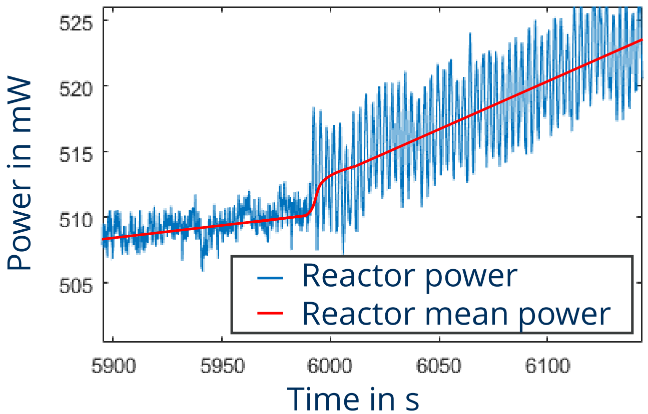
Overall goals of the project

Development of innovative methods for reactor core monitoring

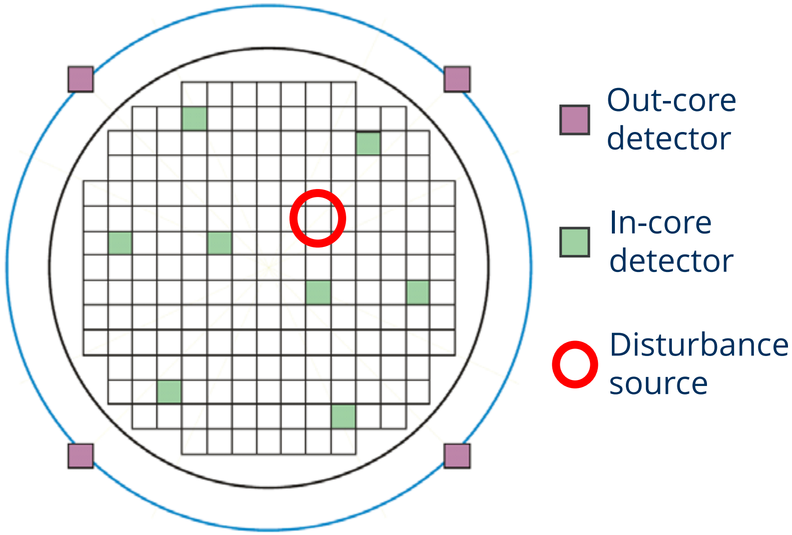
- Based on noise analysis of the neutron-flux fluctuations

$$X(r,t) = X_0(r,t) + \delta X(r,t)$$

- Neutron-flux fluctuations due to statistical character of fission, mechanical vibrations, coolant turbulence, …
- Develope tools which allow in-situ and in-time core diagnostics
  - Use inverse reactor transfer function
- Show location and type of disturbance source



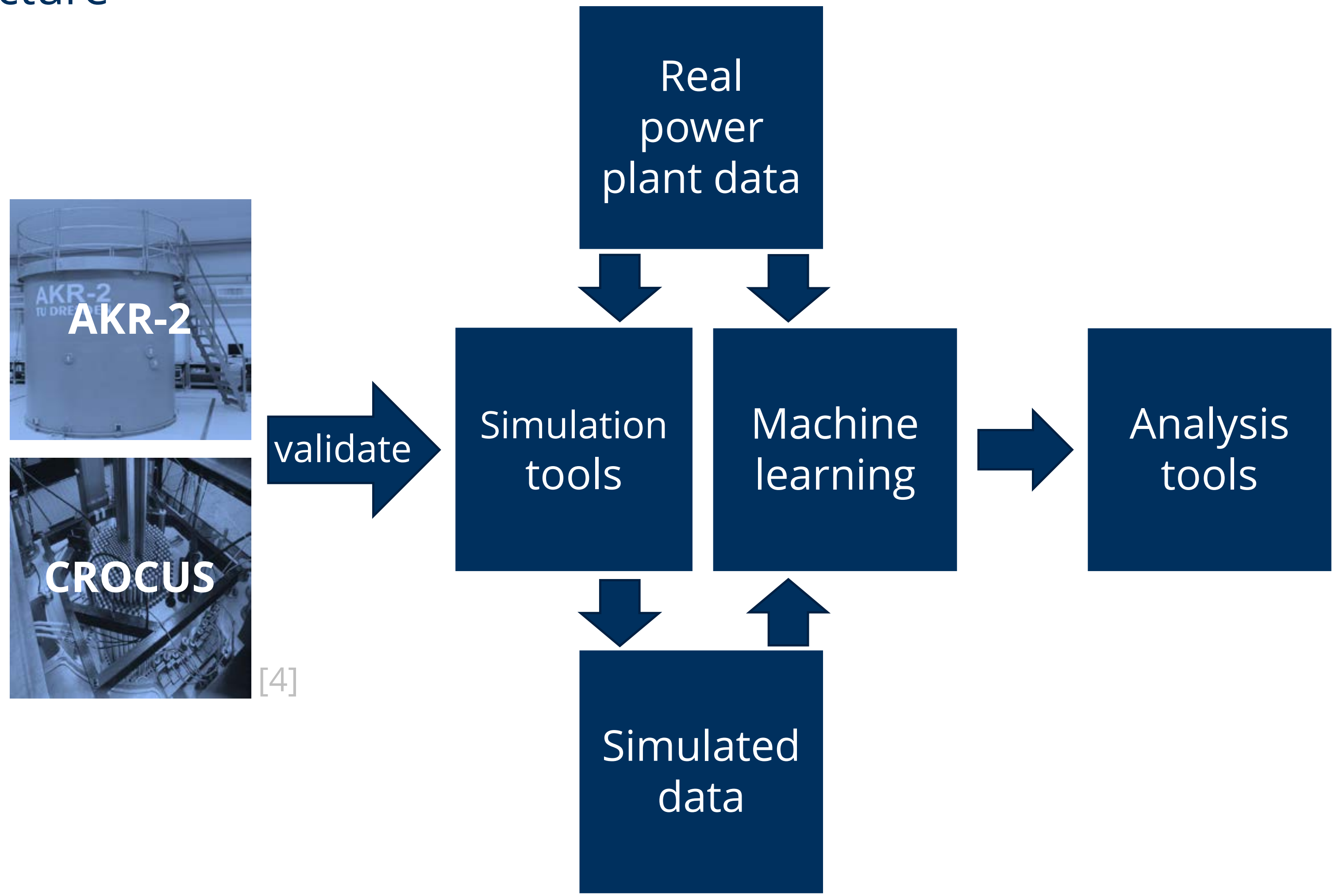
Zero-power reactor answer to oscillating pertubation



Detector positions radial-azimutal [3]

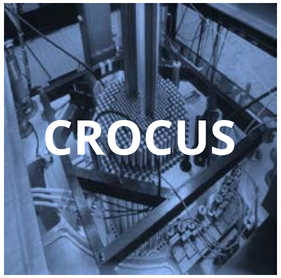
Embedding in the European project CORTEX

Structure



Embedding in the European project CORTEX

Structure



Absorber of variable strength

- Rotating absorber
- Vibrating absorber

Vibrating fuel rods

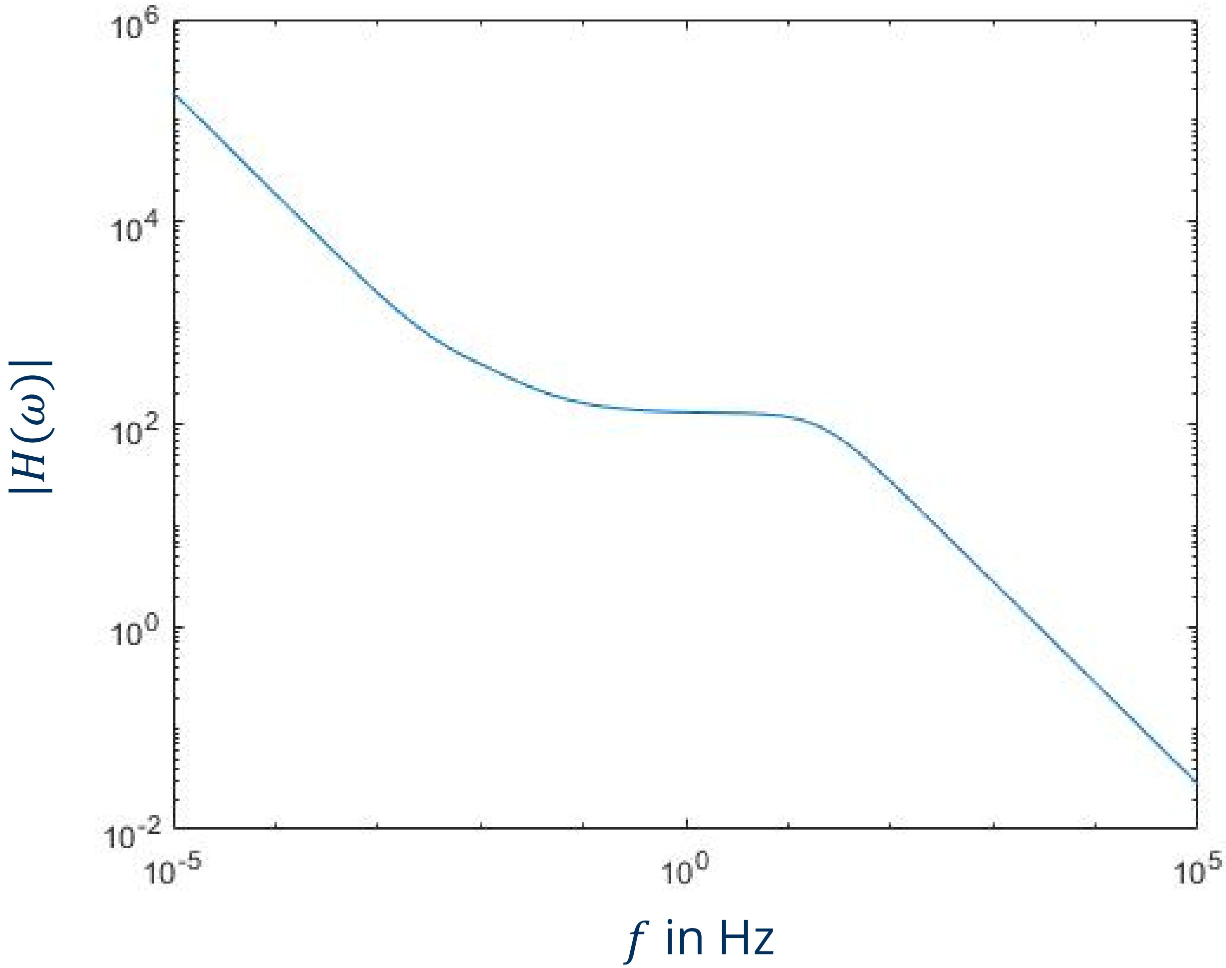
- COLIBRI [I]

compare with

Industrial scale measurement system

TÜVRheinland®
iSTec
Genau. Richtig.

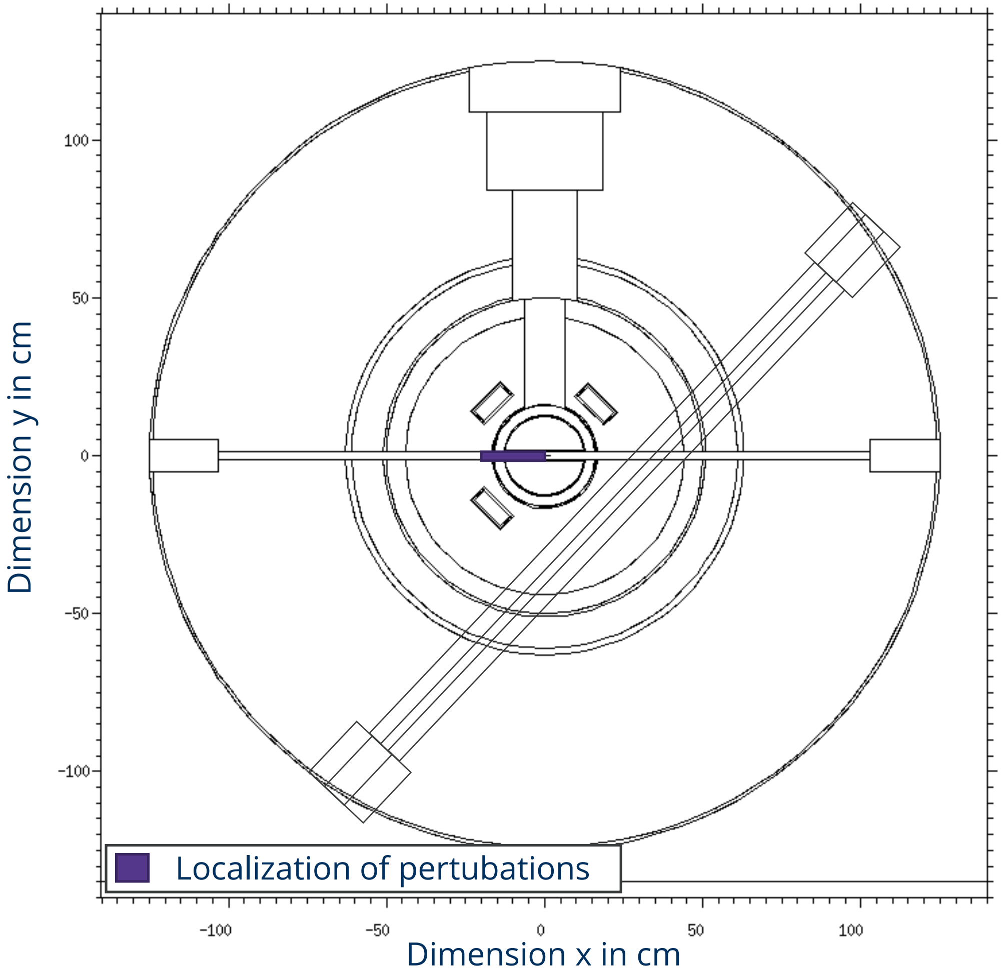
Zero-power transfer function of the AKR-2



Theoretical shape of the zero-power transfer function of the AKR-2, kinetic parameters are calculated with Monte-Carlo codes (MCNP & SERPENT)

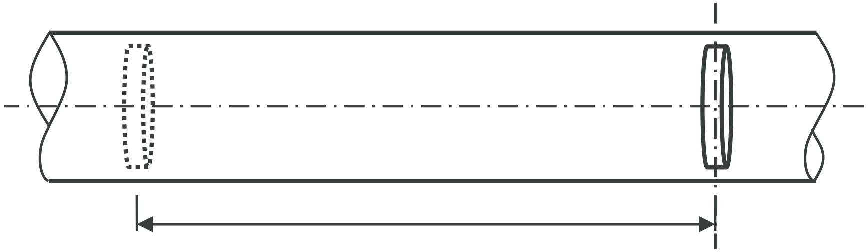
Experimental setup at AKR-2

Design of the pertubation systems



Mesh of cross sections of AKR-2 at height of 122,130 and 138 cm from ground level

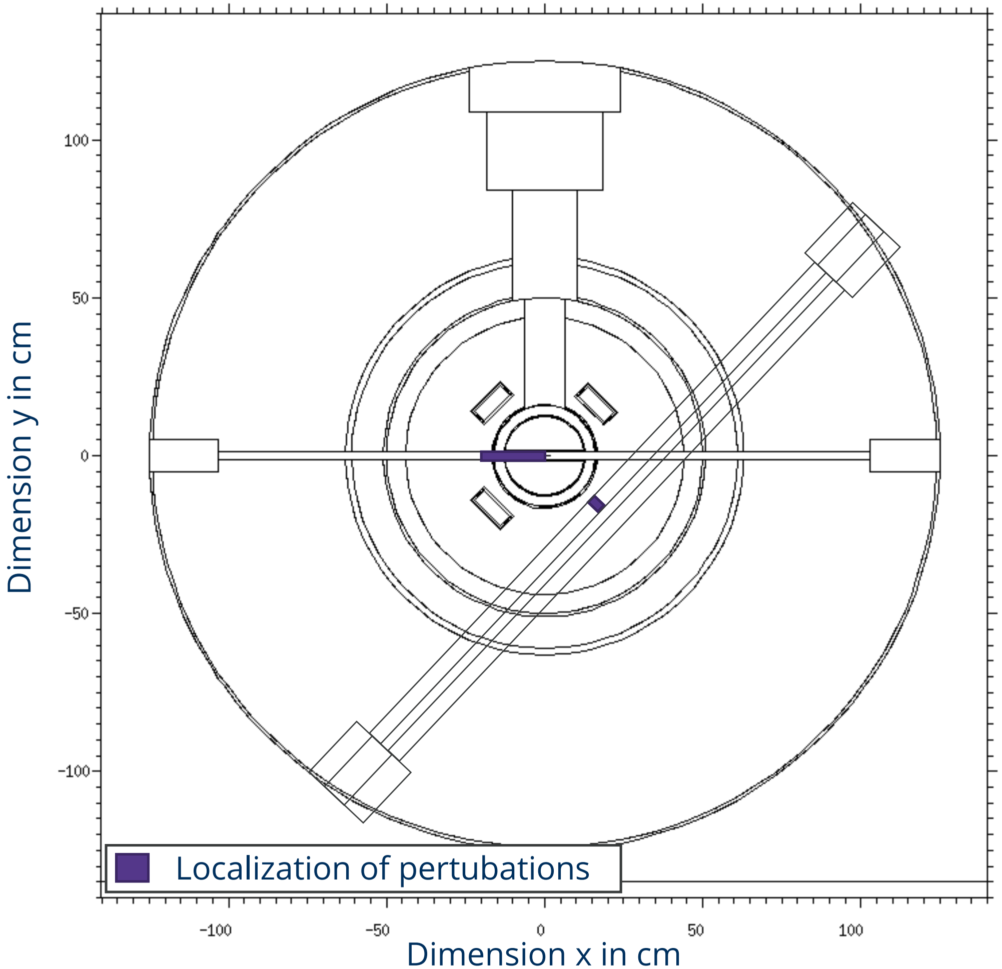
Vibrating absorber



Shape and movement of the linear moving absorber

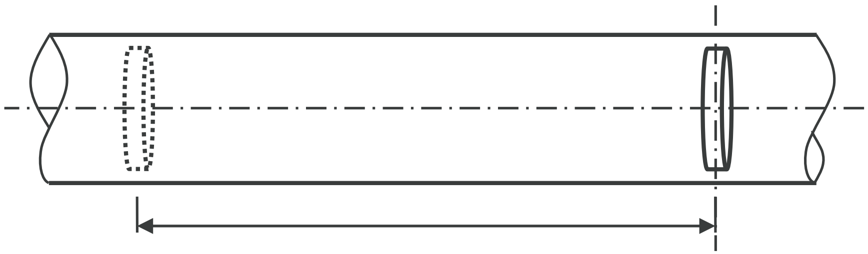
Experimental setup at AKR-2

Design of the pertubation systems



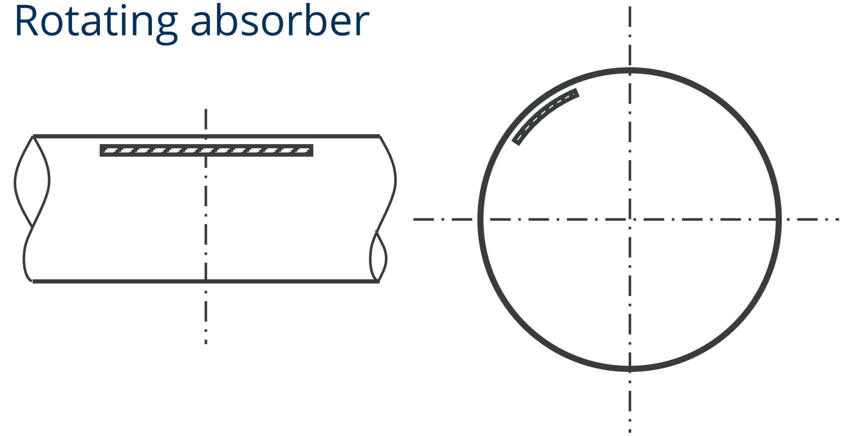
Mesh of cross sections of AKR-2 at height of 122,130 and 138 cm from ground level

Vibrating absorber



Shape and movement of the linear moving absorber

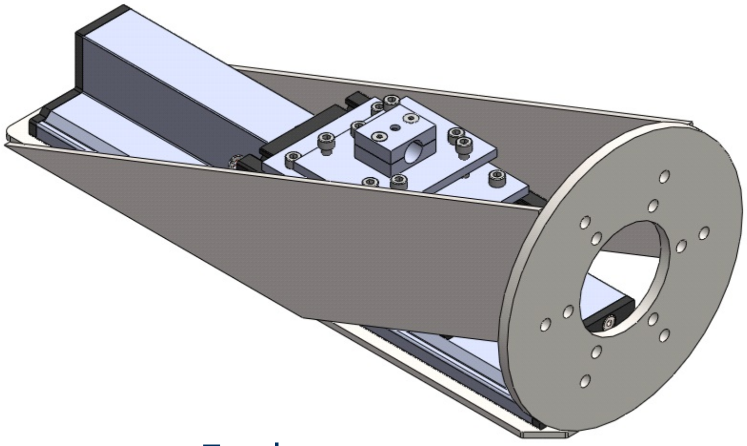
Rotating absorber

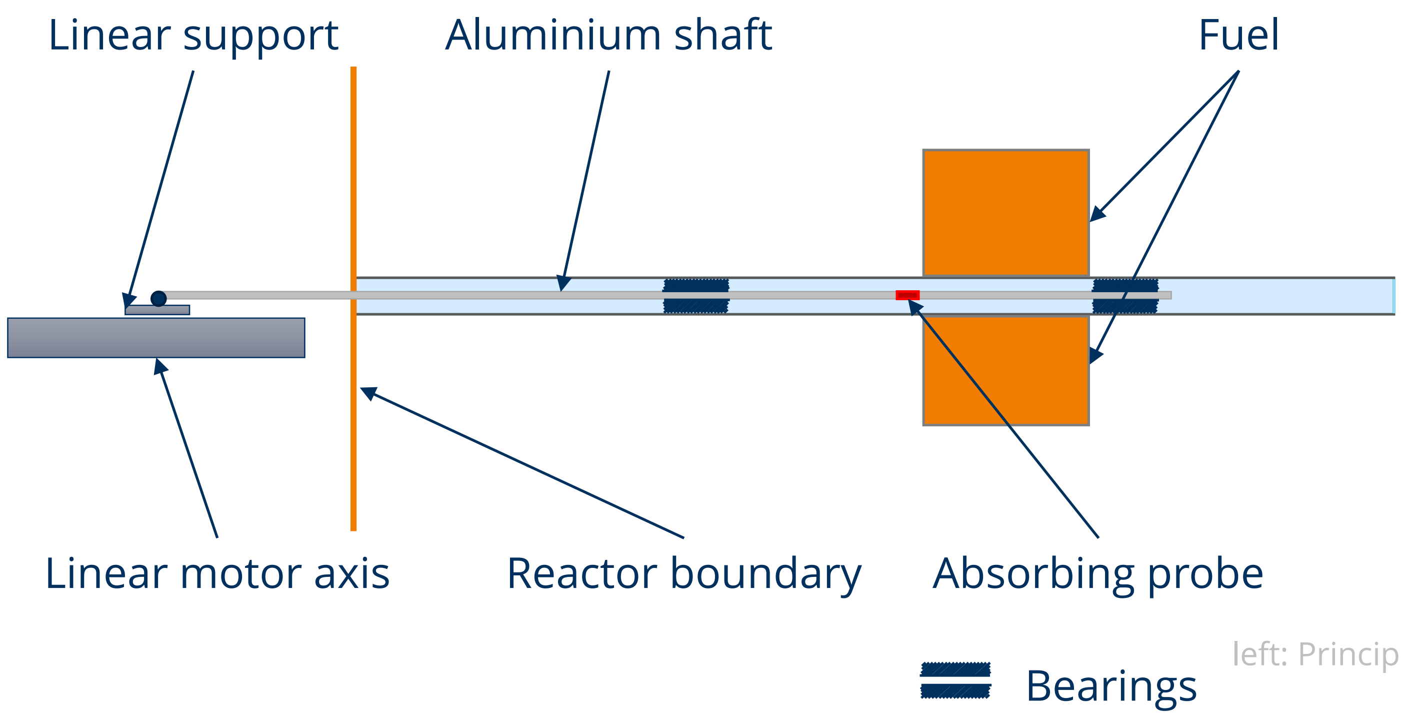


Shape and position of the rotating absorber

Experimental setup at AKR-2

Design of the pertubation systems
Vibrating absorber

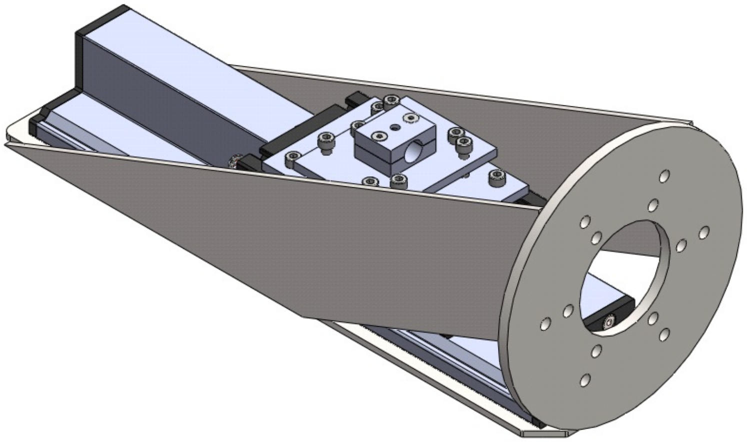


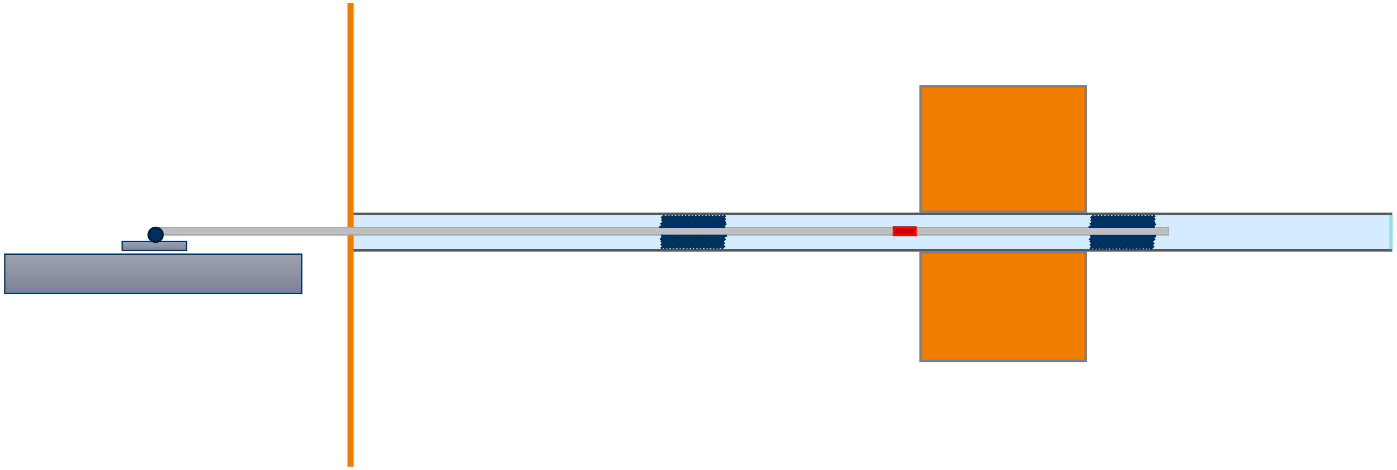


Pile-oscillator:
left: Principle of experiment at AKR-2
above: 3D-model

Experimental setup at AKR-2

Design of the pertubation systems
Vibrating absorber

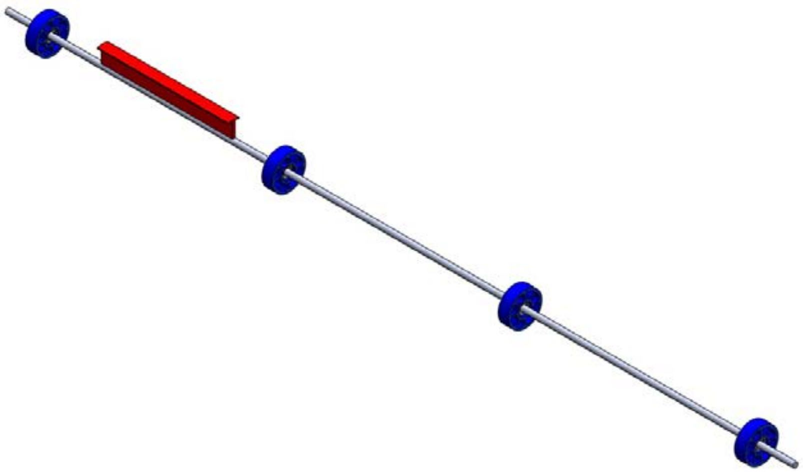


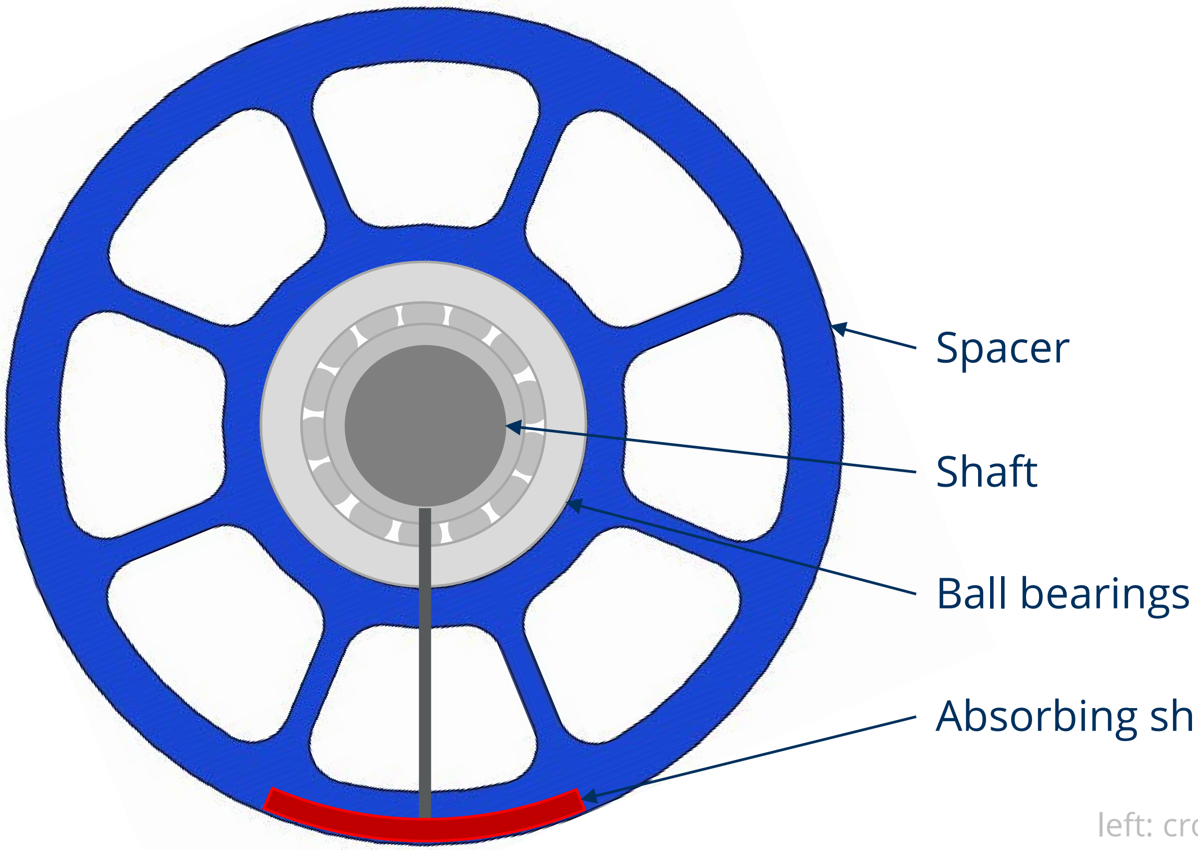


Pile-oscillator:
left: Principle of experiment at AKR-2
above: 3D-model

Experimental setup at AKR-2

Design of the pertubation systems
Rotating absorber

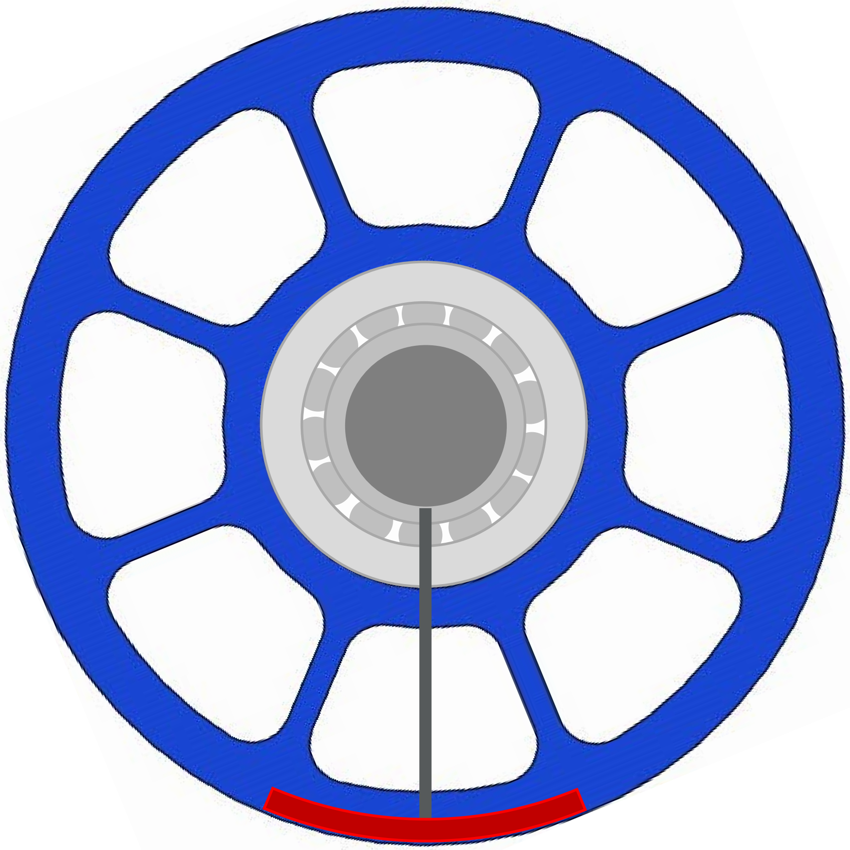


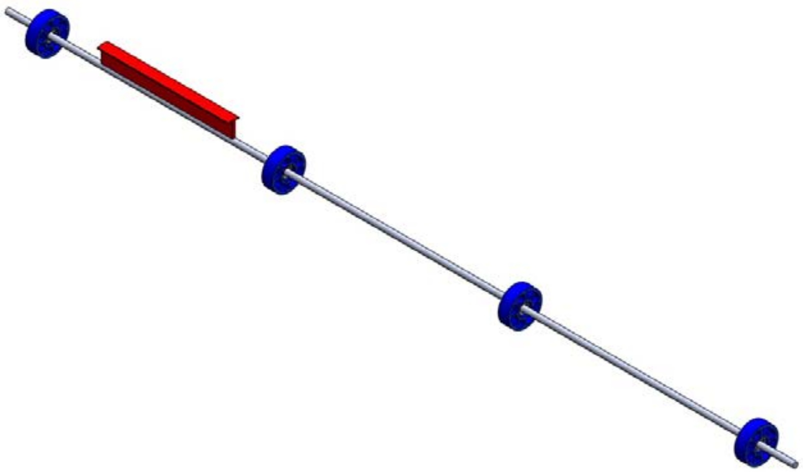


Rotating absorber:
left: cross section figure of principle build
above: 3D-model

Experimental setup at AKR-2

Design of the pertubation systems
Rotating absorber





Rotating absorber:
left: cross section figure of principle build
above: 3D-model

Experimental setup at AKR-2

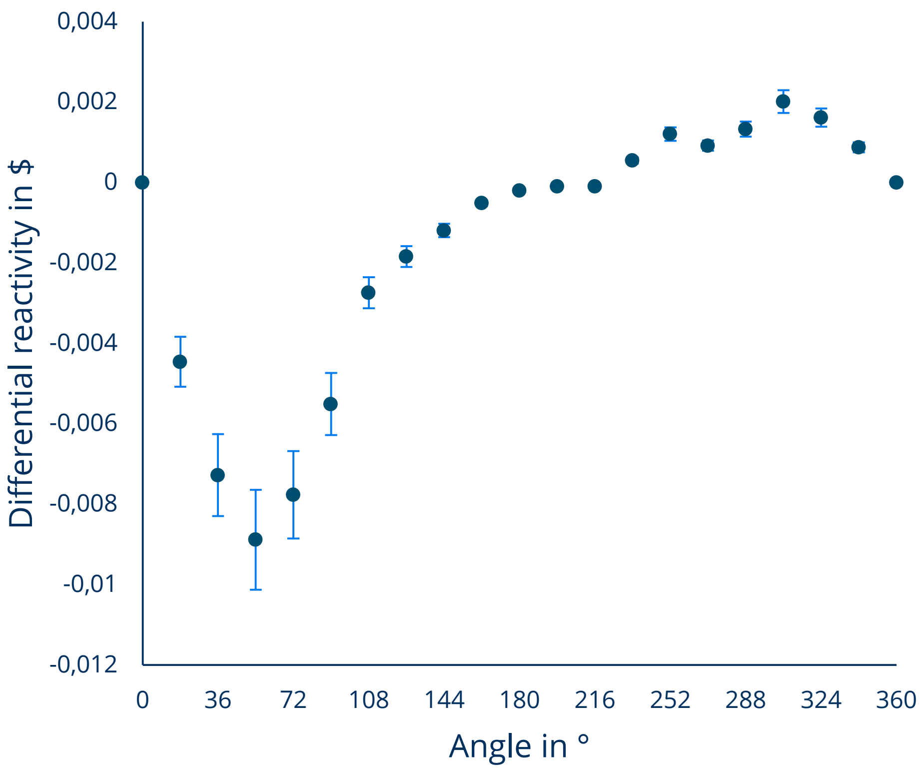
Design of the pertubation systems
Reactivity impact

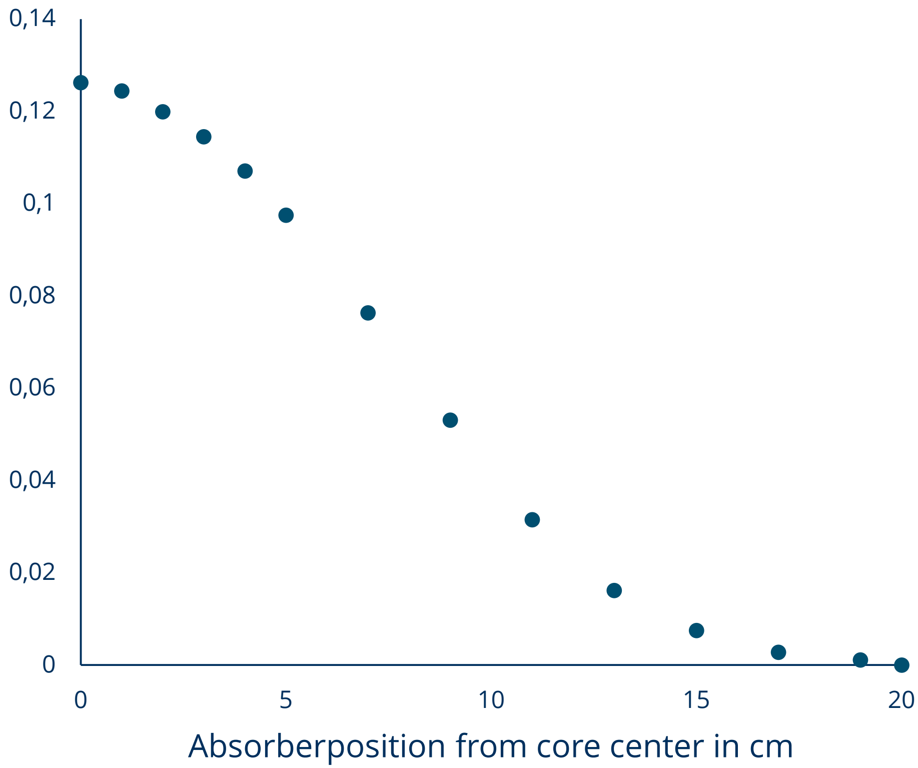
Rotating absorber

Total reactivity: $\rho_t' = 0.0109\ \$$

Vibrating absorber

$\rho_t' = 0.0126\ \$$

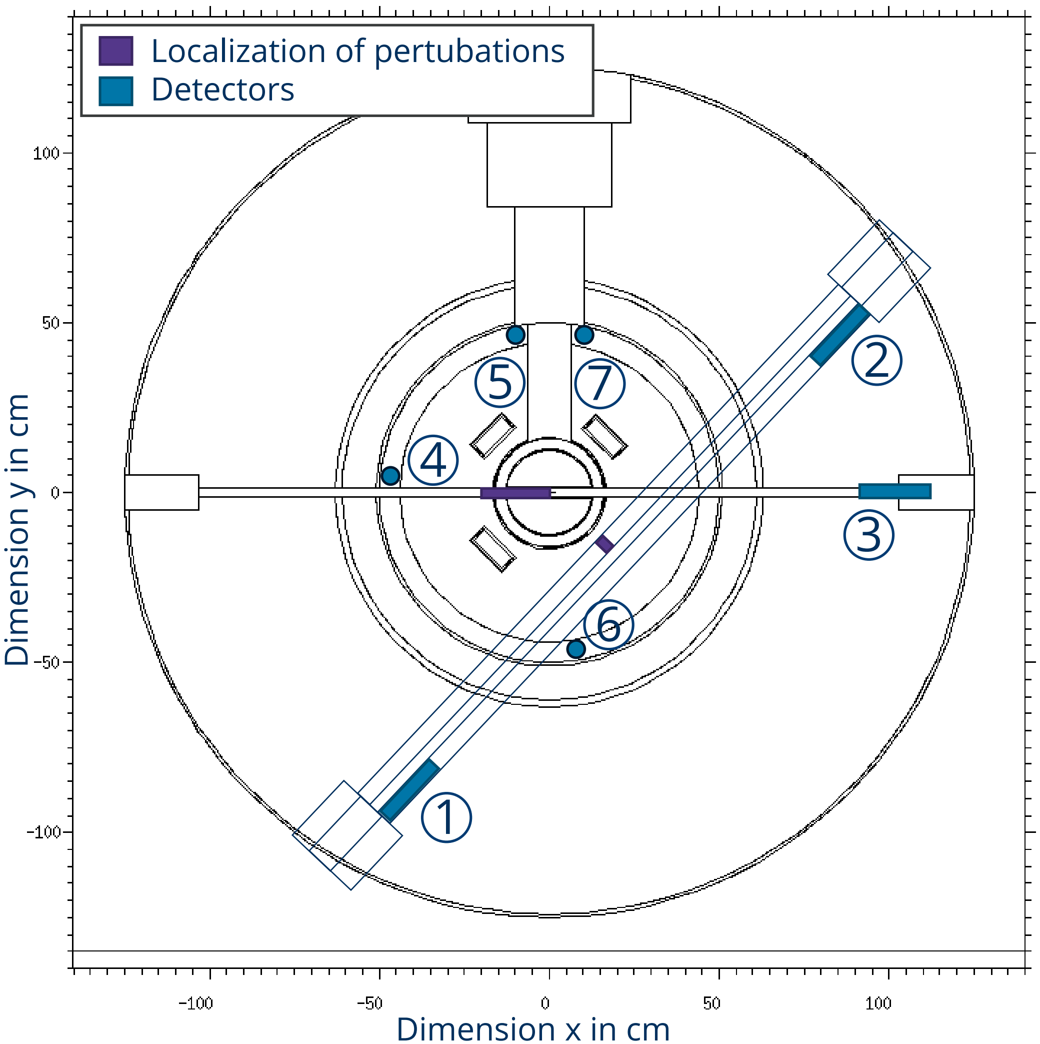




Differential reactivity of rotating (left) and linear moving (right) absorber with delayed neutron fraction β = 0.00766

Experimental setup at AKR-2

Detector positions



① to ③ He-3 proportional counter

④ Fission chamber

⑤ & ⑥ Fission chamber, wide range

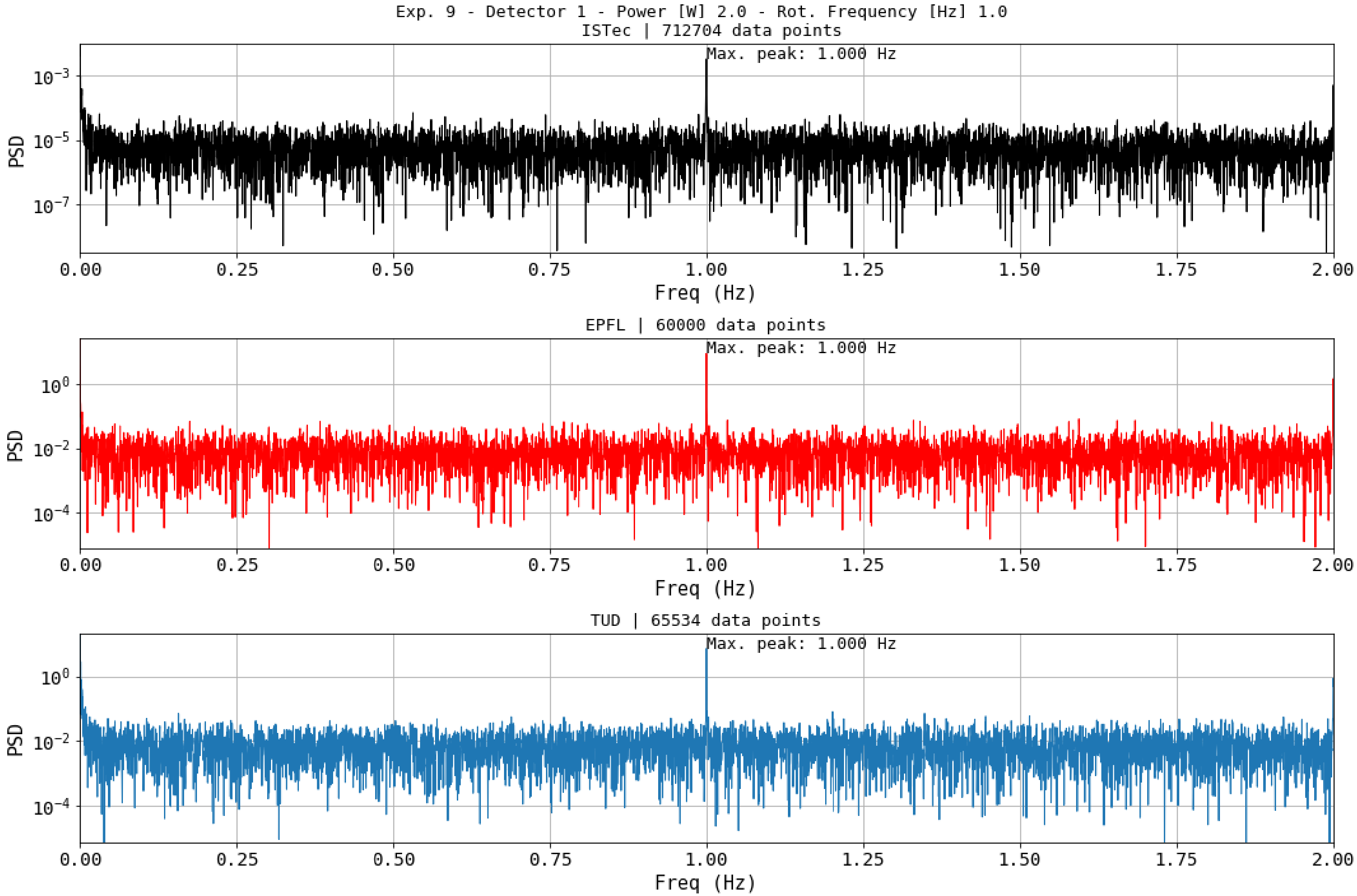
⑦ γ- compensated ion chamber

TUD EPFL
ISTEC

Mesh of cross sections of AKR-2 at height of 122, 130 and 138 cm from ground level

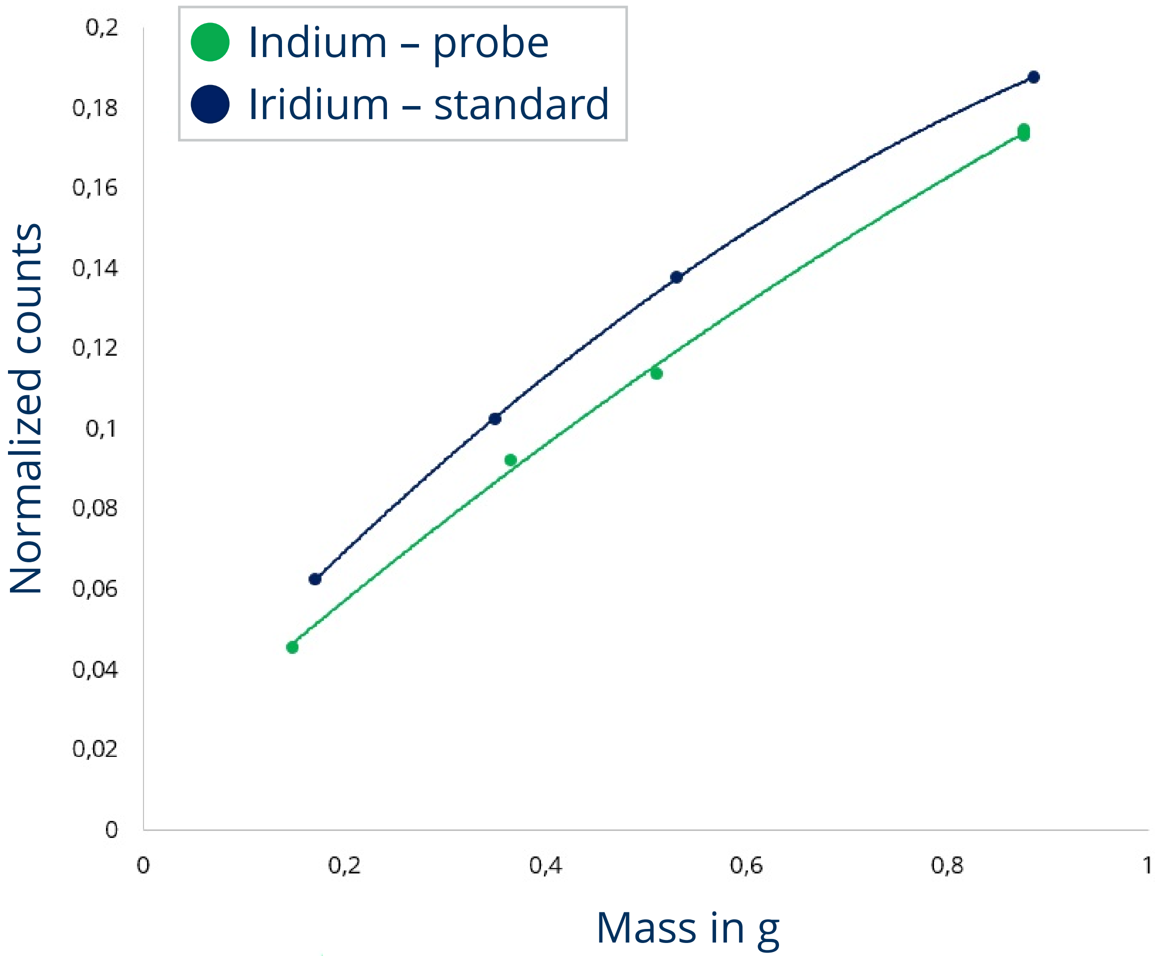
Comparison of signals

Power spectral density (periodogram) comparison for *Rotating Absorber* [5]



Applications beyond CORTEX

Vibrating absorber → Pile-oscillator



$\sigma_{a,In}$ = 202,7 b

theoretical: 197 b

Deviation of 2,9 %

Pile-oscillator meassurement of standard and probe with polynominal fit [6]

Future sight

After shutdown of BER-II (Berlin), AKR-2 one of two remaining, accessible neutron source sites in Germany

Proved applicability in research.

- Two more measurement campaigns in CORTEX
  - Development of the pertubation and data aquisition systems
- Neutron imaging
- Diffractometer
- Moderator test station

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Generation of high precise data for the verification of computational tools for reactor signal analysis

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Sources

[1] Foto AKR-2, https://tu-dresden.de/ing/maschinenwesen/iet/wket/forschung/unsere-forschungsbereiche/ausbildungskernreaktor-akr-2

[2] CORTEX-Logo, http://cortex-h2020.eu/ ; Horizon2020-Logo, https://twitter.com/EU_H2020

[3] Schnitt Reaktor, iSTec GmbH: ISTec-A-2420, 2012

[4] V. Lamirand, S. Hübner, *First experimental campaigns in AKR-2 & CROCUS reactors*, presentation, Annual CORTEX meeting, Munich 2018

[5] V. Lamirand, A. Rais, *Qualification of the acquisition systems for experimental campaigns*, presentation, Annual CORTEX meeting, Munich 2018

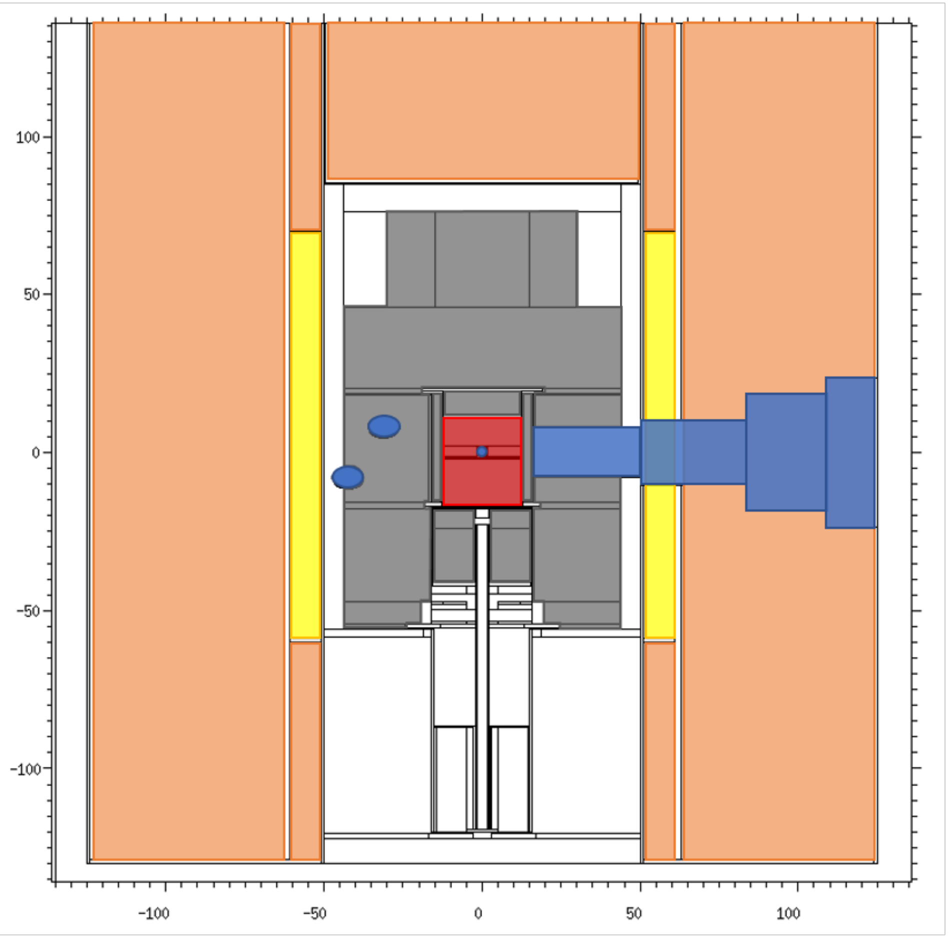
[6] S. Hübner, *Neuauslegung, Inbetriebnahme und Test eines hochpräzisen Pile-Oszillators für den AKR-2*, Diploma-Thesis, TU Dresden, Dresden 2018

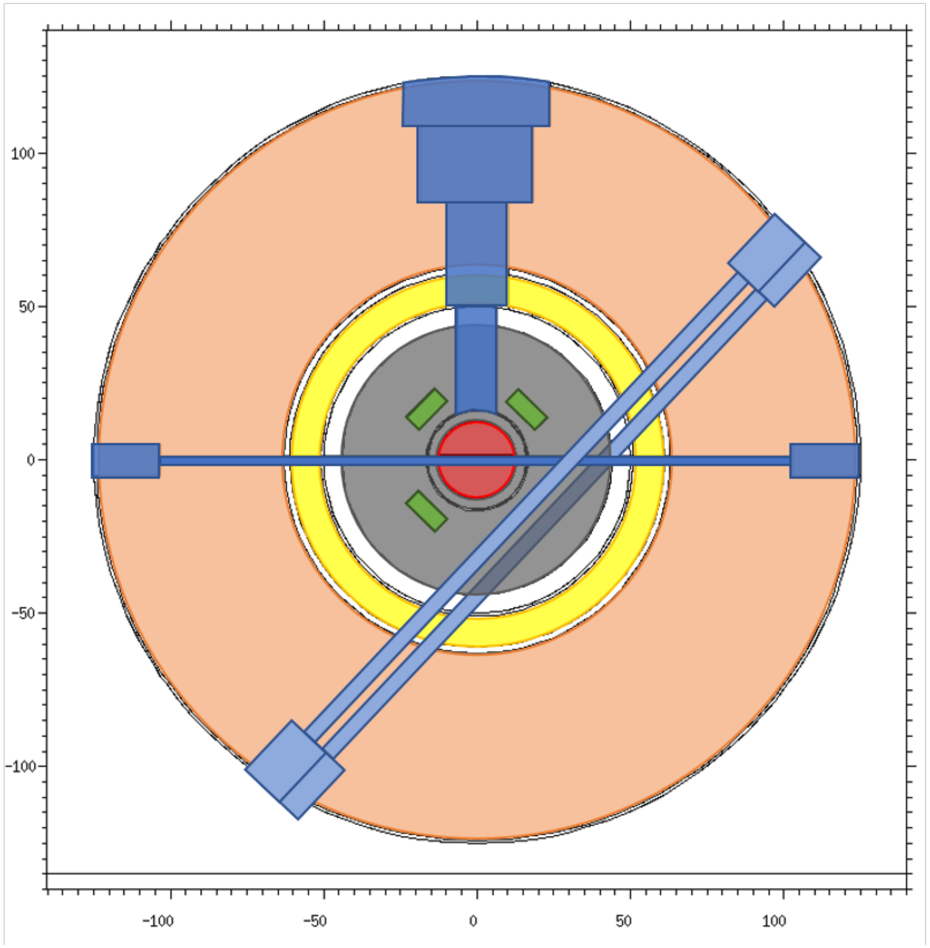
[I] V. Lamirand, M. Hursin, P. Frajtag, G. Perret, O. Pakari and A. Pautz, *Future Experimental Programmes in the CROCUS Reactor*, Conference proceedings – oral presentations, RRFM/IGORR, Berlin 2016

Backup

AKR-2 Components

Fuel | Reflector | Control- and Safetyrods | Experimental Channels | Shielding





Diffusion equation

Initial condition: critical reactor $(\rho = 0, k = 1)$ ρ ... reactivity k ... multiplication factor

2-group diffusion equation:

	Diffusion	*Loss*	*Source*	
Fast neutrons (1):	$\nabla \cdot (D_1 \nabla \Phi_1)$	$- (\Sigma_{a,1} + \Sigma_m)\Phi_1$	$+ \epsilon v \Sigma_{f,2} \Phi_2$	$= \dot{n}_0 = 0$
Thermal neutrons (2):	$\nabla \cdot (D_2 \nabla \Phi_2)$	$- \Sigma_{a,2} \Phi_2$	$+ p \Sigma_m \Phi_1$	$= \dot{n}_0 = 0$

D ... diffusion coefficient Φ ... neutron flux Σ ... macroscopic cross section

ε ... fast fission factor v ... mean velocity p ...resonance escape probability

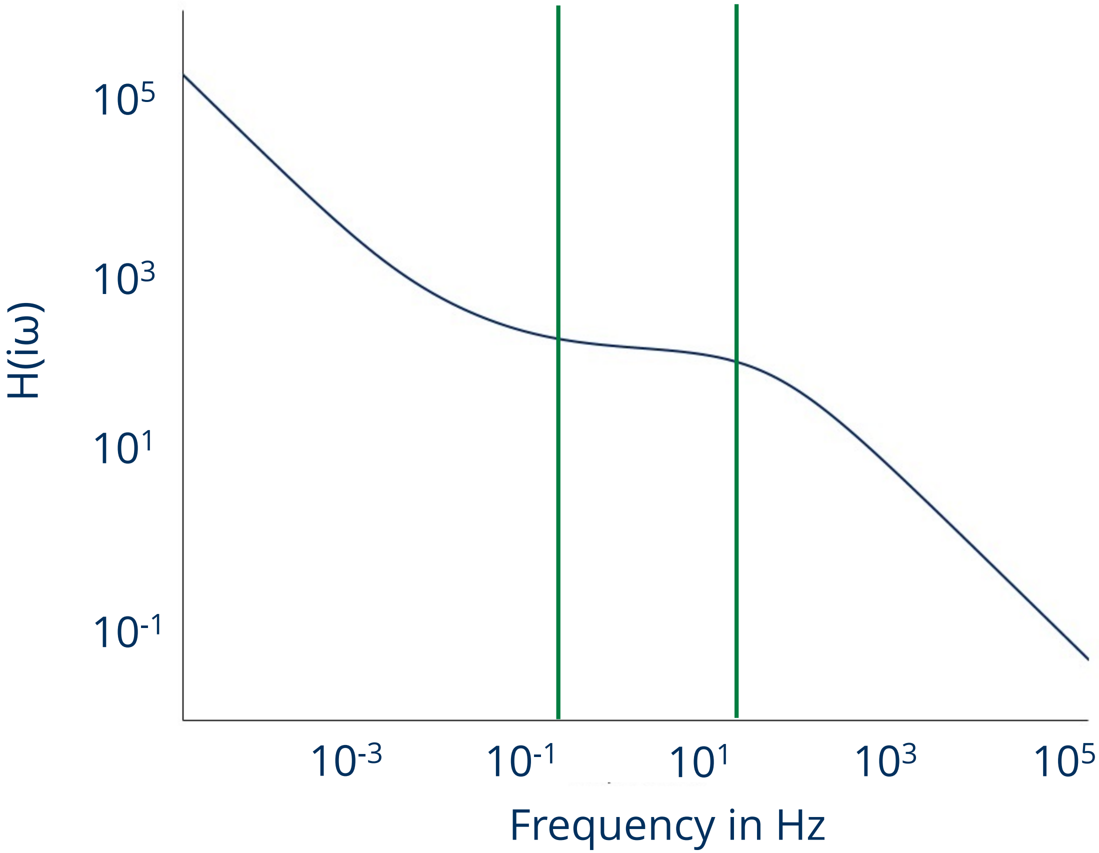
$$\rho_a = \frac{-\delta \Sigma_{a,2} \Phi_2 \Phi_2^{+} \Delta V}{\int_{V_R} (\Phi_1 + \varepsilon v \Sigma_{f,2} \Phi_2 \Phi_1^{+}) dV}$$

Zero-power transfer function

$$H(s) = \frac{\mathcal{L}\{n(t)\}}{\mathcal{L}\{\rho(t)\}} = \frac{N(s)}{R(s)}$$

$$H(s) = \frac{n_0}{\Lambda \cdot s + \beta - \rho_0 - \sum_{i=1}^{6} \frac{\beta_i \cdot \lambda_i}{s + \lambda_i}}$$

$$s = i\omega$$



Λ … mean, eff. generationtime of prompt neutrons

β … fraction of delayed neutrons

λ … precursor decay constants

i … i^th group of delayed neutrons

Zero-power transfer function of the AKR-2 for a sinusoidal input signal

Pile-oscillator evaluation method[1]

$$\Delta S(m) = \Delta S_0 + A_1 m + A_2 m^2$$

$$A_1 = C \cdot \frac{\Sigma_a}{\rho(m,V)}$$

$$\sigma_{a,U} = \frac{A_{1,U}}{A_{1,S}} \cdot \sigma_{a,S} \cdot \frac{N_U(M,\rho)}{N_S(M,\rho)}$$

$\sigma_{a,In}$ = 202,7 b

Theoretical value: 197 b

Deviation of 2,9 %

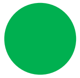
Deviation of the regressions:

Iridium (standard) :	2,2 %
Indium (probe) :	13,7 %
Sum :	13,9 %

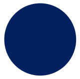
[1]P.S. Christensen. *A Description of the Pile Oscillators at DR 1*. Technical report, The Danish Atomic Energy Commission Research Establishment Risö, 1966.

Precision of "old" and "new" Pile-oscillator

Mean deviation:



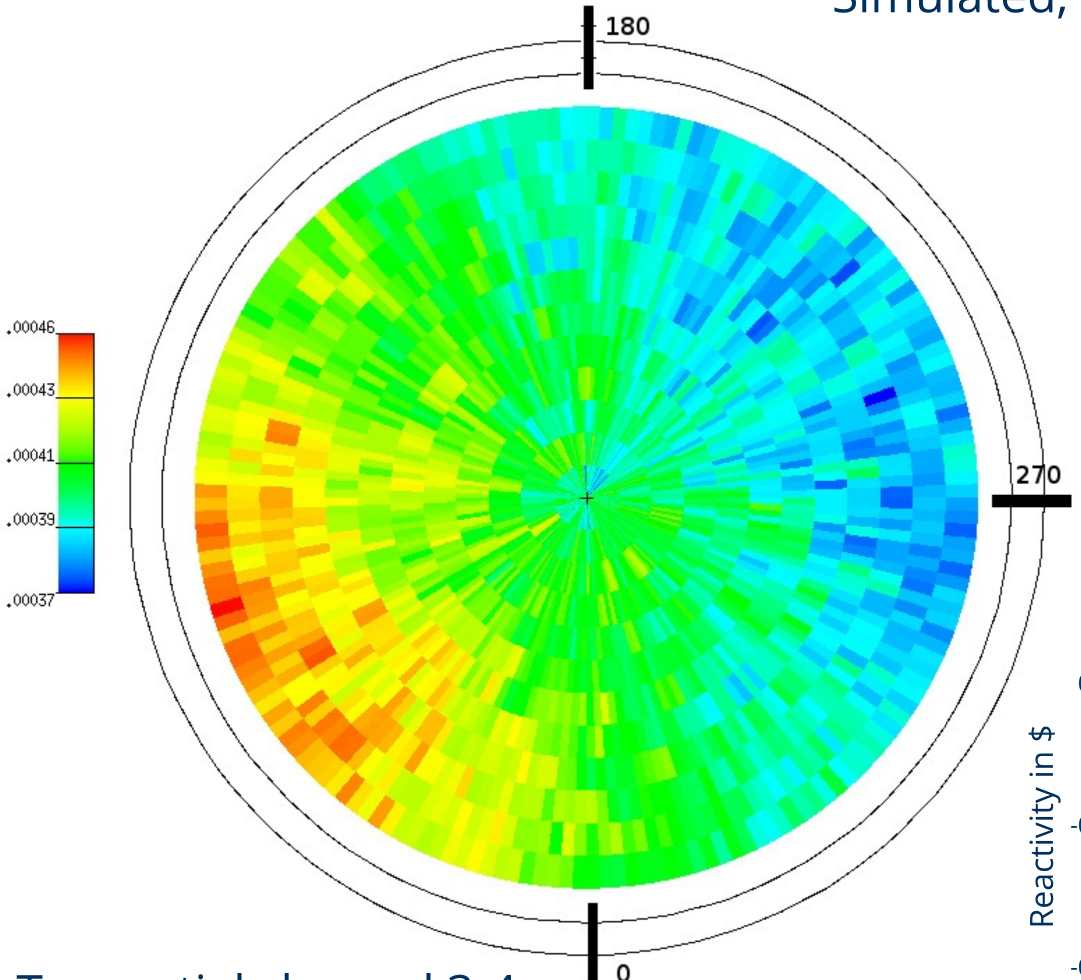
2,44 %



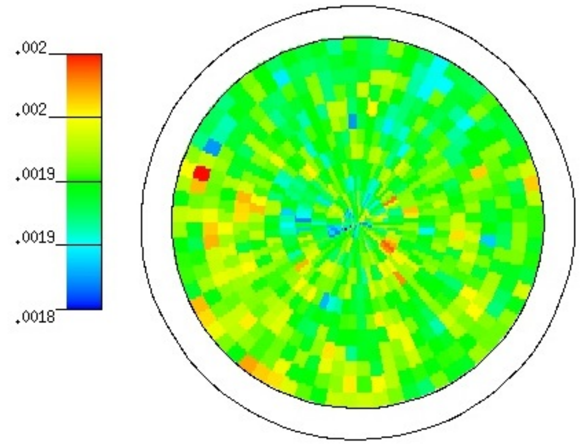
0,22 %

Simulated neutron flux in experimental channels of AKR-2

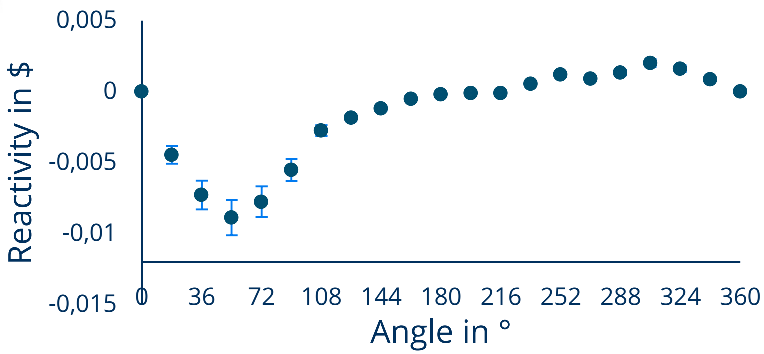
Simulated, normalized neutron-flux in:



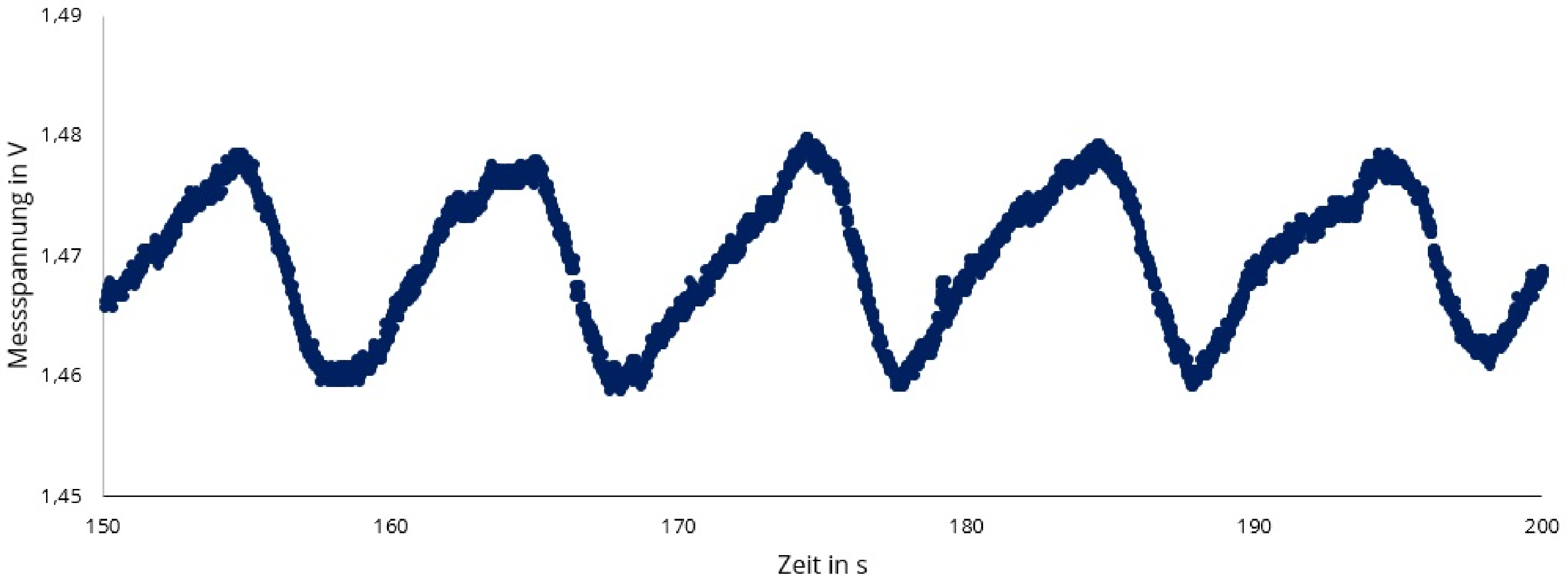
Tangential channel 3-4



Central channel 1-2



Reactor signals of AKR-2, examples



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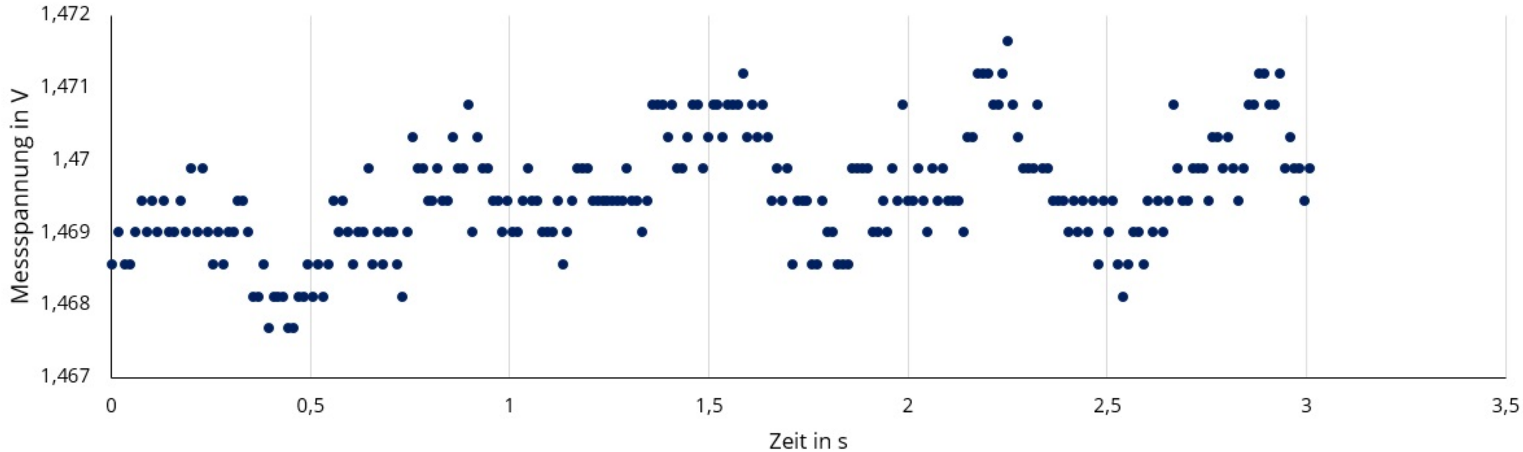
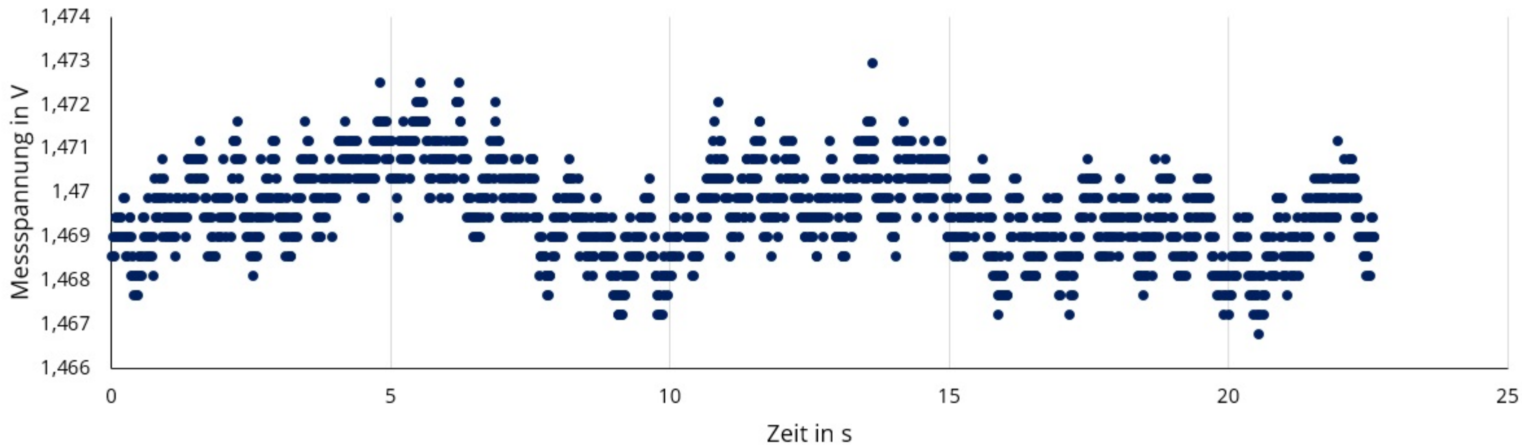
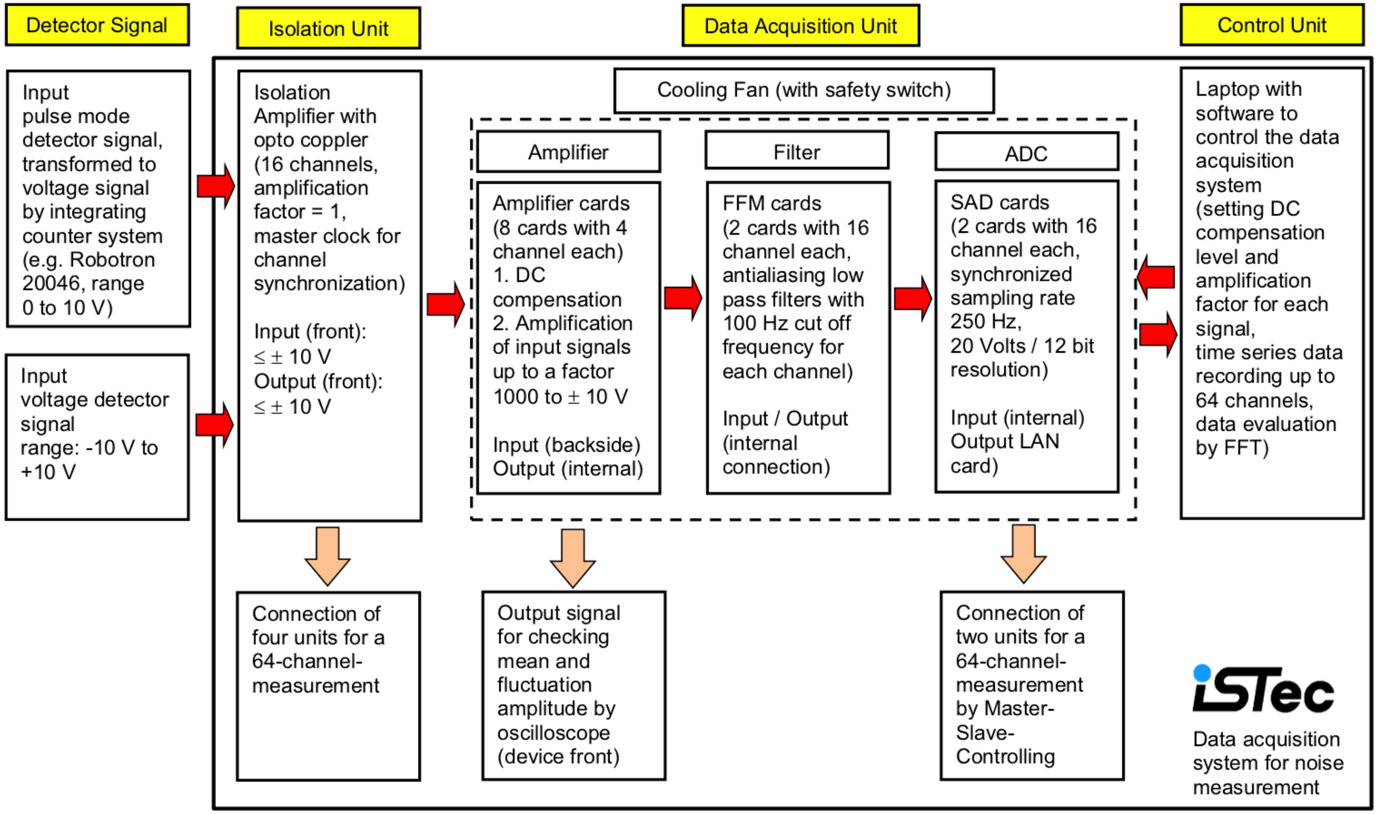


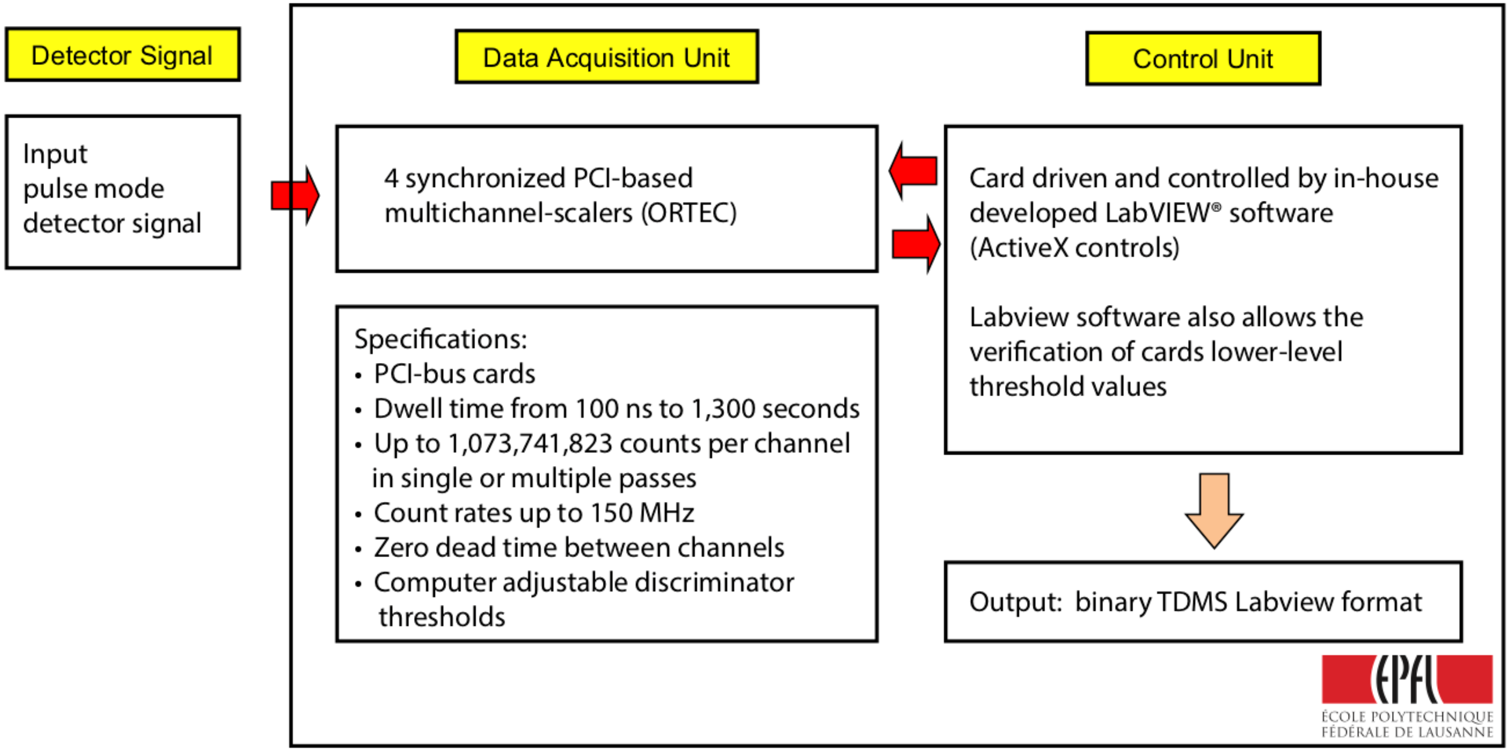


Data Acquisition System, ISTEC



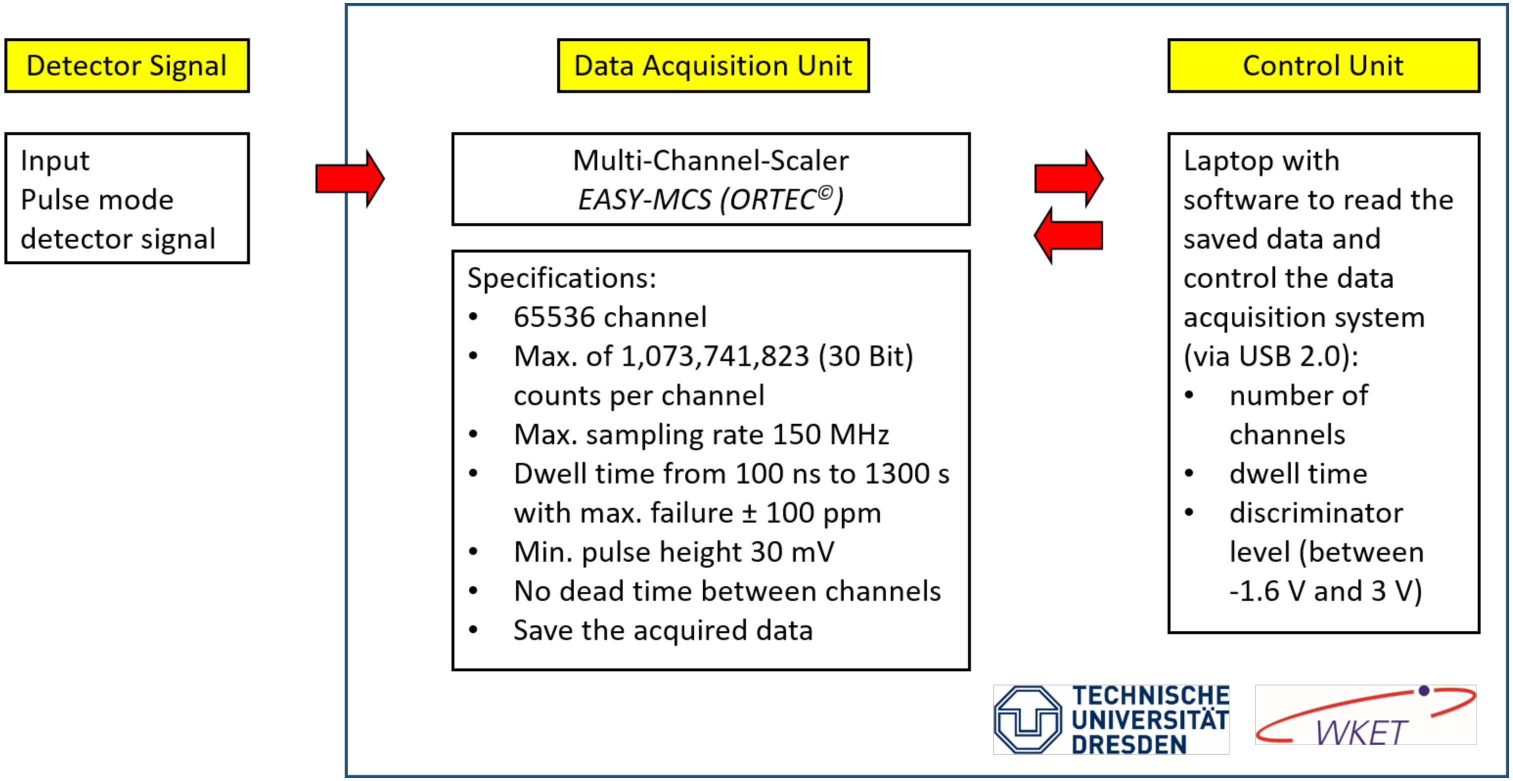
V. Lamirand, A. Rais, *Qualification of the acquisition systems for experimental campaigns*, presentation, Annual CORTEX meeting, Munich 2018

Data Acquisition System



V. Lamirand, A. Rais, *Qualification of the acquisition systems for experimental campaigns*, presentation, Annual CORTEX meeting, Munich 2018

Data Acquisition System, TUD



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