The COLIBRI programme in CROCUS: characterisation of the fuel rods oscillator

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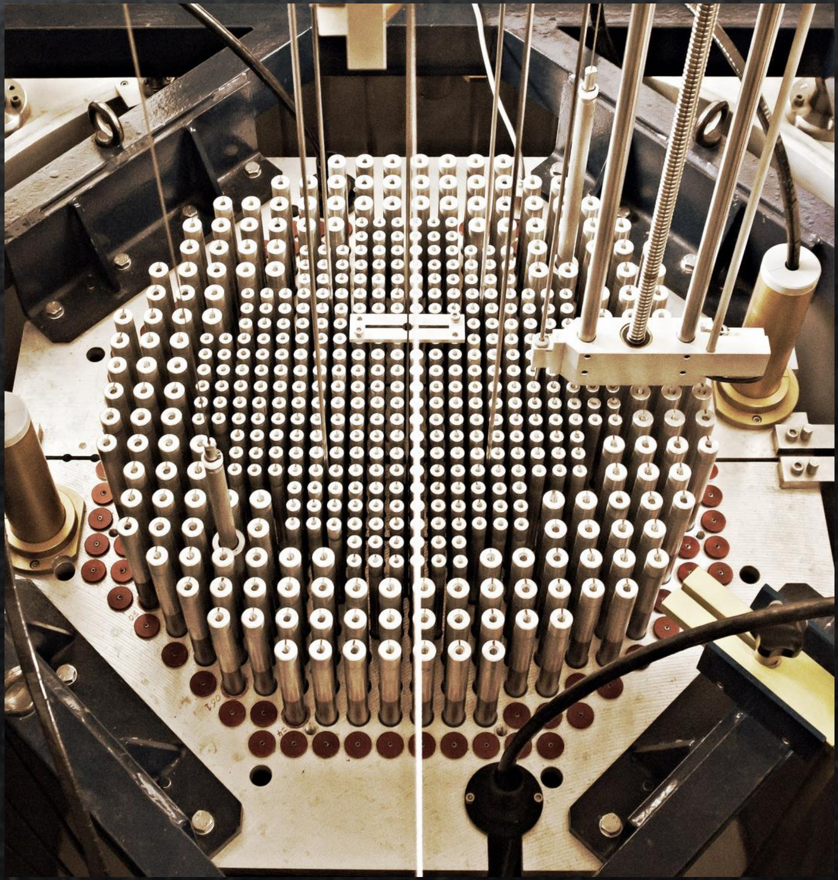


LRS research activities

CROCUS experiments

VOID: void fraction

COLIBRI: fuel oscillation

Intrinsic noise experiments

PETALE: ss. nuclear data

Hi-fi n. experiments

γ characterisation

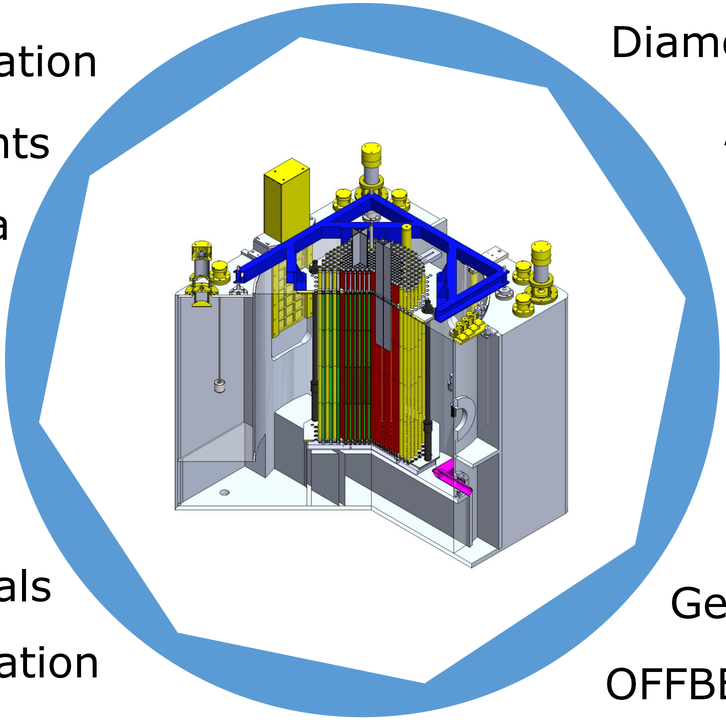
Instrumentation development

Neutron noise stations

Diamond detector

Activation and TL dosimetry

Miniature scintillators



LOTUS and CARROUSEL

Novel detection materials

Neutron modulation

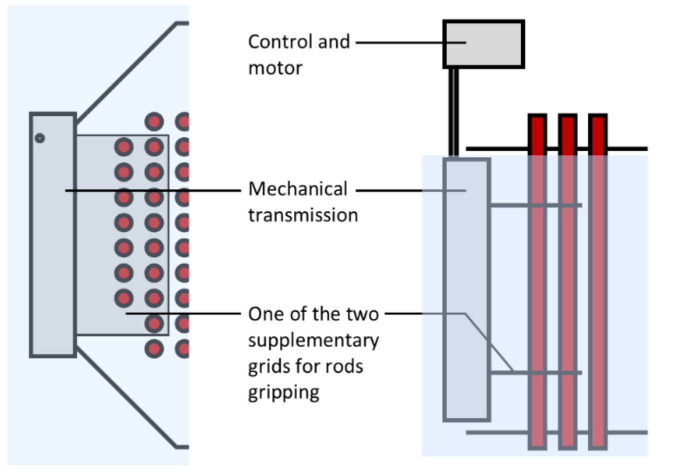
Modelling & code development

Data assimilation

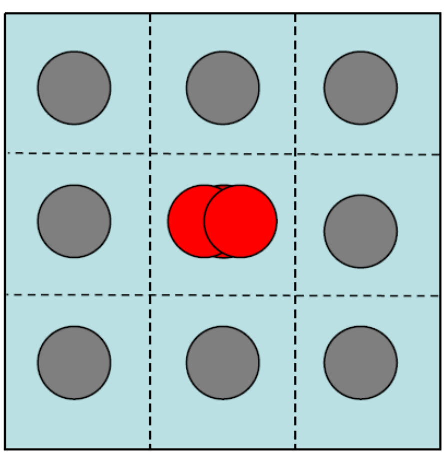
GeN-Foam multiphysics solver

OFFBEAT: OpenFOAM for fuel beh.

Motivation and goals



Initial principle for oscillating fuel rods in CROCUS

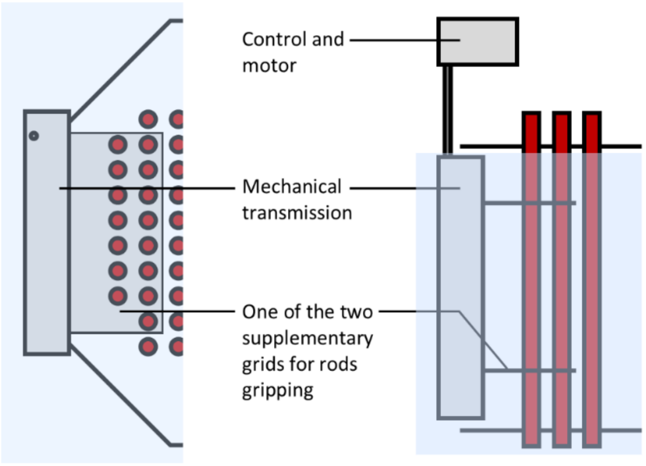


Modelling of fuel rods oscillation in a pin-by-pin simulator (i.e. DORT-TD)

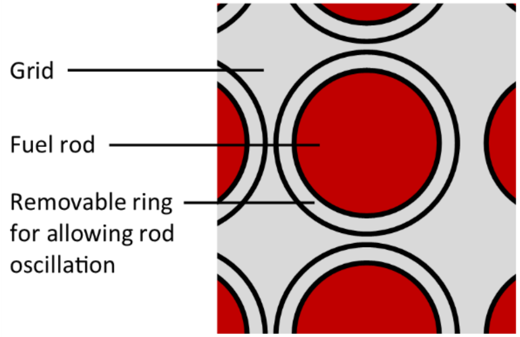
Investigation of power fluctuations induced by fuel oscillations

- Fuel vibration as a possible cause of increased noise amplitude in Swiss PWR reactors during normal operation
- Originally, modelling at PSI and experiments at EPFL[1] for the study of coupling between mechanical noise and neutronics

Motivation and goals



Initial principle for oscillating fuel rods in CROCUS



Removable ring for allowing oscillation

Investigation of power fluctuations induced by fuel oscillations

- Fuel vibration as a possible cause of increased noise amplitude in Swiss PWR reactors during normal operation
- Originally, modelling at PSI and experiments at EPFL[1] for the study of coupling between mechanical noise and neutronics

Experiments in CROCUS for measuring neutron noise induced by fuel vibration

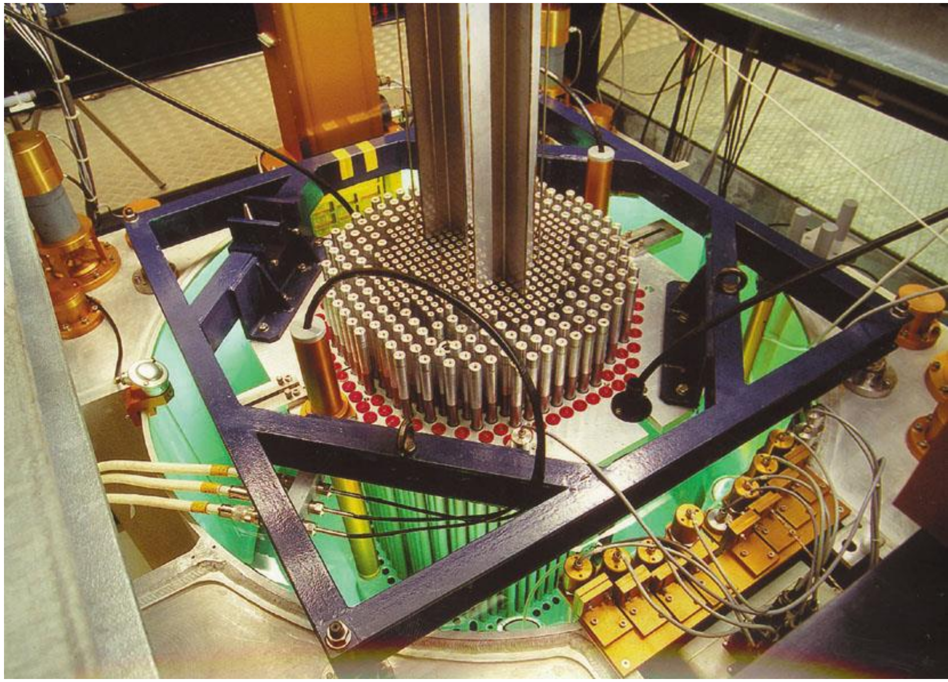
- Design of an in-core device for lateral oscillation of fuel rods at representative amplitudes and frequencies
- Measurement of the perturbation using neutron noise techniques
- Production of sound experimental data for code validation

[1] V. Lamirand et al, "Future experimental programmes in the CROCUS reactor," *Conference Proceedings of RRFM/IGORR 2016*, no. 02-2016, pp. 284-292, 2016.

Boundary conditions

The CROCUS reactor

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



Boundary conditions

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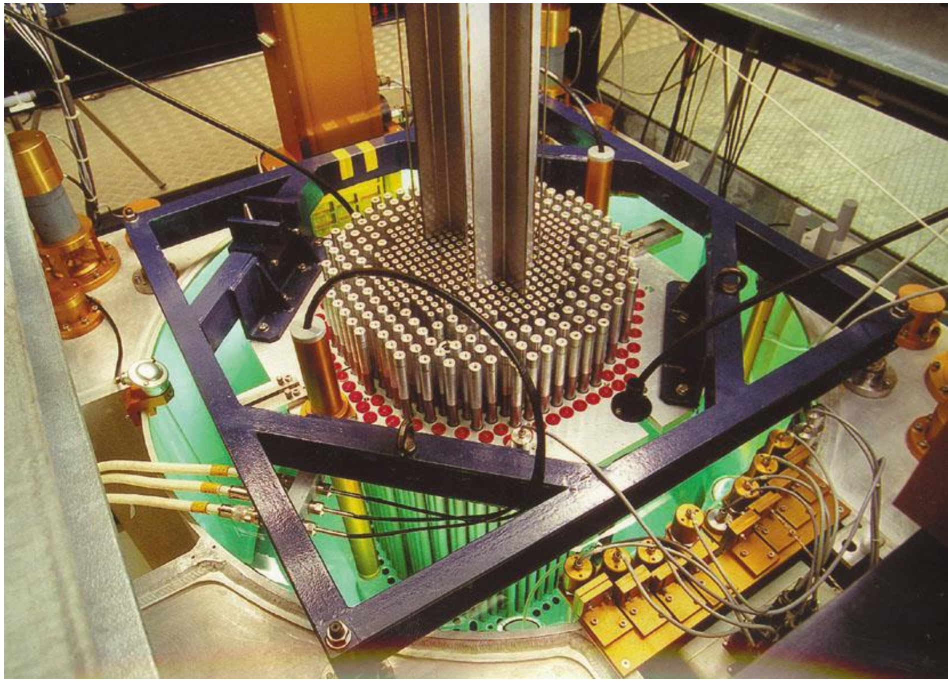
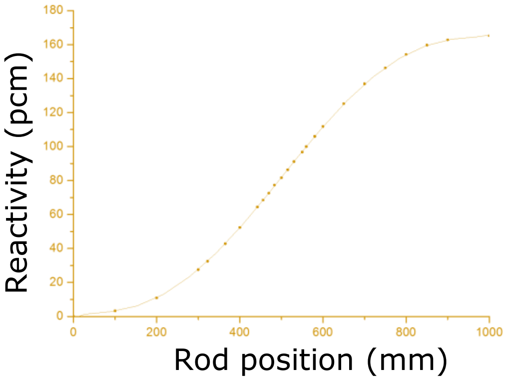
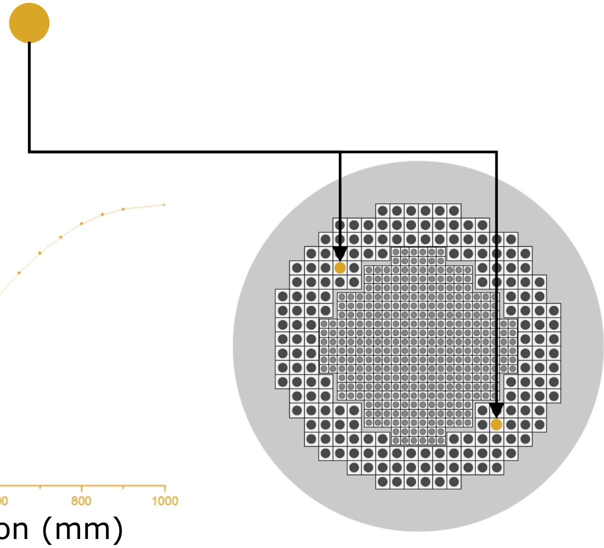


- Reactor type
  - LWR with partially submerged core
  - Room T (controlled) and atmospheric P
  - Forced water flow (160 $l.min^{-1}$)
- Operation
  - Max. 100 W (zero-power reactor)
  - i.e. maximum 2.5×10^{9} $cm^{-2}.s^{-1}$
  - Control: B_4C rods and spillway





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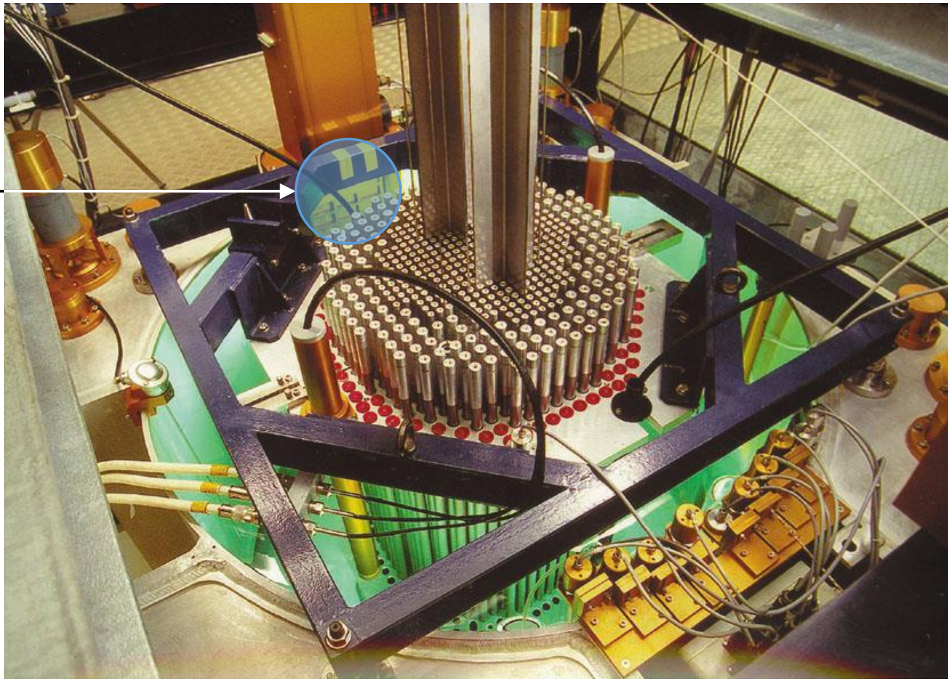

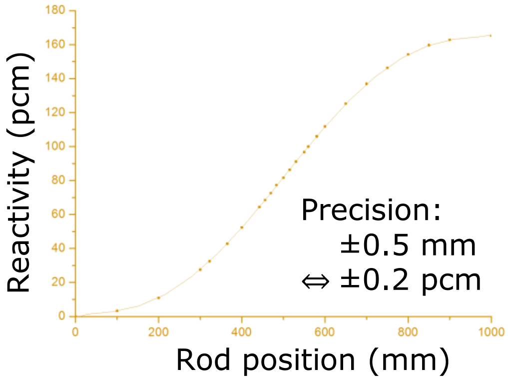

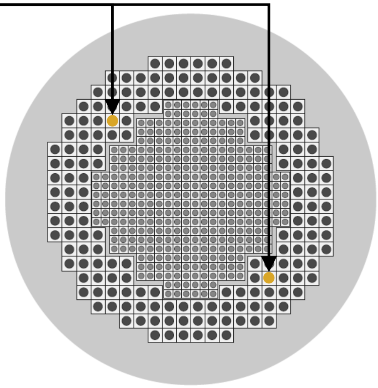

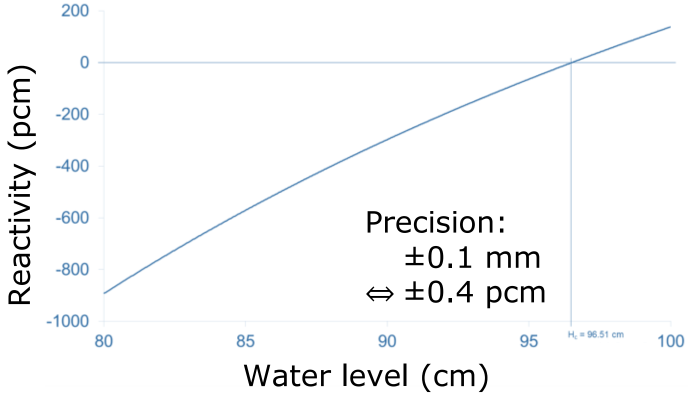

Boundary conditions

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- Reactor type
  - LWR with partially submerged core
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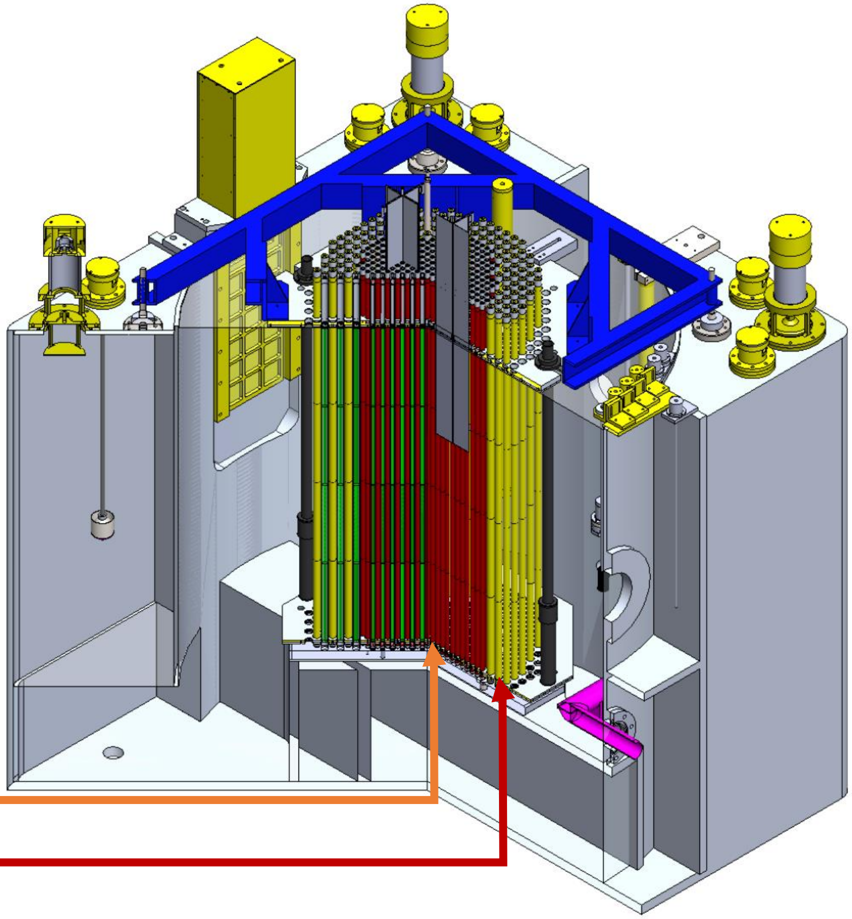
- Operation
  - Max. 100 W (zero-power reactor)
  - i.e. maximum 2.5×10^{9} $cm^{-2}.s^{-1}$
  - Control: B_4C rods and spillway
- Core dimensions
  - ⌀60 cm/100 cm
- Fuel lattices
  - 2-zone (2.5 MR): 336/172-176 rods
  - Inner: UO_2 1.806 wt% 1.837 cm
  - Outer: U_{met} 0.947 wt% 2.917 cm



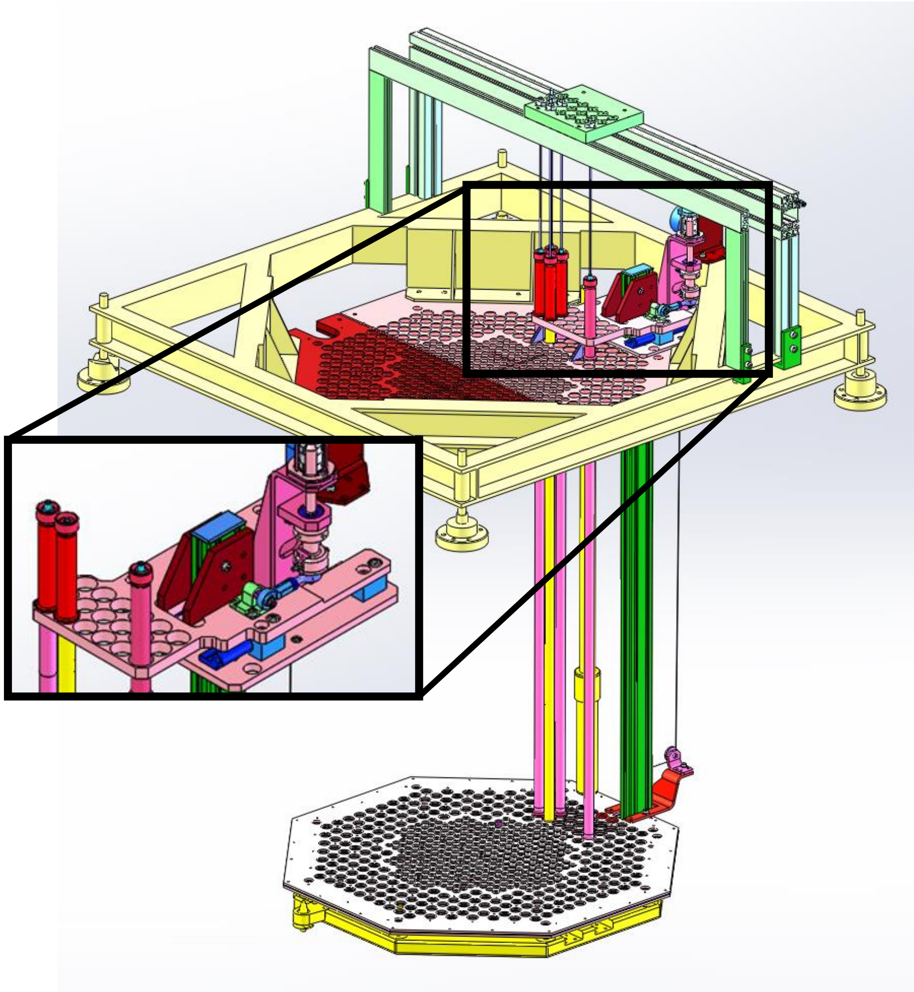
Mechanical design

Boundary conditions for safety

- No friction on fuel cladding or grids
- Movement limited mechanically, not by command
- Only one motor with transmission, for avoiding decoupled oscillation of upper and lower part of the fuel
- Volume and mass above core limited
- Providing calculation results of forces applied to rods

Experimental setup

Mechanical design



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

Boundary conditions for safety

- No friction on fuel cladding or grids
- Movement limited mechanically, not by command
- Only one motor with transmission, for avoiding decoupled oscillation of upper and lower part of the fuel
- Volume and mass above core limited
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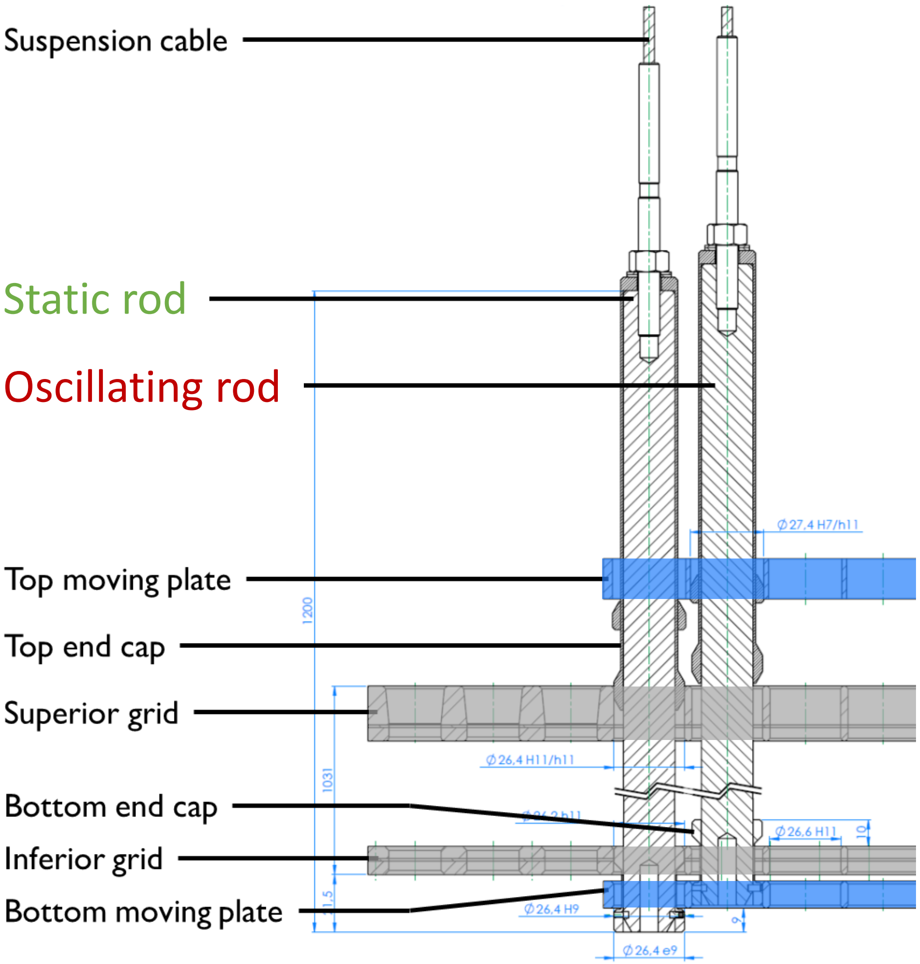
Out-sourced final design[1]

- Up to 18 U_{met} rods, easy selection
- Up to 2 Hz and ±2.5 mm radial

Experimental setup

Mechanical design



Working principle of the final design

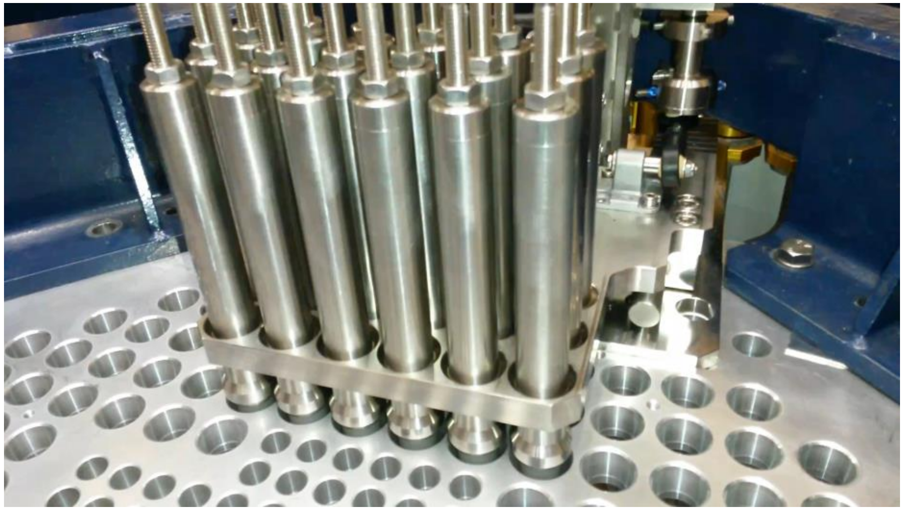
Boundary conditions for safety

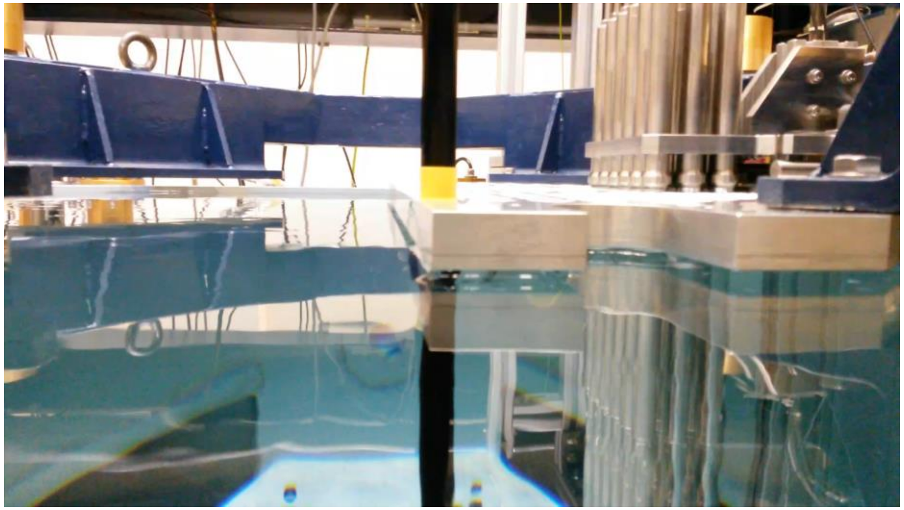
- No friction on fuel cladding or grids
- Movement limited mechanically, not by command
- Only one motor with transmission, for avoiding decoupled oscillation of upper and lower part of the fuel
- Volume and mass above core limited
- Providing calculation results of forces applied to rods

Out-sourced final design[1]

- Up to 18 U_{met} rods, easy selection
- Up to 2 Hz and ±2.5 mm radial
- Top and bottom moving plates
- Rigid transmission via an Al beam
- Up/down position for rod selection
- Cable captor for bottom position

Development and licensing[1]





Adaptation of interfaces
- Authorisation received in June 2015
- New grids installed in January 2017

Tests with dummy rods and weights
- Out-of-vessel in January 2016
- Prototype upgrade
- In-vessel wo/in water in Sept. 2016

Fuel rods modification
- Authorisation received in Jan. 2018
- Modification in the controlled area by the LRS staff in January 2018

Start of the commissioning
- Authorisation received in July 2018

[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

Motivation and means

For safety purposes

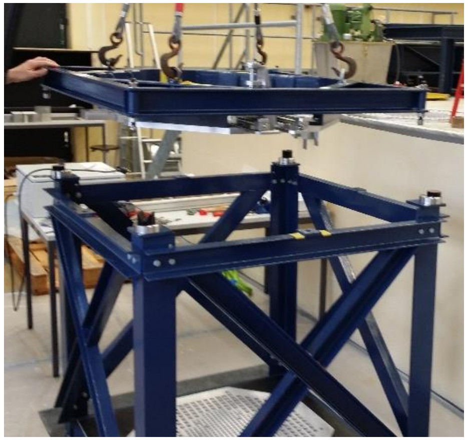
→ Definition of operation limits

For experimental purposes

→ Knowledge of the perturbation

The device was fully tested

- in air and in water
- out of and in the vessel
- empty, 1 and 18 fuel rods loaded



Installation in the unloading stand (left), and of the loaded device at the top (right)

Installation of the device for testing in the vessel

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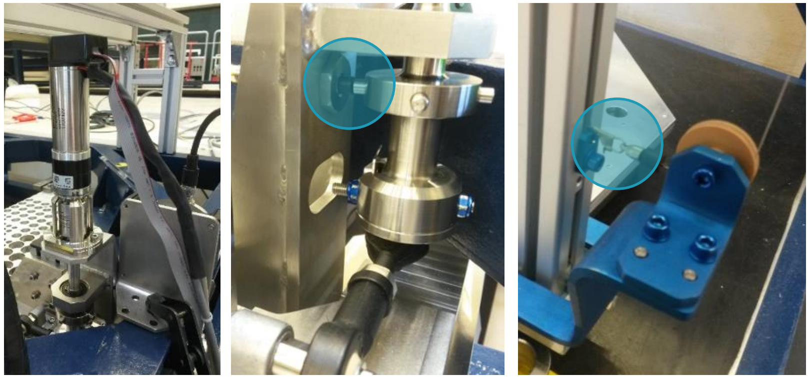
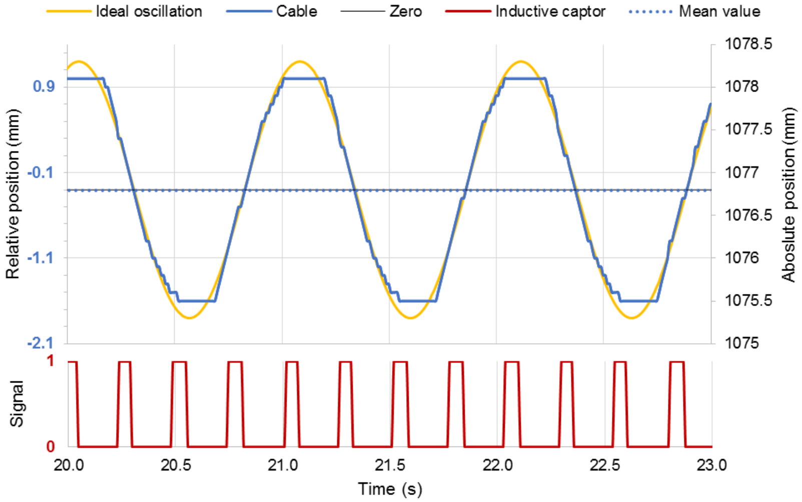
With cable data



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)

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For safety purposes

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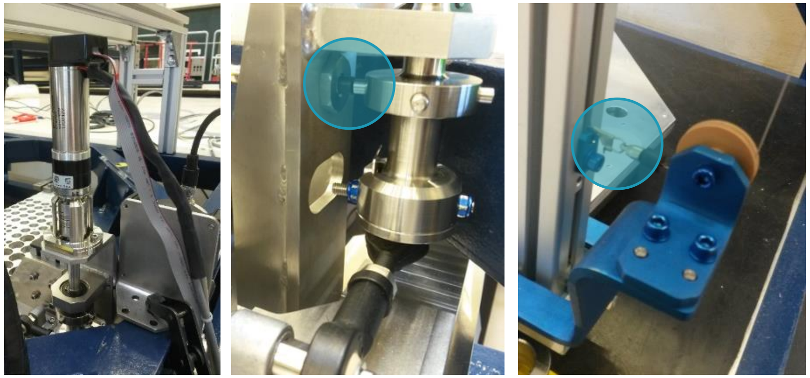
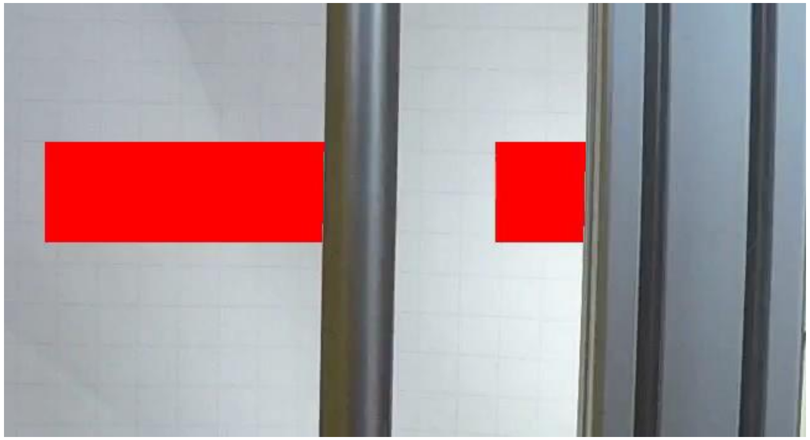
With cable data and videos



Motor, inductive captor and pins, and measuring cable



Video of 1 rod in air, ±1.5 mm and 1 Hz

Mechanical characterisation

Motivation and means

For safety purposes

→ Definition of operation limits

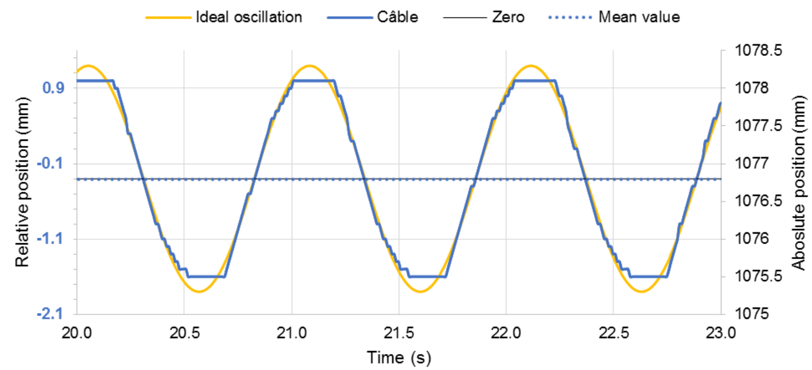
For experimental purposes

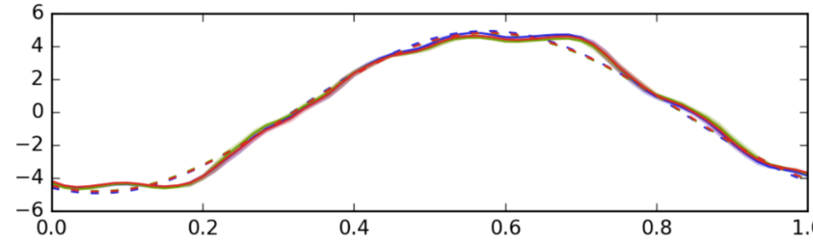
→ Knowledge of the perturbation

The device was fully tested

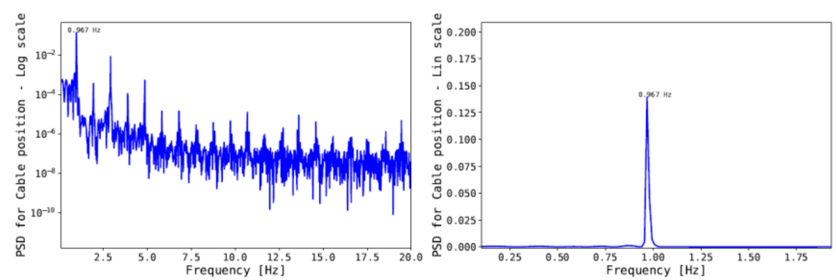
- in air and in water
- out of and in the vessel
- empty, 1 and 18 fuel rods loaded

With cable data and videos





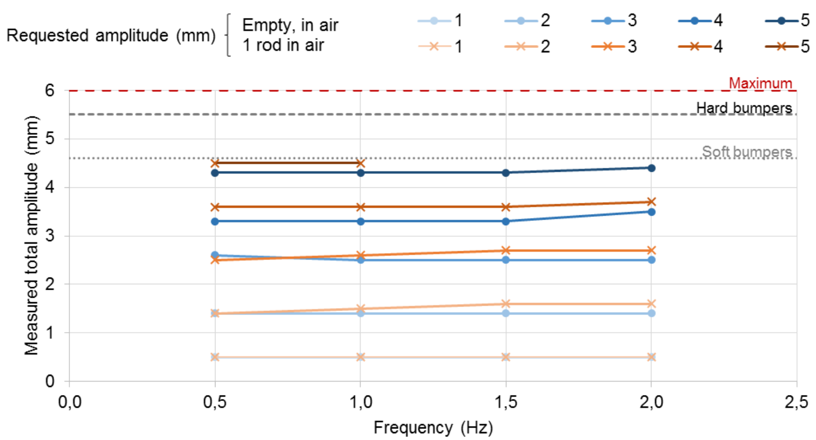
Cable and video data (1 rod in air, ±1.5 mm and 1 Hz)



Associated power spectral density in log and linear scale

Results in air

- Reduced amplitude due to play
- Empty: stable, taken as a reference for the top oscillation
- 1 rod: stable, equivalent to empty within the uncertainties
- 18 rods: amplitude increasing with frequency above 1 Hz



Comparison of the oscillator's behaviour when empty and loaded with 1 rod, in air

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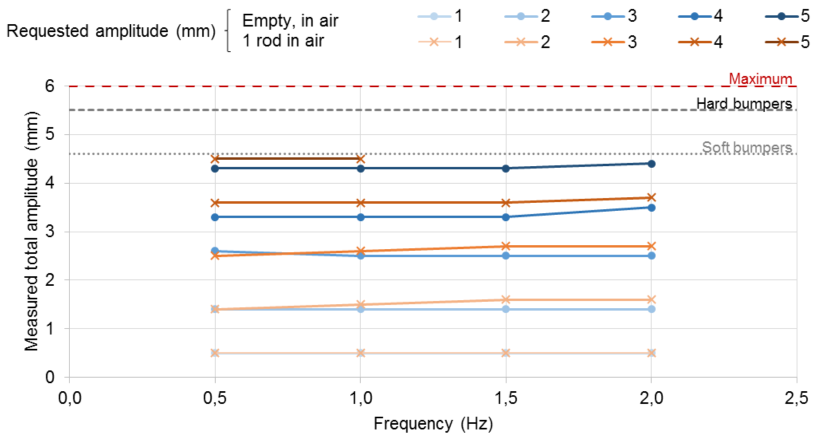

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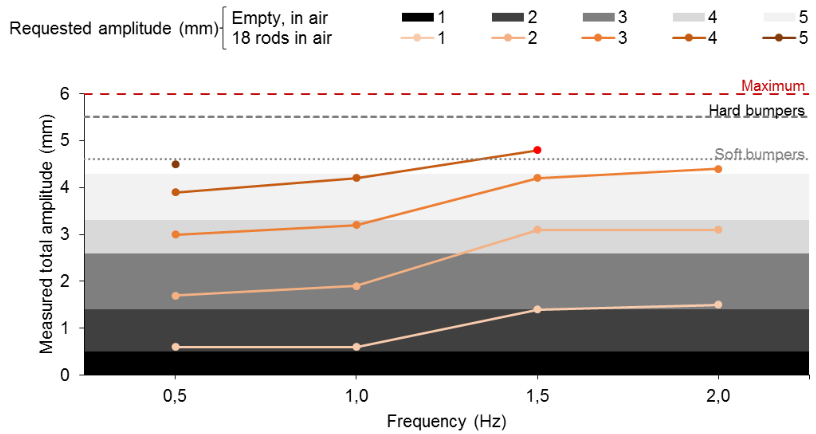

Comparison of the oscillator's behaviour when empty and loaded with 18 rods, in air

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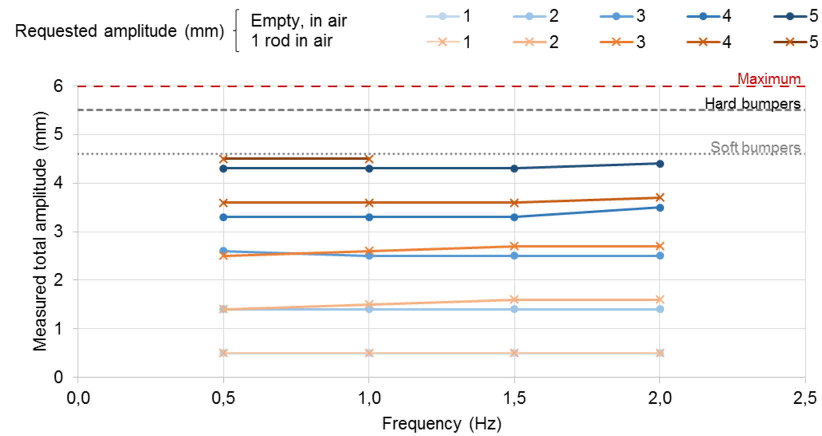
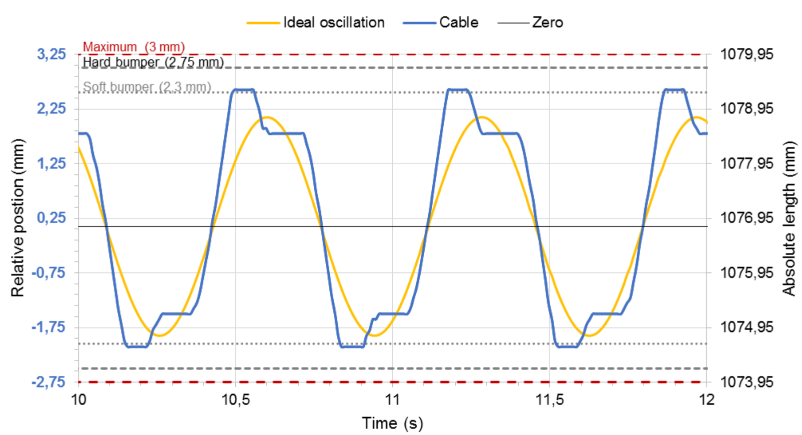
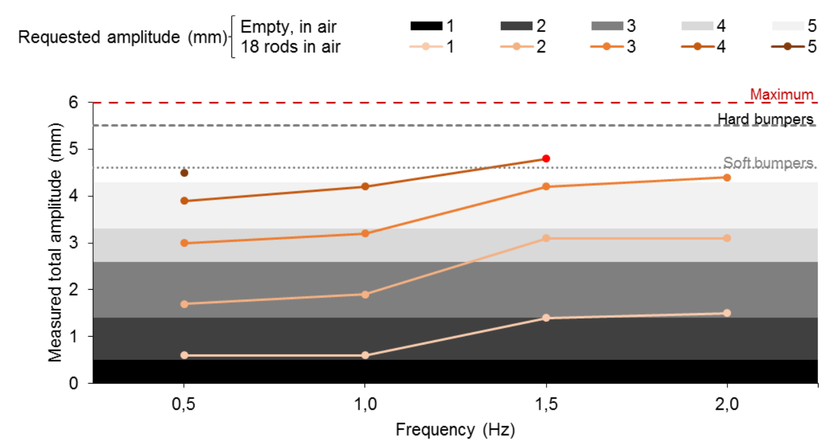


Comparison of the oscillator's behaviour when empty and loaded with 1 rod, in air



Case of a detected hit in the soft bumpers (18 rods, ±2 mm, 1.5 Hz)

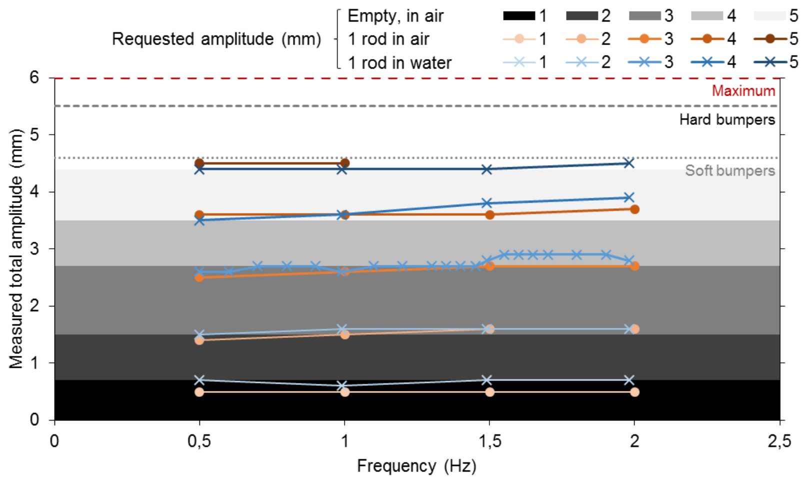


Comparison of the oscillator's behaviour when empty and loaded with 18 rods, in air

Mechanical characterisation

Results in water

- Reduced amplitude due to play
- Empty: stable, taken as a reference for the top oscillation
- 1 rod: stable, equivalent to empty within the uncertainties Confirmed
- 18 rods: amplitude increasing with frequency above 1 Hz



Comparison of the oscillator's behaviour when empty and loaded with 1 rod, in water

Results in water

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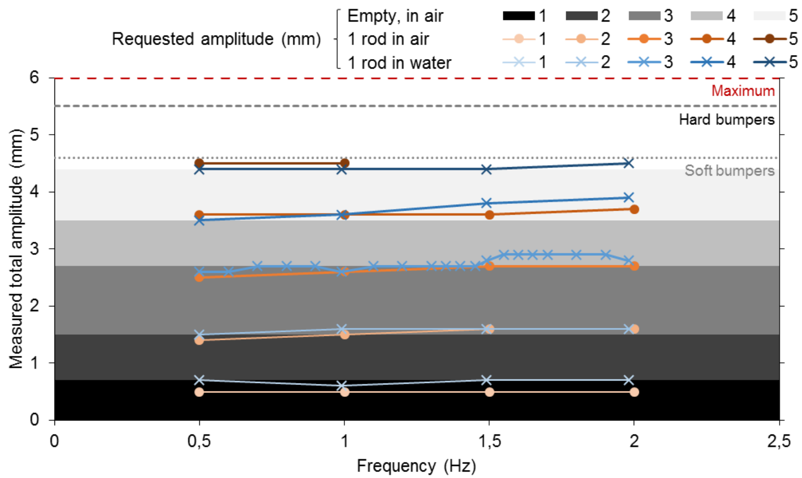
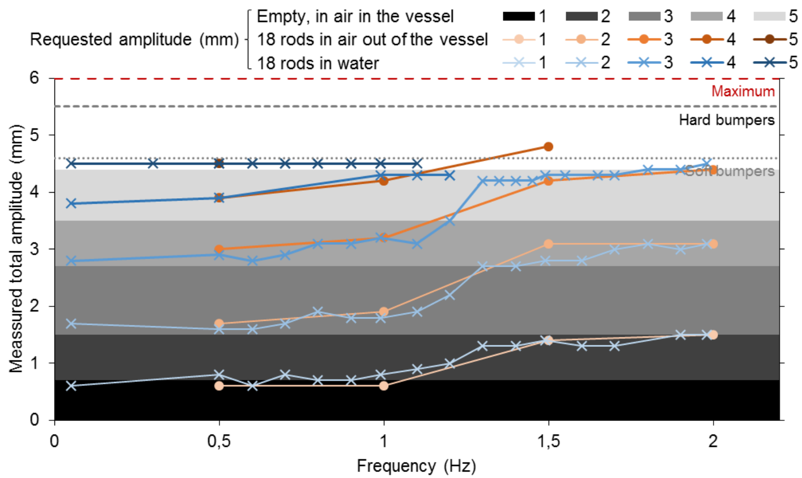
- 1 rod: stable, equivalent to empty within the uncertainties Confirmed
- 18 rods: amplitude increasing with frequency above 1 Hz Confirmed



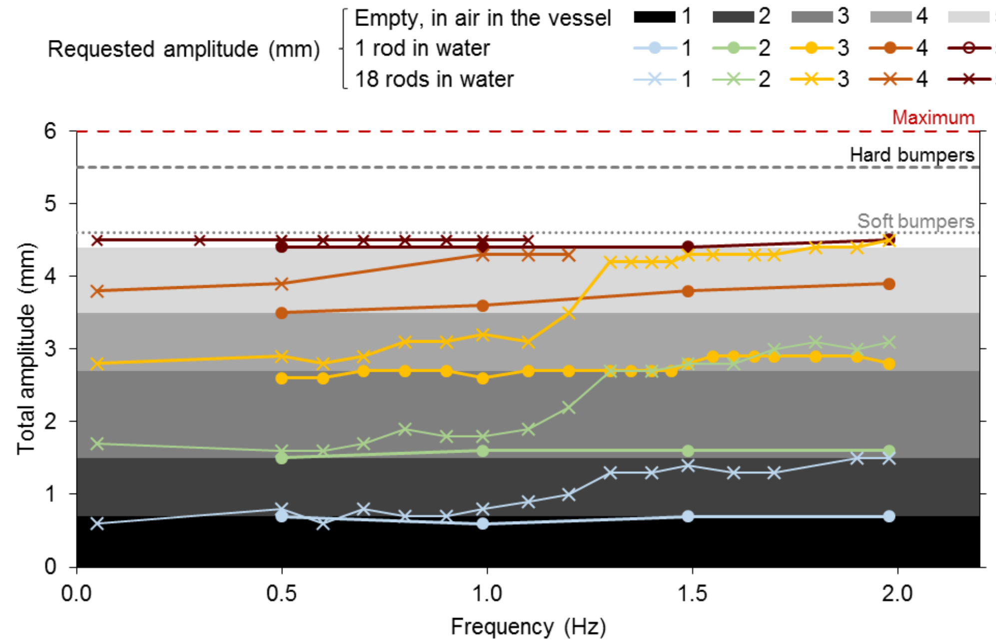
Comparison of the oscillator's behaviour when empty and loaded with 1 rod, in water



Comparison of the oscillator's behaviour when empty and loaded with 18 rods, in air

Operation limits

Based on the shown results, the operation limits were defined and submitted to the Swiss regulator ENSI/IFSN



Comparison of 1 and 18 rods loads

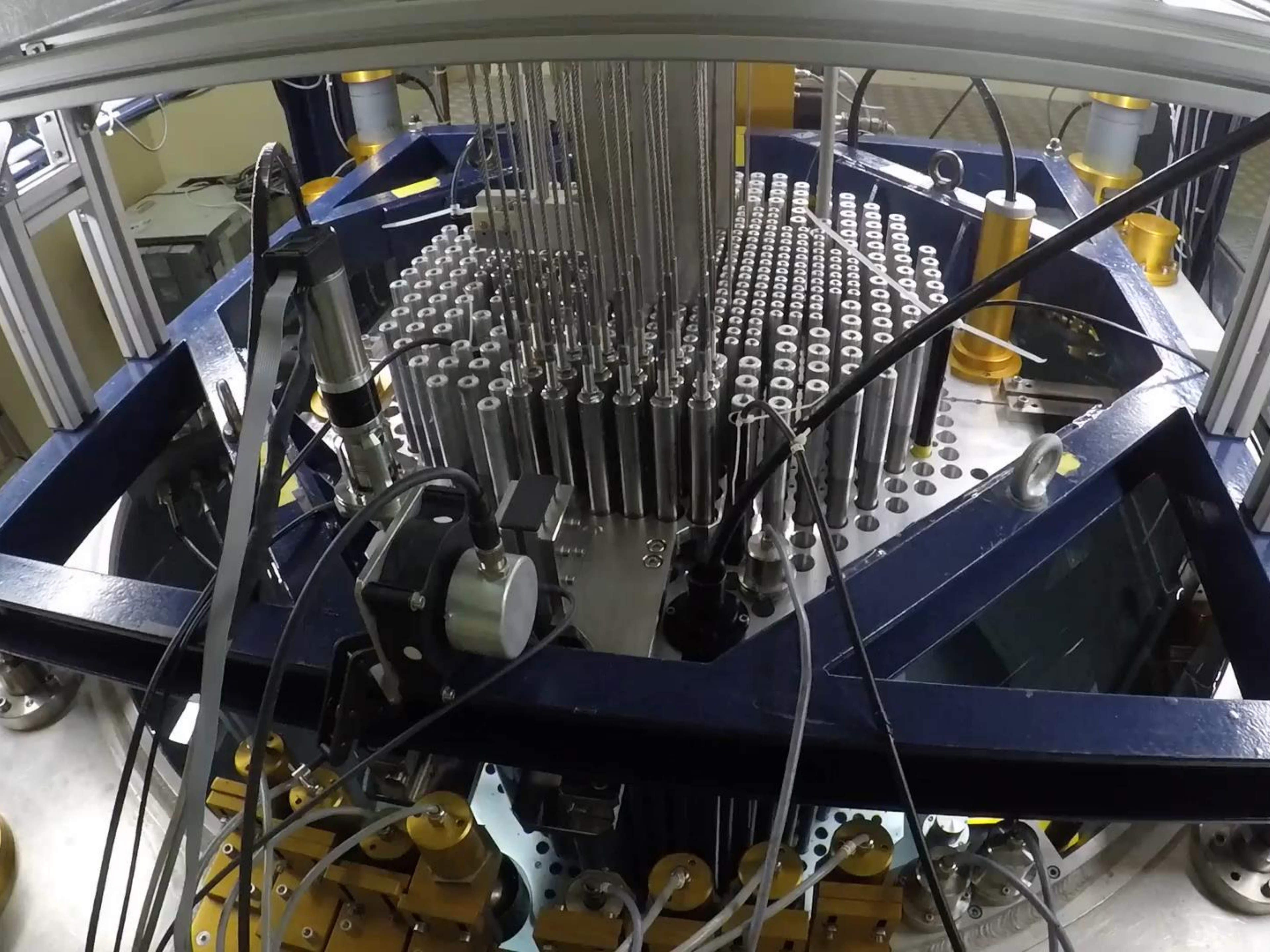
Tests in air

- ✓ Validated
- ? Not tested
- ✗ Invalidated

Tests in water

- Validated
- Not tested
- Invalidated

Amplitude (mm)	Frequency (Hz)																	
	Below	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,0	Beyond
±0,5		✓					✓					✓					✓	?
±1,0		✓					✓					✓					✓	?
±1,5		✓					✓					✓					✓	?
±2,0		✓					✓					✗					✗	✗
±2,5		✓					?					✗					✗	✗
±3,0		✗					✗					✗					✗	✗



Conclusion & outlook

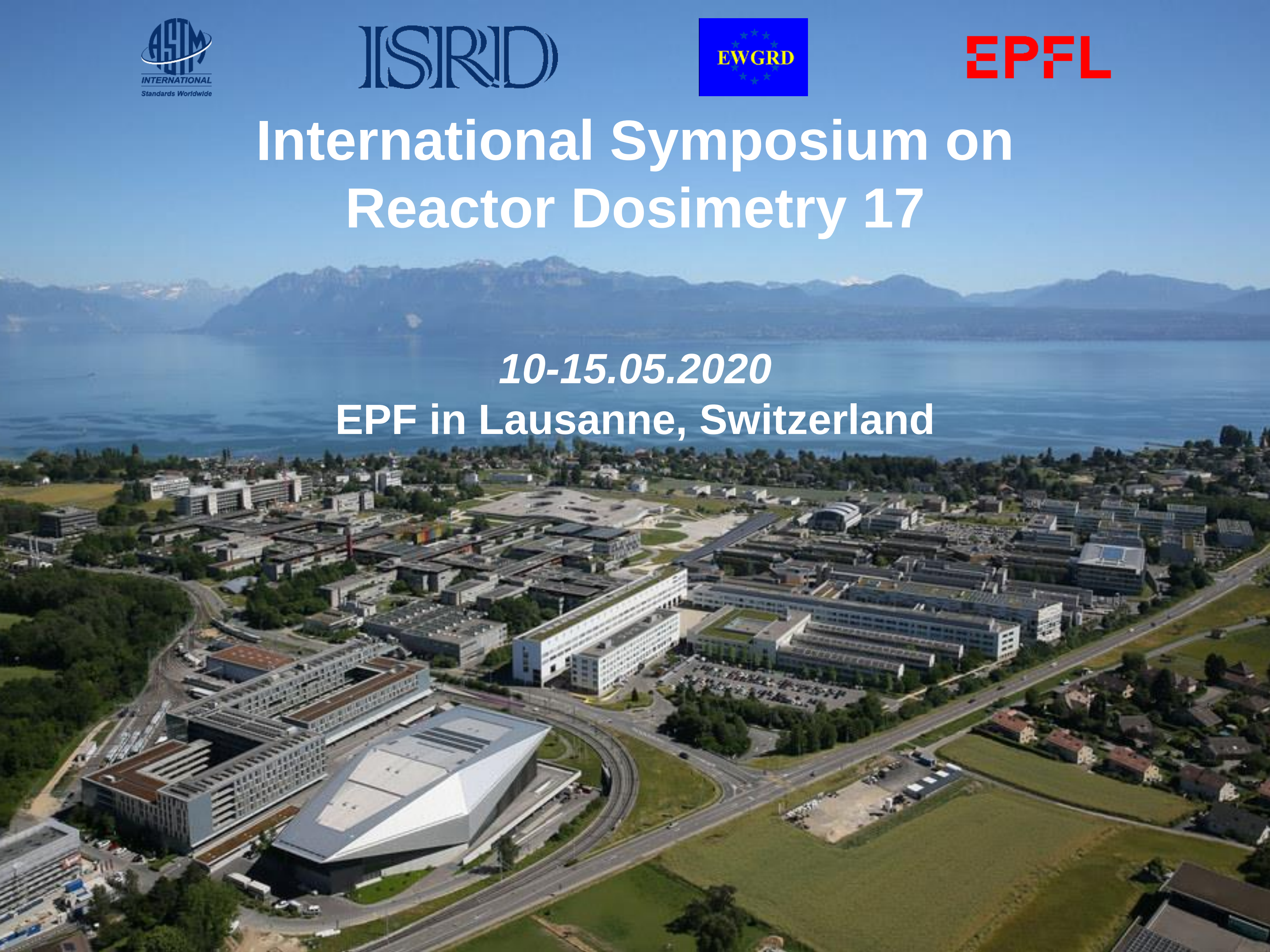
A new experimental programme on noise analysis is currently on-going in CROCUS: COLIBRI.

An in-core device for fuel rods oscillation was developed and characterized, which allows the lateral displacement and oscillation of up to 18 U_m fuel rods of the core outer zone, ±2.5 mm amplitude, and 2 Hz in frequency.

The programme started in September 2018 with the first experimental campaign within the framework of the Horizon 2020 CORTEX project (this conference, #04-1478).

Thank you for your attention!

Vincent Lamirand vincent.lamirand@epfl.ch PI of LRS experimental activities and COLIBRI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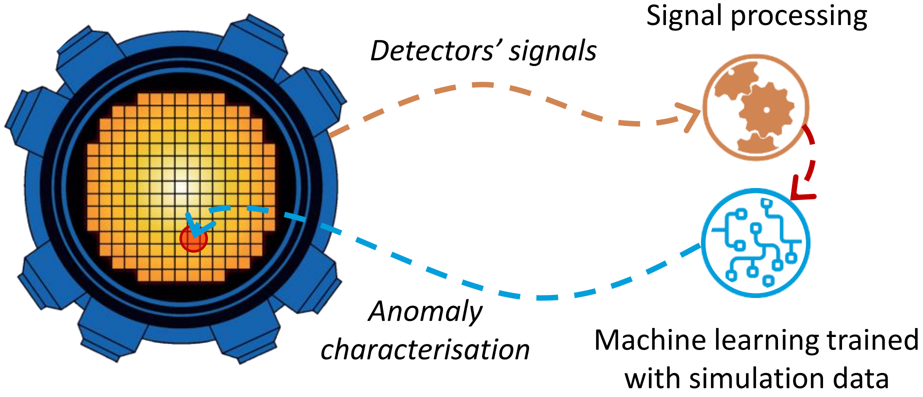
ISRD
EWGRD
EPFL
International Symposium on
Reactor Dosimetry 17
10-15.05.2020
EPF in Lausanne, Switzerland

CORTEX Horizon 2020 Project

CORTEX

Development of an innovative core monitoring technique that allows detecting anomalies in nuclear reactors (excessive vibrations of core internals, flow blockage, coolant inlet perturbations, etc.) using the inherent fluctuations in neutron flux recorded by in-core and ex-core instrumentation



CORTEX Working Packages (WP)

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