New experimental programmes in the CROCUS reactor

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RRFM/IGORR 2016 – Berlin, 15/03/2016

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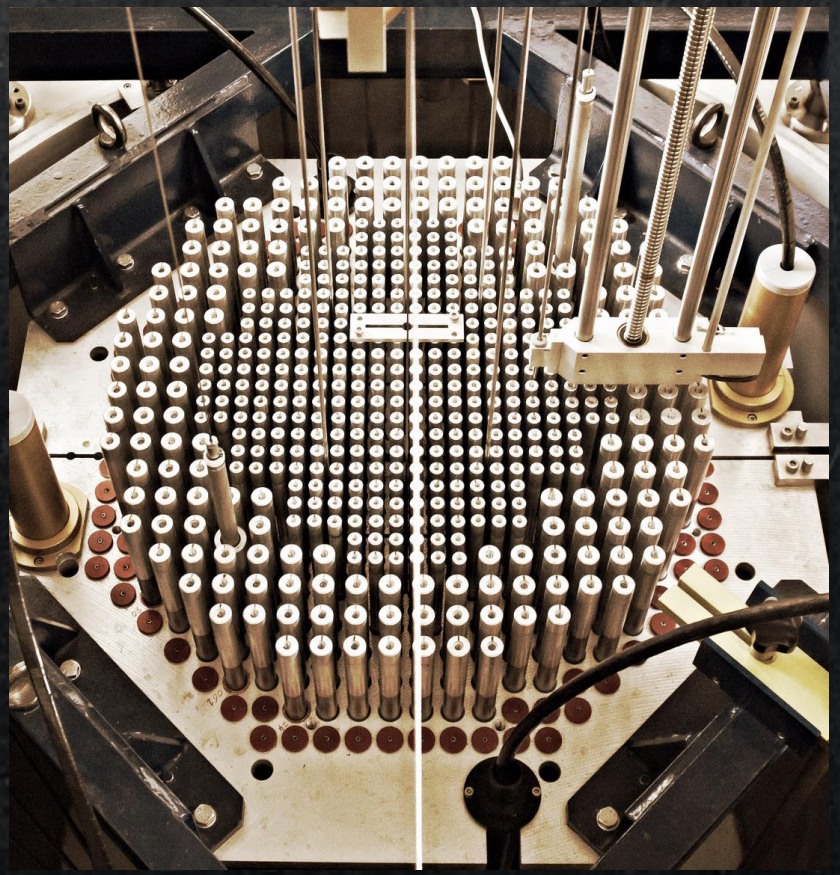
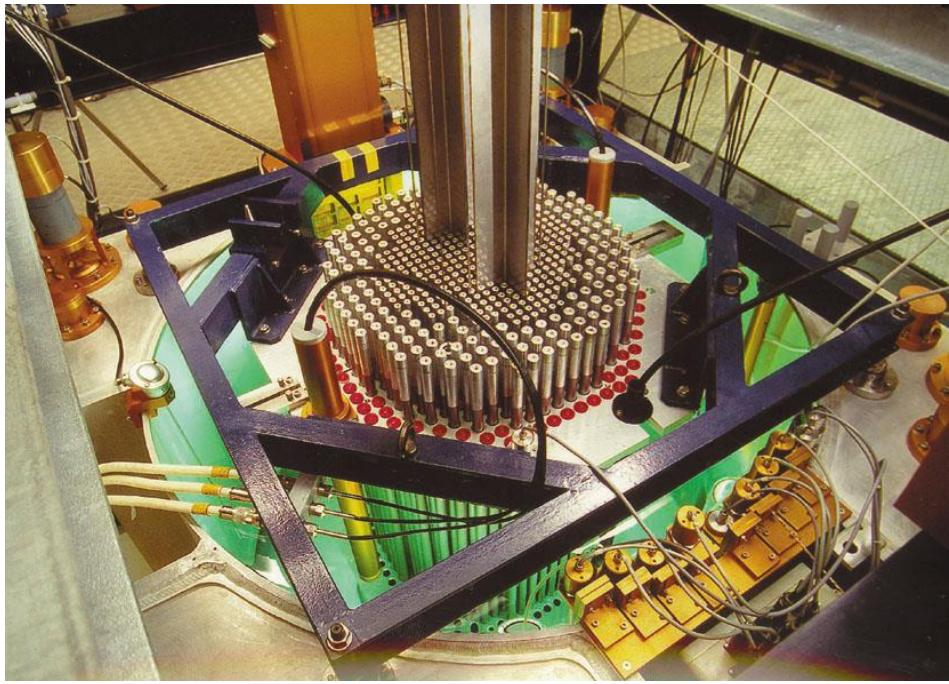


The CROCUS teaching and research reactor

- Reactor type
  - LWR with partially submerged core
  - Atmospheric P and room T
  - Forced convection (160 $l.min^{-1}$)



The CROCUS teaching and research reactor

- Reactor type
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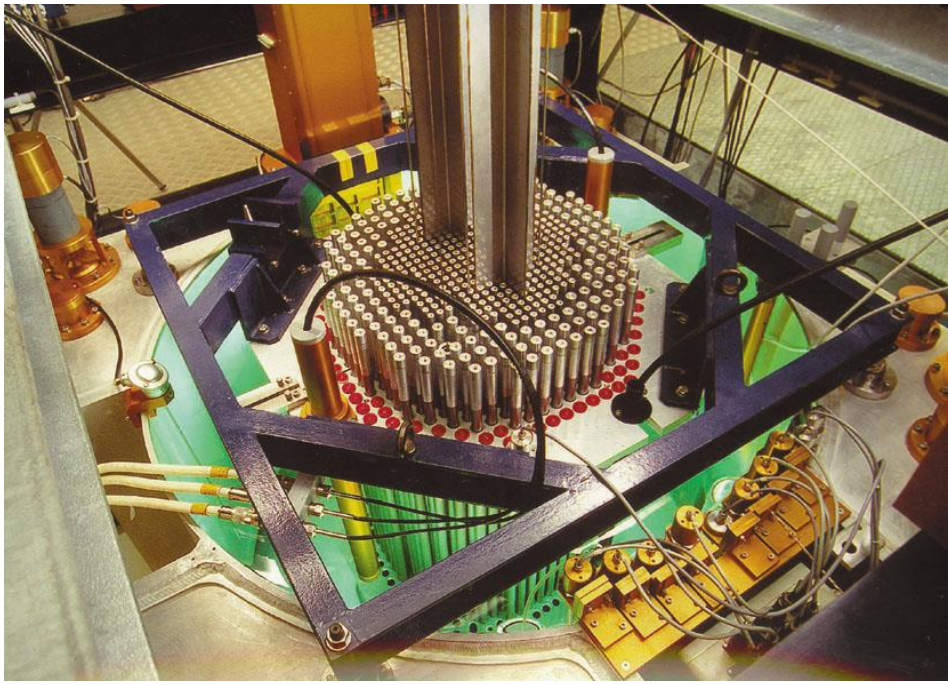
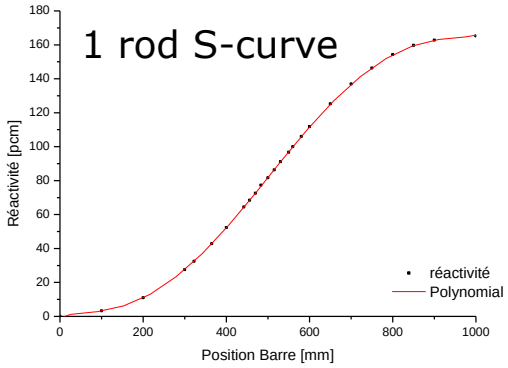
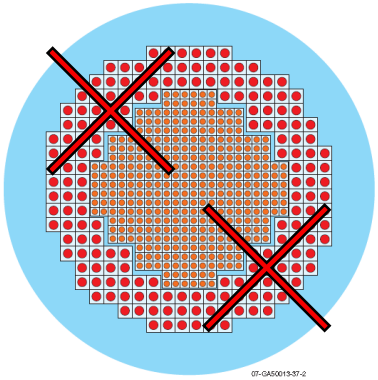
  - Atmospheric P and room T
  - Forced convection (160 $l.min^{-1}$)
- Power
  - 100 W (zero-power reactor)
  - i.e. maximum 2.5×10^9 $cm^{-2}.s^{-1}$
  - Controlled by water level or B_4C rods







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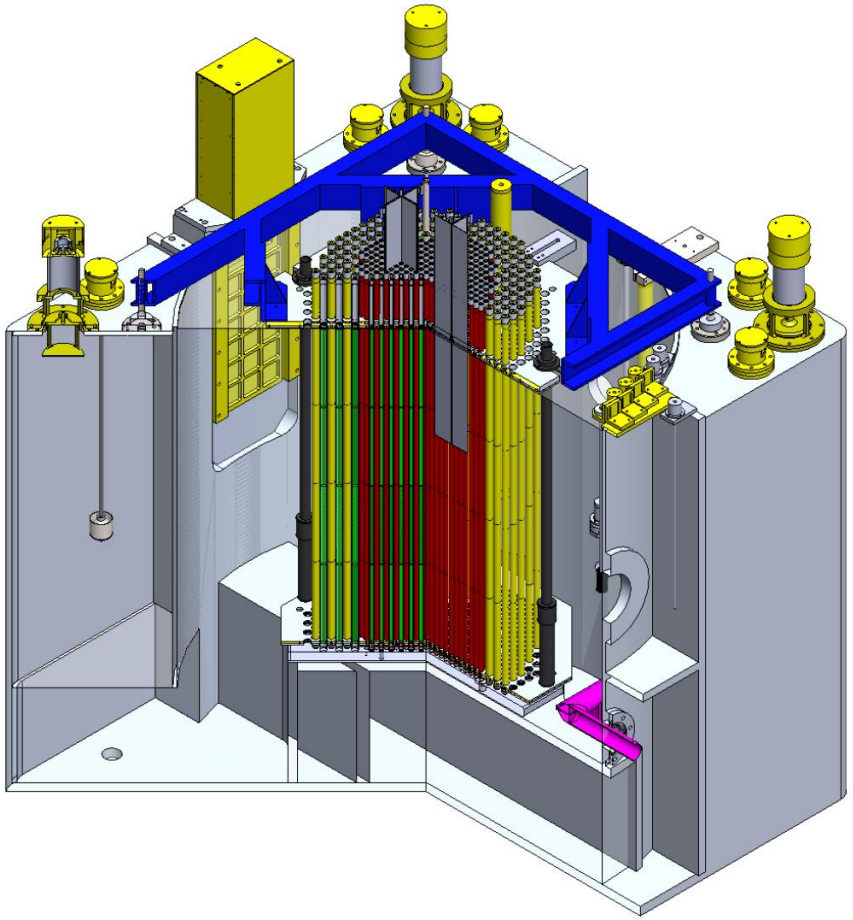
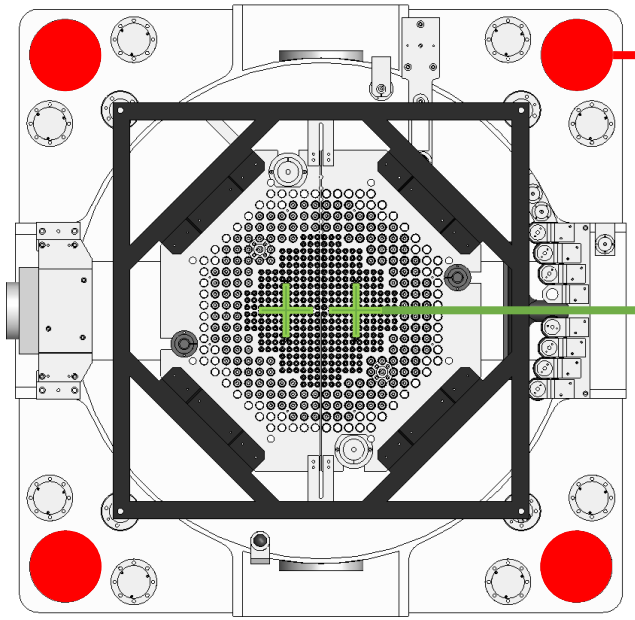
  - Controlled by water level or B_4C rods
- Core dimensions
  - ⌀60 cm/100 cm
- Fuel lattices
  - 2-zone: 336/176 rods actually
  - Inner: UO_2 1.806 wt% 1.837 cm
  - Outer: U_{met} 0.947 wt% 2.917 cm

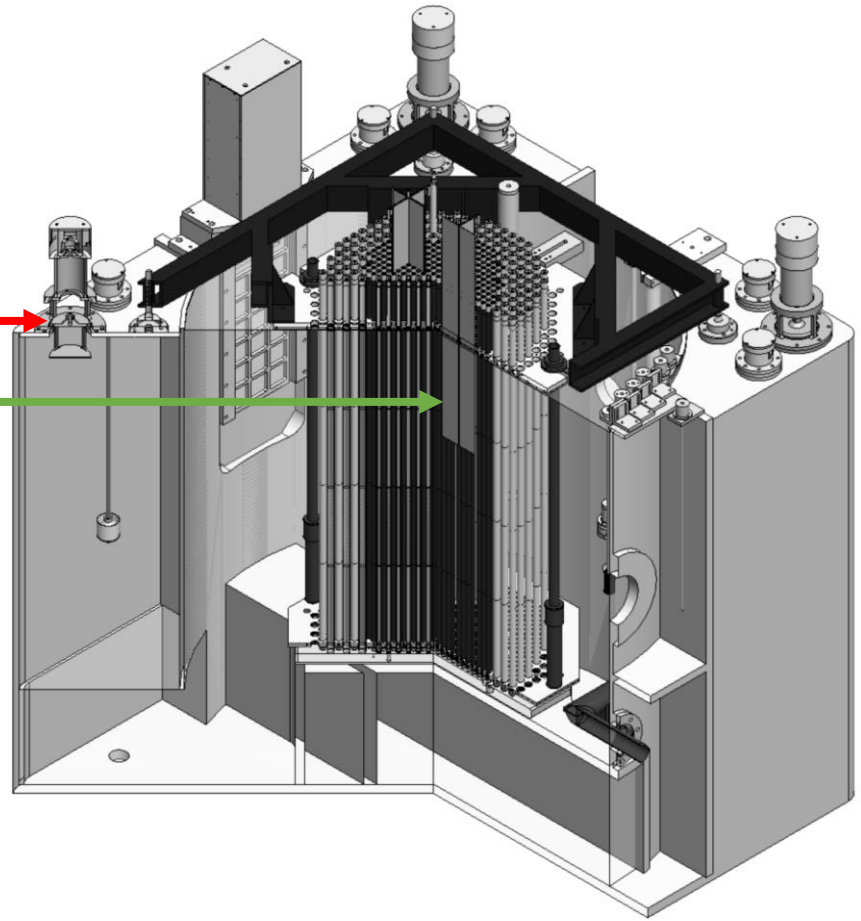


The CROCUS teaching and research reactor

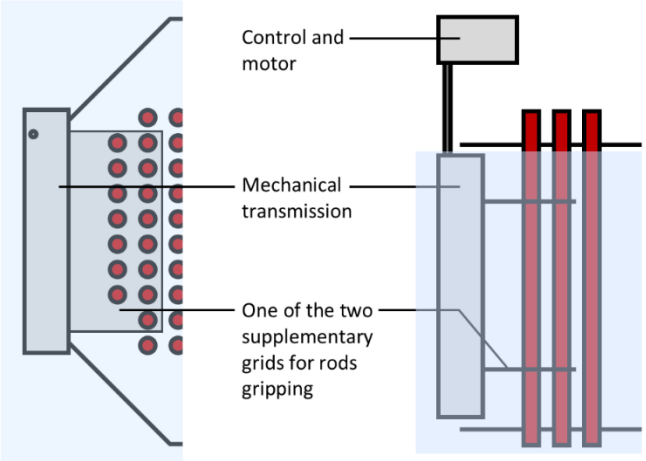
- 1.5 m-thick concrete shielding cavity

- Safety systems
  - 4 valves & expansion tanks (water dumping)
  - 2 cruciform Cd blades (inner zone)

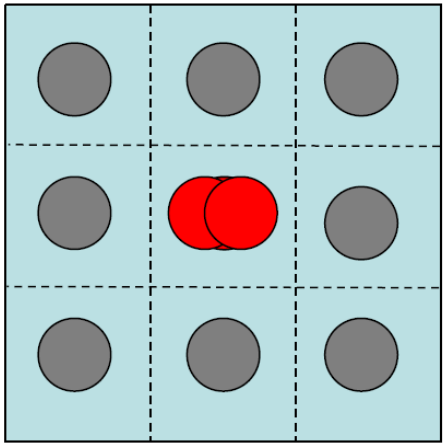




COLIBRI: Fuel rods oscillation experiments



Oscillating fuel rods in CROCUS



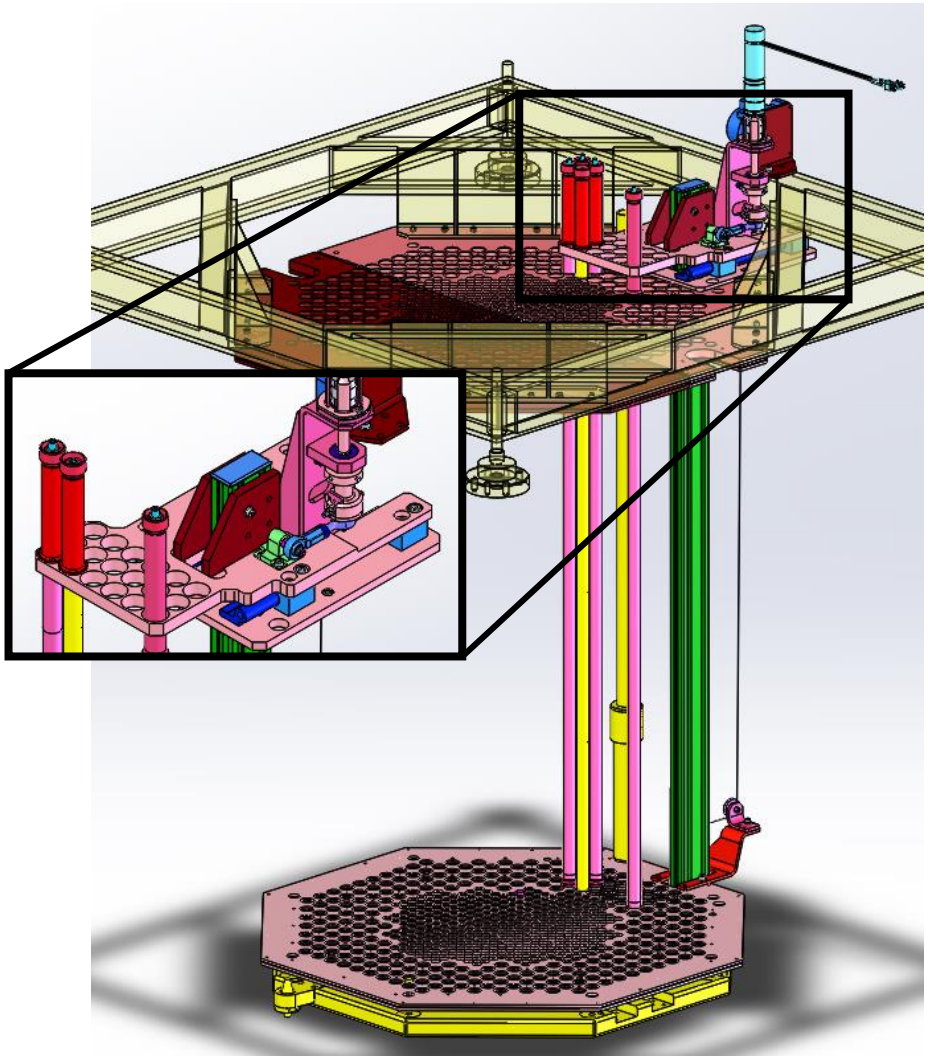
Modelling of fuel rods oscillation in a pin-by-pin simulator (i.e. DORT-TD)

Goals

Investigation of power fluctuations induced by fuel oscillations

- Motivation
  - Parallel code development and experimental prospects of coupling between mechanical noise and neutronics effect
- New experimental program in CROCUS for measuring noise induced by fuel vibration
  - Design of a device for oscillating fuel rods group at various representative amplitudes and frequencies
  - Measurement of the induced perturbation using neutron noise techniques
  - Experiments will serve to validate the simulation tool developed in parallel

COLIBRI: Fuel rods oscillation experiments



View of the oscillation device in-core

Setup and status

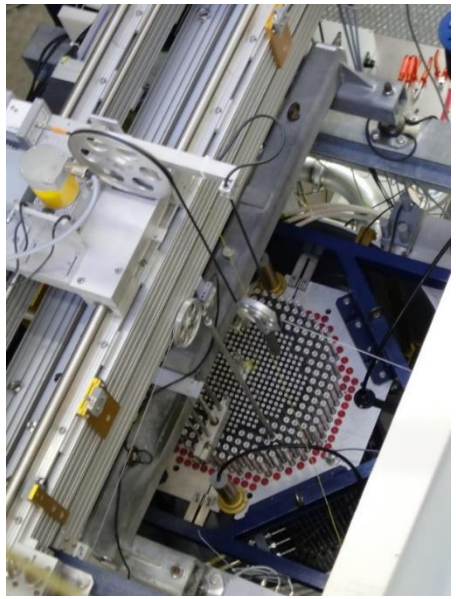
- Specifications of COLIBRI
  - Number of rods selected: up to 18
  - Frequency: from 0.1 to 5 Hz
  - Amplitude: up to ±3 mm radial
- Measurements
  - Induced perturbation (MCNP) for 18 U_{met} rods ±3 mm radial: ±8 pcm
  - Neutron noise measurement station in pulse mode already developed
- Schedule
  - Device tested out of core on reactor interfaces and with dummy fuel rods in January 2016
  - Licensing in progress
  - Start of the experiments in 2016

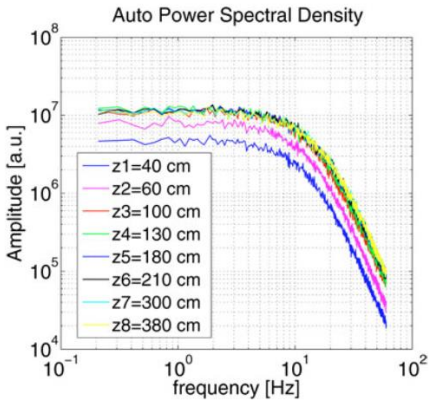
VOID: Void profile through neutron noise

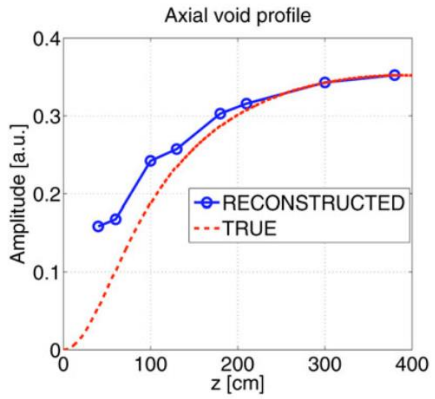
Development of an experimental setup to reconstruct axial void profile in BWR through neutron noise measurements of in-core detectors

Goals

- A theoretical method[1] to reconstruct the void profile within a BWR channel using in-core neutron noise has been developed at Chalmers University
  - Transit time of the bubbles is measured by correlations in detector signals at discrete locations
  - Relationship between void and transit time is known
  - Third order polynomial fit of void profile
- The method will be tested in clean conditions in CROCUS with a channel containing a two-phase flow with known void distribution
- Separate characterisation of the bubble distribution using existing visualization techniques.







[1] V. Dykin and I. Pazsit, "Simulation of in-core neutron noise measurements for axial void profile reconstruction in boiling water reactors," *Nucl. Technol.*, vol. 183, 2013.

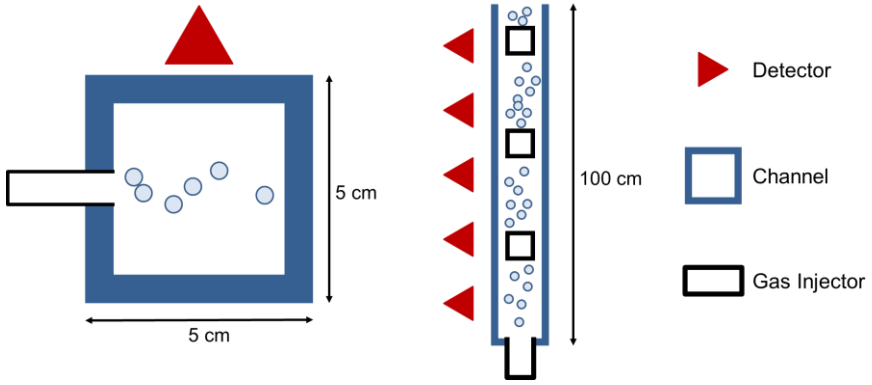
VOID: Void profile through neutron noise

Experimental setup

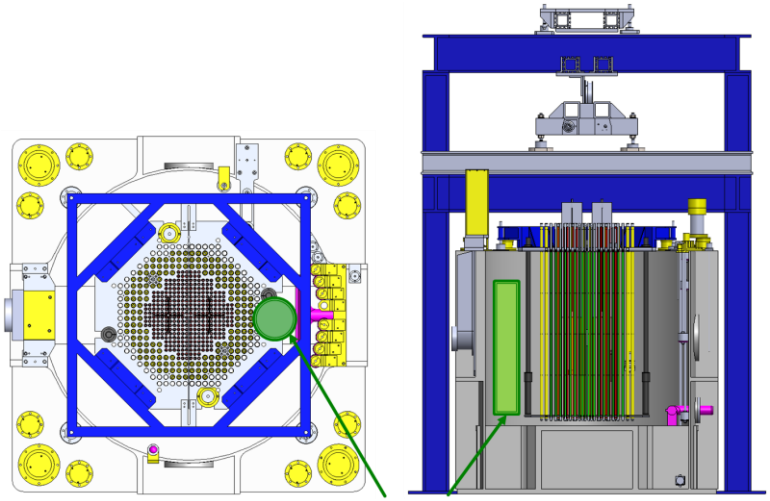
- Flow characterisation setup
  - Out of pile
  - Based on standard techniques for 2-phase flow visualization: attenuation measurements
  - γ-ray source + NaI detector

- Neutron noise analysis setup
  - In-core bubble channel: square Plexiglas tube (5 cm)
  - 5 neutron detectors axially spaced
  - To be set in the reflector
  - Target void: 80% at top to be representative of BWR profile

- Safety assessment
  - Positive reactivity insertion ~20 pcm (MCNP) in case of leakage

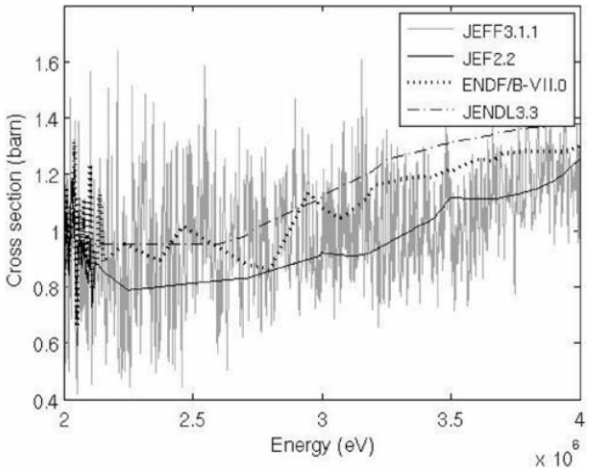


In-core neutron noise setup

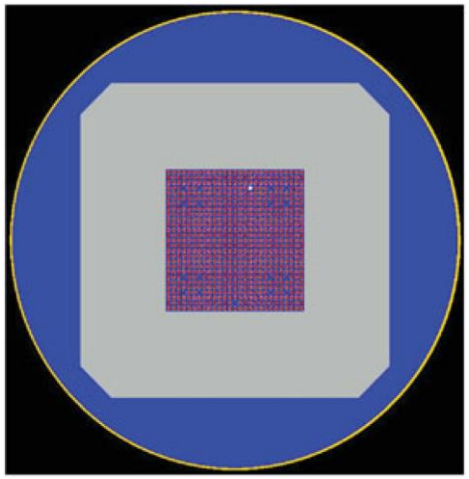


Experimental setup location

PETALE: Qualification of reflector materials



^{56}Fe inelastic scattering cross section



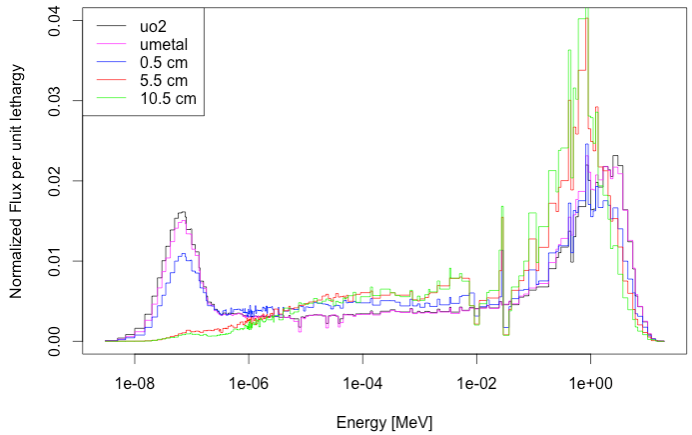
Cross section of the EOLE core for PERLE

Goals

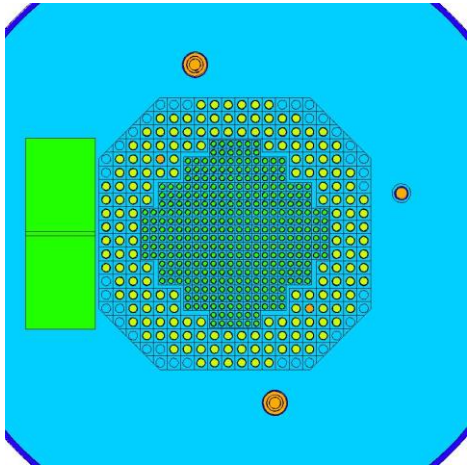
Contribute to the validation effort on the cross sections for materials of heavy steel reflector in GEN-III PWR

- PERLE programme in the French EOLE reactor for nuclear data validation
  - Reactivity effects
  - Reaction rates in pins at interface
  - Attenuation in the reflector: foils, FC

PETALE: Qualification of reflector materials



Flux in fuel pins and at different depths of the slabs



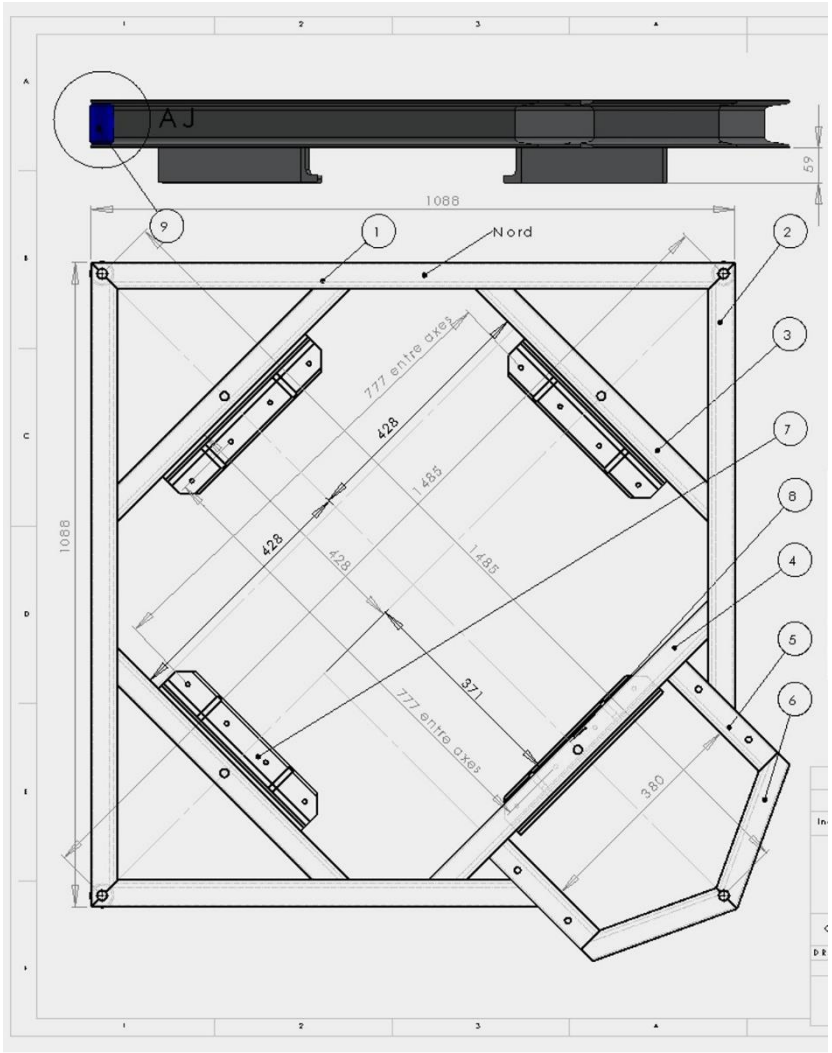
Cross section of the buffer core geometry in MCNPX

Goals

Contribute to the validation effort on the cross sections for materials of heavy steel reflector in GEN-III PWR

- PERLE programme in the French EOLE reactor for nuclear data validation
  - Reactivity effects
  - Reaction rates in pins at interface
  - Attenuation in the reflector: foils, FC
- Proposal for new experiments in CROCUS for separated elements
  - s.s., Fe, Cr and Ni separately
  - In-core experiment for extracting nuclear data in the MeV range from criticality effects and attenuation measurements
  - Analysis using data assimilation

PETALE: Qualification of reflector materials



First design of the modified CROCUS grid frame

Setup and status

Instrumented reflector of material of interest set close to the reactor core

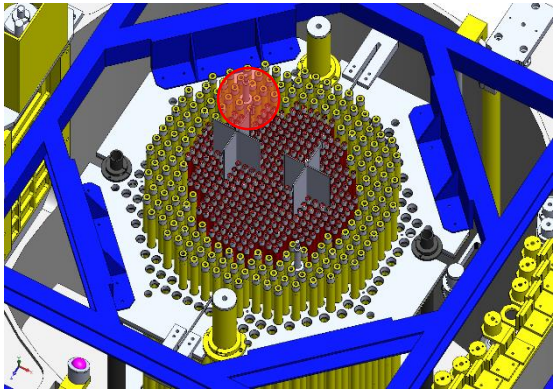
- Instrumented reflector
  - Sheets of s.s., pure Fe, Ni and Cr
  - 30 x 30 cm^2 for reducing impact of scattered thermal neutrons
  - 8 sheets 2 cm-thick (20 cm in NPPs)
  - Instrumentation within the sheets: dosimetry (foils, TLDs), FCs
  - Box-like & in-air positioning device
- Status
  - New Project within SCK-CEA-PSI VEP collaboration
  - Metal sheets purchased in 2015
  - Manufacture of the device and experiments starting in 2017

Diamond detector development

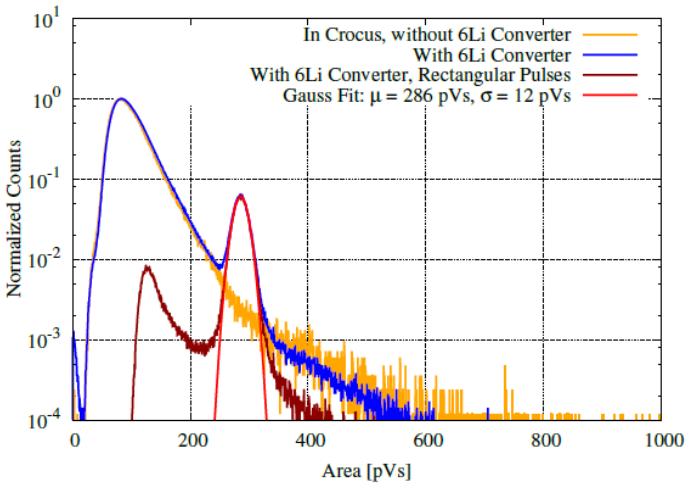
Co-development and testing of sCVD[1] diamond detectors for gammas and thermal/fast neutrons with CIVIDEC: from accelerator toward reactor physics

- Installation and testing campaign in CROCUS in November 2015
  - sCVD[1] detector was installed in the SW guide tube of the CROCUS control rod
  - E. Griesmayer (CIVIDEC) and C. Weiss (CERN) came to install/test the detector in CROCUS and teach how to use it
- Journal paper in preparation
  - Summarizing the installation and testing in CROCUS
  - To be submitted early 2016
  - In collaboration with CIVIDEC/CERN

CIVIDEC sCVD detector



Position of the detector in CROCUS

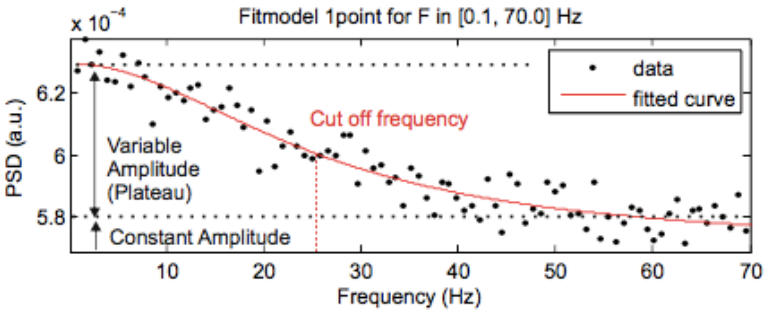


Pulse shape discrimination in CROCUS

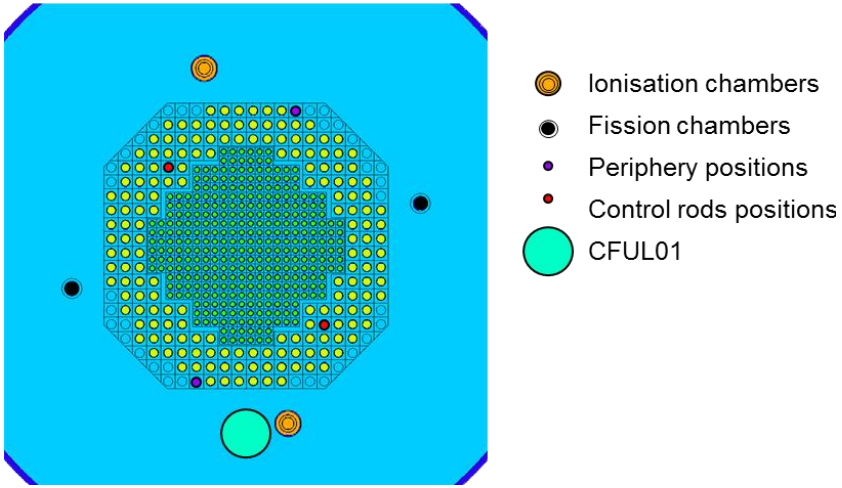
[1] single crystal Chemical Vapor Deposition

Neutron noise station in current mode

- Neutron noise experimental systems were recently developed in CROCUS to measure the reactor's delayed neutron fraction (β) and generation time (Λ)
- Initially based on pulse mode acquisition (individual events), development of a similar measurement station in current mode to discard detector dead-time and gain speed/accuracy
- Status
  - Current selection of hardware and assembling of the measurement station
  - Adaptation of acquisition & processing algorithms
  - Measurements in 2016 in CROCUS and comparison with calculations



PSD data from previous measurements in CROCUS



Considered detectors location

Conclusion and prospects

Research in several directions of nuclear field

- 3 new reactor physics experimental programmes related to:
  - Coupling of thermo-hydraulic and neutronics physics
  - Development of nuclear measurement method
  - Validation of nuclear data
- Development of cutting-edge instrumentation

The CROCUS reactor: a safe multipurpose reactor

- Teaching
- Research

Thanks for your attention