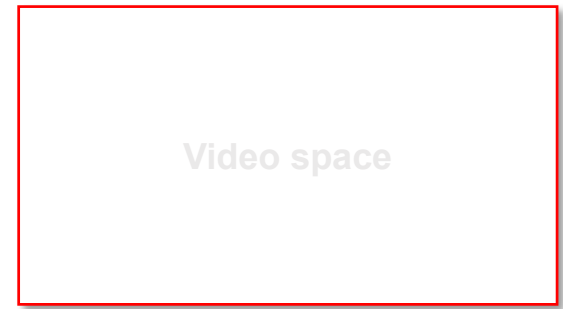


# A quick overview of LRS

Vincent Lamirand  
*On behalf of*  
Andreas Pautz  
Professor

Online – 30.03.2021

# Laboratory for Reactor physics & Systems behaviour



## ■ Mandate of LRS

- **Education** of the next generation of nuclear engineers and scientists
- Safe and efficient **operation of CROCUS**
- Cutting edge **research** and development in the nuclear engineering field.

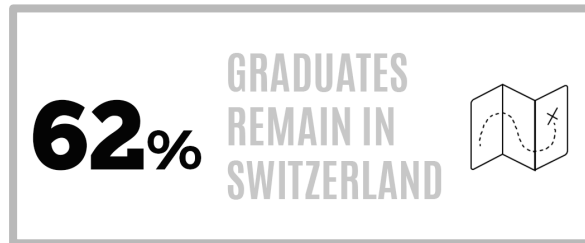
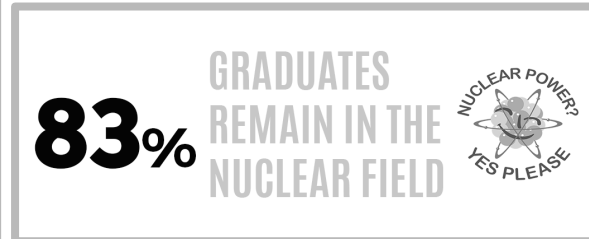
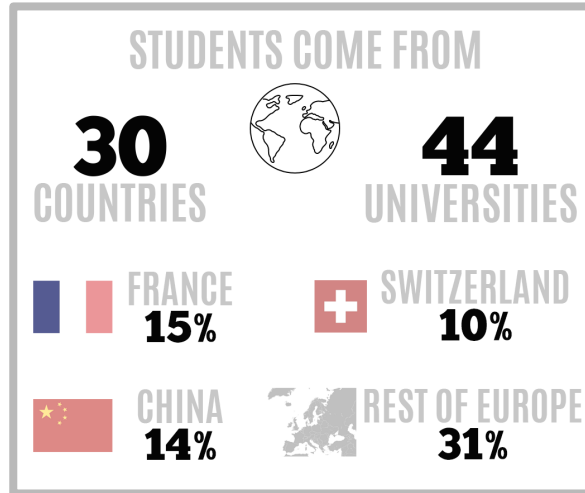
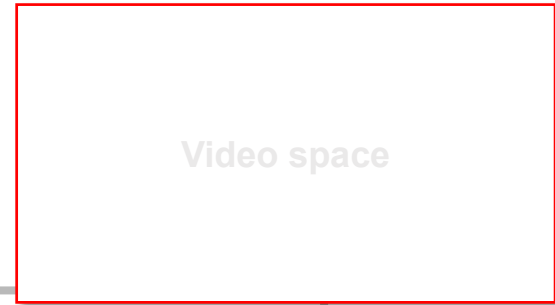
## ■ Team

- Under the supervision of Professor Andreas Pautz, a team of 4 scientists, 2 technicians, a secretary, 1 postdoc and 6 PhD students.



# Joint ETH-EPFL MSc program in Nuclear Engineering

- For more information visit [master-nuclear.ch](https://master-nuclear.ch)



# The CROCUS reactor

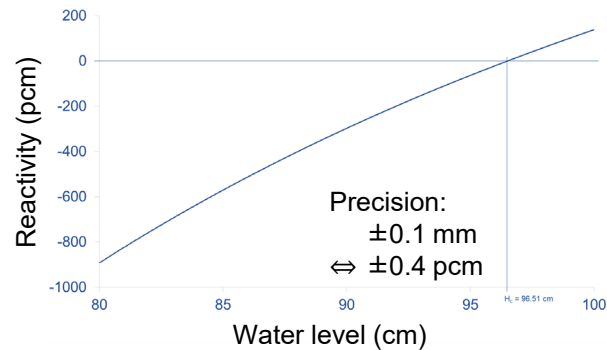
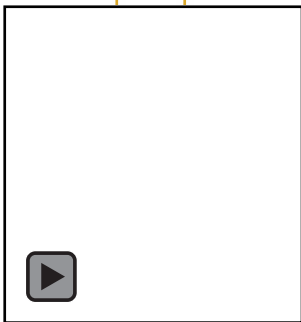
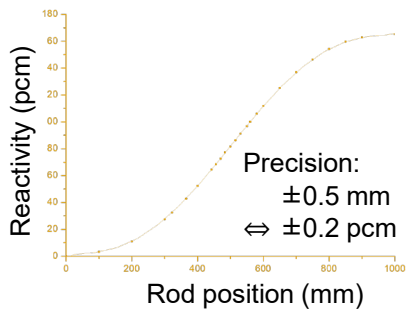
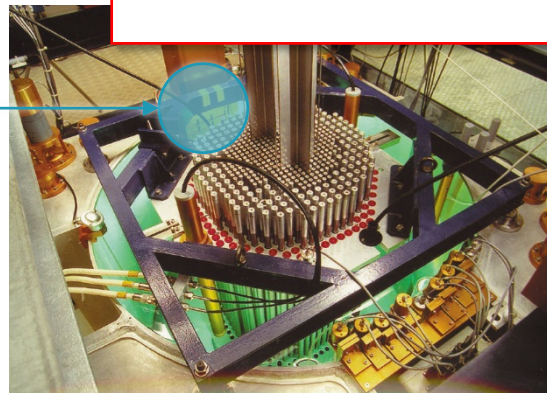
## Reactor type

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

## Operation

- 100 W (zero-power reactor)
- i.e. maximum  $2.5 \times 10^9 \text{ cm}^{-2}\cdot\text{s}^{-1}$
- Control:  $\text{B}_4\text{C}$  rods and spillway

Video space



# The CROCUS reactor

## Reactor type

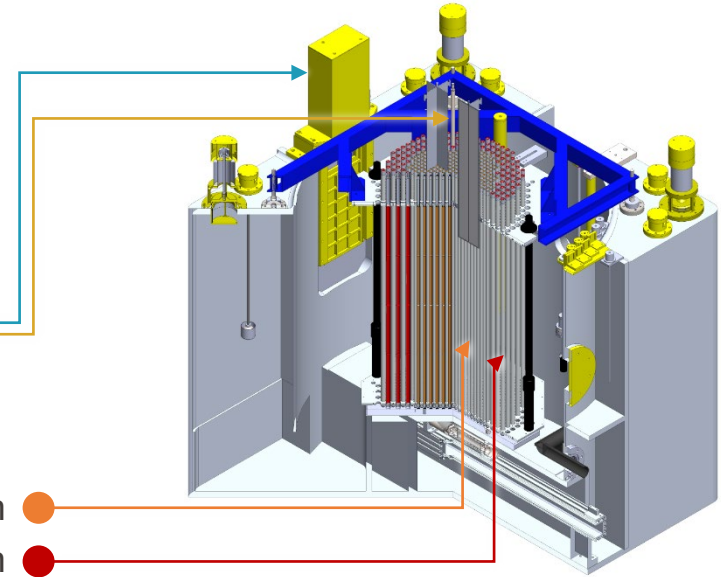
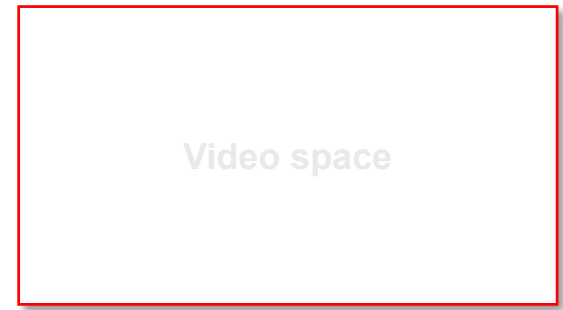
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## Core

- $\varnothing 60 \text{ cm}/100 \text{ cm}$ , 2-zone
- Inner:      336  $\text{UO}_2$       1.806 wt%      1.837 cm
- Outer:      176  $\text{U}_{\text{met}}$       0.947 wt%      2.917 cm



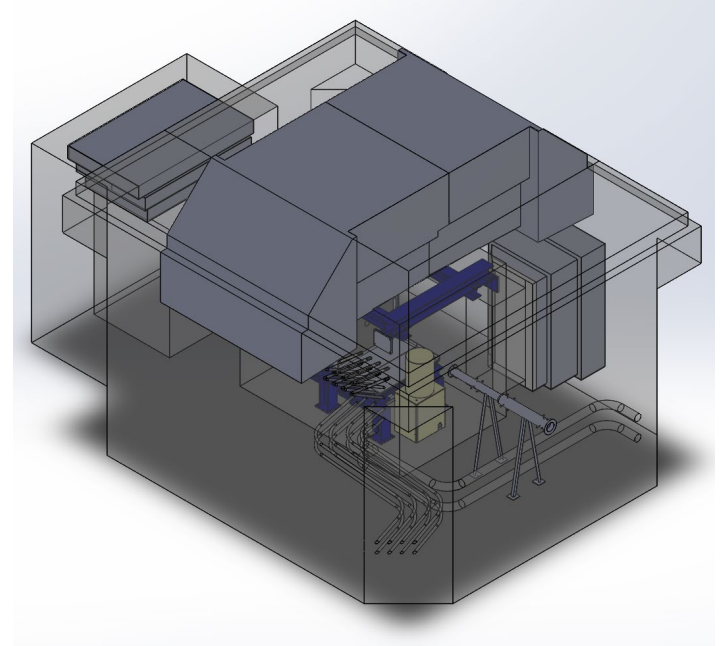
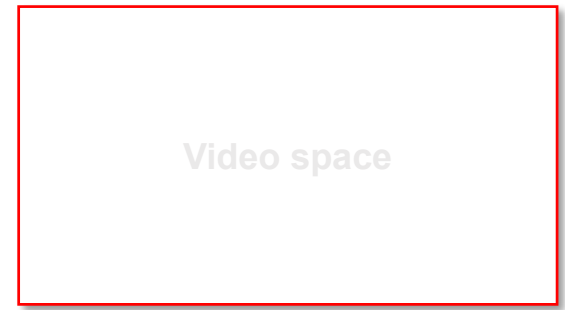
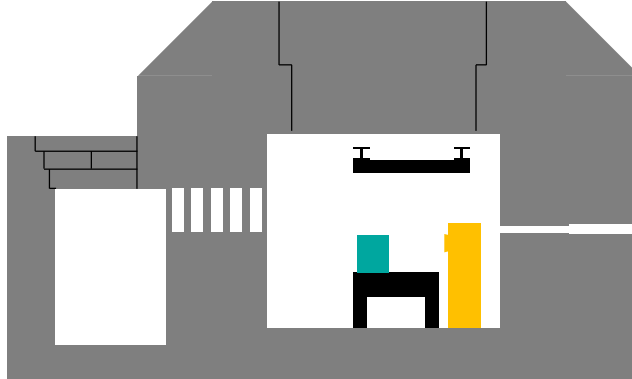
# The LOTUS irradiation platform

## Cavity

- $3.6 \times 2.4 \times 3$  (h) m<sup>3</sup>
- 2.2 m-thick concrete biological shield
- Lateral door and movable lid

## Radiation sources

- PuBe (TBq) neutron sources
- SILC <sup>60</sup>Co irradiator (370 GBq in 2016)





**IAEA**

International Atomic Energy  
Agency

École Polytechnique Fédérale de Lausanne (EPFL)

# IAEA Collaborating Centre

For

Advanced Reactor Experiments and High-Fidelity Multiphysics  
Nuclear Simulation Techniques for Open-Source Code  
Development and Validation

**2019 - 2023**

## Reactor experiments

VOID: void fraction

COLIBRI: fuel oscillation

PETALE: ss. nuclear data

Zero power reactor noise

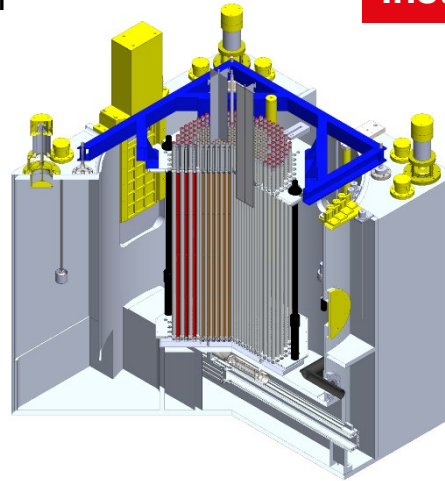
Hi-Res n. experiments

$\gamma$  characterisation

Novel detection materials

Neutron modulation

## Irradiation experiments



## Instrumentation

Neutron noise stations

Diamond detector

Activation and TL dosimetry

Miniature scintillators

Validation and data assimilation

GeN-Foam multiphysics solver

OFFBEAT: OpenFOAM for fuel beh.

## Modelling & code development

Video space



## Reactor experiments

VOID: void fraction

### COLIBRI: fuel oscillation

PETALE: ss. nuclear data

Zero power reactor noise

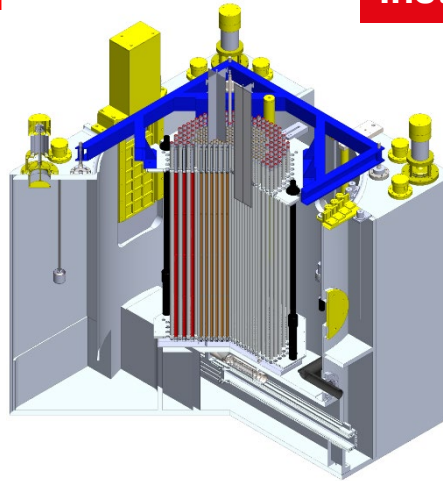
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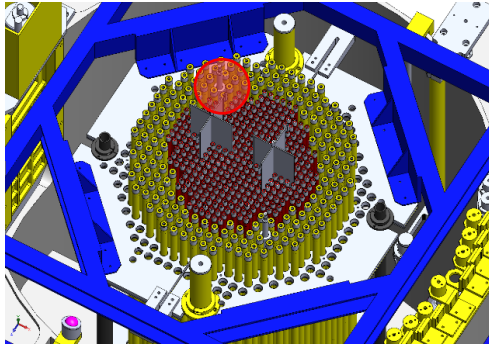
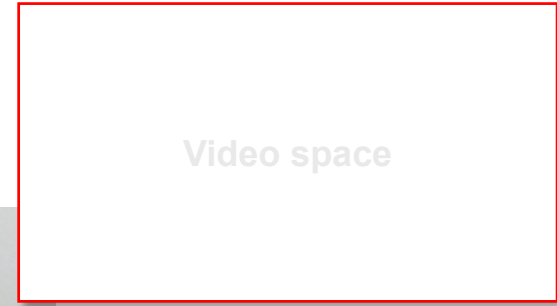
## Modelling & code development

Video space

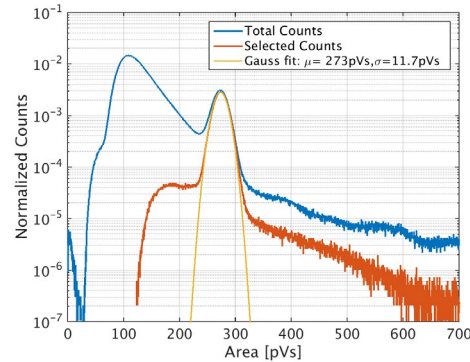
# Diamond detector

Development in collaboration with CIVIDEC/CERN\*

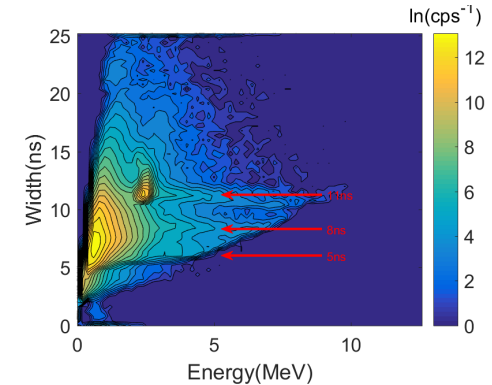
- Sensitivity  $\sim 3 \cdot 10^{-5}$  per thermal neutron
- Linearity of response with reactor power
  - Can accommodate for high count rate
- 6%/94% neutron/gamma detections
  - Detection of fast neutrons



Position of the detector  
in CROCUS



Pulse area discrimination



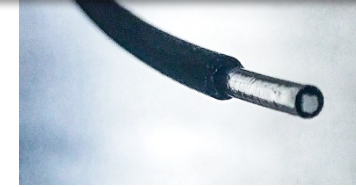
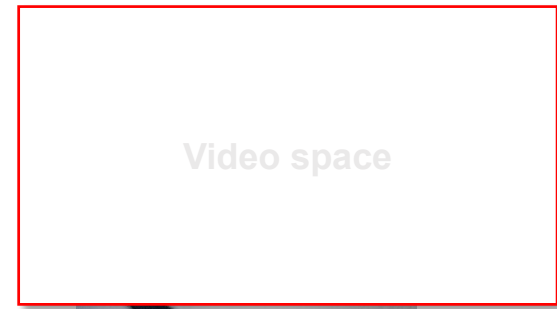
Fast neutrons signature  
( $> 300\text{pVs}$  &  $4\text{ns}$  FWHM)

\* Hursin et al. (2018). Testing of a sCVD diamond detection system in the CROCUS reactor. *European Physical Journal A*, 54(82), 179–184.

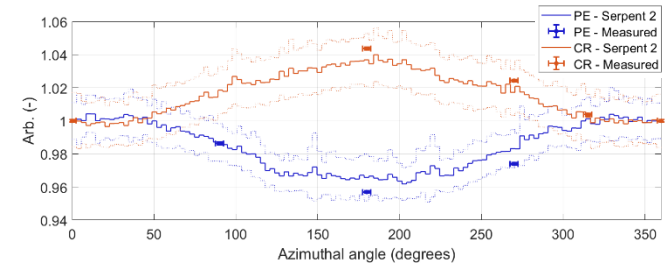
# Miniature neutron scintillators

Co-development with the Detectors Group of the Laboratory for Particle Physics at PSI for **high spatial resolution of thermal/fast neutrons**

- Development of an in-core mm<sup>2</sup> neutron scintillator coupled to fibers and SiPMs<sup>1</sup>
  - Fully characterized
  - Currently building a 150 detectors array!
  
- Application of the detectors to a range of reactor physics experiments **towards the validation of high-fidelity** calculations, e.g.:
  - in-core azimuthal<sup>2</sup> and angular distributions
  - fuel rod displacement: COLIBRI in static
  - full core mapping: COLIBRI in oscillation phase 2



First prototype of an in-core mm-scale neutron scintillator



Measured and computed azimuthal gradients in a control rod guide tube and a periphery channel

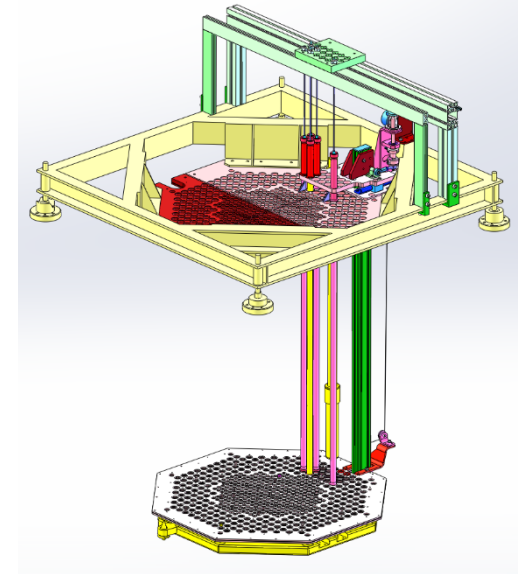
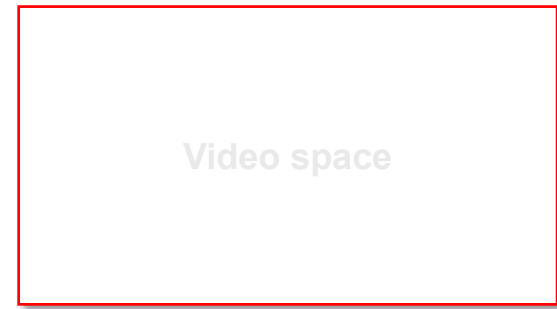
<sup>1</sup> F. Vitullo et al., "A mm<sup>3</sup> Fiber-Coupled Scintillator for In-Core Thermal Neutron Detection in CROCUS," IEEE Trans. Nucl. Sci., vol. 67, no. 4, pp. 625–635, 2020;

<sup>2</sup> F. Vitullo et al., "Highly localized azimuthal measurements in the CROCUS reactor towards the validation of ...," EPJ Web Conf., vol. 247, p. 08014, Feb. 2021.

# COLIBRI: fuel rods displacement

Investigation of **power fluctuations** induced by **fuel vibration**

- Experimental program for measuring noise induced by fuel oscillation
- Device designed for selection of up to 18  $U_{\text{met}}$  rods,  $\pm 2.5$  mm radial, 2 Hz



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

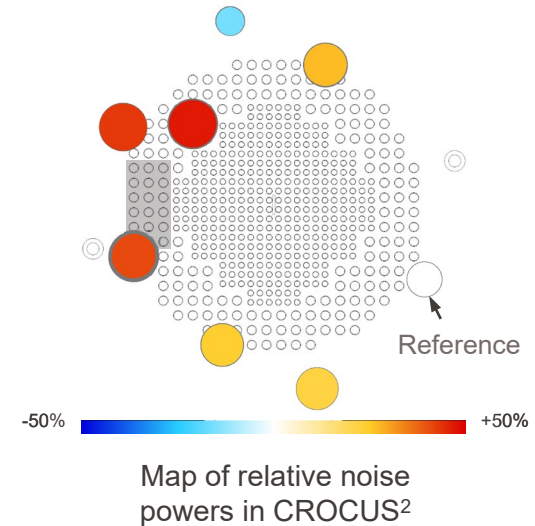
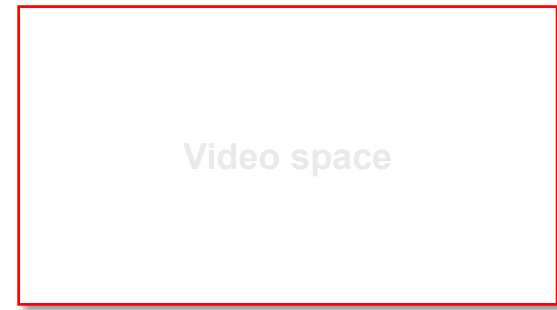
<sup>1</sup> V. Lamirand et al., "The COLIBRI experimental programme in the CROCUS reactor: development...", *RRFM/IGORR 2019*, Swemieh (Jordan), 24-28 March 2019;

<sup>2</sup> V. Lamirand et al., "The COLIBRI experimental program in the CROCUS reactor: characterization of the fuel rods oscillator," *EPJ Web Conf.*, vol. 225, p. 04020, Jan. 2020.

# COLIBRI: fuel rods displacement

Investigation of **power fluctuations** induced by **fuel vibration**

- Experimental program for measuring noise induced by fuel oscillation
- Device designed for selection of up to 18  $U_{\text{met}}$  rods,  $\pm 2.5$  mm radial, 2 Hz
- Oscillation campaigns in 2018<sup>1,2</sup>, 2019 and 2021
  - within the H2020 project CORTEX
  - Up to 18 rods,  $\pm 0.5$  to 2 mm, 0.1 to 2 Hz
  - 11, 15 and 18 detectors in pulse and current modes, and instrumentations from three partners (TUD, ISTec and EPFL)
- Static measurements campaign with miniature scintillators in 2019
- **Phase 2 currently on-going in CROCUS**

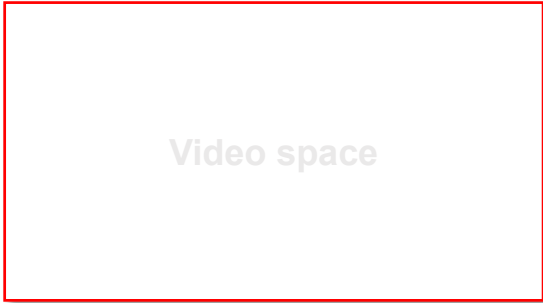


<sup>1</sup> V. Lamirand et al., "Neutron noise experiments in the AKR-2 and CROCUS reactors for the European project CORTEX," *EPJ Web Conf.*, vol. 225, p. 04023, Jan. 2020;

<sup>2</sup> V. Lamirand et al., "Analysis of the first COLIBRI fuel rods oscillation campaign in the CROCUS reactor for ...," *EPJ Web Conf.*, vol. 247, p. 21010, Feb. 2021.

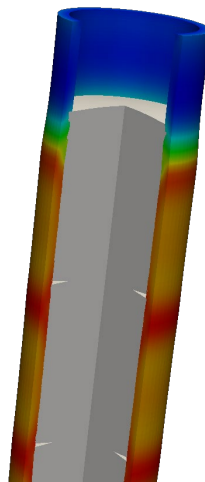
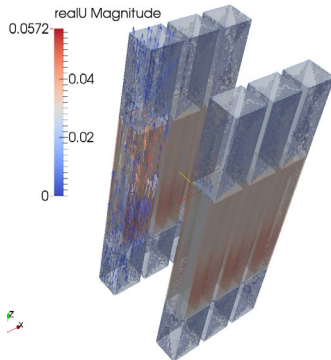
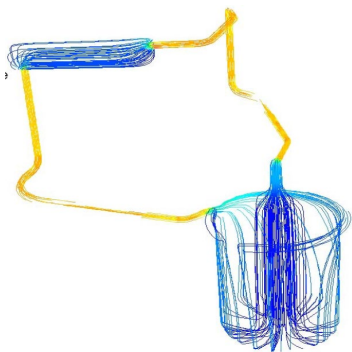


# The GeN-Foam multi-physics solver



EPFL selected as collaborating center of the IAEA for a multiphysics open-source platform for reactor analysis, based on OpenFOAM

- Solvers for neutron transport (diffusion, discrete ordinates, SP)
- Solvers for CFD and core thermal-hydraulics
- Solver for fuel behavior (OFFBEAT)
- Multi-physics solver (GeN-Foam)



Video space

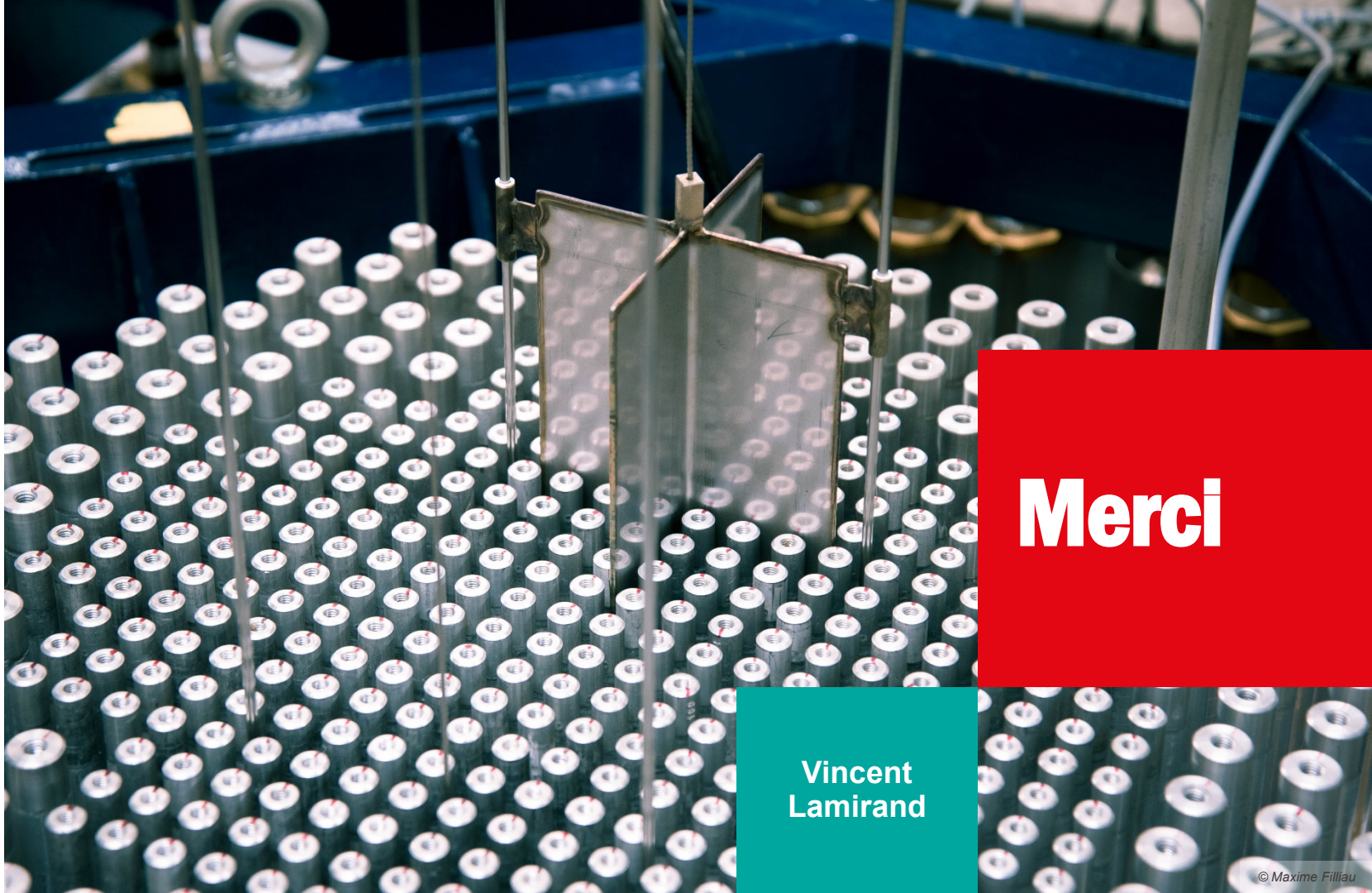
## Examples of past and current proposals

- Development and modelling of a conveyor device for mapping the activity of irradiated metal sheets for the study of heavy reflectors in nuclear power plants
- Characterization of a diamond detector with radioactive sources
- Application of the LRS multi-physics platform to the safety analysis of Generation IV reactors
- Monte-Carlo simulations of the criticality experiments of PETALE

## Contact us!

- |                    |  |                            |
|--------------------|--|----------------------------|
| ▪ Andreas Pautz    | <a href="mailto:andreas.pautz@epfl.ch">andreas.pautz@epfl.ch</a>       | Director of LRS            |
| • Pavel Frajtag    | <a href="mailto:pavel.frajtag@epfl.ch">pavel.frajtag@epfl.ch</a>       | Head of nuclear facilities |
| • Carlo Fiorina    | <a href="mailto:carlo.fiorina@epfl.ch">carlo.fiorina@epfl.ch</a>       | Code development           |
| • Mathieu Hursin   | <a href="mailto:mathieu.hursin@epfl.ch">mathieu.hursin@epfl.ch</a>     | Validation                 |
| • Vincent Lamirand | <a href="mailto:vincent.lamirand@epfl.ch">vincent.lamirand@epfl.ch</a> | Experiments                |



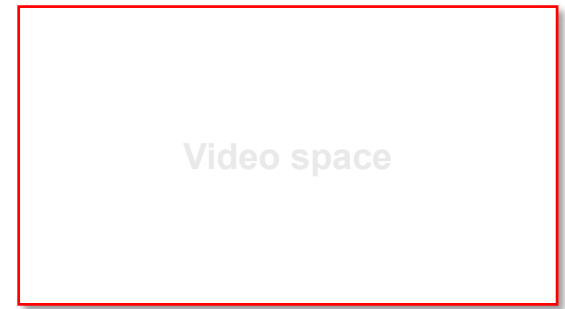


**Merci**

Vincent  
Lamirand

# Joint ETH-EPFL MSc program in Nuclear Engineering

- Swiss MSc between **ETHZ** and **EPFL**
  - Established in 2008, more than 110 graduates
  - Two-year program, 120 ECTS credits
  - In cooperation with the **Paul Scherrer Institute**
- 1<sup>st</sup> semester at EPFL, 2<sup>nd</sup> at ETH, 3<sup>rd</sup>-4<sup>th</sup> at PSI
  - Small program: ~10-15 students/y
  - Extensive use of the **CROCUS** reactor

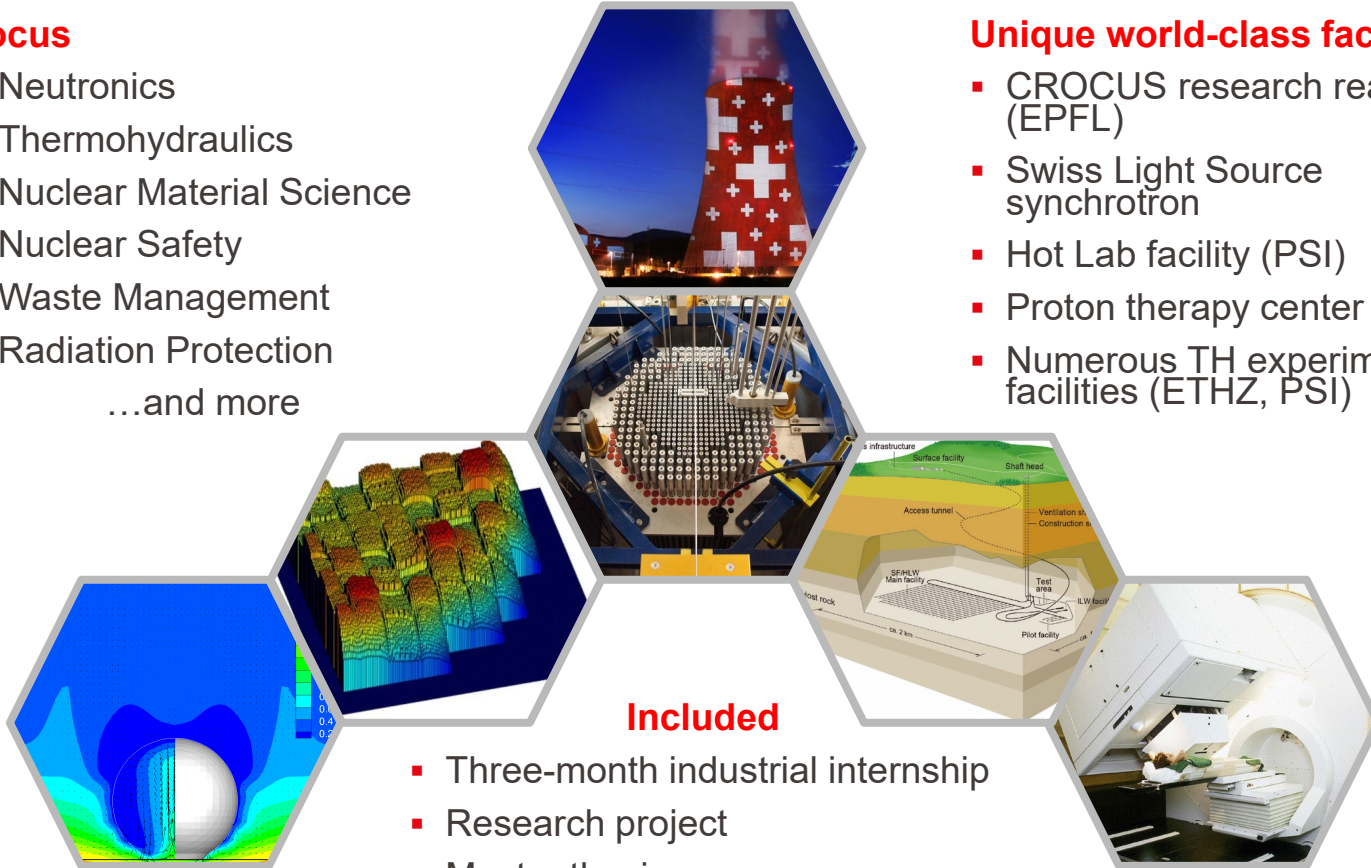


## Focus

- Neutronics
- Thermohydraulics
- Nuclear Material Science
- Nuclear Safety
- Waste Management
- Radiation Protection
- ...and more

## Unique world-class facilities

- CROCUS research reactor (EPFL)
- Swiss Light Source synchrotron
- Hot Lab facility (PSI)
- Proton therapy center (PSI)
- Numerous TH experimental facilities (ETHZ, PSI)



## Included

- Three-month industrial internship
- Research project
- Master thesis