

POLLEN: A Pile-Oscillator for the BLOOM Experimental Program

Thomas Ligonnet^{1,*}, Nicolas Weiss², Vincent Lamirand^{1,3}, Axel Laureau⁴, and Andreas Pautz^{1,3}

¹LRS, EPFL, CH-1015 Lausanne, Switzerland

²IPHYS, EPFL, CH-1015 Lausanne, Switzerland

³NES, PSI, CH-5232, Switzerland

⁴Univ. Grenoble Alpes, CNRS, Grenoble INP*, LPSC-IN2P3, 38000 Grenoble, France

(*) thomas.ligonnet@epfl.ch

Abstract—In the scope of its project on the assimilation and reproduction of experiments for the evaluation of stainless-steel nuclear data HARVEST-X, the LRS launches a pile-oscillation experimental program in the CROCUS reactor: BLOOM. For this program, an oscillator called POLLEN originally developed to be used as a vibrating absorber to compensate the fuel rods oscillator COLIBRI was reworked as a standalone pile-oscillator called. The oscillator operates with an arbitrary periodical shape, an amplitude of 1 m and a frequency ranging from the mHz to the Hz. An emphasis was put in the development of an interface for pseudo-square oscillations for BLOOM. This interface also allows independent adjustment of the ramping time and dwell time of the pseudo-square. The qualification of POLLEN was performed by video analysis of sinusoidal oscillations, using a 4K 30fps camera. With the current system, a precision of 0.2 mm was achieved during slow sinusoidal oscillation and a precision of 0.17 mm was obtained for pseudo square oscillations with a 500 g load. Whereas the results are satisfactory with respect to the current system and fulfill the requirement of the BLOOM program, it is planned to upgrade the system with the addition of a mechanical reference in the system. It is also in consideration to upgrade the acquisition card and controller to 16 bits systems to allow the use of POLLEN in setups where larger displacements are needed. The first in-core oscillation experiments are planned for early 2024.

Keywords —Pile-Oscillation, POLLEN, BLOOM, HARVEST-X, CROCUS, Nuclear data, Stainless-Steel.

I. INTRODUCTION

THE BLOOM (*Bayesian-aided Local Oscillation for Optimized Modulation*) program is an incoming experimental program in the CROCUS reactor at EPFL. BLOOM is part of the HARVEST-X project (*Heuristic Assimilation, Reproduction, and Validation of Experiments for stainless-Steel Cross-sections*), the EPFL follow-up to the EPFL-CEA PETALE (*Programme d'Etude en Transmission de l'Acier Lourd et Eléments*) experimental program [1–3]. The BLOOM program consists in performing pile-oscillations in the CROCUS reactor with an open-loop methodology, similarly to the experiments performed during the CEA MAESTRO-SL campaign [4–8]. Like PETALE, the program will primarily focus on the study of samples related to nuclear grade stainless-steel.

This paper focuses on the developments conducted on the

pile-oscillator POLLEN (*Pile-Oscillator for Localized and Low Effect Noise*). Originally developed to extract samples for the study of transients in CROCUS [9], and adapted for oscillations in the CORTEX project campaigns [10], POLLEN was especially used as a secondary oscillator in synchronization with the fuel rods oscillator COLIBRI [11], oscillating a cadmium sample in the reactor core center. In view of a standalone usage for the BLOOM program, the controls and commands were upgraded, and a system qualification was performed in-house by video analysis.

II. BLOOM IN THE CROCUS REACTOR

A. The CROCUS reactor

CROCUS is a zero-power light water research reactor. It operates at ambient pressure, at a temperature of 20 °C, and is licensed for a maximum thermal power of 100 W. The reactivity is primarily controlled by adjusting the vessel water level using a spillway. This adjustment affects fuel rods immersion, which in turn affects neutron thermalization. It can also be controlled by two optional B₄C control rods. The water level can be adjusted up to ±0.1 mm, equivalent to a reactivity worth of ±0.4 pcm around criticality, and the control rods up to ±0.5 mm, equivalent to a minimum reactivity worth of about ±0.2 pcm based on the rods S-curve [3, 12, 13].

The core consists of two types of fuel rods distributed in two interlocking zones: an inner zone and an outer zone separated by a water gap. The inner zone contains 336 uranium dioxide fuel rods enriched at 1.806 wt.%, while the outer zone has metallic uranium fuel rods enriched at 0.947 wt.%. The number of rods in the outer zone can be adjusted depending on the specific experimental configuration, with currently 180 metallic uranium rods for compensating the SAFFRON array [14]. CROCUS is equipped with four monitors: two boron coated compensated ionization chambers for safety monitoring (east and west) and two fission chambers (north and south) for monitoring and recording the reactor's power history. The fission chambers operate in pulse mode with an adjustable dwell time, typically of 1 second, enabling real-time monitoring of the reactor, and are typically used to reconstruct the reactor power history.

B. The BLOOM pile-oscillation program

The BLOOM program is a pile-oscillation program set to take place in the CROCUS reactor. As a follow-up to the EPFL-CEA PETALE program on stainless steel [1–3], BLOOM aims at producing experimental results usable for Bayesian Monte Carlo data assimilation [15], and comparable to PETALE. In this sense BLOOM is a reproduction of the criticality experiments of PETALE but with a different methodology, one of the objectives being to identify potential methodological biases. Indeed, whereas PETALE had criticality experiments (and transmission experiments), the BLOOM program is composed of a type of modulation experiments called pile-oscillations. In these experiments, the periodic perturbation of the local neutron flux, due to the insertion and extraction of a sample, is measured.

The chosen methodology for the BLOOM program is the open-loop pile-oscillations [4,5], in opposition to closed-loop ones. With this method the oscillations of macroscopic samples are performed in the reactor core without compensation for the periodic change in reactivity. Therefore, it is necessary to not only measure the local flux perturbation but also the general evolution of the neutron population to correct for the induced periodic power drift. This method was already successfully tested by CEA during the MAESTRO-SL campaign [7,8].

In the CROCUS reactor, it is planned to take advantage of LRS recent developments of novel miniature neutron detectors called MiMi detectors to measure the local flux perturbation [16], while the SAFFRON array of 160 detectors will be used to monitor the general and spatial behaviour of the reactor [14].

The primary focus of the BLOOM oscillation program is stainless steel and its components. As in the PETALE program, the reference stainless-steel will be 304L. Its main components iron, nickel, and chromium, will also be taken separately with elemental samples of high purity [1,2]. Especially, it is planned to recut samples from the spare materials of the PETALE program to limit the number of sources of uncertainty during future analysis and comparisons of the results. In addition, it is planned to oscillate other samples such as reference elements D₂O and gold, and possibly other alloys or elements of interest such as stainless-steel 316L, tungsten, and possibly EUROFER.

III. POLLEN DESCRIPTION AND CALIBRATION SETUP

A. Mechanics and Controls

The POLLEN oscillator mechanics is fairly direct. The vertical displacement of a sample is produced by the rotation of a wheel around which a thread, attached to the sample, is lapping, and the verticality of the displacement is assured by gravity. In CROCUS, the oscillation will be performed in an air-filled guide tube at atmospheric pressure. The friction in the guide being low, the maximum downward acceleration and speed are constrained by the gravity as the motor can only slowdown the displacement when going down. A picture of POLLEN with its main elements is displayed in Fig. 1.

The different elements of POLLEN are listed below:

- A wheel of 10 cm in diameter

- A Kevlar thread for sample support
- A Brushless DC motor with 3000 steps and a gear ratio to the wheel of 30
- A 12-bits controller
- A 14-bits data acquisition card (DAQ) with an absolute voltage precision of 26 mV and a voltage range of ± 10 V
- An interface convertor ethernet-RS232
- A Windows computer with LabVIEW-2021 and the motor drivers

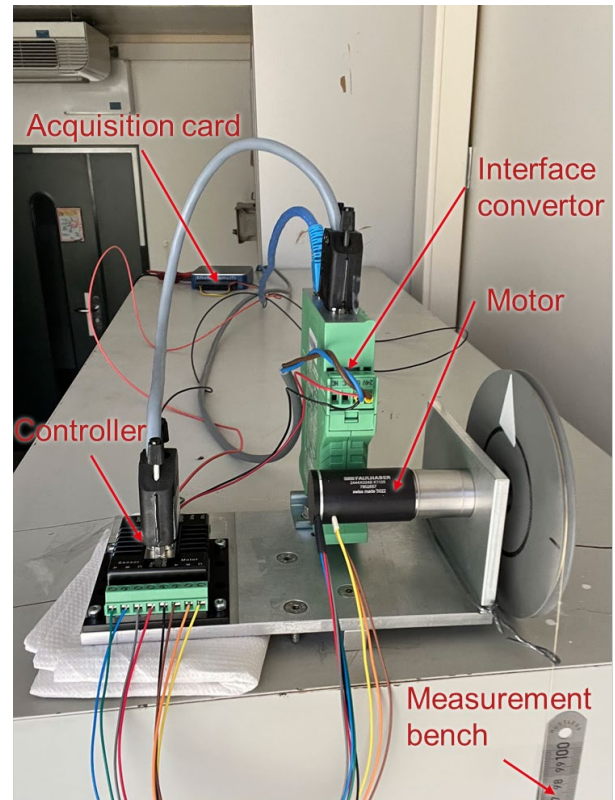


Fig. 1. Picture of the POLLEN pile-oscillator above the measurement bench used for calibration and testing.

The programming of a displacement is as follows:

First the limits in the motor angular speed and acceleration, and the motor PD settings are programmed into the controller using the motor driver and Ethernet-RS232 interface convertor, represented with dashed arrows in Fig. 2. These settings are programmed once with generic values, which avoid the thread jumping out of the wheel, and are independent of the oscillation shape and the LabVIEW interface.

Second, the diameter of the wheel, the maximum range of displacement, and the acquisition card voltage range are set in the LabVIEW interface. For the BLOOM program those values are set to 1 m for the maximum displacement, ± 10 V for the acquisition card voltage range, and 10 cm for the wheel diameter before calibration. At the start of the communication between the LabVIEW interface and the controller, the conversion factor between voltage and motor step is computed from the set parameters and calibration results, and then programmed into the controller.

Third, once an oscillation is defined, the LabVIEW interface converts it to a corresponding voltage table and programs it in the data acquisition card. Following it, the data acquisition card will loop on the table and send in real time the corresponding voltage to the controller. The controller will then rotate the motor to move the sample to the expected height, represented by plain blue arrows in Fig. 2. The rotation of the motor is then done based on the previously mentioned driver settings. The acquisition card will continue to loop on the table until a manual or programed trigger request it to stop at the end of the current period.

Lastly, the position of the motor according to its internal encoder and the voltage measured by data acquisition card internal voltmeter are sent back to the computer LabVIEW interface (orange checked arrows of Fig. 2).

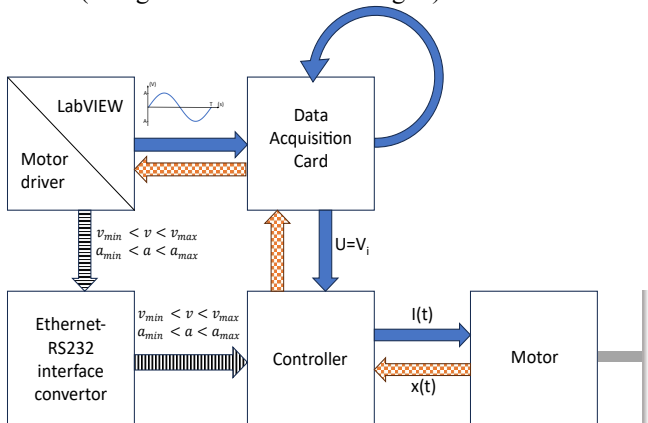


Fig. 2. Scheme of POLLEN control systems. The dashed arrows represent the motor and controller presettings. The blue full arrows are the path of the oscillation commands from the LabVIEW to the motor. The orange plaid arrows represent the feedbacks sent from the motor and data acquisition card to the LabVIEW.

B. POLLEN functionalities

At its inception with less advanced controls, POLLEN was limited to sample unique displacement and extraction. With its first *vibrating absorber* version for CORTEX, it oscillated in response to COLIBRI using an associated trigger signal: thus, without direct user control and at a frequency up to a few Hz. The latest developments aim at a standalone usage for pile-oscillation purposes.

Its first functionality is the possibility to perform single, non-periodic displacements. The firmware developments allowed correcting the loss of reference previously observed in going home. POLLEN can perform displacement to a targeted position, or of a given length relatively to its current position. The possibility to perform single and non-periodic displacement is necessary for the BLOOM program as it allows to obtain a first estimation of the sample reactivity worth in CROCUS.

The second functionality is the possibility to perform periodic displacement of arbitrary shape. The shapes are defined in ASCII files read by the LabVIEW interface. The user then defines the total amplitude of the oscillation as well as its period. This functionality was reworked from the version produced for CORTEX, the interface is created to ease the use and modification of the parameters of oscillation.

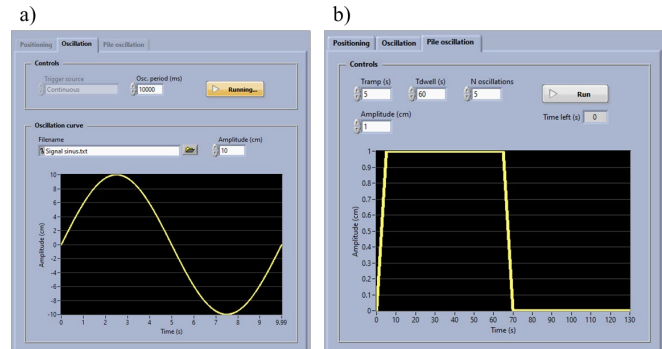


Fig. 3 a) LabVIEW interface for arbitrary oscillation shapes. b) Special interface for the pile-oscillation program.

The last functionality has been developed especially for the BLOOM program. It consists in a preconfigured interface for pseudo square oscillation such as the ones that will be performed during the pile-oscillation program. In this interface the user can define the amplitude of oscillation and, instead of the period, separately the ramping time between positions and dwell time at the positions. Screen shots of the two oscillation interfaces are displayed in Fig. 3.

C. Calibration setup and methodology

The displacements of POLLEN are slow, large, and one dimensional. Thus, the methodology chosen to calibrate and qualify the oscillator is based on video analysis of the displacement. The calibration setup consists of a 1 m long metallic ruler (class II), a 30 fps 4k camera, and an object of appropriate mass and size to displace (in fact, a second metallic ruler), see Fig. 4.

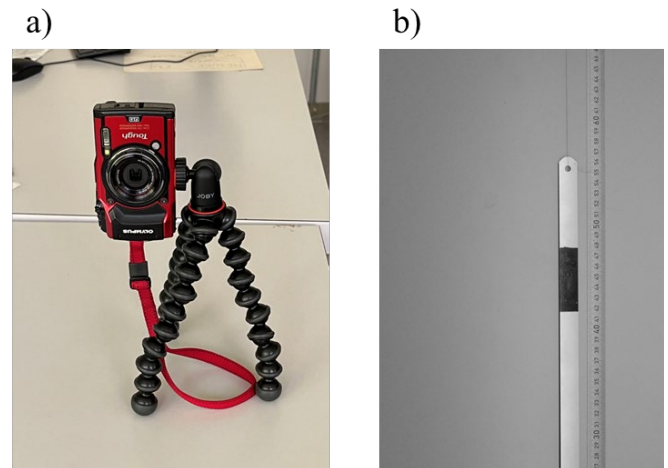


Fig. 4. Calibration and qualification setup. In a) is the 30 fps 4k camera and in b) the object and ruler used for the displacement measurements.

The prerequisites are an object darker than the video background and enough luminosity for the contrast of the ruler graduation. The methodology is the following. The video of the moving object is analyzed frame by frame. First, each frame is converted to a relative grey scale, then in the frames the columns of pixels are swept for an abrupt drop in the pixel brightness, example in Fig. 5.

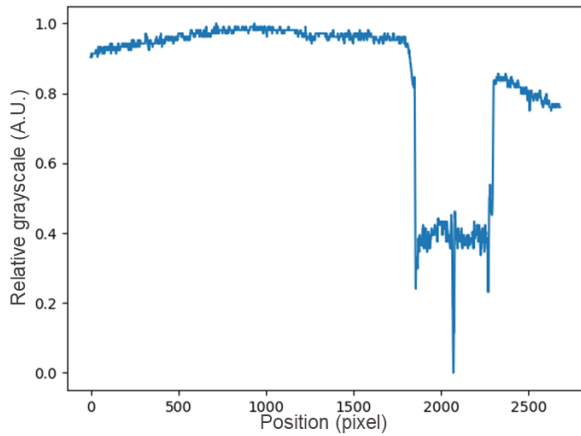


Fig. 5. Example of a swept column of pixel. The presence of the object is causing a sharp drop in the relative greyscale.

Once the position of the object is found, the image is cropped around it, and the column of pixel of the ruler is similarly swept to identify its graduation and determine locally the conversion factor between pixels and mm. Then, the number on the cropped frame are read using the Tesseract OCR [17], and the corresponding graduation and the related pixels are determined to be used as reference. The position in mm of the object is then computed as the reference position plus, the distance in pixel multiplied by the conversion factor between pixels and mm. The movement of the object is then reconstructed from all measured positions.

The theoretical precision of the oscillator is driven by the 12-bits of the controller. The amplitude of the displacement being 1 m the theoretical uncertainty on the displacement is 0.12 mm. In order for the characterization to be consistent with this value, the total amplitude of the displacement for the characterization is 40 cm and the field of view of the camera is fixed with a width of 50 cm allowing an average resolution of 0.125 mm/pixel. The period of the oscillation was fixed at 10 s to have velocities close to the ones planned for pile-oscillations.

IV. CALIBRATION RESULTS

The characterization of the oscillator displacement was done with a sinusoidal oscillation of 20 cm in amplitude and a period of 10 s. The measured signal obtained with the methodology described in Section III.C is displayed in Fig. 6.

The measured main frequency of the measured signal is 10.0 ± 0.2 s. From the oscillation signal amplitude, it is measured that the effective diameter of the wheel is 103.5 ± 0.1 mm. The observed uncertainties at top and bottom positions along the oscillation is 0.2 mm, thus on the same order of the pixel resolution and the controller precision. The highest measured standard deviation for the position in a time bin is 2.2 mm at time 7.43 ± 0.03 s. This value is consistent with the time resolution of the camera as the velocity per frame at this time is 4.3 mm/frame. Tests were also performed with pseudo-square oscillations with ramping times of 5 s, dwell times of 60 s, and

a load of 500 g. The measured standard deviation on the position during the dwell times at top and bottom positions is 0.17 mm.

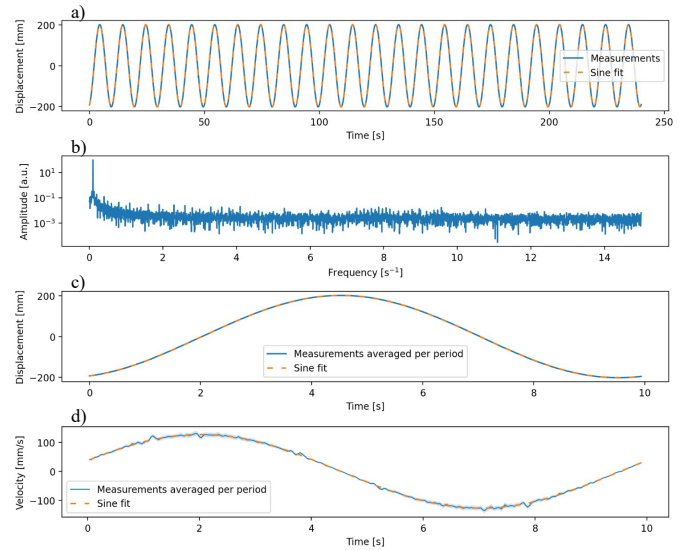


Fig. 6. Video analysis of a 20 cm amplitude sine oscillation with a 10 s period. Subplot a) shows the displacement of the object during the 4 min long video. Subplot b) shows the FFT of the signal. Subplot c) is the average on periods of the displacements. Subplot d) is the averaged measured velocity of the oscillator.

V. FUTURE DEVELOPMENTS OF POLLEN

Although the tests have proven conclusive, additional developments are planned. The first one will be the addition of an absolute reference of the position of the system. Indeed, the current version of POLLEN relies solely on the motor internal encoder to position itself and perform displacements. Thus, an unknown offset may be present at each power up of the system and currently it is required to manually verify the state of POLLEN before each experiment, which is impractical for a reactor use. In addition, an external encoder would be added to the motor to ensure that no drift is happening during and between oscillations.

A second upgrade consists in the replacement of the acquisition card for a model with a better precision on the output voltage. This precision directly affects the sample displacement precision, and may therefore be necessary as mechanical uncertainties are driving the total uncertainty of such experiments. Similarly, it is envisaged to upgrade the controller and motor to 16-bits systems, for greater precision, especially in case POLLEN is used for larger displacements.

VI. CONCLUSION

The POLLEN oscillator has been updated to work as a standalone pile-oscillator for the CROCUS reactor. Unlike its original version, which operated in response to another device, COLIBRI, the new version has been qualified for performing accurate single displacements, enabling sample reactivity worth to be estimated prior to the oscillations. The new interface still allows to choose arbitrary oscillation shapes from ASCII files, to adjust its period, and oscillation amplitude up to a maximum

of 1m. In addition, a dedicated interface was developed for the BLOOM pile-oscillation program. It allows to perform pseudo-square oscillations with adjustable ramping time and dwell time.

Tests and calibrations of the oscillator were performed using video analysis with a 4K 30 fps camera. The results of the tests show an uncertainty on the top and bottom position of the oscillation of the same order than the controller of the motor precision. Similarly, the motor was observed to be stable during pseudo-square oscillations with a 500 g load.

Updates of POLLEN are planned for the near future with the addition of an absolute reference for the position and later on with upgrades to 16 bits systems. The current version is ready for in-core testing with the first oscillation of the BLOOM program planned for early 2024.

16. F. VITULLO et al., "A mm³ Fiber-Coupled Scintillator for In-Core Thermal Neutron Detection in CROCUS," *IEEE Trans. Nucl. Sci.* **67** 4, 625 (2020); <https://doi.org/10.1109/TNS.2020.2977530>.
17. J. OOMS, *tesseract: Open Source OCR Engine* (2023).

REFERENCES

1. V. LAMIRAND et al., "An Experimental Programme optimized with Uncertainty Propagation: PETALE in the CROCUS Reactor," EPJ Web Conf. **211**, O. Serot and A. Chebboubi, Eds., 03003 (2019); <https://doi.org/10.1051/epjconf/201921103003>.
2. T. LIGONNET, Ed., *Preliminary analysis of the PETALE program and comparison to simulations* (2021).
3. V. LAMIRAND et al., *Future experimental programmes in the CROCUS reactor* (2016); <https://doi.org/10.13140/RG.2.1.2309.6728>.
4. W. K. FOELL, "Small-sample reactivity measurements in nuclear reactors," TID-26511, American Nuclear Society, Hinsdale, IL (1972).
5. B. A. BAKER, "Comparison of open loop and closed loop reactivity measurement techniques on the ISU-AGN-201 reactor," Ph.D., Idaho State University (2013).
6. P. LECONTE et al., "MAESTRO: An ambitious experimental programme for the improvement of nuclear data of structural, detection, moderating and absorbing materials - First results for natV, ⁵⁵Mn, ⁵⁹Co and ¹⁰³Rh," in 2013 3rd International Conference on Advancements in Nuclear Instrumentation, Measurement Methods and their Applications (ANIMMA), pp. 1–9 (2013); <https://doi.org/10.1109/ANIMMA.2013.6728101>.
7. B. GESLOT et al., "Innovative Hybrid Pile Oscillator Technique in the Minerve Reactor: Open Loop Versus Closed Loop," *IEEE Trans. Nucl. Sci.* **65** 11, 2767 (2018); <https://doi.org/10.1109/TNS.2018.2874690>.
8. "A hybrid pile oscillator experiment in the Minerve reactor | Elsevier Enhanced Reader," ; <https://doi.org/10.1016/j.anucene.2017.04.036>; (current as of Dec. 15, 2022).
9. A. RAIS, "Performance assessment of a 3-D steady-state and spatial kinetics model for the CROCUS reactor," EPFL (2018); <https://doi.org/10.5075/epfl-thesis-8248>.
10. V. LAMIRAND et al., "Experimental report of the 3rd campaign at AKR-2 and CROCUS," Public Deliverables 2.4, CORTEX, p. 38 (2021).
11. V. LAMIRAND et al., "ANALYSIS OF THE FIRST COLIBRI FUEL RODS OSCILLATION CAMPAIGN IN THE CROCUS REACTOR FOR THE EUROPEAN PROJECT CORTEX," EPJ Web Conf. **247**, 21010, EDP Sciences (2021); <https://doi.org/10.1051/epjconf/202124721010>.
12. U. KASEMEYER et al., "Benchmark on Kinetic Parameters in the CROCUS Reactor," 978-92-64-99020-3, Nuclear Energy Agency of the OECD (NEA), p. 93 (2007).
13. V. LAMIRAND et al., Eds., "Power calibration methodology at the CROCUS reactor," *Adv. Nucl. Instrum. Meas. Methods Their Appl. Animma 2019*, E D P SCIENCES, Cedex A (2020); <https://doi.org/10.1051/epjconf/202022504022>.
14. F. VITULLO, "Miniature and Minimalistic Neutron Detectors for Online High-Resolution Experiments in the Zero-Power Reactor CROCUS," EPFL (2022); <https://doi.org/10.5075/epfl-thesis-9492>.
15. A. LAUREAU et al., "Bayesian Monte Carlo assimilation for the PETALE experimental programme using inter-dosimeter correlation," EPJ Web Conf. **239**, 18004, EDP Sciences (2020); <https://doi.org/10.1051/epjconf/202023918004>.