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#04-176 Design of a 150-miniature detectors 3D core-mapping system for the CROCUS reactor

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The interest of the scientific community in studying the three-dimensional propagation of induced perturbations inside nuclear reactor cores and their prediction with deterministic codes triggered the need for experimental full-core mapping systems. In this optic, the Laboratory for Reactor Physics and Systems Behaviour (LRS) at the École polytechnique fédérale de Lausanne (EPFL), Switzerland, has been designing a 3D core-mapping system for its zero-power research reactor CROCUS. The system is composed of 150 miniature neutron detectors distributed within the core double lattice at three different axial levels. The detector technology is based on the well-proven coupling of a miniature $ZnS{:}Li^6(Ag)$ scintillator to a state-of-the-art silicon photomultiplier (SiPM) via jacketed optical fibers. The challenges in the design of such an extensive mapping system are numerous and the synergy between detector physics, core criticality, mechanical design and electronics acquisition is fundamental.

In CROCUS, the limited space between fuel rods and the need for positioning tools required a downsizing of the detector dimensions compared to the prototype version. The scintillator screen volume was reduced from 0.2 mm^3 to a volume <0.1 mm^3 and the fiber diameter was decreased from 3 mm to 1 mm. This detector arrangement was chosen as a cut-off between the need for size reduction and the preservation of the minimum level of neutron sensitivity required. In addition, smaller scintillator screens reduce the neutron absorption and consequently the reactivity impact on the core. Preliminary results showed that a single of these <0.1mm^3 detector positioned at the core periphery contributes to a reactivity reduction of around 0.7 ± 0.2 pcm. Based on this experimental result, a modelling of the full-system via the MCNP6.2 Monte Carlo code allows to assess the total reactivity impact given by the 150 detectors spread in the CROCUS core and the eventual need for reactivity compensations.

The 150 detectors, split among three identical axial layers, will be arranged to have the best mapping of the induced perturbations in the CROCUS core, e.g. fuel rod oscillations within the COLIBRI program, absorbers insertions or rotations, etc. The mechanical system to held in positions the 150 detectors was designed to be as practical as possible in the manipulation, of easy manufacturing and respectful of the safety standards for nuclear reactors. The detectors will be held in place through 3-mm thick plastic guides running between fuel rods and never entering in contact with the fuel cladding. The optical fibers will be glued to the plastics guides with epoxy and their front-end, consisting in the detector active zone, will be glued and embedded within the plastic itself in order to avoid any unwanted movement of the detectors or loss of neutron absorbers in the core.

An essential role is played by the acquisition system, which was considerably upgraded with respect to the analog read-out used in the prototype. The need for the processing and acquisition of data from 150 channels induced the development of in-house electronics tailored for the application to the 3D mapping system. Standalone electronics modules, each able to process the light signal coming from 32 detectors, were designed and built at LRS. The output signals of these 32-channels modules, consisting in the photon counting in every channel, is sent to an FPGA board equipped with a custom firmware that performs a software-based processing of the photon counting into neutron counting.

The installation of the full-core mapping system for the CROCUS reactor is planned for spring 2021 and it will mark a milestone in proving the feasibility of such first-of-a-kind system, and in providing valuable localized experimental data for the validation of high-fidelity neutronics codes.

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