Contribution of the definition of a new experimental program in the PULSTAR research reactor for the validation of novel high-fidelity multi-physics coupled tools

The PULSTAR experimental reactor [1] is located at North Carolina State University (NCSU) in USA. It is a 1 MW pool-type research reactor with 4% and 6% enriched pin-type fuel consisting of uranium dioxide pellets in zircaloy cladding. It presents unique features, among them a Light Water Reactor (LWR) representative pin lattice, and its capacity to realize reactivity and power ramps. Within a DoE/CEA scientific collaboration, PULSTAR has been identified as a key facility for defining and performing the first LWR highly representative analytical multi-physics benchmark.

Indeed, the current approach to validate multi-physics coupling at CEA is exclusively based on experimental data coming from the exploitation of the current reactor fleet. It allows a global experimental validation on macroscopic physical parameters of interest. This approach is now considered insufficient to perform the experimental validation of advanced high-fidelity coupled multi-physics models. Besides, the analysis of the state-of-the art shows no existing experimental benchmark available in the world for LWRs to validate advanced high-fidelity multi-physics coupling at the pin/sub-channel level/scale. No measurements were performed to meet this objective in the few legacy experimental programs dedicated to multi-physics studies (such as in the SPERT [2], LOFT [3] and CABRI [4] programs).

In this context, a post-doctoral position is proposed at CEA Cadarache. The objective is to contribute to the specifications of a new experimental program in the PULSTAR reactor for the validation of novel high-fidelity neutronics/thermal-hydraulics/fuel physics (multi-physics) coupled tools. This work will be done in the CEA-DoE collaboration framework; the postdoctoral fellow will be jointly supervised by CEA and NCSU. The experimental program will study the coupling between multi-physics parameters in steady state conditions, as well as the effects of neutronics/thermal-hydraulics/fuel physics feedback during transients, at the scale of the fuel pin and the water subchannel. Transients of variable dynamics induced by reactivity injection ramps will be considered, at appropriate reactor power levels. An adequate instrumentation to access the local temperatures of the pellet and the cladding should be proposed. The measurements thus collected, under perfectly controlled experimental conditions, will constitute benchmark data for the validation of multi-physics simulations.

The experimental program supporting the validation of multi-physics tools will be implemented in a two-phase approach:

1. **Multi-physics characterization of the core** – It implies PULSTAR full core neutron and gamma flux characterization. Temperature in water, neutron and photon reaction rate measurements are envisaged both in steady and transient states, with the experimental techniques, and associated instrumentation, currently available. Core kinetics parameters, as well as reactivity worth of transient rods, will be also measured;

2. **Development of a complete high-fidelity multi-physics benchmark including both steady and transient states** to analyze progressively the reactivity feedback effects: the proposed methodology to conduct this key-collaboration is incremental in the complexity of the problem. The realization of the experimental campaign will cover different types of transients, depending on the reactivity injection rate (from 100pcm/s or lower to 300pcm/s) and the total reactivity injection (> or < β). New experimental techniques will be implemented in this phase.

The post-doctoral work will consist in particular in:

- ✓ developing a digital twin of the experimental reactor core, based on a neutronics/thermal-hydraulics/fuel physics coupling with CEA simulation tools,
- ✓ proposing and studying configurations of interest by simulation, to contribute to the definition of the experiment for steady states and transients. A PIRT (Phenomena Identification Ranking Table) [5] will be built; it will lead to the classification of the configurations versus to the experiment parameters and the encountered physical phenomena (Doppler and moderator reactivity feedbacks);
- ✓ contributing to the definition of the target uncertainties to be associated with the measurements by performing sensitivity studies on the physical parameters of interest;
- ✓ contributing to the definition of the possible instrumentation for the experiment, according to the target uncertainties;
- ✓ carrying out sensitivity studies to contribute to the definition of the locations of the detectors in the core;
- ✓ assessing the impact of technological and modeling uncertainties on the studied physical parameters.

This post-doctoral work will be carried out in close interaction with:

- the modeling and instrumentation teams at CEA,
- the modeling and PULSTAR experimentalist teams at North Carolina State University.

References

[1] A. Hawari, "North Carolina State University PULSTAR Reactor," Encyclopedia of Nuclear Energy, 173-181, 2021.

[2] "Reactivity accident test results and analyses for the SPERT III E-Core – A small, oxide-fueled, pressurized-water reactor," Phillips Petroleum Company, Atomic Energy Division, rapport IDO-17281, 1969.

[3] https://www.oecd-nea.org/tiethysweb/facility/iet/19

[4] JM. Labit, N. Marie, JP. Hudelot, E. Merle, "An advanced experimental validation methodology of multiphysics calculation tools on CABRI transients," Proc. Int. Conf. M&C 2019, Portland, Oregon, 2019.

[5] G. Wilson, B. Boyack, « The role of the PIRT process in experiments, code development and code applications associated with reactor safety analysis », Nuclear Engineering and Design, 108, 1-2, 23-37, 1998.

Framework of the post-doctoral position

Employer: French Alternative Energies and Atomic Energy Commission (CEA)

Location: Cadarache, France

Required profile: PhD in applied physics in the nuclear field: reactor physics, thermalhydraulics or nuclear fuel performance

Timeframe: The initial duration of the post-doc is one year that can be extended by one more year

Desired start date of the post-doctoral contract: January 2023

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