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#04-123 Characterization of calorimeter responses under laboratory conditions thanks to an optimized transient thermal test bench

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The nuclear heating named also "absorbed dose rate"is a quantity that it is essential to predict numerically in order to optimize the design of different elements of a nuclear research reactor and of its experimental irradiation devices for instance for safety, thermal and mechanical aspects and then to measure it accurately in order to analyze results associated to in-pile experiments. Heat flow calorimeters are the sensors that permit real time measurement of this key parameter.

Since 2009, Aix-Marseille University and the CEA have been conducting research dedicated to improving such sensors in terms of their size, range, out-of-pile calibration and in-pile measurement methods. In 2015, a new differential calorimeter (called CALORRE) composed of two compact calorimetric cells with predominantly radial heat transfer was patented and tested successfully in the Polish MARIA reactor. At present, a new joint research project, which also involves the Nuclear Reactor Laboratory of the MIT, is in progress. This project, called CALOR-I, focuses on the characterization of a new reduced-height design of the CALORRE calorimeter and its use for the mapping of the nuclear heating rate inside the MITR water loop. The study will be from laboratory calibration conditions to real conditions inside this loop located in the reactor core (a cylindrical pressure vessel of 38 mm in diameter, forced or natural convection, a fluid flow temperature up to 300 °C and a nuclear heating rate up to 2 W/g (in stainless steel) at a thermal power of 6 MWth).

The method of calibration of a calorimeter varies according to the type of calorimeter used. For single-cell or differential calorimeters with an electrical heating system, a steady state thermal calibration is usually applied, whereas for calorimeters without an electrical heating system a transient thermal calibration is used.
Within the framework of the CALOR-I project, the aims of this paper are the optimization of a transient thermal calibration test bench, called BERTRAN, and the study of the response of different calorimeters by using this tool and a 1-D transient thermal model.

First of all, the test bench and its improvement will be detailed. The bench is composed of two temperature-controlled thermostatic baths filled with a heat-transfer fluid which can reach a temperature up to 250℃ without boiling (silicone oil). The hot bath hosts three heating cartridges and the cold bath integrates a heating cartridge and a cooling coil. In addition, inside each bath, there are a cylindrical tube with an internal diameter similar to that of experimental channels and a propeller located at the bottom of the tube in order to create an upward silicone oil flow (adjustable speed). This configuration allows the generation of thermo-hydraulic conditions close to those existing inside experimental channels of research reactors. Moreover, this bench has a mechanical system used to transfer the calorimeter automatically from the hot cavity (at a temperature from 100℃ to 250℃) to the cold cavity (at a temperature from 20℃ to 50℃) (or vice-versa). The bench improvements concern the implementation of two new K-type thermocouples to measure the temperature around the calorimeter and an infrared sensor to determine precisely the position of the calorimeter (the inlet or outlet time in each bath); and the change of the acquisition device to improve the sample time.
Next, the operating protocol allowing the determination of the transient response of the sensors will be described. In fact, after the thermal stabilization of the two baths previously tuned for two different temperature set-points, the calorimeter is inserted inside the cold cavity. When a first stationary state is reached inside the calorimeter, the data acquisition is started. After 10 minutes to ensure stabilization, the calorimeter is transferred automatically and quickly (1-2 seconds) from the cold cavity to the hot cavity (heating phase). After a 10 minutes immersion inside the hot cavity, a second stationary state inside the sensor is achieved, then the reverse transfer of the calorimeter is done (from the hot cavity to the cold cavity, cooling phase). Finally, the calorimeter remains for 10 minutes in the cold cavity in order to reach a final thermal equilibrium.

Then the experimental results obtained by applying this procedure for a parametrical campaign carried out

in July 2020 for a single-cell calorimeter (called KAROLINA) will be presented. The response curves of this calorimeter, for the heating phase and then the cooling phase, will be shown for various experimental conditions, with consideration of repeatability and reproducibility. The influence of the fluid flow conditions (temperature and velocity) and of the operating phase will be given on the response time, the thermal constant and the deduced sensitivity of the calorimeter.
In addition, a 1-D transient thermal model will be described and applied to predict the temperature inside the calorimeter versus time and to analyze the experimental results.

Finally, the results obtained with the KAROLINA calorimeter will be compared to forthcoming experimental results of other calorimeters (CALORRE calorimeter and a Gamma Thermometer). If the health situation causes difficulties in carrying out these experiments, the experimental results already obtained will be compared to 3D thermal simulation results obtained with COMSOL Multiphysics.

Primary author: REBAUD, Jérémy (Aix Marseille Univ, Université de Toulon, CNRS, IM2NP, Marseille, France)

Co-authors: VOLTE, Adrien; LYOUSSI, Abdallah (CEA); Dr KOHSE, Gordon (Massachusetts Institute of Technology, Nuclear Reactor Laboratory, Cambridge, Massachusetts, USA); Dr CARETTE, Michel (Aix Marseille Univ, Université de Toulon, CNRS, IM2NP, Marseille, France); REYNARD-CARETTE, Christelle (Aix-Marseille University)

Presenter: REBAUD, Jérémy (Aix Marseille Univ, Université de Toulon, CNRS, IM2NP, Marseille, France)

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