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#04-119 Study review of the CALORRE differential calorimeter: definition of designs for different nuclear environments

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The high neutron and gamma fluxes as well as strong displacements per atom characterize conditions of materials testing reactors (MTRs). These research reactors constitute major support research facilities and allow experimental and real-condition studies of the behavior of fuels and inert materials (vessel, reflector, cladding, etc.) in an extreme radiation environment. These studies are important as they lead to progress on accelerated ageing of materials and/or advanced scenarios up to accidental conditions and consequently they bring data for safety issues, the lifetime of existing nuclear power plants and their advancements with new concepts. Therefore, new instrumentation is needed to measure online key parameters both before the experiments for the device design and during the experiments for the result interpretation.
The construction of the Jules Horowitz Reactor, a new 100 MWth nominal power MTR with unequalled performance in Europe (high fast neutron flux of 5.5x10^14 n/(cm².s) (from 1 MeV) leading to a high accelerated ageing (up to 16 dpa/year) and a high nuclear absorbed dose rate (up to 20 W/g in aluminum)), initiated new collaborative research work. Since 2009 Aix-Marseille University and the CEA (within the framework of the joint laboratory LIMMEX - Laboratory for Instrumentation and Measurement in Extreme Environments) and its IN-CORE program - Instrumentation for Nuclear Radiations and Calorimetry online in REactor) have been developing a new research topic. More precisely, they have been focusing on innovation in instrumentation and advanced measurement methods for the quantification of key nuclear parameters such as neutron and photon fluxes and nuclear absorbed dose rate, also called nuclear heating rate. The online measurement of this latter quantity requires specific sensors: non-adiabatic calorimeters. With regard to the state of the art, two distinct sensors are used in MTRs: French differential calorimeters (CALMOS, CARMEN or CALORRE type) and European single-cell calorimeters (such as gamma thermometers or KAROLINA-type calorimeters). These two types of calorimeter allow the quantification of the nuclear absorbed dose rate thanks to temperature measurements and preliminary calibration under non-irradiation conditions from steady thermal states in the case of integrated heating elements or from transient thermal states in other cases.
The paper will present a review of recent work carried out on a new differential calorimeter called CALORRE and patented by AMU and the CEA in 2015. The work allows the design and the characterization of several CALORRE configurations over a wide range of nuclear absorbed dose rate (up to 20 W/g).
The first part of the paper will describe the first design of CALORRE calorimeter fabricated for a range up to 2 W/g and its first qualification under real conditions during an irradiation campaign inside the MARIA reactor (in November 2015).
The second part will be dedicated to the characterization of the response of 6 new configurations of CALORRE calorimetric cell by means of a comprehensive approach coupling experimental, theoretical and numerical work from laboratory conditions to nuclear environments. The experimental metrological characteristics of the 6 configurations, in terms of sensitivity, linearity, range, reproducibility and response time, will be detailed. Their responses will be compared and analyzed thanks to a 1-D theoretical thermal model. Moreover, by means of a predictive model (based on a heat balance and calibration curves under laboratory conditions), their response under real conditions will be predicted. Then, thanks to this panel of configurations, the influence of various parameters such as the sensor geometry, its size and its structural material will be given. The advantages of this kind of calorimeter will be discussed and compared to other calorimeters (differential and single-cell calorimeters). Finally, 3-D thermal simulations allowing the optimization of the calorimeter assembly in term of compactness will be summarized for the chosen JHR configuration (for high nuclear absorbed dose rates) already fabricated, tested up to 60 W under laboratory conditions (electrical power range

ten times higher than that of previous calibrations for common differential calorimeters).
The last part will present new results obtained within the framework of a new research program called CALOR-I, funded by Aix-Marseille University, involving the Nuclear Reactor Laboratory of the MIT and the CEA (2020-2022), and focusing on the mapping of an in-core water loop of the MITR reactor in terms of nuclear heating rate by means of a new CALORRE calorimeter in particular. The criteria for the choice of this new configuration of CALORRE will be detailed (mass, size, temperature, sensitivity). Then, the parametrical study for the definition of a new CALORRE differential calorimeter assembly with three calorimetric cells and two kinds of sample material will be presented.

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