Review Report on PhD Thesis of Mikolaj TARCHALSKI

Entitled

"Nuclear Heating Measurements in the MARIA Reactor and Implementation of Neutron and Photon Calculation Scheme"

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The general topics concerns the energy deposition derived from nuclear reactions in the nuclear MARIA reactor, based in Poland, which is an open pool material testing reactor with pressurized fuel channels. This work focuses in i) nuclear heating calculations coming from prompt particles and radiation in MARIA reactor, ii) new measurement methods in MARIA core (Gamma calorimeter) and iii) implementation of these experimental results into the final nuclear heating calculation. Mikolaj TARCHALSKI prepared this thesis in both Poland (NCBJ, Swierk-Otwok) and France (CEA and AMU, Marseille).

The thesis consists of five chapters, an introduction, the state of the art, three chapters corresponding to the core of the thesis, a conclusion and the bibliography. The thesis is written and organized carefully. It is written in high-quality English on 176 pages all together. The structure of the thesis conforms to principles and requests to the structure of scientific thesis.

The state of the art (36 pages) presents a literature review on nuclear heating which appears as an essential key parameter for safe and efficient operation of nuclear reactors used for both electricity production and research. The growth of knowledge (modelling, calculations and experiments) in nuclear heating appears at the beginning of the 70's. Calorimeters were developed and the first-time Gamma Heating Measurements (GHM) for MARIA reactor (topic of this thesis) has been carried out in the 80's. M. TARCHALSKI develop the mechanism of nuclear heating and describes the different sources (particles, radiations, interactions). **If measurements concern European results (Fig. 2.4), it would be interesting to compare same results in other nuclear plants especially in England and USA for example.**
A large part of the state of the art is then devoted to the nuclear parameter measurement methods concerning detectors based on the temperature measurements of materials placed in the centre of the detector: the single-cell (KAROLINA calorimeter) and differential calorimeter (MARIA calorimeter). A synthetic discussion gives the differences between these two calorimeters.
The third part of this state of the art presents the calculation tools used in MARIA simulation, especially the WIMS/REBUS calculation scheme. Calculations were conducted with the French codes TRIPOLI-4© and APPOLO2. The last part concerns the MARIA description and the measurements capabilities. **The necessary literature introduction is given to make the thesis self-contained and gives a solid background to the results (experiments and calculations) reported in this thesis.** The main conclusion of the chapter is the need to verify the ability to simulate nuclear heating with more efficiency and to measure this phenomenon with accurate measurements.

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The instrumentation and measurement method are described in the third chapter (37 pages). X different devices used in the experimental campaign are detailed.

1) The Karolina calorimeter: is the polynomial expression of conversion voltage-to-temperature (page 56) obtained with identification of the coefficients from the experiments in the test bench presented pages 71-73 or according to the manufacturer? The temperature range 0 to 500°C determines the temperatures with accuracy within the range -0.05 to +0.04 °C. Is it an accuracy obtained with the furnace used for the calibration pages 70-71 ? And how is this accuracy obtained ?
2) Gamma Thermometer: **I do not understand the unit of the response time constant " $\lambda = 0.0546\ s^{-1}$ " (page 57). Generally, the unit of time constant is "s" not "s^{-1}".**

For the KAROLINA calorimeter calibration, the equation (3.21) page 77 considers a time constant κ defined in "s^{-1}". Is it a current denomination in nuclear terminology ? What is the accuracy of the specific heat of graphite equation (3.24) page 77 ? The sensitivity equation (3.31) of the calorimeter averaged on three out-of-core calibration is interesting but is valid only between 30°C to 120°C. The method of KAROLINA calorimeter calibration focuses on time constant determination and nuclear heating measurements. How do you explain the horizontal start from 0 to 3 s for the HVA KAROLINA (Fig. 3.18, page 82) and HVA GT26 (Fig. 3.19, page 83). **Could you consider that is a delay of thermal diffusion inside the material ?**

Globally, calibration procedure allowed the determination of the sensitivity inside or outside the core with a very good agreement and repeatability and this is an interesting result.

The development of MARIA calculation model concerns the fourth chapter (62 pages). Calculations were conducted with the French codes TRIPOLI-4© and APPOLO2. These calculations allow to determine all prompt components (neutron and photon separately). This specific part of the thesis is not in the field of reviewer's researches and competences. Then, I prefer not to judge this scientific work done.

The last chapter compares calculations and experimental results (15 pages). To increase reliability of measurements, two independent sensors were used: KAROLINA calorimeter and gamma thermometer. Results present different behaviours of these two instruments depending on the measurement location (different channels). As the heating growths, for a same core hight, the difference between these detectors differs because of the radiation effect (Fig. 5.1 page 155) : the graphite may have different value of emissivity than the stainless steel for the same wavelength and temperature range. The high uncertainties of calculations results for GT: the diameter core is 2.1 mm and with 1 mm diameter thermocouple inside. **In order to reduce these uncertainties, smallest thermocouple diameters (0.5 mm for example) may be used**. These 0.5 mm diameter present a sufficient strength to be handled. The work of M. TARCHALSKI showed that a satisfactory agreement between calculations and experimental data for neutron and gamma energy deposition characteristic. In the MARIA reactor the difference between calculated heating and measured one was estimated to 10%.

Mikolaj TARCHALSKI proved his ability to perform research and to achieve original scientific results. To sum up, this dissertation represents high level scientific work. Innovative experiments were conducted in the MARIA reactor. Experiments are well planned and properly discussed and results are compared to numerous simulations. Mikolaj TARCHALSKI published some results of his research in peer-reviewed conferences and journals. Finally, the thesis fulfils all the conditions for receiving the PhD degree in Physics and Material Science of Aix Marseille Université (France) and National Centre for Nuclear Research in Swierk/Otwock (Poland).

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