Nuclear Instruments and Methods in Physics Research A 780 (2015) 68–80

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

# Experimental validation of photon-heating calculation for the Jules Horowitz Reactor

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ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form
9 January 2015
Accepted 14 January 2015
Available online 24 January 2015

Keywords:
Photon heating
Research reactors
Experimental validation
TLDs
OSLDs
Representativeness

ABSTRACT

The Jules Horowitz Reactor (JHR) is the next Material-Testing Reactor (MTR) under construction at CEA Cadarache. High values of photon heating (up to 20 W/g) are expected in this MTR. As temperature is a key parameter for material behavior, the accuracy of photon-heating calculation in the different JHR structures is an important stake with regard to JHR safety and performances. In order to experimentally validate the calculation of photon heating in the JHR, an integral experiment called AMMON was carried out in the critical mock-up EOLE at CEA Cadarache to help ascertain the calculation bias and its associated uncertainty. Nuclear heating was measured in different JHR-representative AMMON core configurations using ThermoLuminescent Detectors (TLDs) and Optically Stimulated Luminescent Detectors (OSLDs). This article presents the interpretation methodology and the calculation/experiment ($C/E$) ratio for all the TLD and OSLD measurements conducted in AMMON. It then deals with representativeness elements of the AMMON experiment regarding the JHR and establishes the calculation biases (and its associated uncertainty) applicable to photon-heating calculation for the JHR.


## 1. Introduction

The Jules Horowitz Reactor (JHR) is the next international Material-Testing Reactor (MTR) under construction at CEA Cadarache. Before 2020, it will replace the MTR OSIRIS (Saclay, France) for the irradiation of material and fuel samples with intense neutron fluxes. These irradiations experiment, by aging samples in an accelerated way in a severe environment, help develop metal alloys for Gen-III and Gen-IV reactors and better assess strength of alloys currently used in Gen-II reactors. The JHR will also produce radioactive isotopes for medical purpose (especially 99-technetium) and n-doped silicon for high power electronics. As for its design, the JHR core (see Fig. 1) is made up of an aluminum rack hosting from 34 to 37 cylindrical fuel assemblies, surrounded by a beryllium reflector and by zircaloy shields inserted on half the core perimeter. Reactivity control is assured by sets of hafnium rods inserted in the fuel assemblies.

The accurate control of photon heating in the different JHR structures is an important stake for JHR design and safety studies. Photon heating is the main contributor to total heating in non-fissile materials and leads to temperature increases. Heated materials must therefore be accordingly cooled down so as to eliminate risks of local boiling, e.g. around hafnium rods, and of creep deformations, e.g. of the aluminum rack. A good knowledge of the profiles of photon heating in irradiation devices is also necessary for the design of irradiation experiments. Temperature of irradiated samples is one of the key parameters to establish the representativeness of JHR irradiation with regards to irradiation in other light-water reactors, e.g. Pressurized-Water Reactors (PWR). Depending on expected values of heating, irradiation devices must appropriately be designed with systems to monitor and control sample temperature. It was estimated [1] that an uncertainty of 5% (at one standard deviation) on calculated photon heating, associated with the nuclear data used in the photon calculations, is required to meet these challenges.

Due to the JHR specific geometry and choice of materials, feedback on photon-heating calculations and its uncertainty was limited and mainly based on work conducted in 2006 during the ADAPH experiment in CEA Cadarache [2,3]. A new experiment, AMMON [4], was therefore carried out from late 2010 to early 2013 in the EOLE critical mock-up at CEA Cadarache. One of its purposes was to provide nuclear-heating measurements with ThermoLuminescent Detectors (TLDs) and Optically Stimulated Luminescent Detectors (OSLDs) in order to gain insight on photon-heating calculation for the JHR. In particular, nuclear heating was measured in 3 different AMMON core configurations: a reference configuration, a configuration with a hafnium control rod and a configuration with a solid beryllium block.

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http://dx.doi.org/10.1016/j.nima.2015.01.054
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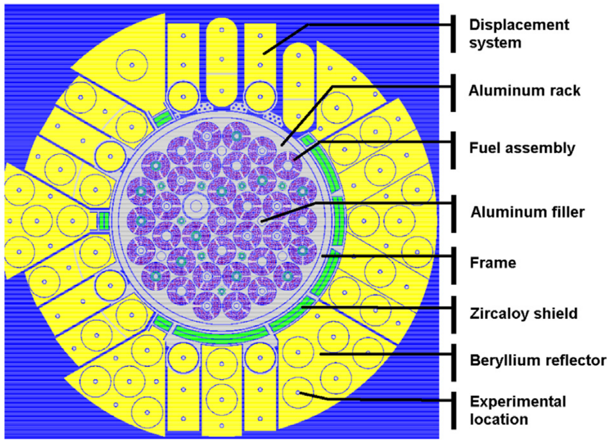


**Fig. 1.** JHR starting core.

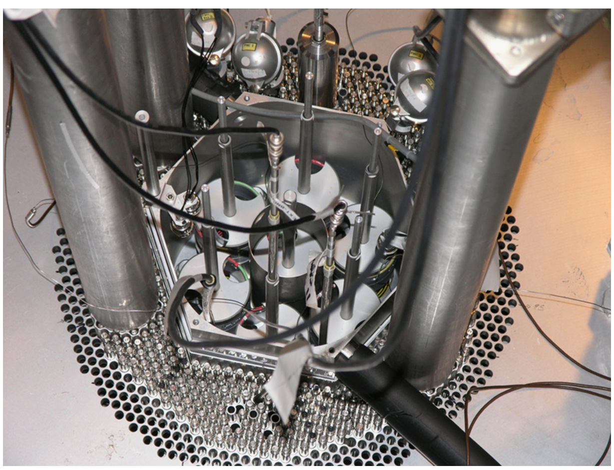

**Fig. 2.** AMMON/REF configuration in the EOLE experimental reactor.

In this article, we first deal with the interpretation of all the TLD and OSLD measurements conducted in the different AMMON configurations. That is, we present a methodology to calculate photon heating, including the contribution of prompt photons, delayed fission photons and delayed activation photons, and compare it to the TLD and OSLD measurements in AMMON, corrected for neutron dose, in order to yield the calculation/experiment ($C/E$) ratio on photon heating in AMMON. Note that $C/E$ ratios for TLD and OSLD measurements from the AMMON reference configuration have already been determined in Ref. [5]. Nevertheless, the interpretation of the reference configuration is done anew in this article for consistency with the results of the other AMMON configurations presented here.

The photon-heating calculation methodology that we present in this article presents a limited number of physical approximations. Thus, we will assume the $C/E$ discrepancies we obtained on the AMMON core are mainly due to biases in the nuclear data used for photon-heating calculation. In order to define the $C/E$ biases due to nuclear data and applicable to a photon-heating calculation in the JHR, representativeness elements of the AMMON core with regards to the JHR core are necessary and form the second part of this article.

The plan of this presentation is as follows. First, we get acquainted with the AMMON experiment and we describe the nuclear-heating measurements carried out in the AMMON core. Second, we tackle the interpretation of these measurements and yield the $C/E$ bias applicable to photon-heating calculation in the AMMON. Third, with the help of simple physical considerations, we study the representativeness of the AMMON with regards to the JHR core and deduce the $C/E$ biases (with its associated uncertainty) applicable to photon-heating calculation in the JHR and due to nuclear data. Fourth and last, we open perspectives on the nuclear-heating measurement methods and the interpretation methodology used for the AMMON experiments.

## 2. Nuclear-heating experimental data provided by AMMON

### 2.1. AMMON core description

The AMMON core (Fig. 2) consists of an experimental zone dedicated to the analysis of the JHR neutron and photon physics surrounded by a driver zone loaded in the EOLE facility.

Depending on the configuration, the experimental zone contains 6 or 7 JHR standard assemblies inserted in an aluminum alloy hexagonal rack (30 cm side length). The JHR fuel assembly is composed of curved fuel plates, maintained by 3 aluminum alloy stiffeners (Fig. 3). The external diameter of the assembly is about 10 cm for a 60-cm active height. The fuel plates are composed of fuel (with 27% $^{235}U$ enrichment) and Al–Fe–Ni cladding. Each JHR assembly hosts in its central cavity an aluminum absorber rod follower and an aluminum tube (Fig. 3). Also, in the rack, 6 cylindrical fillers are inserted between fuel assemblies. The tubes and fillers can be instrumented with neutron and gamma detectors.

Nuclear heating was measured in the so-called reference, hafnium and beryllium configurations of the AMMON core (noted, respectively, REF, HAF – split in two subconfigurations called HAF-Hf and HAF-Al – and BER). In the REF configuration, the experimental zone contains 7 JHR standard assemblies. In the HAF configuration, a hafnium control rod is fully inserted in the central assembly,

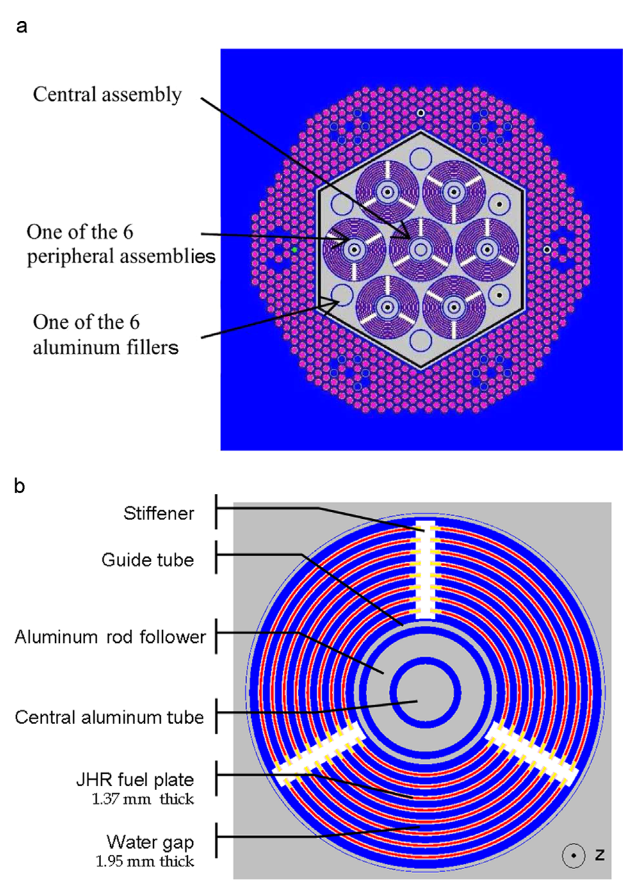


**Fig. 3.** AMMON/REF: radial cross-section of the core (a) and of the assembly (b).