Nuclear Instruments and Methods in Physics Research A 724 (2013) 76–82

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Measurement of photon flux with a miniature gas ionization chamber in a Material Testing Reactor

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ARTICLE INFO

Article history:
Received 18 February 2013
Received in revised form
10 April 2013
Accepted 30 April 2013
Available online 18 May 2013

Keywords:
Ionization chamber
Fission chamber
MCNP
Material testing reactor
Nuclear heating

ABSTRACT

Nuclear heating measurements in Material Testing Reactors (MTR) are crucial for the design of the experimental devices and the prediction of the temperature of the hosted samples. Nuclear heating in MTR materials (except fuel) is mainly due to the energy deposition by the photon flux. Therefore, the photon flux is a key input parameter for the computer codes which simulate nuclear heating and temperature reached by samples/devices under irradiation. In the Jules Horowitz MTR under construction at the CEA Cadarache, the maximal expected nuclear heating levels will be about 15 to 18 W g^{-1} and it will be necessary to assess this parameter with the best accuracy. An experiment was performed at the OSIRIS reactor to combine neutron flux, photon flux and nuclear heating measurements to improve the knowledge of the nuclear heating in MTR. There are few appropriate sensors for selective measurement of the photon flux in MTR even if studies and developments are ongoing. An experiment, called CARMEN-1, was conducted at the OSIRIS MTR and we used in particular a gas ionization chamber based on miniature fission chamber design to measure the photon flux. In this paper, we detail Monte-Carlo simulations to analyze the photon fluxes with ionization chamber measurements and we compare the photon flux calculations to the nuclear heating measurements. These results show a good accordance between photon flux measurements and nuclear heating measurement and allow improving the knowledge of these parameters.

1. Introduction

A new Material Testing Reactor (MTR), the Jules Horowitz Reactor (JHR), is under construction at the CEA Cadarache (French Atomic Energy and Alternative Energies Commission). This new facility will be dedicated to nuclear research on materials and fuels. The quality of the experiments to be conducted in this reactor is largely linked to the good knowledge of the irradiation conditions. One of the key parameters is nuclear heating. Nuclear heating is mainly due to the energy deposition by the photon flux. Therefore, photon flux is a key input parameter for the computer codes which simulate nuclear heating and temperature reached by samples under irradiation. In the JHR, the maximal expected nuclear heating levels will be about 15 to 18 W g^{-1} and it will be necessary to assess this parameter with the best accuracy.

The literature shows that there is no standard sensor able to measure photon flux about a few 10^{14} γ cm^{-2} s^{-1} [1]. Studies and developments have been made with self powered gamma detector (SPGD) in Austria [2], USA [3], Belgium [4], India [5] and recently in France [6] to measure the photon flux in MTR. However, these sensors are not yet usual. Generally, the best known sensors to measure high photon flux in nuclear facilities are ionization chambers. This type of sensor is for example usual for reactor ex-core measurements and is voluminous. However, it has already been reported that miniature fission chambers without fissile coating operated in current mode may theoretically be used to assess the photon flux in MTR [7–11]. The expected current level of these sensors should be sufficient to be measured under MTR conditions. In fact, these fission chambers without fissile coating work as ionization chambers.

Since 2009, a new collaborative research program called IN-CORE “Instrumentation for Nuclear radiations and Calorimetry Online in Reactor” is under progress between CEA and Aix-Marseille University [12–14]. This program focuses on the assessment of the irradiation conditions inside experimental channels of the JHR, through the accurate evaluation of fast and thermal neutron fluxes, photon flux and nuclear heating. One aim of this program is to design a new suitable mobile experimental device called CARMEN for the measurement of these parameters at reactor start-up. A first prototype of CARMEN has been designed and tested in 2012 in so-called “CARMEN-1” experiment in the OSIRIS reactor (70 MW) at the CEA Saclay (France).

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http://dx.doi.org/10.1016/j.nima.2013.04.083

In this paper, we present firstly the numerical method to analyze the photon flux with the ionization chamber measurements. Then, the CARMEN-1 experiment is described together with the experimental measurements. Finally, the photon flux evaluations are compared to the nuclear heating measurements and the results are discussed.

2. Monte-Carlo simulations

The literature has shown that a miniature fission chamber manufactured without fissile coating and irradiated in high photon flux in a MTR could deliver a measurable current [11]. It has been shown that this particular sensor could deliver a current level above the μA. As this sensor works as ionization chamber, its current is proportional mainly to the photon flux and secondary to the neutron flux. A numerical method is chosen to evaluate the photon flux from the measured current. In this section, a preliminary physical analysis is detailed to show the principle of functioning of the fission chamber without fissile coating used as ionization chamber. Then, the Monte-Carlo model to calculate the photon flux with current measurements is detailed.

2.1. Physical analysis

Neutrons and photons interact with the fission chamber structures (Fig. 1) but only one part of the sensor is at the origin of the signal. Indeed, the current measured by the sensor is collected between the anode and the cathode in which a gas is in an electric field. Even without fissile coating, a current is created in the fission chamber by the collection of electrons with a voltage supply on the electrodes.

Photons encountered in MTR (energy between few keV to few MeV) interact mainly by photoelectric and Compton effects with the body of the sensor and for a minor part with the gas ($\sim$ 1% by [11]). One part of these electrons created by photon interactions ionizes the gas and creates pairs of electron-ion that are then separated by the electric field between the electrodes. Neutrons interact mainly by radiative captures with the body of the sensor and the created photons interact as above. Moreover, the body of the sensor is activated by the neutron flux and the β^- decay of some activated isotopes generates electrons that also participate in the ionization of the gas.

2.2. Monte-Carlo model

Models and simulations of the transport of the neutrons, photons, electrons and their interactions are calculated with MCNP5 code. The physical studies of the origin of the current measured by the ionization chamber show that only one part of the sensor has to be taken into account for the Monte-Carlo model of photon flux analysis (Fig. 2).

The characteristics of the fission chamber used in CARMEN-1 experiment are in the Table 1.

To simulate the current collected by the sensor, we made two calculations. On one hand we calculated the instantaneous energy deposition by the electrons due to the neutron and photon interactions and on the other hand we calculated the energy deposition by the electrons due to the activation (and subsequent decay) of stainless steel.

Firstly, for the photon and the neutron contribution in the current collected by the ionization chamber, we calculate the energy deposited by electrons between the electrodes. In order to obtain the instantaneous current, one has to take into account the average energy necessary to create a pair of electron-ion in the gas; the current is deduced by the following equation:

$$i = \frac{F8^{*}(\phi_{total} S/4) q_e}{W}$$

with:

i	current due to the neutron or the photon flux [A];
$F8^{*}$	result of the energy deposit for one particle incident [MeV]
ϕ_{total}	neutron or photon flux [n, γ $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$];
S	external area of the sensor [cm²];
q_e	elementary charge [1.60×10^{-19}C];
W	average energy necessary to create a pair of electron-ion in the gas [15] [26.4×10^{-6} MeV].

Due to the neutron flux, the stainless steel body of the ionization chamber is activated. The second calculation aims to evaluate the

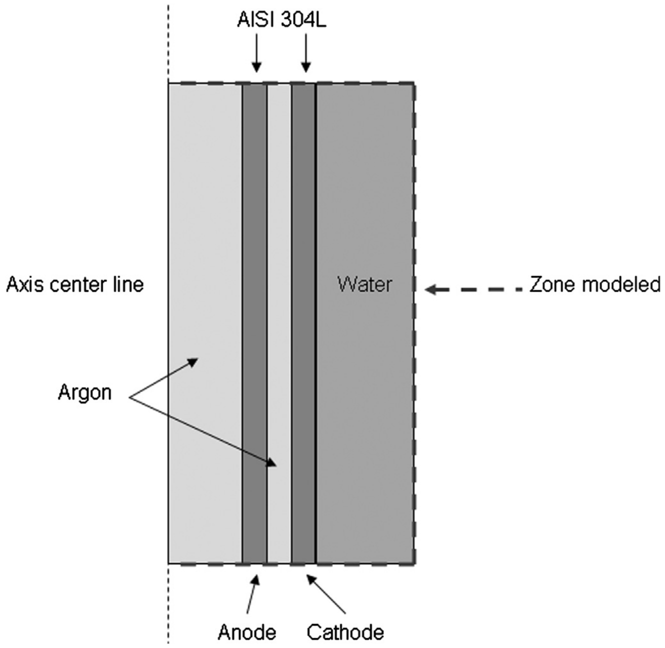

Fig. 2. Geometry of the ionization chamber for MCNP5 simulations.

Table 1
Dimensions of the ionization chamber.

Anode	Internal diameter (mm)	1.5
	External diameter (mm)	2.0
Cathode	Internal diameter (mm)	2.5
	External diameter (mm)	3.0
Gas	Gap (mm)	0.5

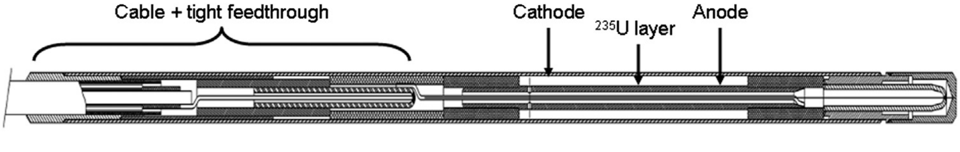

Fig. 1. Overall plan of a fission chamber with uranium 235.