Characterization of the gamma flux in a tangential channel of the CENM TRIGA MARK II research reactor

A. Gruel[1] (adrien.gruel@cea.fr), D. Fourmentel[1], C. El Younoussi[2], B. El Bakkari[2], Y. Boulaich[2], B. Nacir[2], A. Lyoussi[1]

[1] CEA, DEN, Cadarache, DER/SPESI, F-13108 Saint Paul lez Durance, France
[2] DIN/CNESTEN, POB 1382, Rabat, Morocco

Abstract— The CNESTEN (National Center for Energy Sciences and Nuclear Technology, Morocco) operates a TRIGA Mark II reactor, which can reach a thermal maximum power at steady state of 2 MW. In reactors devoted to research and experiments, it is mandatory to characterize the neutron and photon fields in the irradiation positions. Together with a computational model of the core, it ensures the ability to reach the requested uncertainties when performing experiments, such as detectors testing, irradiation for hardening or nuclear data measurements.

The neutron field of different irradiation positions has been characterized by dosimetry techniques and compared to the MCNP full model of the reactor. Preliminary photon propagation calculations are also performed with this model, but up to now, no experimental validation of the results exists. The aim of the newly set collaboration between CEA and CNESTEN is to characterize the gamma field of these positions. The first position investigated is the part of the NB1 tangential channel closest to the core.

Among gamma measurements techniques, and according to the constraints arising from using this channel, it was chosen to use thermos- and optically stimulated luminescent detectors.

This paper presents the experiments carried out in September 2018 as well as their results. Three detectors types were used: TLD400 (CaF_2:Mn), TLD700 (^{7}LiF:Mg,Ti) and OSLD (Al_2O_3:C). Measurements were performed in several steps: background measurements, transient measurements (divergence phase + SCRAM), and irradiation at steady state. In the end, these measurements will provide a dose as well as a gamma flux value for this position.

Index Terms—CaF_2, gamma flux, LiF, OSLD, TRIGA, TLD

I. INTRODUCTION

THE ability of a reactor to carry out precise irradiations, for detectors testing or calibration, irradiation for hardening, medical isotopes production, or nuclear data measurements lies with its neutron and gamma fields characterization. The Moroccan TRIGA Mark II research reactor, operated by the CNESTEN in Rabat, undergoes a continuous effort in modelling, since several years [1]-[3]. In order to experimentally validate this calculation scheme, as well as to have reference measurements for the neutron and gamma

parameters of different positions in- and ex-core, a collaboration between CEA and CNESTEN has been set within the IAEA ICERR (International Centre based on Research Reactors) framework. Together with the computational model of the core, it will ensure the ability to reach the requested uncertainties when performing experiments.

The work presented here deals with the preliminary gamma measurements performed in 2018 in the tangential channel of the reactor.

The first part of the paper describes the reactor configuration, measurements techniques and experimental setup of the gamma measurements. The second part deals with the analysis of the results and the forthcoming work.

II. EXPERIMENTAL SETUP

A. Reactor characteristics

The TRIGA MARK II research reactor can be operated at a maximum thermal power of 2 MW. It is a pool-type reactor, water-moderated and cooled. The core is composed of 121 available positions, in which are set 96 U-ZrH fuel elements, 5 fuel-follower control rods, 17 graphite elements, a pneumatic transfer tube, and 2 water filled core positions (Fig. 1).
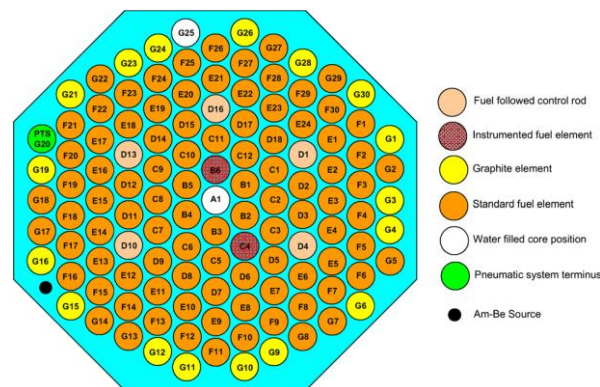

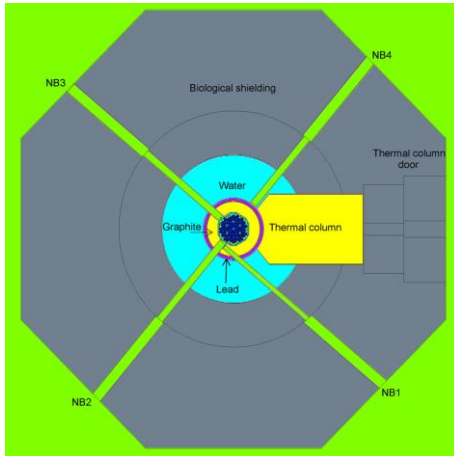Fig. 1. Core configuration of the reactor.

Fig. 2. Radial view of the MCNP model of the core, showing the irradiation channels and the thermal column.

Going from the outside of the biological shielding to the core or lead shield, 4 beam ports are available for experimentations (Fig. 2). There are three radial channels (NB2-4) and a tangential one (NB1). The larger irradiation device is the thermal column, which extends from the graphite reflector.

The first position investigated is the part of the NB1 tangential channel closest to the core. This channel penetrates the concrete shield, the aluminium tank and stops outside the reflector assembly. It is in line with void in the reflector graphite and lead to maximise the neutron flux. The NB1 channel is 3-m long and has a 15-cm diameter section in its inner part. This channel is closed during reactor operation.

As this channel has to be closed during irradiation, it was chosen to use dosimeter-type gamma-sensitive detectors. They are described in the following section.

B. Optically stimulated luminescent detectors and thermoluminescent detectors

We used two types of thermoluminescent detectors (TLD): TLD400 (CaF_2:Mn) and TLD700 (^{7}LiF:Mg,Ti) obtained from ThermoFisher Scientific. The dose reader is a Harshaw model 3500, which can heat a single TLD up to 400 °C. The readout process for the TLD400 is the following: pre-heating at 150 °C for 5 s, then heating up to 350 °C at a 10 °C.s^{-1} rate and maintaining this temperature for 30 s. For TLD700, the read out consists of a pre-heating at 140 °C for 10 s, then heating up to 280 °C at a rate of 15 °C.s^{-1} and maintaining the temperature at 280 °C for 23 s [4]. Prior to each irradiation, the residual dose in the detectors is annealed (1 h at 400 °C + 2 h at 100 °C).

We also used nanoDots optically stimulated luminescent detectors (OSLDs) from Landauer. The integrated dose is read thanks to a light stimulation of the detector. The read out process is non-destructive, and the detector cannot be annealed afterward.

For both types of detectors, the relation between the charge integrated in the detector and the KERMA (Kinetic Energy Released per unit MAss) in air is determined by calibration measurements in a reference gamma field. For the dose range investigated here, this is a proportional relation:

$$Q = F_c . K \qquad (1)$$

Q being the charge read after irradiation (nC), K the KERMA (mGy) to which the detectors are exposed to, and F_c the calibration factor (nC.mGy^{-1}).

Each detector is calibrated individually. The uncertainty lies between 2% and 3% for TLD400, within 0.5% and 2.5% for TLD700 and within 1% to 2% for the OSLD. The calibration was carried out at CEA Cadarache at the radiation protection division, at a distance of 80 cm of a ^{60}Co source.

III. MEASUREMENTS AND ANALYSIS

A. Measurements procedure

In order to position the detectors at the closest point to the core inside the NB1 tanential channel, a specific device was manufactured (Fig. 3). The detectors were placed inside natural PEHD sealed capsules, glued at the end of a 1-m plastic tube. This ensures the reproducibility of the measurements, as this device was always put the same way in the channel. Positions were arranged in three concentric circles around the central one, and numbered from #1 to #33. Given the number of detectors available, 12 positions were actually used. OSLDs were taped between the capsules (Fig. 3, right).

Prior to the measurements at steady state, the gamma background coming from the previous irradiations was assessed. Then, a dose measurement during transients (divergence up to 10 W then rod-drop) was carried out, and finally a dose measurement at 10 W during 10 min.

The duration and power were adjusted so as to obtain an integrated dose around a gray, in order to be within the calibration and linear operating range of the detectors. Each time, the dose readout was performed around 24 hours after an irradiation (background, transient or steady state) so as to avoid fading effects.

Fig. 3. Holding device for the detectors in the NB1 tangential channel.

B. Results and analysis

The net results (background and transients subtracted) for the dose during a 10 min at 10 W irradiation are displayed in Fig. 3. Background and transient doses are assessed for each individual position inside the holding device. The position #1 correspond

to the device center, #2 to #8 to the first ring, #10 to #16 to the second ring and #18 to #29 to the third one. From the individual measurements on each irradiation, there is no noticeable difference between the inner and outer positions, nor between detectors located on the core side (positions on the left half of the holding device, see Fig. 3) and on the reflector side (positions on the right half of the holding device, see Fig. 3). One can assume that the gamma flux is homogeneous at the measurement position. All averaged results are consistent within 2σ (2.1σ agreement between TLD400 and OSLD, Tab. I). Final integrated dose is 298 mGy, the propagated uncertainty is 4.3 mGy (considering that all measurements are independent). The standard deviation between the three types of detectors is significantly higher than the propagated uncertainty: 18 mGy.
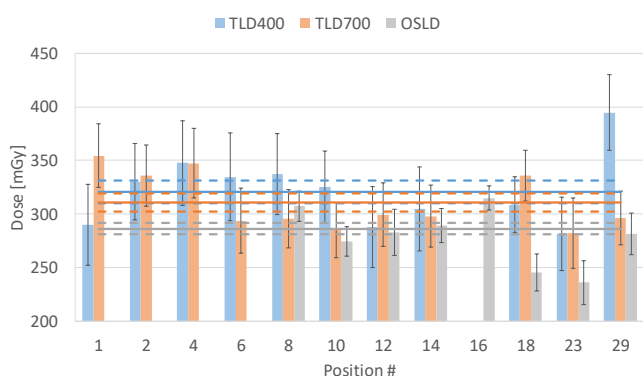

Fig. 3. Results of doses measurements in the different positions. The different colors stand for each type of detector, the solid and dotted lined line are the weighted average and the associated uncertainty (1σ), respectively.

TABLE I
ABSOLUTE NET DOSE MEASUREMENTS FOR 10 MIN AT 10 W (MGY).

Detector	Dose	Uncertainty	Standard deviation
TLD400	321	11	33
TLD700	311	9	26
OSLD	286	6	27

It is worth noting that the measurements are systematically more discrepant in the outer rings rather than the inner ones. For a given experiment (background, transient or steady state measurement), the discrepancy between the detectors is around 5% to 10% in the first ring, 7% to 15% in the second one, 15% to 30% in the third one. The cause of such behavior is not yet determined, but several causes could be considered:
- inhomogeneity of the gamma flux, not measured given the observed uncertainties, but nevertheless existing;
- reproducibility issues in the positing of the device within

the channel (angle, distance to the channel end);
- positioning of the detectors within the capsules, since the latter were larger than the TLD, thus enabling some movement and different orientations of the detectors with regard to the reactor environment.

In order to obtain more precise results, it would have been interesting to run longer irradiations or at higher power, since the net dose (corrected from background and transients) integrated during the 10 W irradiation was of the same order of magnitude as the background.

IV. CONCLUSION AND OUTLOOKS

A first set of measurements for the gamma characterization of the core and irradiation positions of the CENM's TRIGA reactor were performed in 2018. Thermo- and optically stimulated-luminescent detectors were used to assess the gamma dose at the closest positions to the core of the tangential NB1 channel. Results for the total dose during an irradiation obtained with the different detectors are consistent.

A deeper analysis of these results should take into account the neutron sensitivity as well as the delayed neutron and gamma components. The use of ^{6}LiF TLDs or metallic foil dosimeters would be accurate. A precise modeling of the detectors as well as their surroundings could improve the comparison.

Given the operation capabilities of the reactor (power up to 2 MW), an appropriate readout and annealing operating mode could enable to measure the gamma dose at higher power levels.

REFERENCES

[1] Y. Boulaich *et al.*, 'Steady-state thermal-hydraulic analysis of the Moroccan TRIGA MARK II reactor by using PARET/ANL and COOLOD-N2 codes', *Nuclear Engineering and Design*, vol. 241, no. 1, pp. 270–273, Jan. 2011.
[2] E. Chham *et al.*, 'Neutronic and thermal–hydraulic analysis of new irradiation channels inside the Moroccan TRIGA Mark II research reactor core', *Applied Radiation and Isotopes*, vol. 116, pp. 178–184, Oct. 2016.
[3] B. El Bakkari *et al.*, 'Monte Carlo modelling of TRIGA research reactor', *Radiation Physics and Chemistry*, vol. 79, no. 10, pp. 1022–1030, Oct. 2010.
[4] H. Amharrak, *Développement et optimisation de méthodes de mesures d'échauffements nucléaires et de flux gamma dans les réacteurs expérimentaux : identification, maîtrise, traitement et réduction des incertitudes associées*, thesis, Aix-Marseille, 2012.