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Fission products detection in irradiated TRIGA fuel by means of gamma spectroscopy and MCNP calculation

M. Cagnazzo[a,b,*], A. Borio di Tigliole[b,1], H. Böck[a], M. Villa[a]

[a] Atominstitut, Technische Universität (TU) Wien, Stadionallee 2, 1020 Vienna, Austria
[b] University of Pavia, Corso Strada Nuova, 65, 27100 Pavia, Italy

HIGHLIGHTS

- Fission products activity axial distribution detection for irradiated fuel elements.
- MCNP detector simulation.
- Fission product activity contribution due to other reactions rather than fission.
- Results are coherent with the irradiation history of each fuel element.
- Results are usable for burn-up calculation validation.

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ABSTRACT

Aim of this work was the detection of fission products activity distribution along the axial dimension of irradiated fuel elements (FEs) at the TRIGA Mark II research reactor of the Technische Universität (TU) Wien.

The activity distribution was measured by means of a customized fuel gamma scanning device, which includes a vertical lifting system to move the fuel rod along its vertical axis. For each investigated FE, a gamma spectrum measurement was performed along the vertical axis, with steps of 1 cm, in order to determine the axial distribution of the fission products. After the fuel elements underwent a relatively short cooling down period, different fission products were detected. The activity concentration was determined by calibrating the gamma detector with a standard calibration source of known activity and by MCNP6 simulations for the evaluation of self-absorption and geometric effects. Given the specific TRIGA fuel composition, a correction procedure is developed and used in this work for the measurement of the fission product Zr^{95}.

This measurement campaign is part of a more extended project aiming at the modelling of the TU Wien TRIGA reactor by means of different calculation codes (MCNP6, Serpent): the experimental results presented in this paper will be subsequently used for the benchmark of the models developed with the calculation codes.

1. Introduction

After 50 year of operation, the TRIGA MARK II (GA, 1962) research reactor of the Technische Universität (TU) Wien underwent a major refurbishment, including in 2013 the core conversion (Böck et al., 2013a) from mixed HEU (High Enriched Uranium) and LEU (Low Enriched Uranium) to a fully LEU fuel loading. Unfortunately, the new core configuration provided for an excess of reactivity well below the value expected from the calculation (Böck et al., 2013b). The discrepancy between the previous MCNP calculations and the experimental data resulted in an underestimation of fuel needs to ensure the next 20 years of operation. To find an explanation for this discrepancy and aiming at developing and validating a model to be used for the optimization of fuel management, a research project was initiated. This work is part of this project which aims at characterizing the reactor core by means of neutron flux measurements, Monte Carlo codes modelling and study the evolution of fuel burn-up and other reactor critical parameters (such as excess of reactivity and shut-down margin).

The measurements of the fuel elements (FEs) performed in this work, will be used to benchmark the models of the TRIGA reactor developed using Monte Carlo codes such as MCNP6 and Serpent. Subsequently, the validated models will be used to investigate fuel burn-up evolution and reactor critical parameters.

* Corresponding author at: Atominstitut, Technische Universität (TU) Wien, Stadionallee 2, 1020 Vienna, Austria.
E-mail address: mcagnazzo@ati.ac.at (M. Cagnazzo).
[1] Present address: International Atomic Energy Agency.

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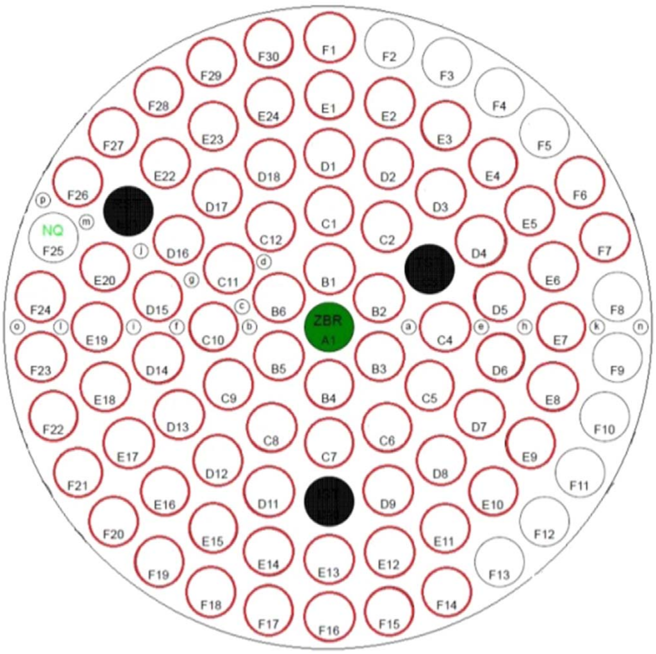

Fig. 1. Radial section of TRIGA reactor core in the configuration of the measurements.

2. The TRIGA Mark II research reactor

The TRIGA (Training Research and Isotope production General Atomics) MARK II reactor of the TU Wien is a pool-type light water reactor, with a nominal power of 250 kW in a steady-state operation.

The core geometry is a cylinder with 91 locations distributed in 6 concentric rings (Fig. 1); the rings are labelled as A (central hole), B, C, D, E and F, which respectively have 1, 6, 12, 18, 24 and 30 locations. These locations can be filled either with fuel elements or with other core components like dummy elements (i.e. graphite elements), control rods, neutron sources and irradiation channels.

Following the recent core conversion, all fuel elements in the current core configuration have the same characteristics. As shown in Fig. 2, they have a cylindrical geometry and each fuel element consists of an active part (enriched U-ZrH fuel meat), two axial graphite reflectors, and burnable poison (Molybdenum) discs. The active part is a metallic alloy of U and ZrH: about 8.5% in weight of the mixture is low-enriched uranium (19.95% enrichment in U^{235}), while the remaining 91.5% in weight is ZrH (1.6-wt% hydrogen and 89.9-wt% zirconium). The dimensions of TRIGA FE(s) are typically 3.76 cm in diameter and 72.06 cm in length; with 38.1 cm extension of the active part. All FEs cladding is made of stainless steel.

Fig. 1 represents the picture of the TRIGA reactor core in the configuration of the fuel elements measurement here explained: it consisted of 76 FEs, Dummy elements (F2, F3, F4, F5, F9, F10, F12, F13), Central Irradiation Thimble (A1), Fast-transfer irradiation facilities (F8, F11), Control rods (C3, D10, E21) and a Neutron source (F25).

3. Fuel elements activity measurement

This measurement campaign was conducted in occasion of a planned reactor shut-down: this allowed to measure the irradiated fuel elements after a cooling down period of 251 days.

The FEs selected for the gamma scanning did not change their irradiation position during their entire irradiation history at the TRIGA reactor in Vienna: this choice facilitates the benchmarking and validation of the Monte Carlo models. The selected FEs were located in ring B (B2, B4), ring C (C1), ring D (D1) and ring E (E1). They underwent irradiation for 2191 h (at 250 kW) over a period of 800 days. After the measurement, they were reinserted in the previous core positions. The history and data of the measured FEs are summarized in Table 1.

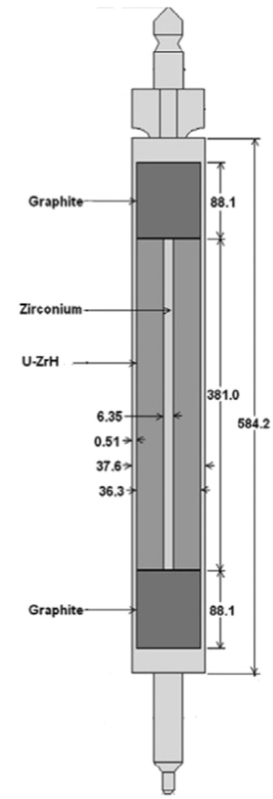

Fig. 2. TRIGA fuel element type 104.

The FEs gamma spectrometry was carried out by means of a fuel-scanning machine (FSM) (Böck and Hammer, 1981; Böck et al., 2011) specifically developed for optical inspection and gamma spectrometry of spent fuel at the TRIGA reactor in Vienna. As shown in Fig. 3, the FSM consists of a shielded apparatus and a mechanism for the movement of the FE, including an electronic control unit. Several radial openings in the shield allow inspection of a FE placed into the FSM. The upper part of the apparatus is a fuel transfer cask. This configuration allows to transfer one fuel element from the reactor tank to the FSM using a standard TRIGA fuel transfer cask and the crane in the reactor hall. When a FE is placed in the FSM, it lays on a piston which moves the FE along its vertical axis with the possibility of adjusting the speed and steps (steps can be done every millimetre) through an electronic control unit. The axial position of the FE is provided by a digital indicator on the fuel inspection unit.

In the radial opening used for the present FEs measurement, a collimator of 1 cm in diameter was placed. On the opposite side of the radial opening a p-type coaxial High Purity Germanium (HP-Ge) detector (aluminium window, 41 mm × 41 mm, 15 mm × 10 mm) was positioned, shielded by a lead shield with conical shape. The acquisition system included a digital Multi Channel Analyzer (model MCA-527 GBS Elektronik) (MCA-527 Digital Multi-Channel Analyzer – User Manual, 2012)) and the WinSpec (WinSpec Spectroscopy Software, 2012) data collection and analysis software.

The measurement was performed in the reactor hall, during a reactor shut-down period, i.e. in a condition of negligible back ground radiation coming from the reactor. For this measurements, the FEs were scanned in steps of 1 cm along their vertical axis: 38 gamma spectra per each FE were acquired to cover the full active length part of the element. As the FSM do not include the option of automatic rotation of the FE, the vertical scanning was performed with the same side of the element facing the detector. However, this condition is not expected to