Radiation Physics and Chemistry 104 (2014) 363–367

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

Benchmark experiments for validation of reaction rates determination in reactor dosimetry

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HIGHLIGHTS

- Use of zero power reactor for validation of reaction rates calculations.
- Reaction rates measurement in reactor core by He-3 detector and Au wires.
- Validation of reaction rates calculation by MCNP5.
- Comparison of measured and calculated RR for different positions in core.

ARTICLE INFO

Article history:
Received 21 June 2013
Accepted 1 February 2014
Available online 7 February 2014

Keywords:
Reactor dosimetry
Monte-Carlo calculation
Zero power reactor
Reaction rates determination

ABSTRACT

The precision of Monte Carlo calculations of quantities of neutron dosimetry strongly depends on precision of reaction rates prediction. Research reactor represents a very useful tool for validation of the ability of a code to calculate such quantities as it can provide environments with various types of neutron energy spectra. Especially, a zero power research reactor with well-defined core geometry and neutronic properties enables precise comparison between experimental and calculated data. Thus, at the VR-1 zero power research reactor, a set of benchmark experiments were proposed and carried out to verify the MCNP Monte Carlo code ability to predict correctly the reaction rates. For that purpose two frequently used reactions were chosen: He-3(*n*,p)H-3 and Au-197(n,γ)Au-198. The benchmark consists of response measurement of small He-3 gas filled detector in various positions of reactor core and of activated gold wires placed inside the core or to its vicinity. The reaction rates were calculated in MCNP5 code utilizing a detailed model of VR-1 reactor which was validated for neutronic calculations at the reactor. The paper describes in detail the experimental set-up of the benchmark, the MCNP model of the VR-1 reactor and provides a comparison between experimental and calculated data.

1. Introduction

The modern Monte Carlo calculations of neutron doses are based on precise determination of energy dependent neutron flux which can be further multiplied by flux-to-dose conversion function, e.g. the activation reaction cross-section or flux-to-dose coefficients. Therefore, the ability of a code to determine correctly the neutron energy spectra and fluxes in complex environments is of high importance. Integral irradiation experiments based on various neutron detectors response measurement can serve as valuable calculations quality check as they can provide information about detector responses under various neutron energy spectra. Thus, once the reaction cross sections are known with high precision, the level of agreement between calculated and measured detector responses provides information on code ability to determine the true neutron energy spectra and flux levels, and precision of the model. Zero power research reactors provide a valuable tool for such experiments as they can provide environments with wide range of neutron energies; moreover, the spectra differ at various core positions. As these reactors operate with physically fresh cores, such experiments can be precisely modeled in modern codes. The importance of such data for the purposes of validation could be documented by the effort of NEA on collecting such kind of data into specific databases of benchmark experiments (e.g. dedicated to reactor physics OECD NEA, 2012a or particle transport OECD NEA, 2012b).

2. Materials and methods

2.1. Detectors

Among the materials often used for neutron detection the isotopes of He-3 and Au-197 play an important role. The former is

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http://dx.doi.org/10.1016/j.radphyschem.2014.02.004
0969-806X

often used in gas filled detectors to convert neutron to charged particle, the latter, on the other hand is being used in activation methods. The cross sections of both materials are illustrated in Fig. 1 (Janis). While the reaction He-3(n,p)H-3 exhibits $1/v$ behavior over wide range of energies, Au-197 (n, γ)Au-198 reaction possesses significant resonance around 5 eV and other resonances at higher energies. The used He-3 detector was a small gas filled detector DeXtray 0.5NH1 operated in pulse mode. The detector active volume is very small, diameter as well as length of active part of the detector is 1 cm. The detector responses were obtained online via EMK-310 multichannel analyzers produced by TEMA company (Kolros et al., 2010). The Au-197 was used in a form of 1 mm thick gold wires. The responses were obtained through activation technique. For the analysis, instrumentation for automatic wire movement above a collimator and scintillation detector was used (Kolros et al., 2000). Thus, the response of the wire was measured with the step of 1 cm.

2.2. Training reactor VR-1

The VR-1 reactor is a light water pool type reactor operated at Czech Technical University in Prague. It uses LEU IRT-4 M type fuel assemblies (8-, 6- and 4-tube modifications) with enrichment of 19.7% (NZCHK, 2004). The nominal power of the reactor corresponds to 1 kW. During operation the change in core temperature is negligible, as well as the effect of reactor burn-up could be neglected. Estimated burn-up is below 0.01 grams of heavy metal per year. Thermal neutron flux in the core center at the reactor operated at the nominal power of ca. 1 kW can reach approximately 2×10^9 n/cm^{2}s^{-1}. The fuel assembly is shown in Fig. 2.

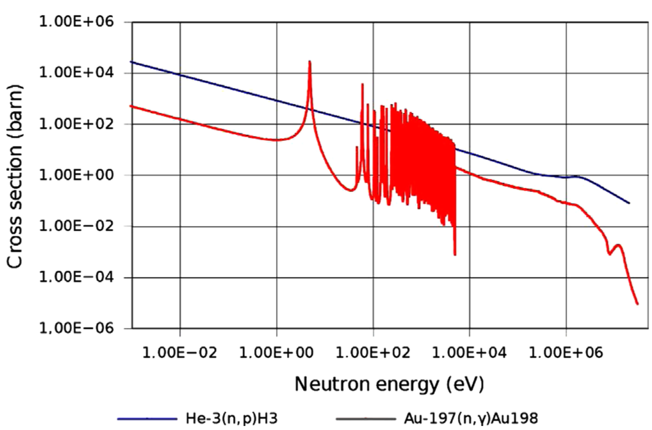

Fig. 1. IRT-4 M fuel assembly (eight-tube modification).

2.3. Reactor irradiation

The irradiation experiment was performed with core configuration C7 at the VR-1 reactor. The response of small He-3 gas filled detector was measured in more than hundred positions, covering various parts of the reactor. The measurements were performed inside thin dry experimental channel with diameter of 12 mm, inside which the detector can be moved vertically. The channel was gradually inserted in many core locations to cover the horizontal distribution. Similarly, the gold wires were used to obtain information on horizontal and vertical reaction rate distribution. To obtain vertical distribution, the wire attached to plexi-glass holder was inserted into dry experimental channel. For the horizontal measurements alongside the reactor core, thick plexiglass desks were used as wire holders placing the wires to the center of reflector positions. The horizontal distribution was measured along positions *C*8-*F*8 and along *C*3-*F*3. In both cases the distribution was measured in two heights: 270 and 370 mm above the core grid, the latter position corresponds to core vertical mid-plane. The last wire was irradiated inside vertical experimental channel in E6 position. Totally, five wires were irradiated in the core. The configuration of the core is presented in Fig. 3. As well, positions of He-3 measuring locations (green) and gold wire (red lines and dot) ones are indicated.

2.4. MCNP modeling

For calculation of reaction rates the MCNP5 code (X-5 Monte Carlo Team, 2008) and a very detailed MCNP model of VR-1 reactor were used (Rataj et al., 2012). The model contains all details of core geometry including fuel assemblies, rods, experimental channels and devices, as well as supporting structures and reactor vessel. The physical properties of the fuel assemblies were modeled using tube-averaged values of geometrical properties and assembly averaged values of material properties given by NZCHK (2004). Concerning the geometry description, the fuel passports (NZCHK, 2004) contain information of active length of individual tubes for each assembly, however, without the information of absolute position of fuel/non-fuel boundary of individual tubes. Such information is provided only in the general description of the fuel assembly and this value is used in the model. The cladding thickness was set within production uncertainties in such way to

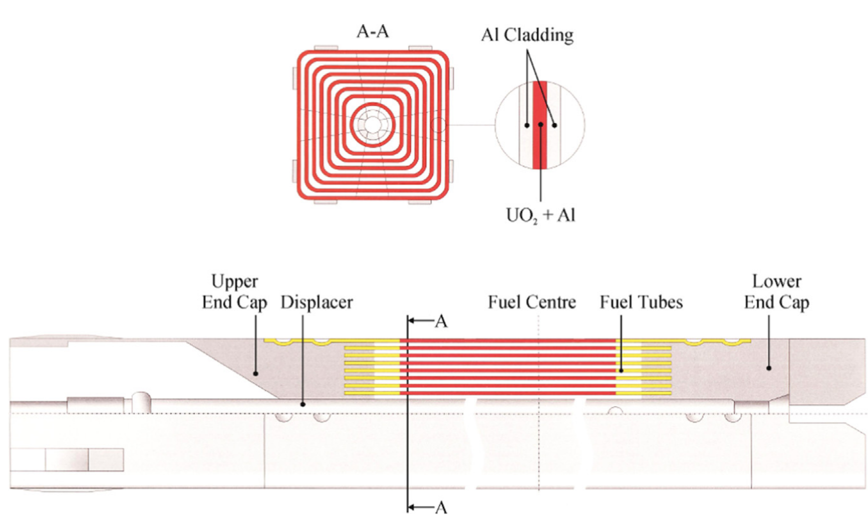

Fig. 2. IRT-4 M fuel assembly (eight-tube modification).