DETERMINATION OF NEUTRON FLUX DENSITY DISTRIBUTION IN THE CORE WITH LEU FUEL IRT-4M AT THE TRAINING REACTOR VR-1

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ABSTRACT

The objective of this work was to determine the neutron flux density distribution in various places of the training reactor VR-1 Sparrow. This experiment was performed on the new core design C1, composed of the new low-enriched uranium fuel cells IRT-4M (19.7 %). This fuel replaced the old high-enriched uranium fuel IRT-3M (36 %) within the framework of the RERTR Program in September 2005. The measurement used the neutron activation analysis method with gold wires. The principle of this method consists in neutron capture in a nucleus of the material forming the activation detector. This capture can change the nucleus in a radioisotope, whose activity can be measured. The absorption cross-section values were evaluated by MCNP computer code. The gold wires were irradiated in seven different positions in the core C1. All irradiations were performed at reactor power level 1E8 (1 kW_{therm}). The activity of segments of irradiated wires was measured by special automatic device called "Drat" (Wire in English).

Introduction

The objective of this work was to determine the neutron flux density distribution in the core C1 of the training reactor VR-1 Sparrow, operated by the Department of Nuclear Reactors at the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague. This experiment was performed on the new core design C1, composed of new low-enriched uranium fuel cells IRT-4M (19.7 %) manufactured at the Novosibirsk Chemical Concentrate Plant of the TVEL Corporation. This fuel replaced the old high-enriched uranium fuel IRT-3M (36 %) of the same producer.

The knowledge of the neutron flux density is very important because it designates irradiation conditions in the reactor. Consequently, the neutron flux density sets down the possible utilisation of the reactor for miscellaneous purposes, e. g., experiments and radionuclide fabrication.

There exists a variety of methods for neutron flux density measurements (e. g. fission chambers, self-powered detectors, activation detectors, and calorimeters).

Materials and methods

The measurements in this paper used the neutron activation analysis method. The principle of this method consists in neutron capture in a nucleus of the material forming the activation detector. This capture can change the nucleus in a radioisotope, whose activity can be measured. Therefore, activation detector segments irradiated in locations with higher neutron flux density showed higher activity. To obtain the absolute value of a neutron flux density from measurements of the activity of an irradiated detector, the exact cross-section value for neutron absorption in the chosen place of gold wire had to be known. This value is changing with neutron spectra and the neutron spectra are different in various locations of the core. One way how to solve this problem with cross-section value heterogeneity is the use of a computer code to evaluate the cross-section. The absolute value of neutron flux density can be written in the following form

$$\Phi = \int_0^{+\infty} \Phi(E)\,dE = \frac{N_{tot}\cdot\lambda}{p\cdot\varepsilon\cdot\sigma_{ef}\cdot n\cdot V\,(1-e^{-\lambda\cdot t_0})(e^{-\lambda\cdot t_1}-e^{-\lambda\cdot t_2})}\ , \qquad (1)$$

where N_{tot} is the total count of impulses in the chosen peak, λ is the decay constant, p is the number of emitted photons to the chosen peak per one decay, ε is detection efficiency for the chosen peak, n is the atomic density of the detector material, V is the volume of the detector, t_0 is the time of irradiation and t_1 and t_2 are times of the measurement beginning and end, respectively (t=0 is the end of irradiation). The effective cross-section σ_{ef} evaluated by MCNP code can be expressed by Equation 2 and its distribution for a gold wire placed at the end of tube post of the core C1 in coordinate C3 is shown in Figure 1.

$$\sigma_{ef} = \frac{\int_0^{+\infty} \Phi(E) \cdot \sigma_a(E) dE}{\int_0^{+\infty} \Phi(E) dE} \quad . \tag{2}$$

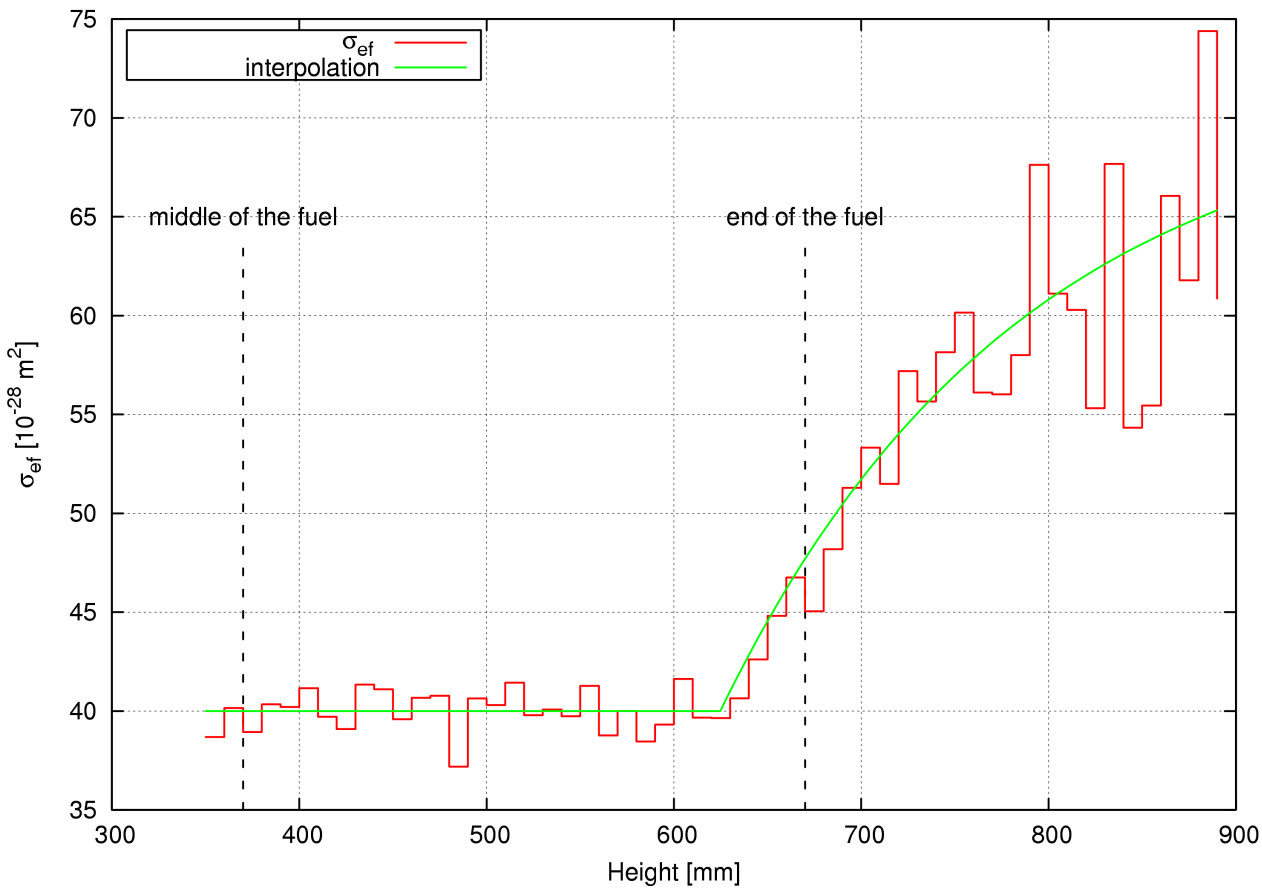

Fig. 1: Effective cross-section for gold wire in the tube post end of the core C1

Gold wires (1 mm in diameter) were used in this work as activation detectors for the neutron flux density distribution determination. The obtained absolute values were effected by the self-shielding phenomenon caused by the thickness of gold wires. That is why the thin gold foils (0.05 mm thick, 0.5 ” in diameter) were used for the absolute value normalization. Five gold wires were irradiated in seven different positions in the core C1. Six positions are displayed in Figure 2. The seventh irradiation was performed at the end of tube post (pneumatic dispatch; in coordinate C3) designated for samples irradiation. All irradiations were performed at reactor power level 1E8 (1 kW_{therm}).

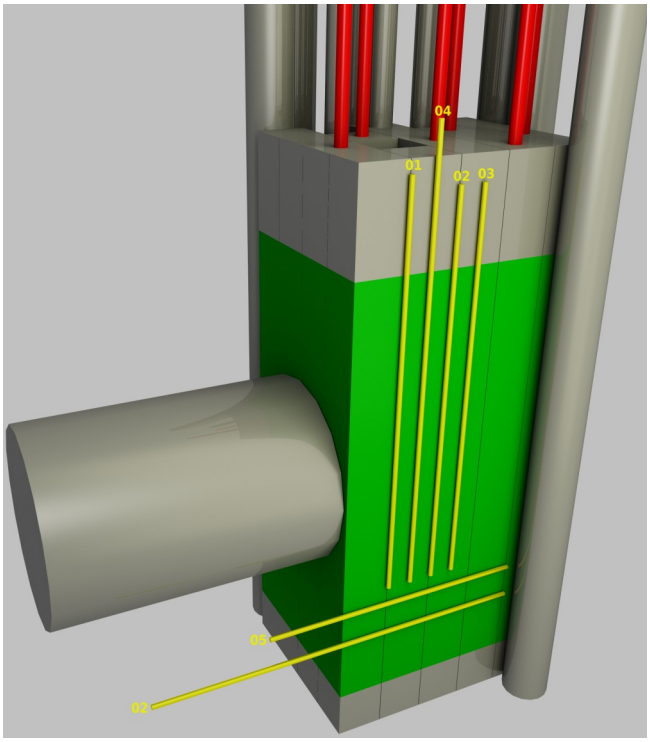

Fig. 2: 3D model of the core C1 with gold wires

The activity of segments of irradiated wires was measured by a special automatic device called “Drát” (Wire in English). This device, which is able to measure the activity of wire sample segments automatically, consists of a movable bench for samples emplacement, propulsion system, controlling system, lead shielding, and scintillation detector placed below the movable bench. The “Drát” device was programmed to measure the activity of irradiated wires segments for a time enough long to reduce the variance. Activities of irradiated gold foils were acquired via an HPGe detector with europium etalon energetical and efficiency calibration. MCNP code was also used to distinguish the fraction of thermal, epithermal and fast neutrons.

Results

The measured activities of gold samples were introduced into Equation 1 and the final results were obtained. These results for the neutron flux density and its distribution in the core C1 are in good agreement with theoretical expectations and MCNP calculations. The absolute values of neutron flux density distribution for all horizontal and vertical wires can be seen in Figures 3 and 4, neutron flux distribution of three energetic groups (thermal, epithermal and fast) is shown in Figure 5. Table I sums up the results in the most significant places of the core C1.

Table I: Results in the most significant places of the core C1

Position in the core	**Φ [m^{-2}s^{-1}]**			
	thermal (< 0.4 eV)	epithermal (0.4 eV–0.1 MeV)	fast (> 0.1 MeV)	total
the end of tube post	4.66E+011	2.58E+011	3.06E+011	1.03E+012
wire #3 – middle of the fuel	3.85E+011	3.75E+011	4.92E+011	1.25E+012
wire #3 – end of the fuel	1.37E+011	7.52E+010	9.29E+010	3.06E+011

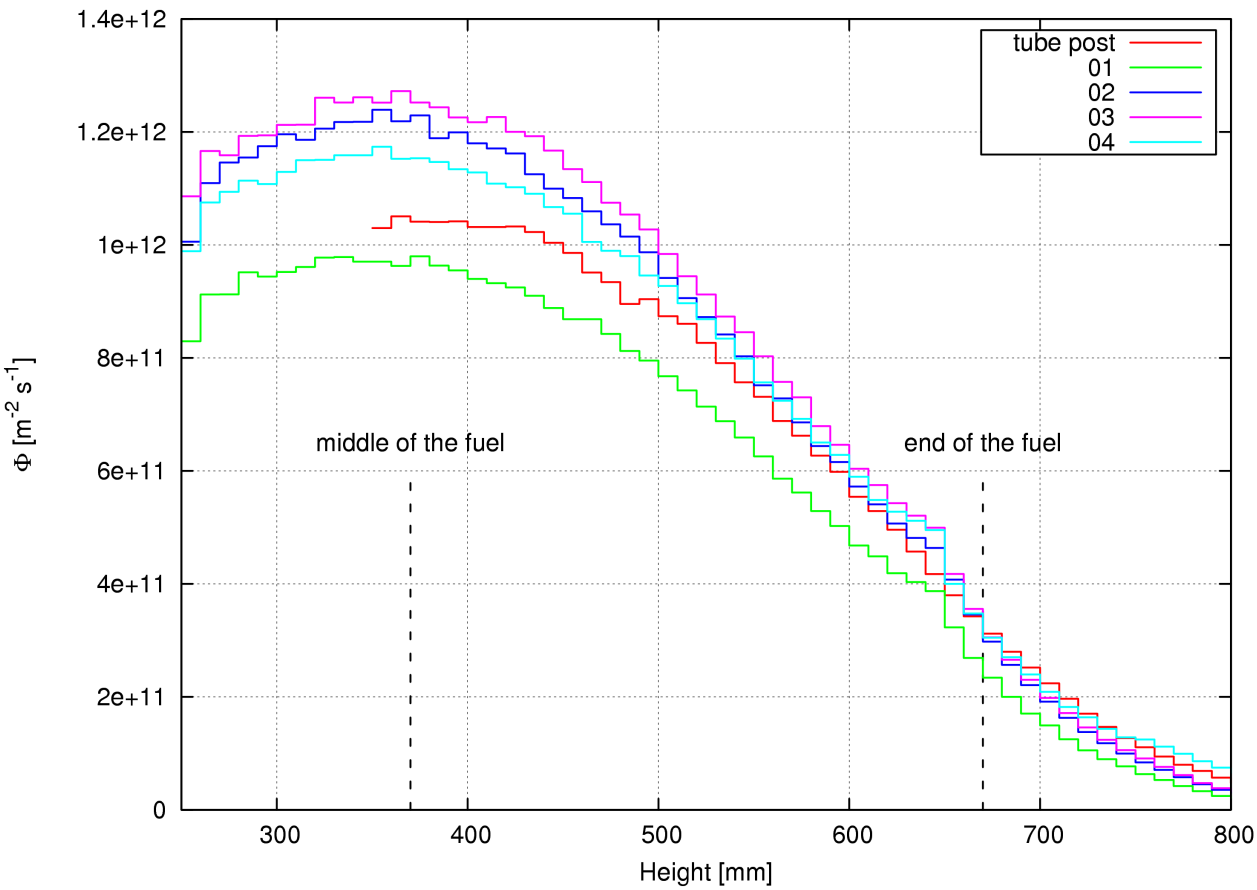

Fig. 3: Neutron flux density; vertical wires

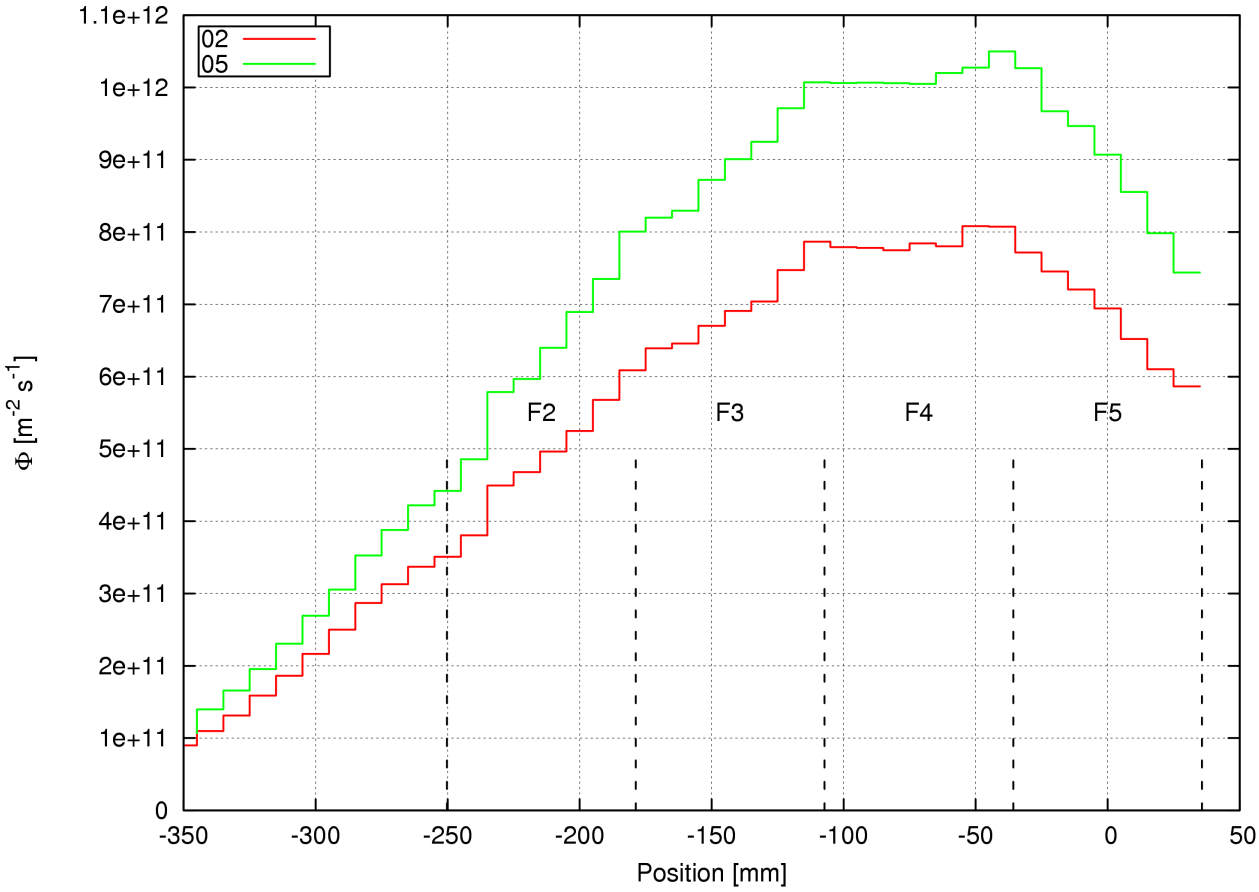

Fig. 4: Neutron flux density; horizontal wires

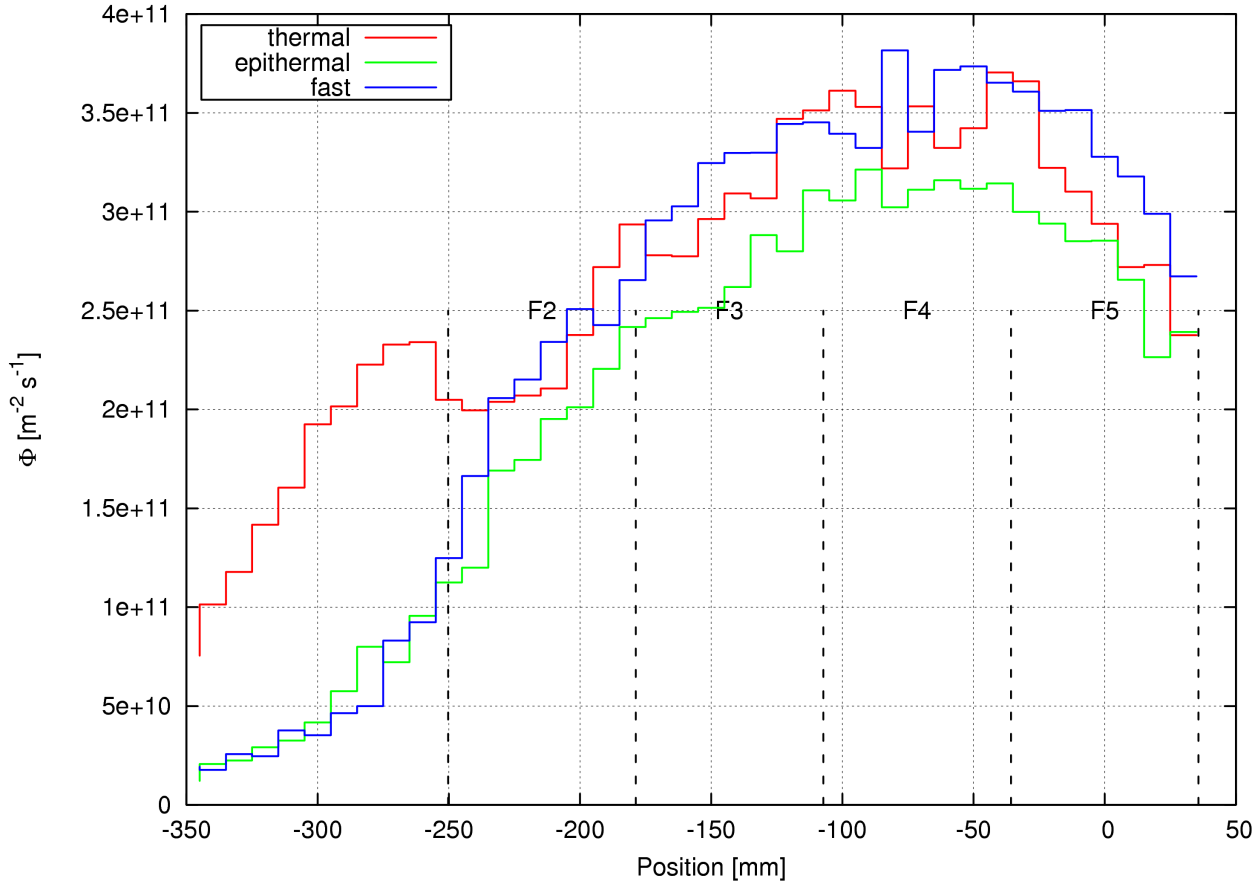

Fig. 5: Thermal, epithermal, and fast neutron flux density; horizontal wire No. 5

Discussion, conclusion

Axial and radial reflector peaks are not visible in charts of total neutron flux density distribution in Figures 3 and 4, but these peaks can be found in charts of thermal neutron flux density distribution, e. g., in Figure 5, because neutron transport between fuel and reflector (moderator) causes an increase in fraction of the thermal group of neutrons and a decrease in the fraction of epithermal and fast groups of neutrons.

All the measurements have verified theoretical expectations. The self-shielding effect of gold wire was also observed during data processing.

References

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