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TECHNICAL NOTE

Analysis of thermal neutron flux measurement in the Cobalt Irradiation Device at ETRR-2

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Abstract The measurements of geometrical distribution of thermal neutron flux in research reactors are often used in the field of reactor operation and reactor physics. Usually such measurements are carried out by using the gold wire activation method. This method has been used for measuring a thermal neutron flux at the location of a Cobalt Irradiation Device (CID) of ETRR-2. A special device was used for locating samples in an irradiation box and the measurements were performed for seventy-two positions. The Monte Carlo MCNP-4B code has been used for the modeling and simulation of ETRR-2 core with structural materials and surrounding beryllium reflectors. The device used in the flux measurement was also simulated in the MCNP-4B model. The thermal flux has been calculated and compared with the experimental one. The results show good agreement between the measured and calculated flux.

Key words ETRR-2 • CID • MCNP-4B • thermal neutron flux

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Introduction

ETRR-2 is an open pool type reactor with a nominal power of 22 MW. The reactor core is cooled and moderated by demineralized water and reflected by beryllium blocks. The core is configured in a 5×6 grid surrounded by a zircalloy chimney with a double wall which defines an inner space used for the second shutdown system. The inner space is filled with nitrogen during normal operation and a gadolinium solution ($Gd(NO_3)_3$ in water) in case of emergency. The core has 29 positions for fuel elements and one position for the central irradiation box currently occupied by the CID. The fuel elements are of low enriched uranium type (19.75% U-235) with aluminum cladding. Each fuel element has 19 fuel plates. The reactor is controlled by six absorber plates made from Ag–In–Cd alloy. External irradiation grid arrays are positioned around the reactor chimney. The irradiation grid has locations for beryllium reflectors, empty boxes and external irradiation devices [2]. The configuration of ETRR-2 core and the location of cobalt irradiation box are shown in Fig. 1.

The cobalt irradiation box has the basis of 8×8 cm and the height of 80 cm. Two irradiation bundles are placed in the device. Each bundle consists of 16 Al tubes filled with cobalt pellets in the form of cylinders of 1 mm in diameter and 1 mm in height. The effective height of each bundle, without the separators and terminal flanges, is 32 cm.

The CID is designed to produce 50,000 Ci/year (1.85×10^{15} Bq/year) of Co-60 with a specific activity of 200 Ci/g (7.4×10^{12} Bq/g). The two bundles are irradiated for two years and one bundle is extracted annually.

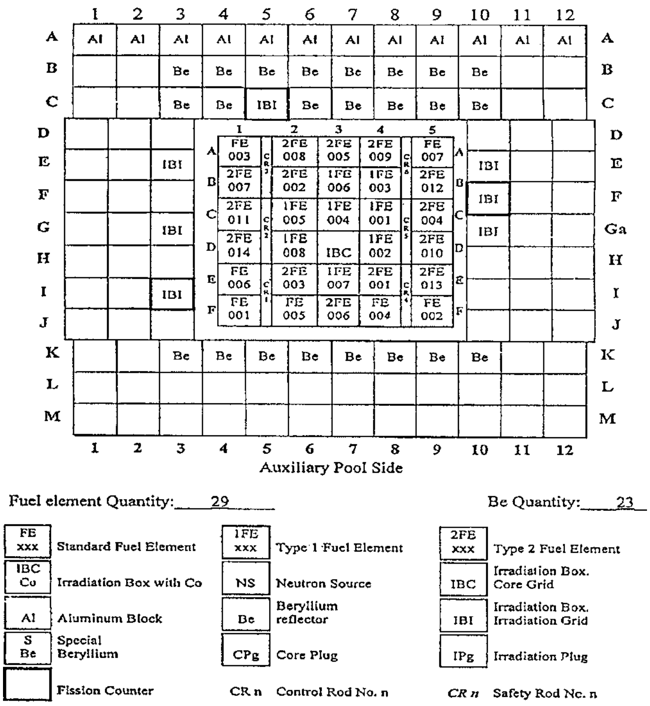

Fig. 1. Configuration of ETRR-2 core.

Experimental

The thermal neutron flux has been measured at the location of the CID using the activation method. Activation wire detectors, made from 0.112% Au diluted in Al, were placed

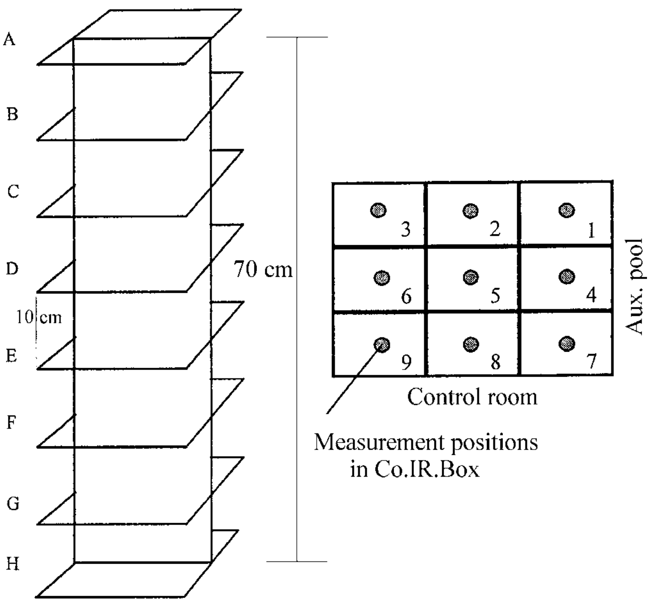

Fig. 2. Schematic drawing of the measuring device in Co. IR. Box.

Table 1. Control rod configuration.

Control rod positions (% withdrawn)					
CR-1	CR-2	CR-3	CR-4	CR-5	CR-6
100	100	0.0	22	100	0.0

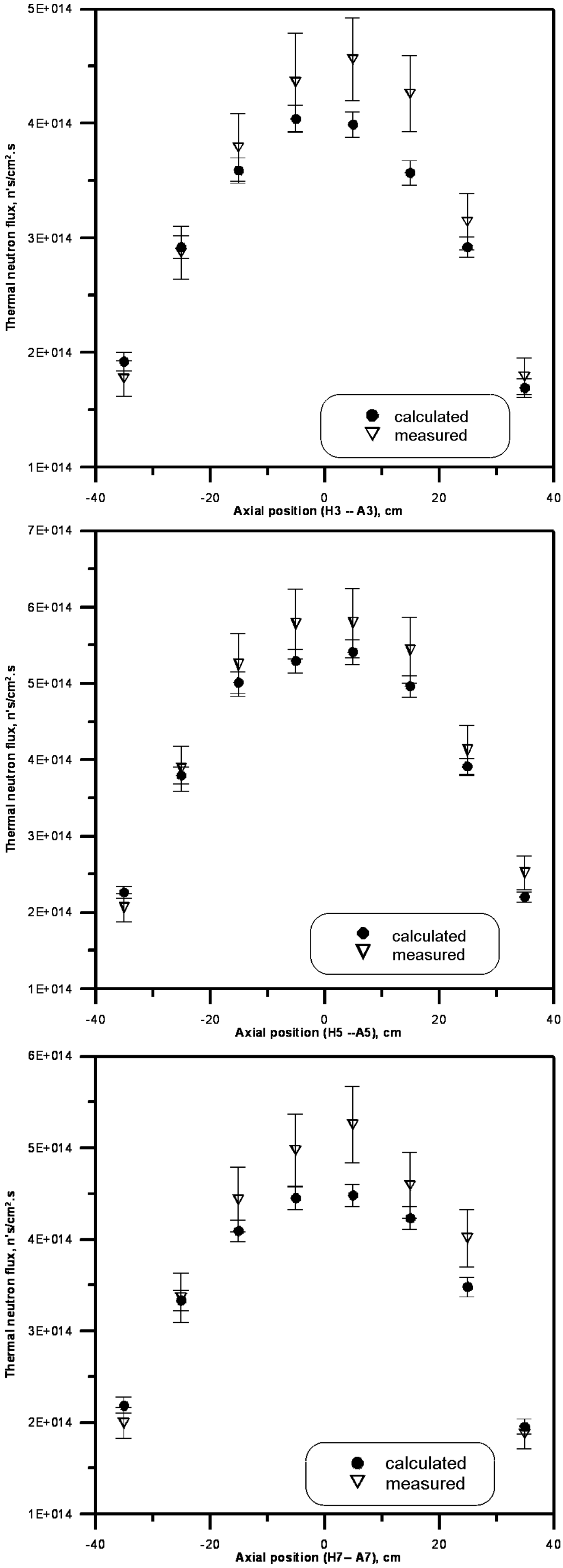

Fig. 3. Axial distributions of thermal flux in lines 3, 5 and 7.

Table 2. Comparison of calculated and measured thermal flux.

Pos.	Calculated	Measured	C/M	Pos.	Calculated	Measured	C/M
A1	1.84E14	1.93E14	0.95	**E1**	4.38E14	4.50E14	0.97
A2	1.89E14	2.02E14	0.93	**E2**	4.81E14	4.51E14	1.06
A3	1.69E14	1.79E14	0.94	**E3**	4.04E14	4.36E14	0.93
A4	2.16E14	2.12E14	1.02	**E4**	5.17E14	4.84E14	1.06
A5	2.20E14	2.51E14	0.88	**E5**	5.29E14	5.78E14	0.92
A6	1.87E14	1.95E14	0.96	**E6**	4.73E14	4.72E14	1.01
A7	1.95E14	1.87E14	1.04	**E7**	4.45E14	4.97E14	0.89
A8	2.05E14	2.03E14	1.01	**E8**	4.73E14	4.27E14	1.11
A9	1.63E14	1.86E14	0.88	**E9**	4.12E14	4.68E14	0.88
B1	3.06E14	3.34E14	0.92	**F1**	4.07E14	4.21E14	0.97
B2	3.14E14	3.42E14	0.92	**F2**	4.24E14	4.26E14	1.00
B3	2.92E14	3.14E14	0.93	**F3**	3.59E14	3.79E14	0.94
B4	3.44E14	3.80E14	0.90	**F4**	4.45E14	4.65E14	0.96
B5	3.91E14	4.12E14	0.95	**F5**	5.01E14	5.24E14	0.95
B6	2.96E14	3.37E14	0.88	**F6**	4.36E14	4.51E14	0.97
B7	3.48E14	4.01E14	0.87	**F7**	4.09E14	4.43E14	0.93
B8	3.33E14	3.55E14	0.93	**F8**	4.38E14	4.55E14	0.96
B9	2.78E14	2.91E14	0.95	**F9**	3.75E14	4.23E14	0.88
C1	3.90E14	4.50E14	0.87	**G1**	3.21E14	3.21E14	1.00
C2	4.09E14	4.61E14	0.88	**G2**	3.37E14	3.60E14	0.93
C3	3.57E14	4.26E14	0.84	**G3**	2.92E14	2.87E14	1.02
C4	4.47E14	4.92E14	0.91	**G4**	3.57E14	3.34E14	1.06
C5	4.95E14	5.43E14	0.92	**G5**	3.73E14	3.88E14	0.96
C6	4.00E14	4.46E14	0.90	**G6**	3.28E14	3.34E14	0.98
C7	4.23E14	4.59E14	0.92	**G7**	3.33E14	3.36E14	0.99
C8	4.16E14	4.87E14	0.85	**G8**	3.37E14	3.42E14	0.98
C9	3.85E14	4.51E14	0.85	**G9**	3.02E14	3.47E14	0.92
D1	4.31E14	4.51E14	0.95	**H1**	1.87E14	1.59E14	1.17
D2	4.73E14	5.18E14	0.91	**H2**	2.18E14	1.96E14	1.11
D3	3.99E14	4.56E14	0.88	**H3**	1.92E14	1.77E14	1.09
D4	5.00E14	5.47E14	0.92	**H4**	2.30E14	2.02E14	1.14
D5	5.41E14	5.79E14	0.93	**H5**	2.26E14	2.06E14	1.10
D6	4.42E14	5.02E14	0.88	**H6**	2.13E14	1.97E14	1.08
D7	4.48E14	5.25E14	0.85	**H7**	2.18E14	1.99E14	1.10
D8	4.73E14	5.39E14	0.88	**H8**	2.22E14	1.95E14	1.23
D9	4.14E14	4.82E14	0.86	**H9**	2.01E14	1.88E14	1.06

in equidistant positions in a special device in order to use the same weighting volume for each measurement point [3]. Bare and covered samples of Cd were fixed in the device, which was inserted in place of CID. Figure 2 shows a schematic drawing of the device used in the activity measurement. Figure 2 shows the planes, which are labeled from A to H, and the measurement positions at each plane.

An NaI detector was used to determine the activity of the samples. The detector efficiency was calibrated with a set of calibration sources. The thermal neutron flux has been derived from the measured activity and normalized to 22 MW. The measurements were performed for the core configuration 1/98, and with the control rod configuration given in Table 1.

Computational means

The core configuration 1/98 with the control rod pattern shown in Table 1 has been modeled using the Monte Carlo

MCNP-4B [1]. The measuring device shown in Fig. 2 was also present in the reactor model. The libraries for the transport calculations were based on the continuous energy ENDF/B-VI cross-section set. The code was used to predict the thermal neutron flux distributions in the seventy-two measurement positions in the device.

Results and discussions

The validity of the calculations was verified by a comparison with the experimental values. Table 2 presents the comparison between the calculated and measured thermal neutron flux and the ratio of the two values (C/M) for the seventy-two positions. We observed that the deviation of the calculated neutron fluxes from the corresponding measured ones was less than 15% for most of the foils applied in the experiment.

Figure 3 shows the calculated and measured axial distributions of thermal neutron flux in the three vertical lines, diagonal, of the measuring device. The Figure shows consistency between the calculated and measured values in the majority of the analyzed points.

Due to the use of Monte Carlo method, the uncertainties of the calculated thermal neutron flux are assumed to be caused mainly by the input data of the calculations. These are the ENDF/B-VI neutron data, geometry simulation and nuclear density of each core components. Regarding the experimental results, the main source of errors comes from the efficiency of the detector and the atomic number density of each foil.

Conclusions

The thermal neutron flux distributions in the cobalt irradiation device were determined by the multi-activation foil method. The computational analysis of the thermal flux distributions was carried out using the three-dimensional Monte Carlo transport calculations. The results of this analysis demonstrate that good agreement between the calculations and the measurements can be achieved, i.e. it is possible to calculate the absolute thermal flux with a reasonable accuracy.

References

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