Results of the reactor dosimetry experiments performed for verification of the neutron transport calculations at the Hungarian Paks Nuclear Power Plant

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Abstract. The operational lifespan of all four units at the Hungarian Paks Nuclear Power Plant (NPP) has been extended by 20 years beyond the original 30-year term. This extension has been implemented gradually, in one- to two-year increments, since 2013. The Hungarian Atomic Energy Authority, responsible for granting approval for these life extensions, has prescribed the continuous and rigorous monitoring of the reactor pressure vessel (RPV) throughout the plant's extended service life. Among the key requirements is the validation of the neutron transport calculations, with specific attention to the large Lead Factor (LF), which reaches around 12 at the reactor core's center. To meet these regulatory requirements, neutron transport calculations and reactor dosimetry measurements using neutron activation detectors (neutron monitors) have been conducted both inside and outside the RPV. Inside measurements were taken in the RPV surveillance channel, while outside measurements were conducted in the cavity adjacent to the outer wall of the RPV. These efforts aim to determine the key parameters of the neutron irradiation and validation is achieved if the experimental results agree with the neutron transport calculations at both the surveillance position and the RPV's outer wall (in the cavity), ensuring that the calculations are also valid for the inner wall of the RPV. This paper presents the validation of experimental data used to confirm the accuracy of the neutron transport calculations. The results of irradiations conducted over one- and four-year periods are compared and analyzed to demonstrate the authenticity of the experimental data for validation of the calculation results.

1 Introduction

As it is known, the Hungarian Paks Nuclear Power Plant (NPP) consists of four VVER-440 type reactors. In this type of reactor, the irradiation channels used for the reactor pressure vessel (RPV) surveillance investigations are located inside the RPV but are positioned far from its inner wall. Therefore, the value of the Lead Factor (fast neutron flux ratio between the RPV surveillance position and the corresponding RPV wall position, LF) is rather large (at the vertical center of the reactor core it is ~ 12). In this case the neutron spectrum at the channel for RPV surveillance investigations can significantly differ from the one appearing at the pressure vessel wall.

The service life of the NPP has been extended (from the original 30 years) by 20 years from 2013, in 1-2 years steps for the different reactor units. The Hungarian Atomic Energy Authority, which issues the permission for the service life extension of the NPP, has prescribed the continuous and extensive investigation and control of the condition of the RPV during the complete service life of the nuclear power plant.

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Among others, the validation of the neutron transport calculation results by experiments at the RPV surveillance positions and at the RPV wall is also prescribed [1], taking into consideration the large value of the Lead Factor, mentioned above. The neutron transport calculation results were already validated with experimental data more times in the RPV surveillance positions, but – to fulfill the above requirement of the authority – in the latest validating procedure (the experimental data of which will be analyzed here) the results of the theoretical calculations and of the corresponding experimental data were compared on both sides of the RPV, i.e. inside: in the RPV surveillance channels, and outside: in the „cavity" at the outer wall of the reactor pressure vessel. This validation procedure is important in the present case, because: if the results of the measurements and of the neutron transport calculations agree both in the surveillance positions and at the outer wall of the reactor pressure vessel (in the cavity), then we can consider the neutron transport calculations to be validated, and to be acceptable also at the inner wall of the RPV.

In this paper, the authenticity of the experimental data for the latest validation of the theoretical calculation results will be shown. Therefore, the different experimental data obtained in more different time irradiations and in more irradiation, places will be presented together with their intercomparison and analysis in the RPV surveillance positions and at the outer wall of the RPV (i.e., in the cavity).

As it has been shown earlier that the different reactor units of the NPP – due to their very similar construction and fuel load patterns – are behaving in similar way, it became clear that the verification of the theoretical calculation results by experiments is not a unit specific task. Therefore, the Hungarian Atomic Energy Authority appointed the reactor unit No. 2 for the validation task [1] as a reference for the other reactor units. Thus, the presented experimental results and their analysis refer to the reactor unit No. 2.

2 Analysis of the experimental results

2.1 Summary of experimental circumstances

Experiments on reactor unit No. 2, aimed at validating the neutron transport calculation results, were made during reactor cycles No. 28-31, spanning from August 2012 to October 2016) [2]. Comparing the characteristics of the reactor operation during this time, it has turned out that the length of different (28th, 29th, 30th and 31st) reactor cycles expressed in calendar days and in effective days (corresponding to 100 % reactor power) are about the same (the difference between the corresponding data is generally less than 1 %) [2]. That means, that the reactor was operated during the four-year irradiations at its maximum power.

During reactor cycles No. 28, 29, 30, and 31, activation neutron detectors (neutron monitors) were irradiated in the RPV surveillance positions and at the outer wall of the pressure vessel (in the cavity) in the following ways:

- four times one-year irradiation, and parallelly four-year irradiation in the cavity, and
- four-year irradiation in the RPV surveillance positions (in parallel with the cavity ones).

The irradiation circumstances will be shown in **Figures 1** and **2**.

As the experimental data were planned to be used for the validation of the theoretical calculations, their authenticity was an essential requirement. Therefore, the original experimental results have been re-evaluated before the validation procedure: they were compared with each other, and consistency investigations were made between the corresponding experimental data. Then the obtained results were analyzed (see Chapter 2.2).

2.1.1 Experimental circumstances in the RPV surveillance positions

Two irradiation chains situated parallel with each other, and containing capsules filled with surveillance specimens and neutron monitor sets were irradiated in the RPV surveillance channels [2]. One of the irradiation chains contained 7, the other one contained 4 irradiation capsules. In each capsule two neutron monitor sets were present, one below the specimens, the other one above them (see **Figure 1**). The distance between the middle of the two neutron monitor sets was 58 mm. The coordinates of the irradiation positions (their distance from the bottom of the reactor core) will be presented in tables containing the results of the measurements.

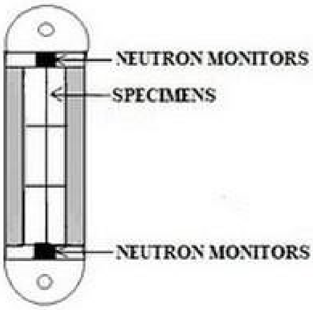

Figure 1. Simplified drawing of the construction of the normal irradiation capsule used in the RPV surveillance irradiations.

The neutron monitor sets - due to the long (four years) irradiation time - contained neutron detectors having reaction products only with long half-life compared with the irradiation time. They were the following ones: Cu, Nb, and Co-Al. The Co content of the Co-Al alloy was 0.1%. The response region of the applied neutron monitors in the investigated neutron spectra is shown in **Table 1.**

Table 1. Response regions of the neutron monitors used in the RPV surveillance positions and at the outer wall of the RPV (in the cavity).

Neutron monitor	Nuclear reaction	Short reaction name	90% of response region (MeV)	
			RPV Surv. position	Cavity
Fe	$^{54}Fe(n,p)^{54}Mn$	Fe54P	Not used	1.8 – 8.2
Nb	$^{93}Nb(n,\gamma)^{94}Nb$	Nb93G	2.8E-8 – 3.2E-2	2.8E-8 – 3.2E-1
	$^{93}Nb(n,n')^{93m}Nb$	Nb93N	0.6 – 5.5	0.4 – 5.5
Cu	$^{63}Cu(n,\alpha)^{60}Co$	Cu63A	4.5 – 12.5	4.5 – 12.5
Co	$^{59}Co(n,\gamma)^{60}Co$	Co59G	1E-8 – 1.4E-4	1E-8 – 2.2E-4
Ag	$^{109}Ag(n,\gamma)Ag^{110m}$	Ag109G	Not used	2.8E-8 – 6.9E-5

2.1.2 Experimental circumstances in the cavity

At the outer wall of the RPV, in the cavity, a sample holder was situated opposite to the RPV surveillance channels, for fixing the neutron detectors during their irradiation. On the sample holder four irradiation positions (S1, S2, S3, S4 – see **Figure 2**) are present for neutron spectrum measurement. The irradiation positions S1 and S3 are vertically in the height of the weld No. 5/6, while the positions S2 and S4 are vertically in the height of the core center. The sample holder contains also other irradiation positions for neutron flux distribution measurements, but the results of these measurements are not presented here, because they were not used in the validation procedure.

The neutron monitor sets irradiated in the cavity for neutron spectrum measurement contained the following activation neutron detectors: Fe, Cu, Nb, Co-Al, and Ag-Al. The Co content of the Co-Al detectors was 0.1%. The Ag content of the Ag-Al detectors was 1% in case of the one-year irradiations, but in case of the four-year irradiation this detector was not used, due to the short half-life (249.8 d) of the ^{110m}Ag reaction product. The response region of the applied neutron monitors in the investigated neutron spectra is shown in **Table 1** also in case of these irradiations.

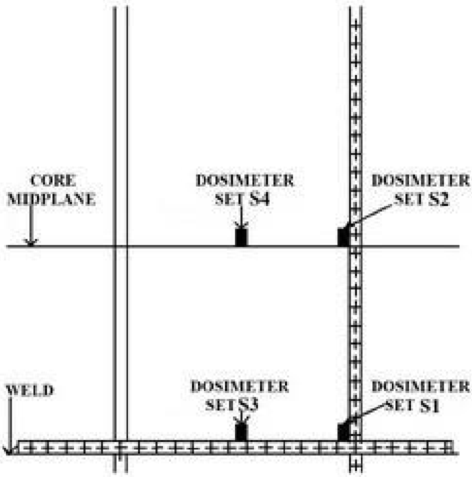

Figure 2. Placing of the neutron monitor sets on the sample holder in the cavity.

2.1.3 Measurement of the activity of the neutron monitors

The activity of the irradiated neutron monitors was measured by a HPGe semiconductor detector. To measure the intensity of the X-ray lines (K_α and K_β) of the ^{93m}Nb metastable isotope produced in the ^{93}Nb(n,n') reaction, the Nb was dissolved by chemical procedure, and special samples were prepared from it.

To determine the reaction rate from the measured activity of the neutron monitors, the" History Factor" (HF) of the irradiation (showing the activation and decay characteristics of the monitors during the irradiation) must be known. The History Factor of the different irradiations was calculated using the procedure described in Reference [3]. As the value of the HF is the same for the different irradiation positions both in the RPV surveillance channels and in the cavity, the reaction rates (R) derived from the specific activities (A_s) with the aid of these History Factors will not be analyzed here, as they do not have extra information compared with the specific activity values.

2.1.4 The value of the fast neutron flux above 0.5 MeV irradiating the neutron monitors

In the case of the radiation damage investigations of the RPV of the VVER-440 type nuclear reactors, the fast neutron fluence above 0.5 MeV $\Phi(E>0.5\text{ MeV})$ is used for characterizing the fast neutron exposition of the pressure vessel. The radiation damage of the RPV is then investigated as a function of this parameter. For determination the fast neutron fluence above 0.5 MeV, the fast neutron flux above 0.5 MeV energy must be known at the place of the irradiation, which can be derived from the neutron spectrum present at this point.

In the present case, the neutron spectrum fitting to experimental data was determined with aid of the neutron spectrum adjustment code SANDBP [4], using the reaction rates calculated from the experimentally determined activities.

2.2 Results and their analysis

In the following chapters the specific activity (A_s) of the irradiated neutron monitors and the neutron flux above 0.5 MeV ϕ(E>0.5 MeV) obtained at the different irradiation places will be analyzed. The reaction rates (R) derived from the specific activity values - due to the above-mentioned reasons – will not be investigated here.

After re-evaluating the experimental results, consistency investigation was made between all the specific activities both in the RPV surveillance positions and in the cavity. If deviation was found, the error was searched and corrected. By the end of the procedure, we could reach that all the specific activity data both in the RPV surveillance positions and in the cavity agreed with the requirements within their two standard deviation values, i.e., they could be consistent with each other. This circumstance already contributes to the authenticity of the evaluated experimental data.

2.2.1 Evaluation of the experimental results in the RPV surveillance position

In the RPV surveillance channels two irradiation chains (named 4G1F and 4G2F) were situated parallel with each other (details in Chapter *2.1.1.*) and irradiated for four years in the frame of the 28th – 31st reactor cycles. As the coordinates of four irradiation capsules (and so also of the corresponding neutron monitor sets) present in the two chains agree (within some millimeters) with each other, the data of these monitor sets will be presented and compared below. The results obtained only in case of the fast neutron reactions will be shown here, but conclusions similar to the ones of the fast neutron reactions can be drawn also in case of the thermal neutron reactions [2].

During the evaluation of the experimental data, first the specific activity (A_s) of the different neutron monitors was determined. **Table 2** shows the A_s values and their ratio in case of the ^{93}Nb(n,n') and of the ^{63}Cu(n,α) reaction of the neutron monitors in the nearly identical irradiation positions of the parallel irradiation chains.

Table 2. Specific activity (A_s) values and their ratio in case of the ^{93}Nb(n,n') and ^{63}Cu(n,α) nuclear reactions of the neutron monitors, in the nearly identical irradiation positions of the parallel irradiation chains (4G1F and 4G2F) situated in the RPV surveillance channels.

RPV Surveillance irradiation positions – Specific activities (As) and their ratios (four-year irradiation)						
Reaction Nb93N						
Irradiation chain 4G1F			**Irradiation chain 4G2F**			**As ratio 4G1F/4G2F**
Irradiation position	**Co-ordinate (mm)**	**Specific activity (As) (Bq/mg)**	**Irradiation position**	**Co-ordinate (mm)**	**Specific activity (As) (Bq/mg)**	
4G1F1	2583.5	4.57E4 ± 9.21%	4G2F1	2589.5	4,75E4 ± 9.12%	0.962
4G1F2	2454.5	1.01E5 ± 8.95%	4G2F2	2457.5	1.12E5 ± 9.16%	0.902
4G1F3	2321.5	1.68E5 ± 9.11%	4G2F3	2328.5	1.64E5 ± 9.12%	1.024
4G1F4	1422.5	2.58E5 ± 9.11%	4G2F4	1444.5	2.68E5 ± 9.12%	0.963
Reaction Cu63A						
Irradiation chain 4G1F			**Irradiation chain 4G2F**			**As ratio 4G1F/4G2F**
Irradiation position	**Co-ordinate (mm)**	**Specific activity (As) (Bq/mg)**	**Irradiation position**	**Co-ordinate (mm)**	**Specific activity (As) (Bq/mg)**	
4G1F1	2583.5	3.21E2 ± 4.72%	4G2F1	2589.5	3.15E2 ± 5.22%	1.019
4G1F2	2454.5	7.08E2 ± 4.74%	4G2F2	2457.5	6.89E2 ± 4.73%	1.027
4G1F3	2321.5	1.11E3 ± 5.22%	4G2F3	2328.5	1.12E3 ± 4.72%	0.991
4G1F4	1422.5	1.73E3 ± 5.22	4G2F4	1444.5	1.76E3 ± 4.72%	0.983

The A_s values in **Table 2** are calculated for the center of the irradiation capsule, and the coordinates mean the distance of the irradiation positions from the bottom of the reactor core. From these data it can be seen, that the specific activity (A_s) values in the nearly identical irradiation positions agree with each other within one standard deviation value of the investigated data. This very good agreement of the specific activity values shows their reliability.

The reaction rates (R), derived from experimental data, were calculated using the measured specific activity (A_s) values and the History Factor of the irradiation [2,3], which was determined from the reactor's operational characteristics (details in Chapter *2.1.3.*). As previously noted (Chapter *2.1.3.*), the reaction rates will not be analyzed here due to the nearly equal History Factor values observed across different irradiation positions. However, these reaction rates will be utilized in the neutron spectrum adjustment procedure.

The value of the fast neutron flux, irradiating the neutron monitors (and the specimens as well) can be calculated from the neutron spectrum adjusted to the experimental data. **Table 3** shows the value of the fast neutron fluxes above 0.5 MeV ϕ(E>0.5 MeV) in the investigated irradiation places, and their ratio between the corresponding irradiation positions of the irradiation chains 4G1F and 4G2F. The fast neutron flux values presented here refer to the center of the irradiation capsules, and the coordinates mean the distance of the irradiation positions from the bottom of the reactor core.

The data in **Table 3** show a good agreement**:** the fast neutron fluxes above 0.5 MeV between the corresponding positions of the two irradiation chains agree with each other within their one standard deviation value. Also, this result shows the authenticity of the experimental data in the RPV surveillance positions.

Based on the neutron spectrum fitted to the experimental data, the ratio of the fast neutron fluxes above 0.5 MeV and above 1 MeV has also been determined in the irradiation positions mentioned in **Table 3** [2]. The obtained results have shown that the ratios of the mentioned fast neutron fluxes (ratio of the flux values above 0.5 MeV and above 1 MeV) agree with each other within 1 % in all the investigated irradiation positions of the two irradiation chains (the details of the results can be found in Reference [2]). This circumstance indicates that the neutron spectrum in the fast neutron energy region is the same throughout the investigated irradiation region.

Table 3. The fast neutron flux values above 0.5 MeV ϕ(E>0.5 MeV) and their ratio in the nearly identical irradiation positions of the parallel irradiation chains (4G1F and 4G2F) situated in the RPV surveillance channels.

RPV surveillance irradiation positions – Neutron flux values above 0.5 MeV ϕ(E>0.5 MeV) (four-year irradiation)						
Irradiation chain 4G1F			**Irradiation chain 4G2F**			**ϕ ratio 4G1F/ 4G2F**
Irradiation position	**Co-ordinate (mm)**	**ϕ(E>0.5 MeV) ($cm^{-2}s^{-1}$)**	**Irradiation position**	**Co-ordinate (mm)**	**ϕ(E>0.5 MeV) ($cm^{-2}s^{-1}$)**	
4G1F1	2583.5	3.96E11± 7.51%	4G2F1	2589.5	4.02E11± 7.40%	0.985
4G1F2	2454.5	8.09E11± 7.82%	4G2F2	2457.5	8.82E11± 7.65%	0.917
4G1F3	2321.5	1.28E12± 7.24%	4G2F3	2328.5	1.39E12± 7.21%	0.921
4G1F4	1422.5	2.20E12± 7.18%	4G2F4	1444.5	2.28E12± 7.60%	0.965

2.2.2 Evaluation of the experimental results in the cavity

At the outer wall of the RPV, in the cavity, the one- and four-year irradiations were performed during the reactor cycles No. 28 - 31. The results of the neutron spectrum measurements performed in the irradiation positions S3 and S4 (being in the height of the weld 5/6, and in the height of the reactor core center, respectively) will only be presented here, as these points are in the most threatened regions of the RPV from the point of view of radiation damage. But the results in the other (S1 and S2) irradiation positions show the same character [2].

Table 4 contains the measured specific activity values (A_s) of the different neutron monitors in the irradiation positions S3 and S4 deriving from the one- and four-year irradiations. The data indicate that for the one-year irradiations, the corresponding A_s values obtained from different reactor cycles often agree within 1-2 standard deviations (but in all cases within 3 standard deviation values) of the investigated data. It means that the loading pattern of the reactor core with the fuel elements was very similar across different reactor cycles. The only exception is the reactor cycle No. 29. Here the A_s values can differ from the other corresponding ones more than three standard deviation values. Looking at the reason for this deviation, it has turned out that in the reactor cycle No. 29 in the outer assemblies of the reactor core, some of the applied fuel elements were of higher burn-up than in the case of the other, one-year irradiations. Most probably this was the reason for the detected difference in the value of the specific activities obtained in the reactor cycle No. 29.

The reaction rates (R) derived from the specific activities will not be analyzed neither here due to the uniformity of the History Factor values at the different irradiation places (see Chapter 2.1.3.), but they will have an important role in the neutron spectrum adjustment procedure.

Table 4. Measured specific activity values (A_s) of the neutron monitors irradiated in the positions S3 and S4 in the cavity, at the outer wall of the RPV.

Cavity – Specific activity values (As) in the *S3* irradiation position (one- and four-year irradiations)					
Neutron monitor reaction	**Specific activity values (As) and their standard deviation [%]**				
	Reactor cycle No. 28 As (Bq/mg)	**Reactor cycle No. 29 As (Bq/mg)**	**Reactor cycle No. 30 As (Bq/mg)**	**Reactor cycle No. 31 As (Bq/mg)**	**Reactor cycle No. 28-31 (4 years) As (Bq/mg)**
Fe54P	2.30E2± 3.75%	2.08E2± 3.44%	2.41E+2±3.53%	2.24E2± 3.70%	Fe monitor not used
Cu63A	5.59E0± 3.35%	5.02E0± 3.37%	5.89E+0±3.36%	6.14E0± 3.40%	1.77E1± 3.50%
Nb93N.	7.75E2± 5.60%	6.60E2± 5.58%	7.76E+2±5.70%	8.53E2± 6.45%	3.09E3± 6.43%
Nb93G	7.80E0± 3.60%	6.78E0± 3.66%	7.56E+0±3.70%	No data	3.24E1± 3.62%
Co59G	2.75E5± 4.38%	2.60E5± 4.38%	2.85E+5±4.38%	3.18E5± 4.50%	9.35E5± 4.35%
Ag109G	2.57E5± 2.95%	2.29E5± 2.98%	2.50E+5±2.87%	2.54E5± 2.95%	Ag monitor not used
Cavity – Specific activity values (As) in the *S4* irradiation position (one and four-year irradiations)					
Neutron monitor reaction	**Specific activity values (As [Bq/mg]) and their standard deviation [%]**				
	Reactor cycle No. 28 As (Bq/mg)	**Reactor cycle No. 29 As (Bq/mg)**	**Reactor cycle No. 30 As (Bq/mg)**	**Reactor cycle No. 31 As (Bq/mg)**	**Reactor cycle No. 28-31 (4 years) As (Bq/mg)**
Fe54P	2.78E2± 4.05%	2.59E2± 3.63%	2.64E2± 3.61%	2.69E2± 3.98%	Fe monitor not used
Cu63A	6.89E0± 3.45%	6.27E0± 3.38%	6.94E0± 3.45%	7.41E0± 3.40%	2.11E1± 3.42%
Nb93N	9.29E2± 5.75%	8.33E2± 6.17%	9.46E2± 5.70%	9.90E2± 6.45%	3.28E3± 6.48%
Nb93G	9.50E0± 3.65%	8.48E0± 3.29%	9.46E0± 3.80%	No data	3.94E1± 3.55%
Co59G	3.39E5± 4.36%	3.15E5± 4.39%	3.42E5± 4.37%	3.90E5± 4.50%	1.13E6± 4.45%
Ag109G	3.12E5± 2.78%	2.79E5± 2.98%	2.98E5± 3.00%	3.06E5± 2.96%	Ag monitor not used

The neutron spectrum at the investigated irradiation places was derived also in case of the cavity irradiations with aid of the SANDPB neutron spectrum adjustment code [4]. From the neutron spectrum adjusted to the experimental data, the fast neutron fluxes above 0.5 MeV and above 1 MeV have been calculated together with their ratio. The results are shown in **Table 5.**

Table 5. Fast neutron flux values above 0.5 MeV ϕ(E>0.5 MeV), and above 1 MeV ϕ(E>1 MeV), furthermore, their ratio in the irradiation positions S3 and S4 in the cavity, at the outer wall of the RPV. (The coordinates of the irradiation positions (distance from the bottom of the reactor core) are as follows: - S3 (height of the weld 5/6): 276 mm; - S4 (core center): 1275 mm).

Cavity – Fast neutron flux values ϕ(E>0.5 MeV) and ϕ(E>1 MeV), and their ratios (one- and four-year irradiations)						
Reactor cycle No.	**ϕ(E>0.5 MeV) (cm^{-2}.s^{-1})**		**ϕ(E>1 MeV) (cm^{-2}.s^{-1})**		**Ratio ϕ(E>0.5 MeV) / ϕ(E>1 MeV)**	
	S3	**S4**	**S3**	**S4**	**S3**	**S4**
28	3.82E10 ±11.94%	4.57E10 ±11.77%	1.50E10 ±6.12%	1.80E10 ±6.21%	2.55 ±13.42%	2.54 ±13.31%
29	3.25E10 ±5.51%	4.13E10 ±5.70%	1.29E10 ±5.38%	1.63E10 ±5.40%	2.52 ±7.70%	2.53 ±7.85%
30	3.56E10 ±6.21%	4.35E10 ±6.14%	1.41E10 ±6.10%	1.70E10 ±6.17%	2.52 ±8.70%	2.56 ±8.70%
31	3.47E10 ±6.49%	4.02E10 ±6.52%	1.31E10 ±6.37%	1.52E10 ±6.14%	2.65 ±9.09%	2.64 ±8.96%
28-31 (four-year irradiation)	3.55E10 ±6.46%	3.77E10 ±6.57%	1.47E10 ±6.11%	1.57E10 ±6.28%	2.42 ±8.89%	2.40 ±9.09%

The following conclusions can be drawn from the data in Table 5:

- The fast neutron flux values above 0.5 MeV, obtained in case of the one-year irradiations during the different reactor cycles, agree with each other in the investigated (S3 and S4) irradiation positions within 2 standard deviation values of the corresponding data.
- The ratios of the fast neutron fluxes above 0.5 MeV and above 1 MeV agree with each other within one standard deviation value (sometimes within (0.5-1) %) of the investigated data in the S3 and in the S4 irradiation positions, including all the one-year irradiations and also the four-year irradiation. The same result was obtained in the other (S1, S2) irradiation positions as well [2]. It means that the neutron spectrum in the fast neutron energy region was the same in all the investigated points during all the irradiation cycles at the outer wall of the RPV.

All the above results justify the reliability of the experimental results obtained at the outer wall of the RPV.

3 Conclusions

Based on the analysis of the experimental results obtained in the RPV surveillance positions and at the outer wall of the RPV (in the cavity) the following conclusions can be drawn:

1. The results of the reactor dosimetry experiments presented above certify the authenticity and suitability of the experimental data for the validation of the neutron transport calculations at the RPV surveillance positions and at the outer wall of the RPV.

2. The experimental results also show the fact, that the neutron spectrum in the fast neutron energy region is the same in the whole investigated irradiation region both in case of the RPV surveillance positions and at the outer wall of the RPV (in the cavity).

3. This paper concentrates only on the experimental results. The results of the validation of the neutron transport calculations by the experimental data will be presented in another paper. However, referring to the summarizing report [2] we can say that the performed validation procedure has shown that the corresponding experimental and theoretically calculated data, characterizing the neutron irradiation in the RPV surveillance positions and at the outer wall of the RPV, agree with each other generally within their two-standard deviation (but in all cases within their 3- standard deviation) values [2,5].

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