Application of Surface-Harmonics Code SUHAM-U and Monte-Carlo Code UNK-MC for Calculations of 2D Light Water Benchmark-Experiment VENUS-2 with UO^2 and MOX Fuel.

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Abstract

Verification of the SUHAM-U code has been carried out by the calculation of two-dimensional benchmark-experiment on critical light-water facility VENUS-2. Comparisons with experimental data and calculations by Monte-Carlo code UNK with the same nuclear data library B645 for basic isotopes have been fulfilled. Calculations of two-dimensional facility were carried out with using experimentally measured bucklings values. Possibility of SUHAM code application for computations of PWR reactor with uranium and MOX fuel has been demonstrated.

1. Introduction

The management of ex-weapon plutonium withdrawn from defense programs has become important to the international community. For successful utilization of plutonium as mixed – oxide (MOX) fuel in nuclear power plants it is still necessary to validate both the basic nuclear data and methods of calculations to understand better the behavior of MOX fuel in challenging situations and to identify requirements in nuclear data corrections and improvements of numerical methods of neutron-physics modeling. For this purpose the VENUS-2 experimental data have been released by SCK-CEN, Mol, Belgium [1].

In framework of ISTC project #1836, SUHAM-U code [2, 3] which uses the surface harmonics method to solve neutron transport equation is developed. This code uses modern cross-section library based on ENF-B, JEFF and JENDL nuclear data files and microgroup (about 7000) algorithm for resonance shielding calculations and procedure for condensation of microgroup cross-sections to the multigroup (up to 89) ones, which are taken from code system UNK [4]. UNK-MC [5] code uses the collision probability method on the stage of cell calculations and Monte-Carlo method on the stage of multigroup reactor calculations.

From the results of calculational benchmark performed earlier in [2], it was found, that there is a necessity to use experimental data to validate SUHAM-U and UNK codes for neutron-physical calculations of light water reactors.

This paper presents results of SUHAM-U and UNK-MC codes validation on the base of VENUS-2 benchmark-experiment calculations.

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2. Technique of Calculations

SUHAM-U validation and verification was carried out during three stages. On the first stage validation of UNK algorithms of preparing multigroup macroscopic cross-sections was performed. For this purpose cell calculations were performed and cross-sections for UNK Monte-Carlo option were prepared. Then, on the second stage, VENUS-2 assembly calculations using Monte-Carlo method were performed. At the end of the second stage algorithm of preparing the multigroup cross-sections was validated. At the third stage, SUHAM-U calculations were carried out.

Monte –Carlo calculations were carried out using 51 multigroups of macroscopic and microscopic cross-sections. 51-groups cross-sections were condensed with use of the microgroup spectra obtained from collision probability cells calculations (UNK-cell code was applied). Resonance shielding of isotopes ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu was taken into account with application of 7400 microgroups in slowing down energy region. Calculations of two-dimensional facility were carried out with using experimentally measured bucklings values.

Calculations with SUHAM-U code were carried out using 12 multigroup cross-sections. Justification of 12-groups description of energy region was carried out earlier in paper [2]. 12-groups cross-sections were condensed with use of the microgroup spectra obtained from UNK collision probability cells calculations. Resonance shielding of isotopes ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu and additionally Zr (natural blend) was taken into account with application of 7400 microgroups in slowing down energy region. Axial leakage was taken into account with using experimentally measured bucklings.

3. Results of calculations

Values of k_∞, received with application of SUHAM-U and UNK codes and average values of k_∞ given in benchmark description, are shown in Table 1. Comparison of infinite medium neutron multiplication factors, received in presented paper are in good agreement with results, received by benchmark participants [1].

Table 1: Results of k_∞ calculations for all types of fuel rods cells are given in Table 1.

Cell type (enrichment U/Pu, %)	UNK, Collision probability	SUHAM-U, Surface Harmonics	Deterministic codes [1]	Monte-Carlo codes [1]
3.3/0	1.40834	1.40862	1.40400	1.40786
4.0/0	1.33878	1.33902	1.33527	1.33925
2.0/2.7	1.25667	1.25735	1.25546	1.25800

Value of effective neutron multiplication factor, achieved with UNC-MC code (Monte-Carlo method) equals 1.003247±0.000025 ($1.5*10^9$ neutron histories).

Calculation of 2D model of VENUS-2 critical assembly with SUHAM-U gave value of effective neutron multiplication factor equaled 0.994543.

Tables 2 and 3 present results of pin-by-pin power distribution benchmark calculations with SUHAM-U and UNK-MC. The following values were used for comparison of pin-by-pin power distribution:

Max(δE_i) – maximum deviation of calculated pin power values from experimental data (in percents);

AVG – average deviation of calculated pin power values from experimental data (percent distinction);

RMS – root mean square of percent distinction.

$$AVG = \frac{1}{N}\sum_{n=1}^{N} e_n \quad (1)$$

$$RMS = \frac{1}{\sqrt{N}}\sqrt{\sum_{n=1}^{N} e_n^2} \quad (2)$$

During performing of benchmark calculations, a mistake in description of pin power extrapolated values [1] was found. Co-ordinates of point with mistaken power value are (x=-25.83, y=6.93).

Table 2: Results of SUHAM-U validation

Value	Uranium Fuel		MOX
	3.3 %	4.0 %	
Max(δE_i)	-4.8 %	8.0 % (5.9 %)*)	6.5 %
AVG	-0.9 %	-0.1 % (-0.1 %)*)	2.5 %
RMS	1.8 %	2.2 % (2.1 %)*)	3.3 %
Total RMS	(2.5 %)*)		

*) *mistake in power distribution at point (x=-25.83, y=6.93) from [1] 1.05 changed on 1.105, received by interpolation procedure.*

Table 3: Results of UNK-MC validation

Value	Uranium Fuel		MOX
	3.3 %	4.0 %	
Max(δE_i)	-6.6 %	9.0 % (-5.8 %)*)	5.7 %
AVG	-0.4 %	-0.3 % (-0.4 %)*)	1.1 %
RMS	1.7 %	2.1 % (2.0 %)*)	3.0 %
Total RMS	(2.3 %)*)		

*) *mistake in power distribution at point (x=-25.83, y=6.93) from [1] 1.05 changed on 1.105, received by interpolation procedure.*

Distinction between pin-by-pin power values, calculated with UNK-MC and SUHAM-U codes with the same nuclear data library (only Zr data were changed) is presented in Table 4.

Table 4: Distinction between results of SUHAM-U and UNK-MC calculations (percent deviation)

Value	Uranium Fuel		MOX
	3.3 %	4.0 %	
Max(δE_i)	7.5 %	7.3 %	10.7 %
AVG	-0.4 %	0.2 %	1.4 %
RMS	1.5 %	1.7 %	3.0 %
Total RMS	2.2 %		

4. Discussion of results

Comparison of calculated with SUHAM-U code pin-by-pin power values with experimental data shows, that in majority of experimental points, excluding fuel rods allocated near boundary of core and steel baffle, the calculated values are in good agreement with experimental data. Maximum deviations of calculated power values from experimental data are in boundary rods. The most appreciably this tendency is observed from results of UNK-MC calculations – maximum deviation take place only in the last row of fuel rods adjoining to steel baffle. This tendency take place simultaneously in fuel cells of all radial zones: central and intermediate, loaded with uranium dioxide accordingly with 3.3% and 4.0 % enrichment, and peripheral zone, loaded with MOX fuel. In all other cells, deviation of SUHAM-U calculational results from UNK-MC calculational ones does not exceed 2% in zones loaded with uranium dioxide fuel and 3% in zone loaded with MOX fuel. Table 5 presents deviation of SUHAM-U calculation results from Monte-Carlo (UNK-MC) results. Comparison was only made for interior cells. All boundary points near steel baffle (see Fig. 1) are excluded from consideration.

Table 5: Distinction between results of SUHAM-U and UNK-MC calculations made only for interior points excluding boundary with steel baffle (percent deviation).

Value	Uranium Fuel		MOX
	3.3 %	4.0 %	
Max(δE_i)	3.1 %	2.1 %	-1.7 %
AVG	0.3 %	-0.2 %	-0.7 %
RMS	1.0 %	0.6 %	0.9 %
Total RMS	0.9 %		

It should be noted, that results, achieved in present work are very close to results, given in benchmark description. Table 6 presents average results of pin power calculations presented in paper [1].

Table 6: Average deviations of calculated pin power values from measured data (percent deviation).

Value	Uranium Fuel		MOX	All fuel pins
	3.3 %	4.0 %		
AVG	-1.6%	-0.7%	4.3%	0.9%

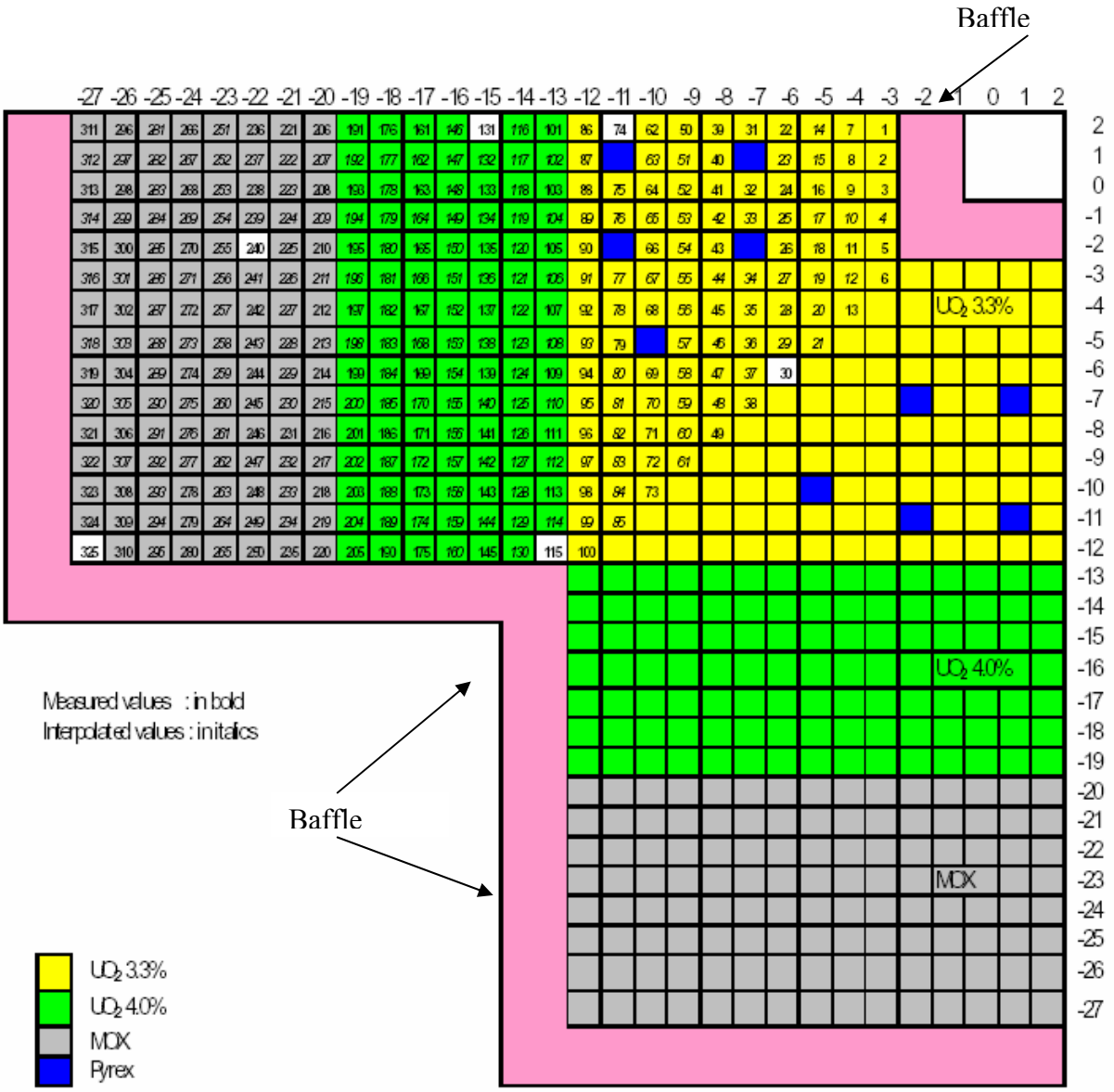
5. Conclusion

Verification of the surface-harmonics SUHAM-U and Monte-Carlo UNK codes has been carried out by the calculation of two-dimensional benchmark-experiment on critical light-water facility VENUS-2.

Calculations of two-dimensional facility were performed with using experimentally measured bucklings values. Possibility of SUHAM-U code application to computations of PWR reactor with uranium and MOX fuel has been demonstrated.

Comparison of infinite multiplication factor for cells calculations, multiplication factor and pin-by-pin power distribution with experimental data and values given in benchmark description has been performed. It was shown, that there exists a tendency of increasing the deviation of calculated values from experimental data and values, calculated with Monte-Carlo code application at points, allocated near boundary of core and steel baffle.

Figure 1: Pin Power Positions Measured in VENUS-2 [1].



Acknowledgements

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