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On the Influence of Differences between Various Group Microconstant Libraries and between Different Transport Options on Calculation Results for Cells and Subassemblies of VVER-1000 Reactor

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1. Introduction

We have carried out a series of calculations for VVER cells with different nuclide compositions and for two subassemblies composed of these cells. Various transport options for WIMS-D4 [1] and WIMS-7B [2] codes were applied with the use of group microconstant libraries contained in these codes.

2. Work Description

Then we carried out similar calculations using our new code SVL where the algorithm for transport computations was based on the Surface Pseudo-Source Method (SPSM) for cells and Surface Harmonic Method (SHM) for subassemblies [3]. The microconstant library is based on UNKDL files (WIMSD4) and on JEF 2.1 files for some nuclides The library like with one of those built into the WIMS-7B code (86.69) where the first number shows the year this library has been initially used and the second number indicates the number of groups.

Results obtained allow one to draw some important conclusions regarding the influence that libraries and transport options might have on calculations of VVER-cells and subassemblies' characteristics.

For comparison, we also presented results of calculations made using alternative codes taken from [4-5].

Tables 1-4 show some of the results obtained with full set of results available in the paper.

3. Results

There are some options for solving transport equation in cells (subassemblies) in the WIMS-D4 and WIMS-7B codes. Results of calculation by the THESEUS (a collision probability module) and DSN (Carlson Discrete S_4 method) options are given in Table 1. The k_{eff} value is calculated with buckling $B^2 = 0.003$ cm^{-2} here and in other cell calculations. Geometry and composition of the cell shown in Appendix A (see Table A1).

Results of calculations obtained by the WIMS-7B and other codes are presented in Table 2. Results of latter codes are taken from a paper [4]. These results as well as many following give the material for analysis of quality of Nuclear Data used in different codes and will be useful for their authors. The composition for this cell is shown in Appendix A (see Table A2).

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Table 1. K_∞ values of VVER-1000 cell with UO_2 fuel.

Codes & Libraries	Nuclides (a)	Energy Groups	K_∞		$K_{eff.}$
			THESEUS	S_4	Transp.
WIMS-D4 Libr. (75,69)	235.4 238.2 235.4 238.4	69 (b) 69 (b)	1.4006 (-1.4) 1.4186 (-0.14)	1.3970 (-1.5) 1.4150 (-0.26)	1.2578 (-0.52) 1.2738 (0.75)
WIMS7B Libr.1986 year Libr.1997 year Libr.1997 year		 69 69 (c) 172(c)	 1.4238 1.4245 (0.05) 1.4233 (-0.03)	 1.4233 1.4239 (0.04) 1.4225 (-0.07)	 1.2682 1.2698 (0.1) 1.2699 (0.01)

[(a)]The WIMSD4 library has nuclides containing the some variants: for examples 238.2 means the U^{238} cross-section obtained from UKNDL files, 238.4 means the U^{238} cross-section corrected after analysis of macroexperiments and so on. Every nuclide of WIMS-7B library has only one variant.

[(b)] In brackets the percentage difference of the given value from that of the WIMS7B code with the (86,69) library is shown.

[(c)] In brackets the percentage difference of the given value from that of the WIMS7B code with the (86,69) library is shown.

Table 2. K_∞ values of VVER-1000 cell with UO_2 fuel.

T, K	K_∞(a)					
	WIMS7B Library		MCU	TVS-M	WIMS-ABBN	HELIOS
Fuel. 1027^0K over materials 575^0K	(86,69) (96,69) (96,172)	1,0979 (-0,1) 1,0976 (-0,1) 1,0990	1,1103 (0,6)	1,1050 (0,1)	1,1024 (-0,1)	1,1090 (0,5)
All materials 300^0K	(86,69) (96,69) (96,172)	1,2128 (-0,1) 1,2143 (0,0) 1,2150	1,2192 (0,1)	1,2177 (0,0)	1,2160 (-0,1)	1,2195 (0,1)

[(a)]In brackets the percentage difference of the given value from that of the WIMS7B code with the (96,172) library is shown.

Table 3. Comparison of the pin cell Keff. values of VVER-1000 reactor

		Keff.						Percent Difference from SVL G_3				
		MCU	TVS-M	WIMS ABBN	HE-LIOS	SVL G_3	WIMS S_{32}	MCU	TVS-M	WIMS-ABBN	HE-LIOS	WIMS S_{32}
	S1	1,0639	1,0617	1,0572	1,0648	1,0620	1,062	0,18	-0,03	-0,45	0,26	-0,04
	S3	-	1,1073	1,1024	1,1110	1,1080	1,108	-	-0,06	-0,51	0,27	-0,03
V1	S4	1,1033	1,1028	1,0962	1,1039	1,0994	1,099	0,35	0,31	-0,29	0,41	-0,03
	S5	1,1161	1,1159	1,1109	1,1173	1,1145	1,114	0,14	0,13	-0,32	0,25	-0,04
	S6	1,2187	1,2200	1,2160	1,2207	1,2212	1,221	-0,20	-0,10	-0,43	-0,04	0,00
	S1	1,0200	1,0233	1,0149	1,0227	1,0167	1,016	0,32	0,65	-0,18	0,59	-0,03
	S3	-	1,0477	1,0385	1,0469	1,0403	1,040	-	0,71	-0,17	0,63	-0,01
V2	S4	1,0368	1,0412	1,0310	1,0389	1,0320	1,032	0,47	0,89	-0,10	0,67	-0,01
	S5	1,0498	1,0569	1,0483	1,0551	1,0492	1,049	0,06	0,73	-0,09	0,56	-0,01
	S6	1,1786	1,1818	1,1779	1,1832	1,1783	1,178	0,03	0,30	-0,03	0,42	0,01
	S1	-	0,9127	0,9136	0,9128	0,9128	0,913	-	-0,01	0,09	-0,00	-0,02
	S3	-	0,9502	0,9506	0,9500	0,9502	0,950	-	0,00	0,04	-0,02	-0,02
V3	S4	-	0,9477	0,9465	0,9453	0,9441	0,944	-	0,38	0,25	0,13	-0,01
	S5	-	0,9621	0,9615	0,9604	0,9597	0,960	-	0,25	0,19	0,07	-0,01
	S6	1,0574	1,0610	1,0619	1,0603	1,0614	1,062	-0,38	-0,04	0,05	-0,10	0,02
	S1	-	1,0965	1,0967	1,1046	1,0937	1,093	-	0,26	0,27	1,00	-0,06
	S3	-	1,1240	1,1237	1,1321	1,1206	1,120	-	0,30	0,28	1,03	-0,05
V7	S4	-	1,1166	1,1151	1,1229	1,1111	1,111	-	0,50	0,36	1,06	-0,05
	S5	-	1,1303	1,1303	1,1369	1,1267	1,126	-	0,32	0,32	0,91	-0,06
	S6	1,2501	1,2509	1,2542	1,2595	1,2500	1,250	0,01	0,07	0,34	0,76	-0,02
	S1	-	0,9281	0,9160	0,9240	0,9254	0,925	-	0,29	-1,02	-0,15	-0,01
	S3	-	0,9731	0,9599	0,9690	0,9704	0,970	-	0,28	-1,08	-0,14	-0,00
V8	S4	-	0,9711	0,9563	0,9646	0,9643	0,964	-	0,71	-0,83	0,03	-0,00
	S5	-	0,9856	0,9728	0,9800	0,9809	0,981	-	0,48	-0,83	-0,09	-0,00
	S6	1,0828	1,0881	1,0780	1,0831	1,0873	1,088	-0,41	0,07	-0,86	-0,39	0,03
	S1	-	1,2797	1,3247	1,3228	1,3192	1,319	-	-2,99	0,42	0,27	-0,05
	S3	-	1,3096	1,3552	1,3543	1,3497	1,349	-	-2,97	0,41	0,34	-0,04
V9	S4	-	1,3001	1,3443	1,3425	1,3377	1,337	-	-2,81	0,49	0,36	-0,04
	S5	-	1,3167	1,3611	1,3593	1,3551	1,355	-	-2,83	0,44	0,31	-0,04
	S6	1,4372	1,4337	1,4747	1,4713	1,4680	1,468	-2,10	-2,34	0,46	0,22	-0,02
	S1	-	0,9648	0,9517	0,9593	0,9514	0,952	-	1,41	0,03	0,83	0,11
	S3	-	0,9762	0,9629	0,9707	0,9621	0,963	-	1,47	0,08	0,89	0,11
V10	S4	-	0,9704	0,9566	0,9643	0,9560	0,957	-	1,51	0,06	0,87	0,10
	S5	-	0,9848	0,9716	0,9799	0,9697	0,971	-	1,56	0,20	1,05	0,09
	S6	-	1,0942	1,0851	1,0910	1,0793	1,081	-	1,38	0,54	1,08	0,12

Comparison of the SVL and WIMS-S_{32} results is presented as the mathematical tests for far as the multigroup libraries for these two codes were the same. Small difference between these codes consisted in forming the boundary condition. The isotropic reflection on external cell boundary is used in WIMS-S_{32} code. Isotropic source (sink) is placed on external cell boundary in the SPSM method. This source is presented by the corresponding angular moment of Grin function for the moderator material. Results show excellent quality of mathematical solving in the SVL code.

Comparison with MCU, TVS-M, WIMS-ABBN, HELIOS results taken from paper [5] again gives the material for analysis of quality of Nuclear Data used in different codes. As the authors knew from private message at present cross-section for Pu^{241} nuclide have changed in the MCU and TVS-M codes.

Table 4. K_∞ values of VVER-1000 graded assembly with UO_2+PuO_2 fuel**.**

T,K	K_∞(a)							
	WIMS7B		Apollo-2	TVS-M	MCU-REA	Casmo-4	Conkemo	MCNP
	Library	Cactus (b)						
Fuel. 1027^0K over materials 575^0K	(86,69)	1,2363 (0,0)	1,2481 (1,0)	1,2501 (1,2)	1,2426 (0,6)	1,2523 (1,3)	1,2429 (0,6)	1,2478 (1,0)
	(96,69)	1,2387 (0,2)						
	(96,172)	1,2362						
All materials 300^0K	(86,69)	1,3839 (-0,2)	1,3957 (0,7)	1,3900 (0,3)			1,3873 (0,1)	
	(96,69)	1,3895 (0,2)						
	(96,172)	1,3864						

(a) In brackets the percentage difference of the given value from that of the WIMS7B code with the (96,172) library is shown.

(b) Cactus is the WIMS-7B option for transport calculation by characteristic method

Differences of libraries of different codes are presented in Table 4. This difference depend both on difference of used nuclear data and on difference method of preparing multigroup cross-section from nuclear data. So, in our opinion, systematic difference of the WIMS-7B results from those of other codes may be explained with improved description of self shielding of absorption resonances of the Pu^{240} and Pu^{241} nuclides in the WIMS-7B code. This conclusion is conformed with that the mentioned difference increased with rising the fuel temperature.

Table 5. K_∞ values of VVER-1000 assembly with UO_2 fuel**.**

State	S2	S3	S4	S5	S6	S7	S10
APPOLO2	1,2938	1,3013	1,3099	1,3264	1,3354	1,2805	1,3647
TVSM	1,2858	1,2927	1,3004	1,3163	1,3241	1,2736	1,3579
MCUREA	1,2865		1,3022		1,326		
CONCEMO	1,2943	1,3017	1,3101	1,325	1,3316		1,3662
CASMO4	1,2842		1,3028		1,3243	1,2813	1,3546
MSNP	1,2918		1,3073		1,3314		1,3633
SVL	1,2874	1,2953	1,3044	1,3214	1,3294	1,2734	1,3585
WIMS7B					1,3296		

State	S11	S12	S13	S14	S15	SA1	SA2
APPOLO2	1,3726	1,3816	1,416	1,4408	1,3507		
TVSM	1,3653	1,3735	1,408	1,4318	1,345	1,0056	0,936
MCUREA		1,3735				1,0053	0,9355
CONCEMO	1,3739	1,3828	1,418	1,4389	1,3525	1,0045	0,9335
CASMO4						1,0063	0,9403
MSNP						1,0055	
SVL	1,3668	1,3764	1,411	1,4357	1,3437	1.0053	0,9304
WIMS7B							0,9306

Data for variants S_{21}- S_{15} and SA1, SA2 are described in Appendix B.

4. Conclusion

The following conclusions may be drawn from our analysis:

1. The library (69.86) gives quite satisfactory results.
2. The difference between these results and those obtained using the library (97.172) is less than 0.2% for multiplication factors.

At present the numerous calculations of different tasks have been performed (exemplarily 250 cells, fuel and critical assemblies, with variants, taking into account changes temperatures, boron concentrations in moderator more than 1 000). Only small part of these results might be presented in this report.. After comparison of our results with those of other authors and with experiments one can draw the following conclusion. In spite of the calculation time by the SVL code is less on orders, sometimes on many orders in comparison with calculation time of another codes, the SVL code do not yield to the best benchmark codes on accuracy of calculation.

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Appendix A

Table A1. Initial data for VVER-1000 cell with UO_2 fuel

№ zone	Radius см	Material	Nuclear density 10^{-24} $см^{-3}$	Temperature (^{0}K)
1.	0.386	U-235 U-238 O	8.6264E-4 2.2169E-2 4.6063E-2	300
2.	0.4582	Zr Hf	4.259E-2 6.597E-6	300
3.	0.6694	H O	6.717E-2 3.358E-2	300

Table A2. Initial data for VVER-1000 cell with UO_2 fuel

№ zone	Radius cm	Material	Nuclear Density 10^{-24} $см^{-3}$	Temperature (^{0}K)
1.	0.386	U-235 U-238 O Xe-135 Sm-149	8.7370E-4 1.8744E-2 3.9235E-2 9.4581E-9 7.3667E-8	300 (1027)
2.	0.4582	Zr	4.230E-2	300(579)
3.	0.6694	H O	6.694E-2 3.347E-2	300
		B (natur) H O	3.3465E-5 4.783E-2 2.391E-2	579

Table A3. Benchmark Fuel Variants

Variant	Description
V1	UO_2 pin cell
V2	MOX pin cell
V3	Spent UO_2 pin cell, no fission product
V7	MOX pin cell with ^{239}Pu only
V8	MOX pin cell with ^{240}Pu only
V9	MOX pin cell with ^{241}Pu only
V10	Reactor MOX pin cell

Table A4. Calculational states

State	Fuel temper. (K)	Non-fuel temper. (K)	Moderator material(a)	$Xe^{135}$and Sm^{149} concentration	Buckling (cm^{-2})
S1	1027	579	MOD1	present	0.003
S3	1027	579	MOD2	present	0.003
S4	1027	579	MOD1	none	0.003
S5	579	579	MOD1	none	0.003
S6	300	300	MOD3	none	0.003

[(a)]Moderator descriptions:

MOD1 - Hot moderator with 600 ppm boron

MOD2 - Hot moderator without boron

MOD3 - Cold moderator with 600 ppm boron

Appendix B

Table B1. Material description

	Material	Isotopic content, 10*24 cm-3					
1	U1					16O	4,60630E-02
		235U	8,62640E-04				
	Fuel	238U	2,21680E-02				
2	CL1	91Zr,nat	4,25900E-02				
		93Nb	4,22500E-04				
	Non-fuel	178Hf	6,59700E-06				
3	CL2	54Fe	5,93300E-02			12C	4,73700E-04
		51Cr	1,68700E-02				
	Non-fuel	56Ni	8,47700E-03				
		47Ti	9,90400E-04				
4	AB1	10B,nat	1,55500E-02			12C	1,96400E-02
	Non-fuel	10B,bup	6,30000E-02				
5	AB2	10B,nat	6,57100E-02			12C	2,05300E-02
	Non-fuel	10B,bup	1,64300E-02				
6	MOD1	16O	2,42200E-02	10B	4,79400E-06		
	Moderator	1H	4,84300E-02	11B	1,94200E-05		
7	MOD2	16O	2,92900E-02	10B	5,79700E-06		
	Moderator	1H	5,85700E-02	11B	2,34800E-05		
8	MOD3	16O	3,35800E-02	10B	6,64800E-06		
	Moderator	1H	6,71700E-02	11B	2,69300E-05		
9	MOD4	16O	6,69500E-03	10B	1,32500E-06		
	Moderator	1H	1,33900E-02	11B	5,36800E-06		
10	MOD5	16O	2,42200E-02				
	Moderator	1H	4,84300E-02				

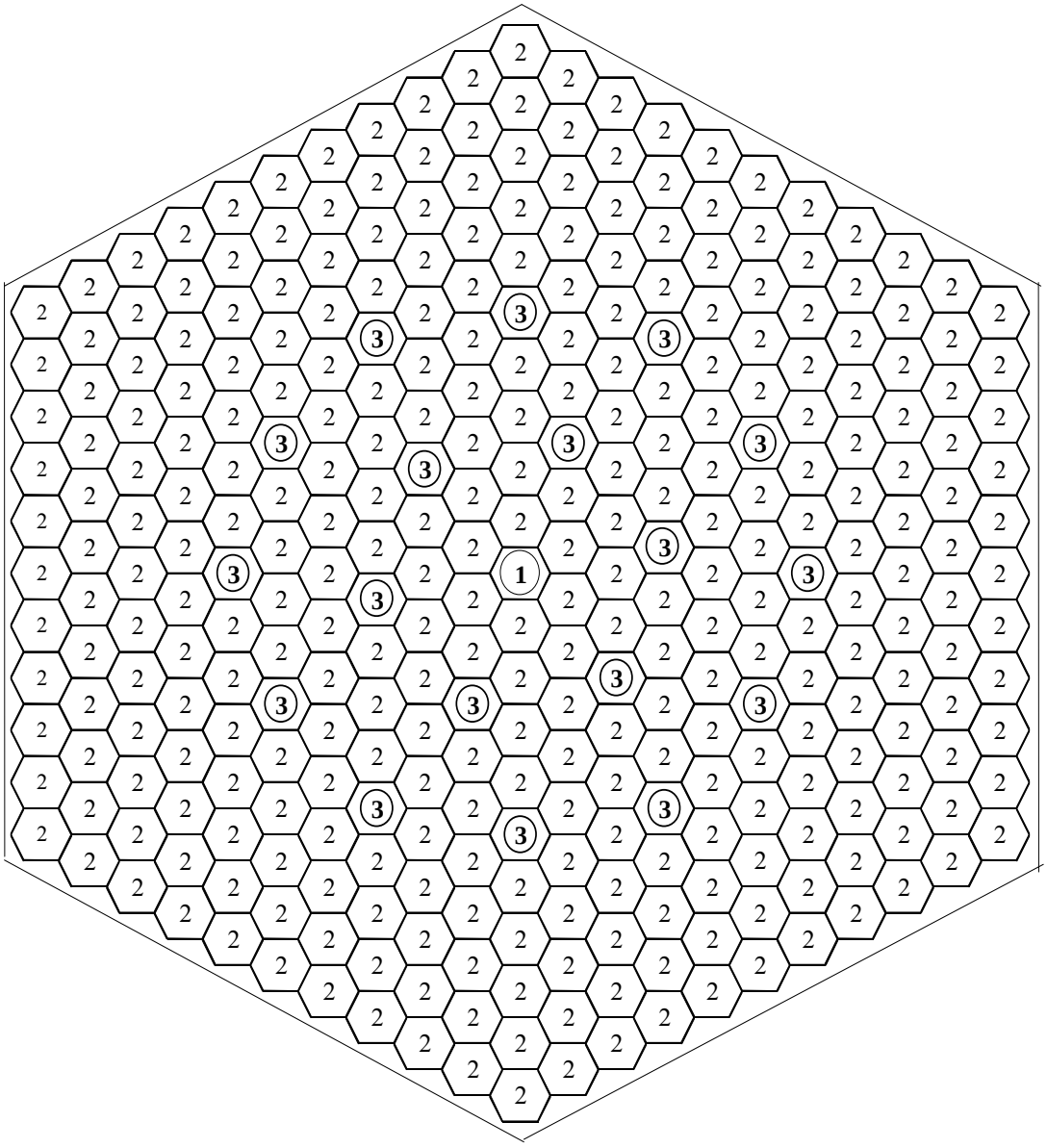

Figure B1. Cartogram of fuel assembly of the VVER-1000 reactor. The assembly have the outer dimension H=23.6 cm.

Nomenclature: 1 – water hole; 2 – cell with UO_2 fuel (3,7%); 3 – cell with water or PEL.

Table B2. Geometry description

Cell type	Comment	Zone number	Zone radius, cm.	Material
G1	Fuel cell	3	R1=0.386 R2=0.4582 h=1.275	U1 CL1 MOD
G2	Central tube cell	3	R1=0.48 R2=0.5626 h=1.275	MOD CL1 MOD
G3	Control rod cell A	5	R1=0.35 R2=0.41 R3=0.545 R4=0.6323 h=1.275	AB1 CL2 MOD CL2 MOD
G4	Control rod cell B	5	R1=0.35 R2=0.41 R3=0.545 R4=0.6323 h=1.275	AB2 CL2 MOD CL2 MOD
G5	Guide tube cell	3	R1=0.545 R2=0.6323 h=1.275	MOD CL1 MOD

Table B3. States description

State	Fuel Temp., K	Non-fuel zones temp., K	Moderator material MOD	Cell of type (fig.B1)		
				1	2	3
S1	1027	575	MOD1	G1	G2	G5
S2	1027	575	MOD1	G1	G2	G5
S3	800	575	MOD1	G1	G2	G5
S4	575	575	MOD1	G1	G2	G5
S5	473	473	MOD2	G1	G2	G5
S6	300	300	MOD3	G1	G2	G5
S7	1500	575	MOD4	G1	G2	G5
S8	2000	575	MOD5	G1	G2	G5
S9	1027	575	MOD5	G1	G2	G5
S10	1027	575	MOD5	G1	G2	G5
S11	800	575	MOD5	G1	G2	G5
S12	575	575	MOD5	G1	G2	G5
S13	473	473	MOD6	G1	G2	G5
S14	300	300	MOD7	G1	G2	G5
S15	1500	575	MOD5	G1	G2	G5
S16	2000	575	MOD8	G1	G2	G5
SA1	1027	575	MOD1	G1	G2	G3
SA2	1027	575	MOD1	G1	G2	G4