SOME RESULTS OF THE VERIFICATION CALCULATIONS BY THE SVL CODE FOR THE VVER SUBASSEMBLIES.

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1. INTRODUCTION

Complex SVS has been presented in our previous paper/1/. The structure of complex has been described in that paper and the some calculation results for the ZR-6 assemblies have been given in Appendix. The goal of the presentation of results was to demonstrate a scale of computation characteristic uncertainty (for example, in the VVER and PWR reactor core) which was connected with uncertainty of knowledge about nuclear micro cross-sections. Therefore considered assemblies have been calculated in the same identical approximations used at SVL code which is the part of complex SVS, but with application of different multi group libraries based on varied fails of evaluated data. In present paper, using the one chosen library of multi group cross-sections we have carried out calculations of 4 variants of the VVER-1000 subassemblies and have compared its results with those obtained by other codes. Each variant has various numbers of calculation states representing different operating conditions. Fuel depletion has been considered and results of calculations have compared with those of other codes. Results of such verification of code SVL may give the presentation about methodical component of uncertainty of the pin-by-pin calculation characteristics of investigated objects. Certainly it should have taken into consideration that the different libraries of multi group micro cross-sections are used at the different codes.

2. CALCULATIONS OF THE VVER SUBASSEMBLIES.

In this part we will consider the VVER-1000 subassemblies given in paper/2,3/. They cover different aspects of UO_2 and MOX in VVER-1000 reactors in normal operating conditions. The benchmarks consist of 4 variants:

- Variant 1: Subassemblies with the UO_2 fuel.
- Variant 2: Subassemblies with the MOX fuel.
- Variant 3: Subassemblies with the UO_2 fuel and the 12 Gd TVEG.
- Variant 4: Subassemblies with the MOX fuel and the 12 Gd TVEG.

Each variant is calculated under various conditions as indicated by different states, described in Table 1.

The benchmark geometries consist of a pin cell, a standard VVER-1000 assembly. The pin cell cases represent a VVER-1000 fuel pin in an infinite triangular lattice with a pitch of 1.275 cm. The fuel pin consists of a 0.772 cm diameter fuel pellet and zirconium cladding with a thickness of 0.0722 cm. The VVER-1000 subassembly configuration, shown in Fig. 1(for the UO_2 fuel), contains fuel rods (cell type 1), guide tubes (cell type 3) and a central instrument tube (cell type 2). The moderator or absorber rod can be in the guide tube. The cladding, guide tube and instrument tube material is zirconium. The control rods use B_4C as the absorber material. For MOX fuel the VVER-1000 subassembly configuration is given in Fig. 2. In variants 3 and 4 from 312 pin cells 12 were the poisoned Gd TVEG (in 1/6 part they occupy cells with the number 241 and 302 on Fig. 1)

It is required to calculate K_{eff}, .reactivity effects and concentration of major actinides and fission products.

Calculations of the different benchmark variants were performed using the SVL/1/ code which is a part SVS/1/ code. SVL code can calculate VVER-1000 pin cells both with fuel and without. The RATIA and FFG options are been used in these calculations. These codes are spectral. The surface pseudosours method/1,4,5,6/ is employed for solving multi-group transport equation by the RATIA option inside of pin

cell. The collision probability method/1/ is applied in the FFG option. The SVL code used “WIMS86” modified cross-section library with 69 energy groups. These options prepare the 4 group characteristics of the surface harmonic method/1/ for all cells from which consist of the VVER-1000 subassembly (look, Fig. 1, 2). Then the subassembly is calculated by SHM-HEX option in 4 group.

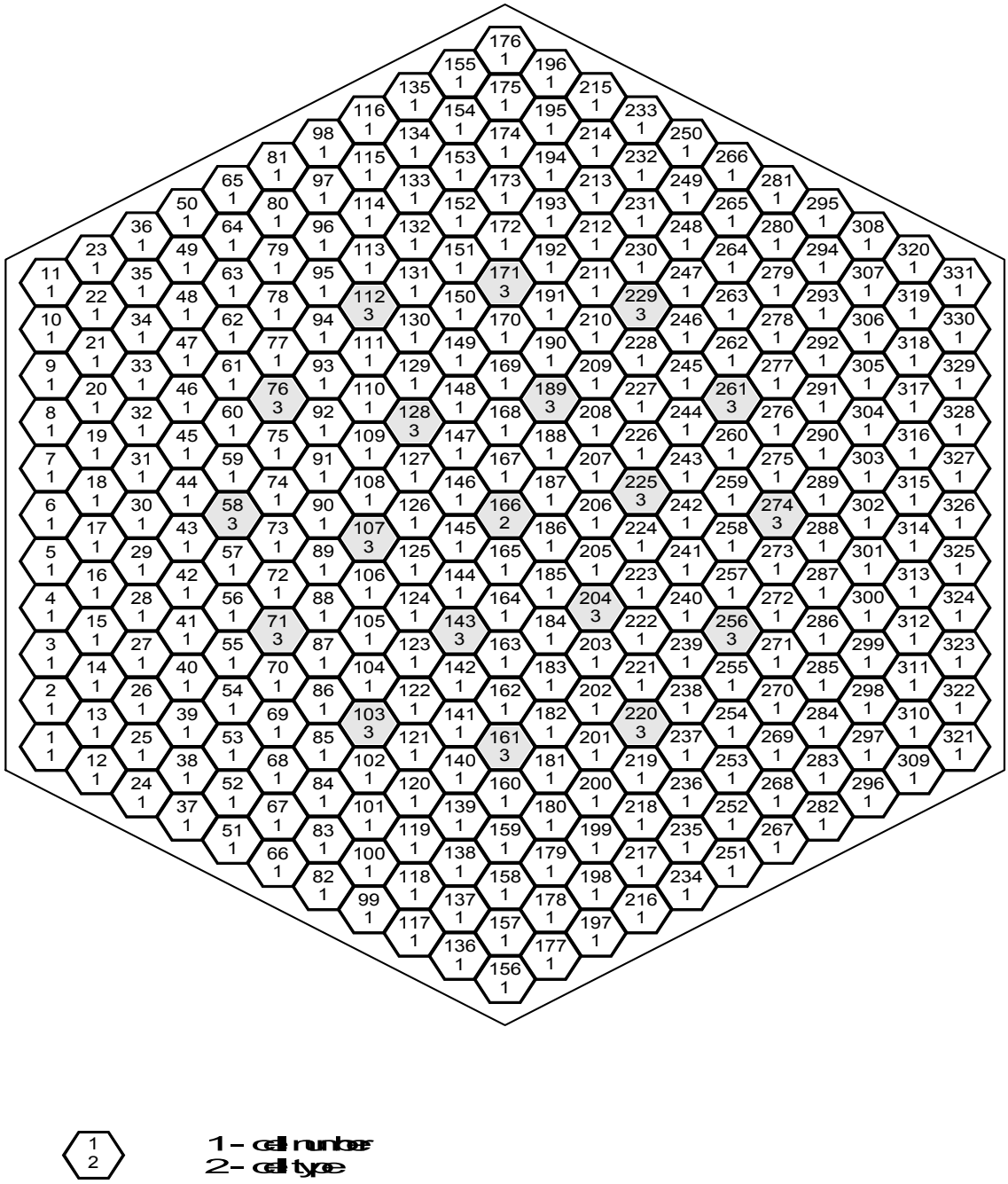

Fig. 1. Cartogram of unprofiled fuel subassemblies of the VVER-1000 reactor.

Nomenclature:

1 – cell with UO_2 fuel (3,7%);

2 – central instrumental tube;

3 – guide tube with water or absorber material;

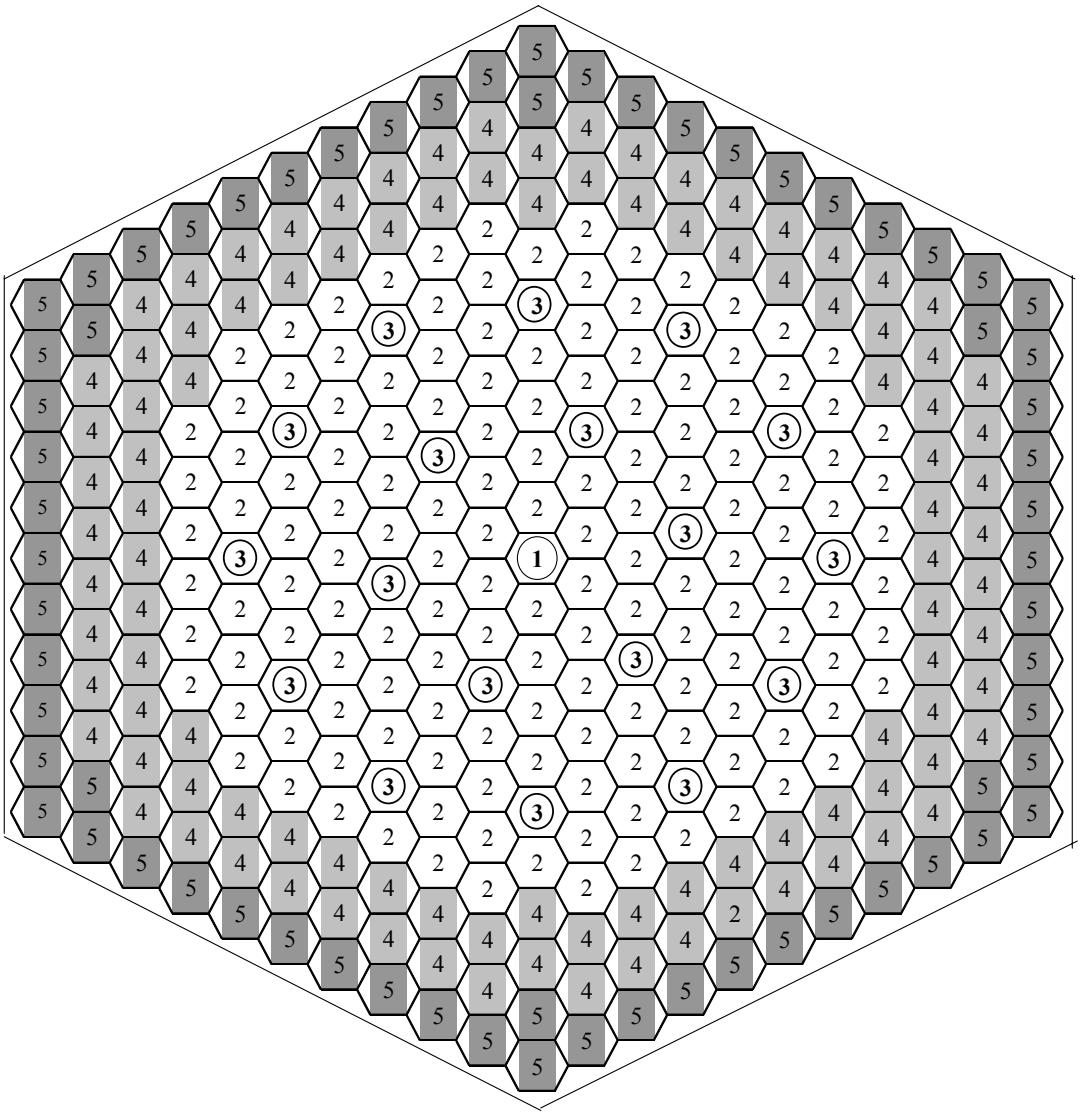

Fig. 2. Cartogram of profiled fuel assemblies of the VVER-1000 reactor
Nomenclature:
1 – central instrumental tube;
2 – cell with MOX fuel (4,2% wt Pu);
3 – guide tube with water or absorber material;
4 – cell with MOX fuel (3,0% wt Pu);
5 – cell with MOX fuel (2,0% wt Pu).

The K_{eff} calculation results for the considered subassemblies are given in Tables 2-5. It should be noted that in the right two columns of these Tables s and d values are given. They mean following:

$$s = \frac{1}{N}\sum_{i=1}^{N}(K_{\inf}^{KL} - K_{\inf}^{X}) * 100 \quad (1)$$

$$d = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[(K_{\inf}^{KL} - K_{\inf}^{X}) * 100 - s\right]^2} \quad (2)$$

where N is a number of compared calculations, X is the name of a code with which is carried out a compare, s is the discrepancy, d is the square root of dispersion.

One can see of Tables 2-5 that s and d between results of SVL code and Monte Carlo codes (MCUREA, KENO, MCNP) are in general no large. Most probably the possible reasons of the observed discrepancies are connected with the different origin of nuclear data. Indirect confirmation of this can serve the following fact. The s and d between results of SVL and WIMS7B codes in Table 2 are very small: -0.09 and 0.03 accordingly. The SVL and WIMS7B codes were based on the same "1986" WIMS Nuclear Data Library.

The results of calculation of various reactivity effects are presented in Tables 6-7 for variants 1 and 2. The following effects were compared: Doppler and total temperature effects, soluble boron worth, control rods worth and effect of core overheating. One can see that results of calculations of all codes are in good agreement with each other.

Table 1. States description

State	Fuel Temp., K	Non-fuel zones temp., K	Moderator (water) Density g/cm^3	Bor consentration in water ppm	Absorber
S2	1027	575	0.723	600	no
S3	800	575	0.723	600	no
S4	575	575	0.723	600	no
S5	473	473	0.875	600	no
S6	300	300	1.003	600	no
S7	1500	575	0.723	600	no
S8	2000	575	0.200	600	no
S10	1027	575	0.723	0	no
S11	800	575	0.723	0	no
S12	575	575	0.723	0	no
S13	473	473	0.875	0	no
S14	300	300	1.003	0	no
S15	1500	575	0.723	0	no
S16	2000	575	0.200	0	no
SA1	1027	575	0.723	600	B_4C(natural)
SA2	1027	575	0.723	600	B_4C(enriched)

Table 2. Deviations in the K_{eff} value from SVL that for the UO_2 subassemblies.

Variant1																		
State	S2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13	S14	S15	S16	SA1	SA2	s	d
APOLLO2	0,26	0,22	0,17	0,18	0,32	0,34	0,65	0,19	0,16	0,10	0,10	0,18	0,27	0,54			0,26	0,15
TVSM	-0,36	-0,45	-0,55	-0,58	-0,53	-0,21	0,98	-0,31	-0,38	-0,48	-0,50	-0,44	-0,16	0,92	-0,04	0,52	-0,16	0,49
MCUREA	-0,31		-0,42		-0,39		0,87			-0,48					-0,07	0,47	-0,05	0,48
CONKEMO	0,30	0,25	0,19	0,08	0,03	0,40	0,66	0,30	0,25	0,19	0,22	0,05	0,41	0,66	-0,15	0,25	0,26	0,20
CASMO4	-0,48		-0,37		-0,52		1,75	-0,55							0,03	0,98	0,12	0,83
MCNP	0,10		-0,03		0,02		1,20	0,09							-0,05		0,22	0,44
WIMS7B					-0,12											-0,06	-0,09	0,03

Table 3. . . Deviations in the K_{eff} value from SVL that for the MOX subassemblies.

Variant2																		
State	S2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13	S14	S15	S16	SA1	SA2	s	d
APOLLO2	0,45	0,44	0,40	0,61	0,80	0,50	-1,04	0,36	0,34	0,32	0,48	0,59	0,40	-1,10			0,25	0,55
TVSM	0,61	0,52	0,41	0,28	0,07	0,79	0,99	0,72	0,62	0,50	0,40	0,18	0,90	0,97	0,34	0,96	0,58	0,28
MCUREA	0,01		-0,29		-0,11		0,19			-0,25					-0,23	0,35	-0,05	0,23
CONKEMO	0,03	-0,02	-0,08	0,04	0,05	0,12	-0,16	-0,02	-0,07	-0,13	0,08	-0,02	0,06	-0,24	-0,61	0,13	-0,05	0,17
CASMO4	0,79		0,66		0,72		-0,09	0,71							1,08	1,83	0,81	0,53
KENO	0,22		0,11		0,26		-0,18	0,11							-0,19	0,34	0,10	0,19
MCNP	0,42		0,21		0,49		-0,18	0,28							-0,03	0,50	0,24	0,24

Table 4 . . Deviations in the K_{eff} value from SVL that for the UO_2 +12 TVEG subassemblies.

Variant3

State	S2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13	S14	S15	S16	SA1	s	d
APOLLO2	-0,32	-0,35	-0,41	-0,52	-0,50	-0,25	0,81	-0,44	-0,46	-0,52	-0,75	-0,71	-0,37	0,68		-0,29	0,44
TVSM	-0,57	-0,66	-0,77	-0,72	-0,67	-0,41	0,98	-0,57	-0,64	-0,75	-0,75	-0,59	-0,40	0,89	-0,08	-0,38	0,54
MCUREA	-0,72		-0,92		-0,80		0,63			-1,01					-0,25	-0,51	0,57
CONKEMO	-0,47	-0,54	-0,61	-0,69	-0,60	-0,36	1,13	-0,58	-0,65	-0,72	-0,81	-0,62	-0,46	1,02	-0,50	-0,36	0,58
CASMO4																	
KENO	-0,50				-0,54			-0,44							-0,32	-0,45	0,08
MCNP	-0,35				-0,41			-0,28							-0,23	-0,32	0,07

Table 5. . . Deviations in the K_{eff} value from SVL that for the MOX+12 TVEG subassemblies.

Variant4

State	S2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13	S14	S15	S16	SA1	s	d
APOLLO2	0,24	0,22	0,20	0,29	0,35	0,29	-0,96	0,14	0,13	0,11	0,14	0,12	0,18	-1,02		0,03	0,42
TVSM	0,50	0,42	0,32	0,20	-0,01	0,65	1,04	0,59	0,51	0,40	0,31	0,09	0,75	1,01	0,30	0,47	0,29
MCUREA	-0,11		-0,44		-0,23		-0,19			-0,36					-0,29	-0,27	0,11
CONKEMO	-0,37	-0,43	-0,49	-0,33	-0,39	-0,29	-0,43	-0,40	-0,46	-0,54	-0,39	-0,48	-0,29	-0,58	-0,64	-0,43	0,10
CASMO4																	
KENO	0,07				0,08			0,00							-0,13	0,01	0,09
MCNP	0,27				0,29			0,17							-0,06	0,17	0,14

Table 6. Reactivity effects (K_{eff}(Sx)- K_{eff}(Sy)) for subassemblies with UO_2 fuel, Variant 1.

Sx	Sy	SVL	APOLLO2	TVSM	MCUREA	CONKEMO	CASMO	MCNP
Boron worth								
S2	S10	-7,17	-7,09	-7,21		-7,18	-7,03	-7,15
S3	S11	-7,20	-7,13	-7,26		-7,22		
S4	S12	-7,26	-7,18	-7,31	-7,13	-7,27		
S5	S13	-9,06	-8,96	-9,12		-5,78		
S6	S14	-10,70	-10,54	-10,77		-10,73		
S7	S15	-7,09	-7,01	-7,14		-7,12		
S8	S16	-1,23	-1,13	-1,17		-1,23		
Doppler effect								
s4	s3	0,91	0,85	0,77		0,84		
s4	s2	1,72	1,60	1,46	1,57	1,57	1,85	1,55
s4	s7	3,14	2,93	2,68		2,88		
s12	s11	0,97	0,90	0,82		0,89		
s12	s10	1,81	1,69	1,56		1,66		
s12	s15	3,31	3,10	2,85		3,02		
Temperature effect								
s4	s5	-1,63	-1,65	-1,59		-1,49		
s4	s6	-2,35	-2,56	-2,37	-2,38	-2,15	-2,15	-2,41
s12	s13	-3,43	-3,43	-3,40		-3,48		
s12	s14	-5,80	-5,92	-5,83		-5,61		
Core overheating								
s2	s8	29,83	29,53	28,39	28,57	29,57	27,48	28,77
s10	s16	35,77	35,49	34,43		35,52		
CR worth								
sa1	s2	-28,44		-28,02	-28,12	-28,99	-27,79	-28,63
sa2	s2	-35,93		-34,98	-35,10	-36,08	-34,40	

Table 7. Reactivity effects (K_{eff}(Sx)- K_{eff}(Sy)) for subassemblies with UO_2 fuel, Variant 2.

Sx	Sy	SVL	APOLLO2	TVSM	MCUREA	CONKEMO	CASMO	MCNP	KENO
Boron worth									
S2	S10	-3,74	-3,64	-3,90		-3,68	-3,67	-3,57	-3,60
S3	S11	-3,78	-3,67	-3,92		-3,71			
S4	S12	-3,82	-3,73	-3,96	-3,87	-3,76			
S5	S13	-5,17	-5,02	-5,34		-0,33			
S6	S14	-6,85	-6,62	-7,01		-6,77			
S7	S15	-3,66	-3,55	-3,83		-3,59			
S8	S16	-0,61	-0,54	-0,59		-0,53			
Doppler effect									
s4	s3	1,05	1,01	0,91		0,97			
s4	s2	1,97	1,92	1,73	1,59	1,83	1,82	1,71	1,83
s4	s7	3,61	3,51	3,16		3,36			
s12	s11	1,09	1,07	0,95		1,02			
s12	s10	2,05	2,01	1,79		1,91			
s12	s15	3,77	3,69	3,29		3,53			
Temperature effect									
s4	s5	-3,27	-3,55	-3,12		-3,43			
s4	s6	-5,68	-6,22	-5,25	-5,90	-5,84	-5,80	-6,06	-5,88
s12	s13	-4,62	-4,84	-4,50		-4,89			
s12	s14	-8,71	-9,11	-8,30		-8,85			

Core overheating									
s2	s8	30,28	31,81	30,10	30,11	30,46	31,34	30,97	30,72
s10	s16	33,41	34,91	33,41		33,61			
CR worth									
sa1	s2	-21,52		-21,93	-21,77	-22,19	-21,39	-22,08	-21,99
sa2	s2	-29,52		-29,37	-29,20	-29,44	-28,77	-29,58	-29,48

Table 8. K_{eff} values in the UO_2 cell (Var1 S1) as function of burn up and comparison with other codes

	K_{eff}						$(K_{eff}(SVL)- K_{eff}(X))*100$				
Mwd/kg	SVL	TVSM	HELIOS	WIMS-ABBN	MCU	WIMS7	TVSM	HELIOS	WIMS-ABBN	MCU	WIMS7 (172)
0	1,0603	1,0617	1,0648	1,0572	1,0638		-0,1	-0,4	0,3	-0,3	-
2	1,0418	1,0451	1,0477	1,0407		1,0430	-0,3	-0,6	0,1	-	-0,1
4	1,0251	1,0278	1,0300	1,0232			-0,3	-0,5	0,2	-	-
5	1,0165	1,0190			1,0187	1,0168	-0,3	-	-	-0,2	0,0
6	1,0079	1,0102	1,0118	1,0053		1,0078	-0,2	-0,4	0,3	-	0,0
8	0,9912	0,9931	0,9942	0,9881			-0,2	-0,3	0,3	-	-
10	0,9753	0,9768	0,9775	0,9718	0,9789	0,9738	-0,1	-0,2	0,3	-0,4	0,1
12	0,9602	0,9613	0,9617	0,9564			-0,1	-0,1	0,4	-	-
14	0,9460	0,9465	0,9468	0,9419			0,0	-0,1	0,4	-	-
15	0,9392	0,9394			0,9383	0,9366	0,0	-	-	0,1	0,3
18	0,9197	0,9189	0,9193	0,9150			0,1	0,0	0,5	-	-
20	0,9075	0,9060	0,9064	0,9025	0,9054	0,9041	0,2	0,1	0,5	0,2	0,3
22	0,8957	0,8935	0,8940	0,8904			0,2	0,2	0,5	-	-
24	0,8843	0,8813	0,8821	0,8787			0,3	0,2	0,6	-	-
25	0,8787	0,8754			0,8762	0,8749	0,3	-	-	0,2	0,4
26	0,8733	0,8696	0,8705	0,8675			0,4	0,3	0,6	-	-
28	0,8626	0,8582	0,8593	0,8566			0,4	0,3	0,6	-	-
30	0,8522	0,8471	0,8483	0,8460	0,8472	0,8482	0,5	0,4	0,6	0,5	0,4
32	0,8421	0,8363	0,8375	0,8356			0,6	0,5	0,6	-	-
34	0,8322	0,8257	0,8271	0,8256			0,6	0,5	0,7	-	-
35	0,8274	0,8206			0,8247	0,8235	0,7	-	-	0,3	0,4
36	0,8226	0,8155	0,8171	0,8158			0,7	0,5	0,7	-	-
38	0,8132	0,8055	0,8072	0,8063			0,8	0,6	0,7	-	-
40	0,8040	0,7958	0,7976	0,7970	0,7980	0,8005	0,8	0,6	0,7	0,6	0,4
42	0,7950	0,7863	0,7883	0,7880			0,9	0,7	0,7	-	-
44	0,7863	0,7771	0,7793	0,7792			0,9	0,7	0,7	-	-
45	0,7820	0,7726			0,7756	0,7790	0,9	-	-	0,6	0,3
46	0,7777	0,7682	0,7704	0,7706			1,0	0,7	0,7	-	-
48	0,7694	0,7595	0,7619	0,7623			1,0	0,7	0,7	-	-
50	0,7613	0,7511	0,7536	0,7543	0,7549	0,7591	1,0	0,8	0,7	0,6	0,2
52	0,7534	0,7430	0,7455	0,7465			1,0	0,8	0,7	-	-
54	0,7457	0,7352	0,7378	0,7389			1,1	0,8	0,7	-	-
55	0,7420	0,7314			0,7360	0,7408	1,1	-	-	0,6	0,1
56	0,7383	0,7276	0,7303	0,7317			1,1	0,8	0,7	-	-
58	0,7312	0,7203	0,7230	0,7247			1,1	0,8	0,7	-	-
60	0,7242	0,7134	0,7161	0,7179	0,7207	0,7240	1,1	0,8	0,6	0,3	0,0

Table 9. Pu^{239} concentration in the UO_2 cell (Var1 S1) as function of burn up and comparison with other codes

	$\rho(Pu^{239})$					$(\rho(Pu^{239})^{SVL}-\rho(Pu^{239})^{X})*100/\rho(Pu^{239})^{SVL}$			
MwD/kg	SVL	TVSM	HELIOS	WIMS-ABBN	MCU	TVSM	HELIOS	WIMS-ABBN	MCU
0	0,000E+00	0,000E+00	0,000E+00	8,737E-19	0,000E+00	-	-	0,0	-
2	1,844E-05	1,834E-05	1,786E-05	1,881E-05		0,5	3,2	-2,0	-
4	3,544E-05	3,528E-05	3,424E-05	3,611E-05		0,4	3,4	-1,9	-
5	4,302E-05	4,285E-05			4,296E-05	0,4	-	-	0,1
6	5,007E-05	4,991E-05	4,832E-05	5,098E-05		0,3	3,5	-1,8	-
8	6,276E-05	6,264E-05	6,051E-05	6,386E-05		0,2	3,6	-1,8	-
10	7,381E-05	7,377E-05	7,113E-05	7,509E-05	7,390E-05	0,1	3,6	-1,7	-0,1
12	8,347E-05	8,356E-05	8,042E-05	8,491E-05		-0,1	3,7	-1,7	-
14	9,193E-05	9,217E-05	8,855E-05	9,351E-05		-0,3	3,7	-1,7	-
15	9,576E-05	9,609E-05			9,620E-05	-0,3	-	-	-0,5
16	9,935E-05	9,977E-05	9,569E-05	1,011E-04		-0,4	3,7	-1,8	-
18	1,058E-04	1,065E-04	1,020E-04	1,077E-04		-0,6	3,7	-1,8	-
20	1,115E-04	1,124E-04	1,075E-04	1,135E-04	1,128E-04	-0,8	3,7	-1,8	-1,1
22	1,165E-04	1,176E-04	1,123E-04	1,186E-04		-0,9	3,6	-1,8	-
24	1,209E-04	1,222E-04	1,165E-04	1,231E-04		-1,1	3,6	-1,8	-
26	1,247E-04	1,262E-04	1,202E-04	1,271E-04		-1,3	3,6	-2,0	-
28	1,280E-04	1,298E-04	1,235E-04	1,305E-04		-1,4	3,5	-2,0	-
30	1,308E-04	1,329E-04	1,263E-04	1,335E-04	1,338E-04	-1,6	3,5	-2,1	-2,3
32	1,333E-04	1,356E-04	1,287E-04	1,361E-04		-1,8	3,4	-2,1	-
34	1,354E-04	1,380E-04	1,308E-04	1,384E-04		-2,0	3,4	-2,2	-
35	1,363E-04	1,391E-04			1,398E-04	-2,0	-	-	-2,6
36	1,372E-04	1,401E-04	1,327E-04	1,403E-04		-2,1	3,3	-2,3	-
38	1,387E-04	1,419E-04	1,342E-04	1,420E-04		-2,3	3,2	-2,4	-
40	1,400E-04	1,435E-04	1,356E-04	1,434E-04	1,439E-04	-2,5	3,1	-2,4	-2,8
42	1,411E-04	1,448E-04	1,367E-04	1,446E-04		-2,7	3,1	-2,5	-
44	1,419E-04	1,460E-04	1,377E-04	1,456E-04		-2,8	3,0	-2,6	-
45	1,423E-04	1,465E-04			1,467E-04	-2,9	-	-	-3,1
46	1,427E-04	1,469E-04	1,385E-04	1,464E-04		-3,0	2,9	-2,6	-
48	1,432E-04	1,478E-04	1,392E-04	1,471E-04		-3,2	2,8	-2,7	-
50	1,437E-04	1,485E-04	1,398E-04	1,477E-04	1,484E-04	-3,4	2,7	-2,8	-3,3
52	1,440E-04	1,491E-04	1,403E-04	1,482E-04		-3,5	2,6	-2,9	-
54	1,443E-04	1,496E-04	1,407E-04	1,485E-04		-3,7	2,5	-2,9	-
55	1,444E-04	1,499E-04			1,494E-04	-3,8	-	-	-3,5
56	1,444E-04	1,501E-04	1,410E-04	1,488E-04		-3,9	2,4	-3,0	-
58	1,445E-04	1,504E-04	1,412E-04	1,490E-04		-4,1	2,3	-3,1	-
60	1,446E-04	1,507E-04	1,414E-04	1,491E-04	1,498E-04	-4,3	2,2	-3,1	-3,6

3. BURN UP CALCULATIONS.

Verification possibilities of the burn up calculations by multi group codes are very limited. Perhaps comparison with results of the other multi group codes is the possible variant only. We cannot be in the firm belief in the correct of “benchmark” solution however. In all codes without exception the burn up calculation is divided into two parts. In first part equation of neutron transport is solved in spatial dimension with given nuclide composition. In second part when flux in zones is known, the equation system of evolution for nuclide concentration is solved. We have investigated errors of transport calculation sufficiently in detail before. The some results of investigations of the part connected with evaluation equation demonstrate here. To avoid the compensation of errors, we deliberately have chosen the simple (with point of view the transport calculation) objects of our investigations namely the regular

UO_2 and MOX lattices given in/2,3/. Below for these lattices we have demonstrated the some comparisons our result with those obtained by other codes.

Fuel burn up is performed only under state 1 to an average burn up of 60 MWd/kgHM. The power density for the burn up calculations is 108 MW/m^3, which is typical of operating VVER-1000 reactors. All depletions are performed with a natural boron concentration of 600 ppm by weight (0.6 g B/kg H_2O).

For comparison we have chosen the K_{eff} value and the concentration of most significant nuclide Pu^{239}. Results calculations and comparisons are presented in Tables 8-9. One can see of these Tables that for all burn up points the differences in K_{eff} values do not exceed 0.7%.

To interpret correctly the comparison results it is necessary to involve the information on burn up dependence of concentrations of basic nuclides and fission products.

4. CONCLUSIONS

The performed verification analysis of the SVL and other codes shows that in the whole the SVL code elaborated by us demonstrates satisfactory accuracy for calculating the VVER-1000 subassemblies both with UO_2 and with MOX fuel.

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