ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 9, September 2016

Investigation of the Pin-By-Pin Fission Rate Distributions for VVER MOX and LEU Fuel Assemblies Using MCNPX Code

Heba K. Louis

***Abstract*— The aim of this work is to investigate the pin power distribution for VVER-1000 fuel assemblies at different operational states and at different burnup points using the MCNPX code. This paper presents the results of the calculations of the A VVER-1000 LEU and MOX Assembly as described in the Computational Benchmark problem. In the present work the Monte Carlo code MCNPX (version MCNPX 2.7.0) with ENDF/B-VII.1 (ENDF71x) library is used. It is to be mentioned here that the earlier Benchmark results used earlier versions of ENDF-B library (ENDF/B-VI), JEF-2.2 library and MCUDAT-2.1.The calculations include the variations of K_{inf} and the pin-by-pin fission rate distributions with respect to burnup. Four calculational states have performed for depletion calculations at three burnup points (0, 20 and 40 MWd/kgHM); these states cover the operational states and cold conditions. Comparisons of the results have performed with the benchmark mean results. An excellent agreement was observed for all results. The presented results of MCNPX code can be used as reference results for LEU and MOX VVER assemblies.**

***Index Terms*—VVER-1000, Pressurized water reactor (PWR), Burnup, fission rate distributions and MCNPX code**

I. Introduction

Due to the lack of experimental data, a number of computational Benchmark problems were formulated for nuclear reactors aiming to give vision about the adequacy of the computational tools and the nuclear data used in the operation and safety assessment of nuclear reactors. A VVER-1000 LEU and MOX Assembly Computational Benchmark [1] is one of these benchmark problems.

The VVER-1000 Benchmarka total of six solutions were performed from five countries with each participant using different methods and data combinations. The participants include the Russian Research Center “Kurchatov Institute” (RRC-KI) using the MCU and TVS-M codes, Belgonucléaire, Belgium using WIMS8A, Oak Ridge National Laboratory(ORNL), USA using the HELIOS code, (GRS), Germany using MCNP4B (at zero burnup only), and KFKI Atomic Energy Research Institute, Hungary using the MULTICELL code. The data libraries utilized by the participants include ENDF/B-VI, JEF-2.2, and MCUDAT-2.1, a compilation of cross section data used with MCU and TVS-M at the RRC-KI. [1]

The aim of this work is to investigate the pin power distribution using the MCNPX code at different operational states. The results of the pin-by-pin fission rate distributions for computational benchmark of (LEU) and (MOX) fuel assemblies by using the Monte Carlo code (version MCNPX 2.7.0) [2] with ENDF/B-VII.1 (ENDF71x) libraries[3] are presented in the next sections. The present results are compared with the benchmark mean results**.**

The benchmark exercise consists of two assembly types: a uniform LEU fuel assembly with 12 U/Gd rods (UGD variant) and a profiled MOX fuel assembly with 12 U/Gd rods (MOXGD variant).The VVER-1000 assemblies are hexagonal in design and consist of one central tube, 312 fuel pin locations (12 of which are U/Gd rods), and 18 guide tubes. The clad and structural materials are composed of a Zr-Nb alloy. The Uniform LEU assembly consists of fuel rods with 3.7 wt. % enrichment. The 12 U/Gd pins have a ^{235}U enrichment of 3.6 wt. % and aGd_2O_3 content of 4.0 wt. %.The profiled MOX assembly contains fuel rods with three different plutonium loadings. The central region contains MOX pins with 4.2 wt. % fissile plutonium (consisting of 93 wt. %^{239}Pu), two rings of fuel rods with 3.0 wt. % fissile plutonium, and an outer ring of fuel rods with 2.0 wt. % fissile plutonium. The 12 U/Gd rods are in the same locations as in the UGD variant configuration and have the same design. [1]

The configuration of the uniform LEU assembly and the profiled MOX assembly are shown in Figures 1and 2 respectively.

The cell numeration in the fuel assemblies to presenting fission rate distribution is shown in figure3.Different calculational states were performed for depletion calculations at three burnup points (0, 20 and 40 MWd/kgHM). The requested state is presented in table1.

Table 1: calculation states

State	Description	Fuel temp. ,K	Non-fuel temp. ,K
S1	Operating poisoned state*	1027	575
S2	Operating non-poisoned state	1027	575
S3	Hot state	575	575
S4	Hot state without boron acid	575	575
S5	Cold state	300	300

*Eq. Indicates equilibrium 135-Xe and 149- Sm concentration

Manuscript received Sept., 2016.
First Author name*, *Heba Kareem Louis
Safety Engineering Department, Nuclear and Radiological Regulation Authority (ENRRA), Cairo, Egypt,(e-mail: heba.louis@yahoo.com)

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 9, September 2016

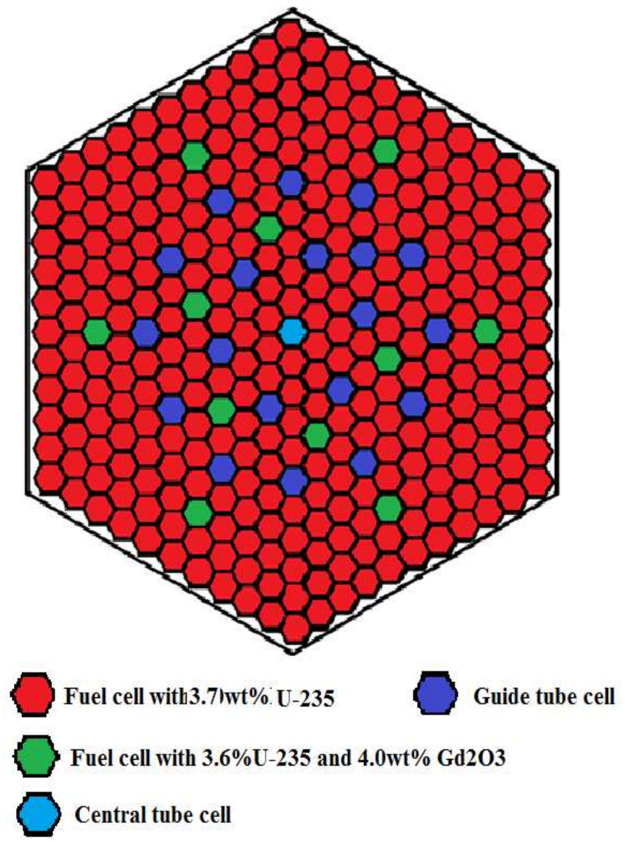

Fig 1: The configuration of uniform LEU fuel assembly with 12 Gd BA rods

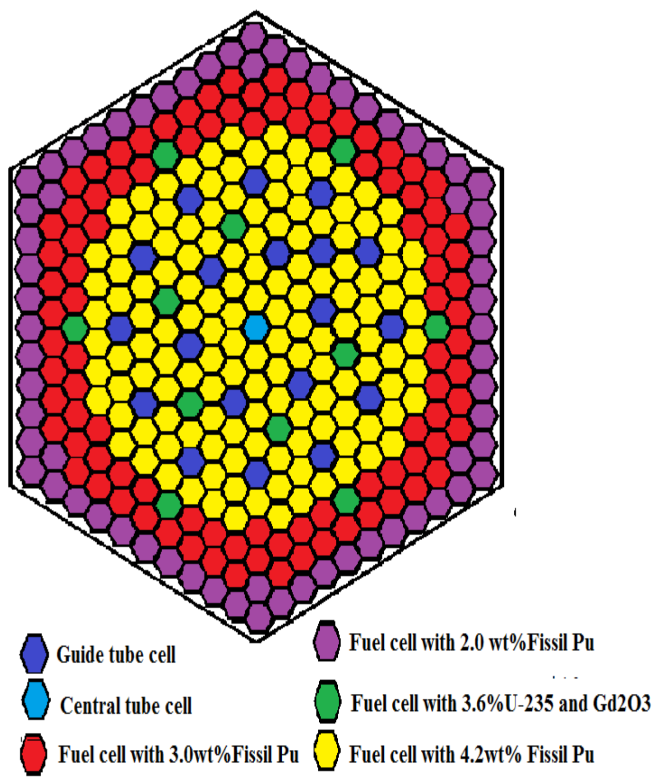

Fig 2: The configuration of profiled MOX fuel assembly with 12 Gd BA rods

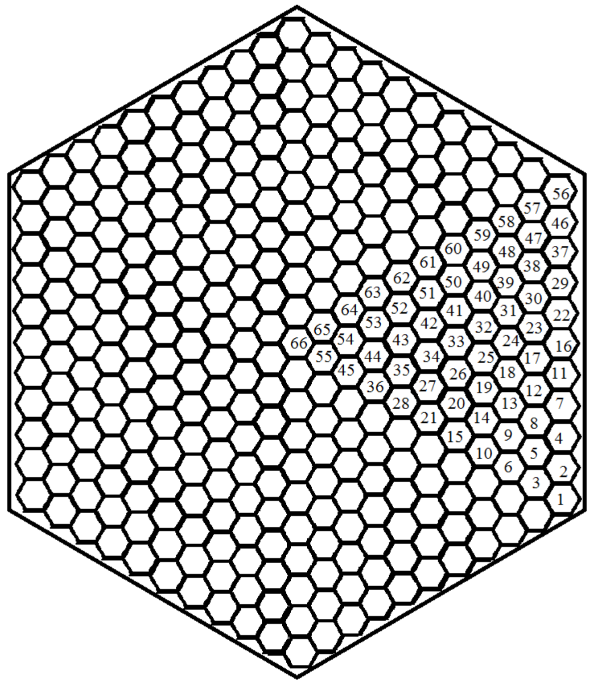

Fig 3: Cell numeration in the fuel assemblies to presenting fission rate distribution

The present calculations were performed for S2, S3, S4 and-S5 states. The present calculations included the variation of k_{inf} and the fission rate distributions with burnup for LEU and MOX assemblies. Also the relative deviation of MCNPX results from mean values is performed. The deviation is calculates as:

$$\text{Relative Deviatio} = 100\% * \frac{(\text{MCNPX value}) - (\text{benchmark mean value})}{(\text{benchmark mean value})}$$

II. RESULTS AND DISCUSSION

As mentioned previously, the calculations of k_{inf} and fission rate for LEU and MOX assemblies for different reactor states at burnup points 0, 20, 40 MWd/kgHM have been performed using MCNPX code with ENDF/B-VII.1 (ENDF71x) library. The MCNPX results are compared with the benchmark's participants mean results.

A. The variation of k-inf with burnup:

The results of k_{inf} with respect to burnup for LEU fuel assembly and MOX fuel assembly at burnup points 0, 20, 40 MWd/kgHM for states S2-S5 are shown in tables 2 and 3 respectively. These tables also show the comparison of the MCNPX results with the benchmark's participants mean results.

From tables 2 and 3 we can see very good agreements for all MCNPX results with Benchmark Mean results.The deviations of the MCNPX results from the mean benchmark results are very small. The maximum deviation from benchmark mean results was 1.32% for MOX assembly and was about 1.1% for LEU assembly.

Table2: k_{inf} with respect to burnup (MWD/KgHM) for UGD variant

Burnup	MCNPX code	Benchmark Mean	Deviation from Mean 100%*(MCNPX-Mean)/Mean
		S2	
0	1.194	1.1899	0.34
20	1.048	1.0504	-0.23
40	0.942	0.9323	1.04
		S3	
0	1.213	1.2074	0.46
20	1.062	1.0659	-0.37
40	0.947	0.9464	0.06
		S4	
0	1.254	1.2422	0.95
20	1.098	1.1042	-0.56
40	0.998	0.9862	1.20
		S5	
0	1.331	1.3209	0.76
20	1.174	1.1746	-0.05
40	1.054	1.0403	1.32

Table3:.k_{inf} with respect to burnup (MWD/KgHM) for MOXGD variant

Burnup	MCNPX code	Benchmark Mean	Deviation from Mean 100%*(MCNPX-Mean)/Mean
		S2	
0	1.171	1.1754	-0.37
20	1.082	1.0807	0.12
40	0.941	0.9394	0.17
		S3	
0	1.183	1.1891	-0.51
20	1.093	1.0959	-0.26
40	0.960	0.9534	0.69
		S4	
0	1.252	1.2489	0.25
20	1.144	1.1507	-0.58
40	1.004	1.0025	0.15
		S5	
0	1.322	1.3175	0.34
20	1.203	1.2179	-1.22
40	1.067	1.0558	1.06

B. Fission rates distributions:

The pin-by-pin fission rate distributions for LEU and MOX assemblies have performed by MCNPX codes with S2, S3, S4 and S5 states at three burnup points (0, 20 and 40 MWd/kgHM).

The results of MCNPX code have compared with the benchmark mean results for the four operational states at burnup = 0 MWD/kgHMfor LEU and MOX assemblies are presented in tables 4 and 5 respectively. Also table 4 and 5 present the relative deviations between MCNPX results and the benchmark mean results for UGD variant and MOX variant at four states. The results of pin-by-pin fission rate distributions for UGD variant at four operational states at three burnup points (0, 20 and 40 MWd/kgHM) are presented in figures 4 -7 while for MOXGD variant are presented in figures 8 -11

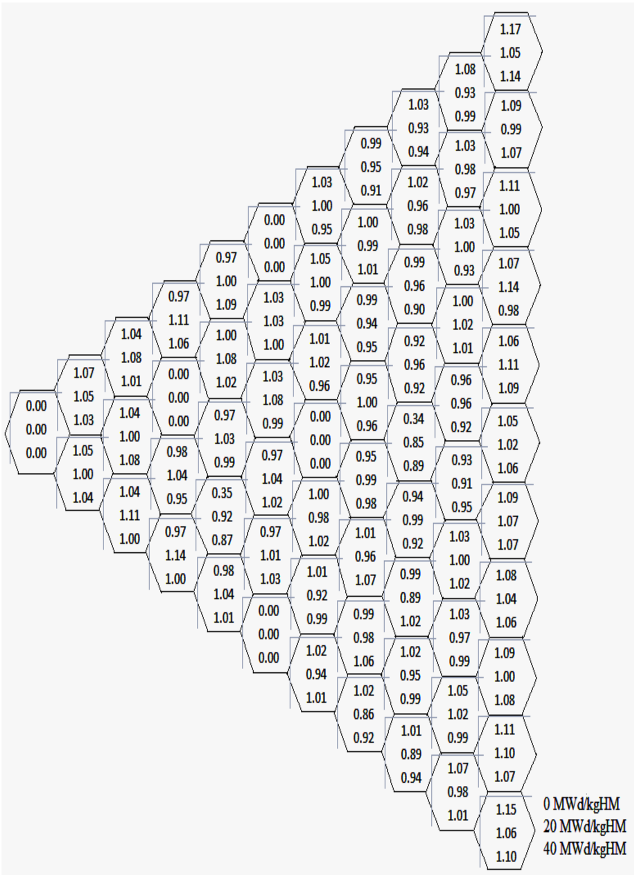

Fig.4: Pin-by-pin fission rate distributions for UGD variant at burnup = 0, 20 and 40 MWD/kgHMfor state S2)

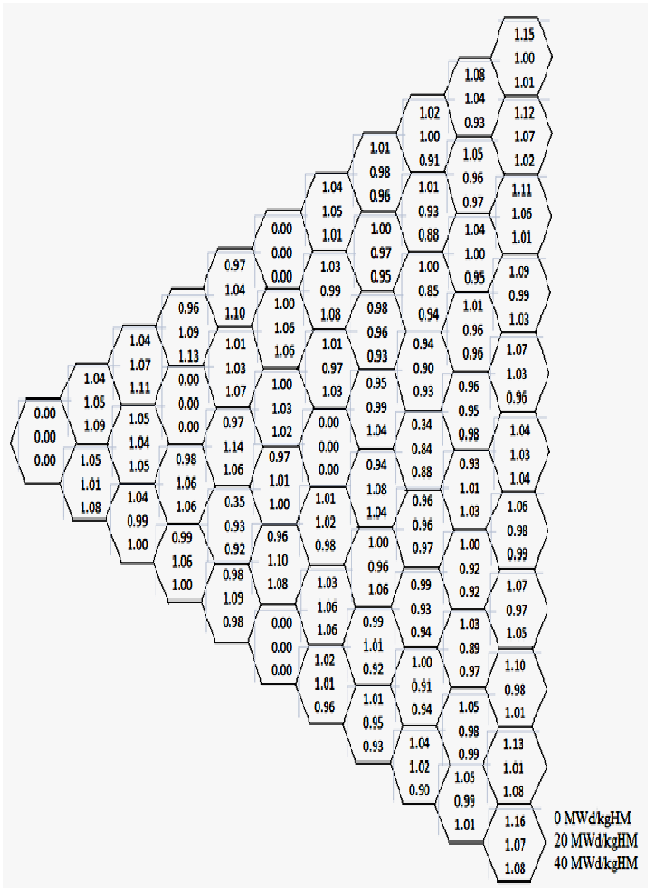

Fig.5: Pin-by-pin fission rate distributions for UGD variant at burnup = 0, 20 and 40 MWD/kgHM for state S3)

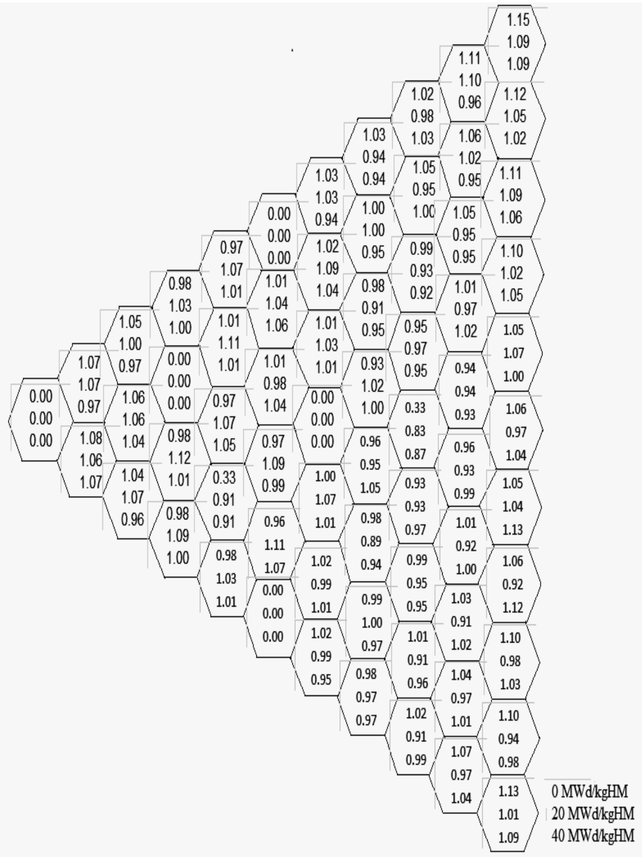

Fig.6: Pin-by-pin fission rate distributions for UGD variant at burnup = 0, 20 and 40 MWD/kgHM for state S4)

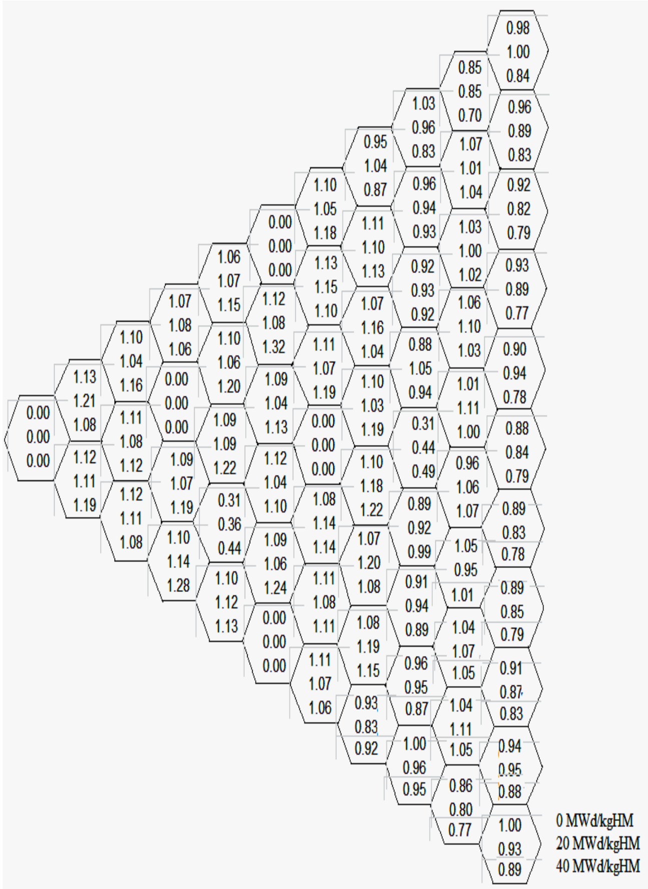

Fig.8: Pin-by-pin fission rate distributions for MOXGD variant at burnup = 0, 20 and 40 MWD/kgHM for state S2)

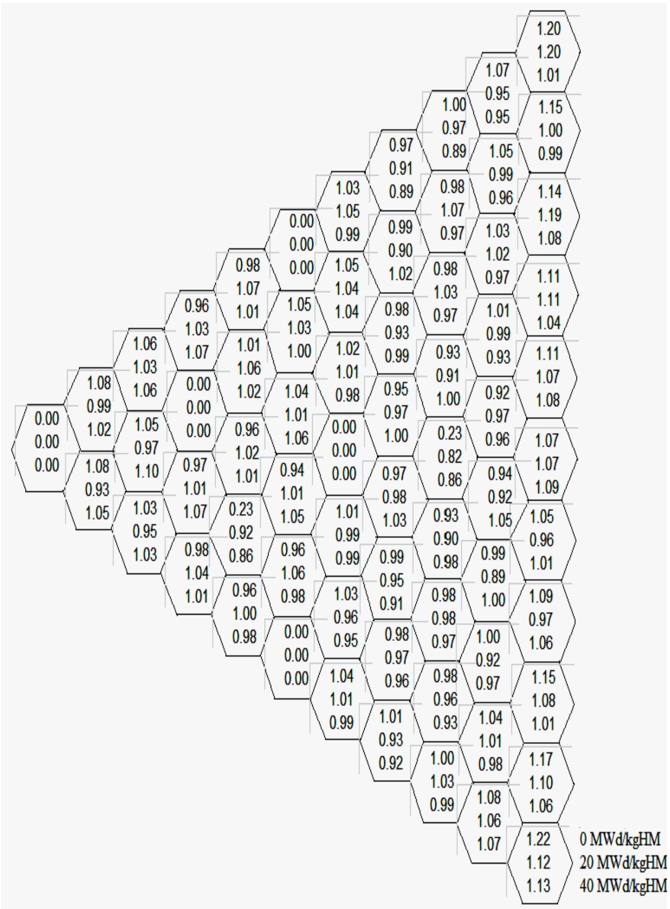

Fig.7: Pin-by-pin fission rate distributions for UGD variant at burnup = 0, 20 and 40 MWD/kgHM for state S5)

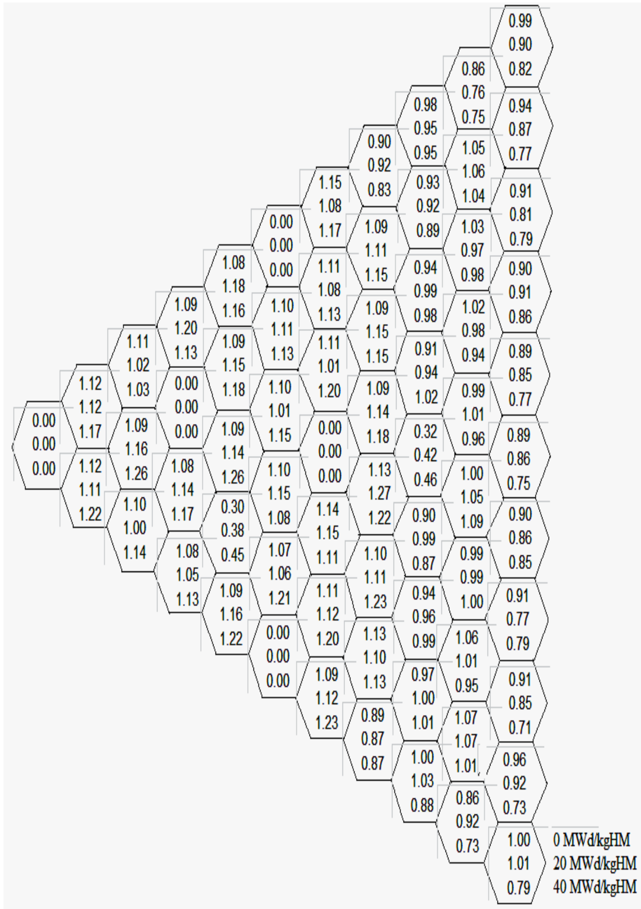

Fig.9: Pin-by-pin fission rate distributions for MOXGD variant at burnup = 0, 20 and 40 MWD/kgHM for state S3)

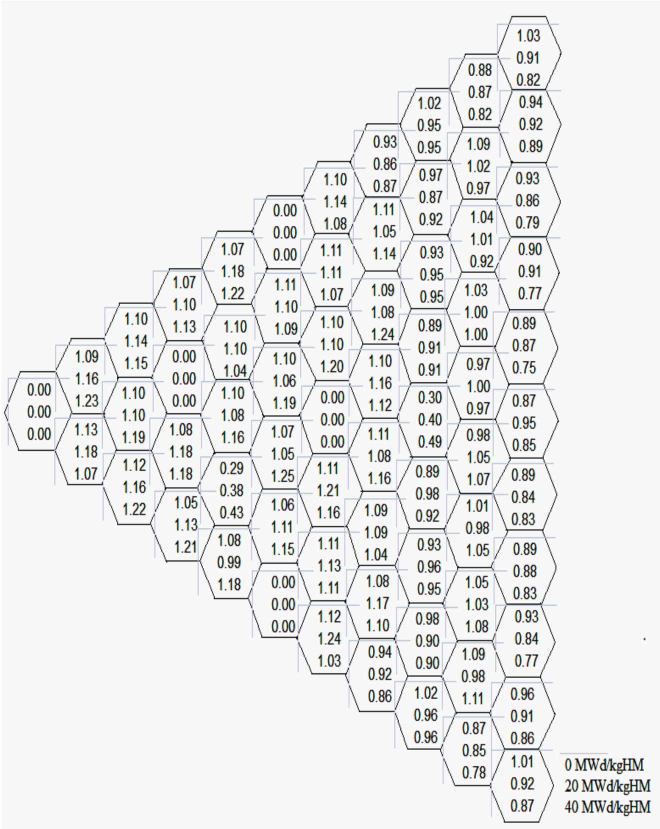

Fig.10: Pin-by-pin fission rate distributions for MOXGD variant at burnup = 0, 20 and 40 MWD/kgHM for state S4)

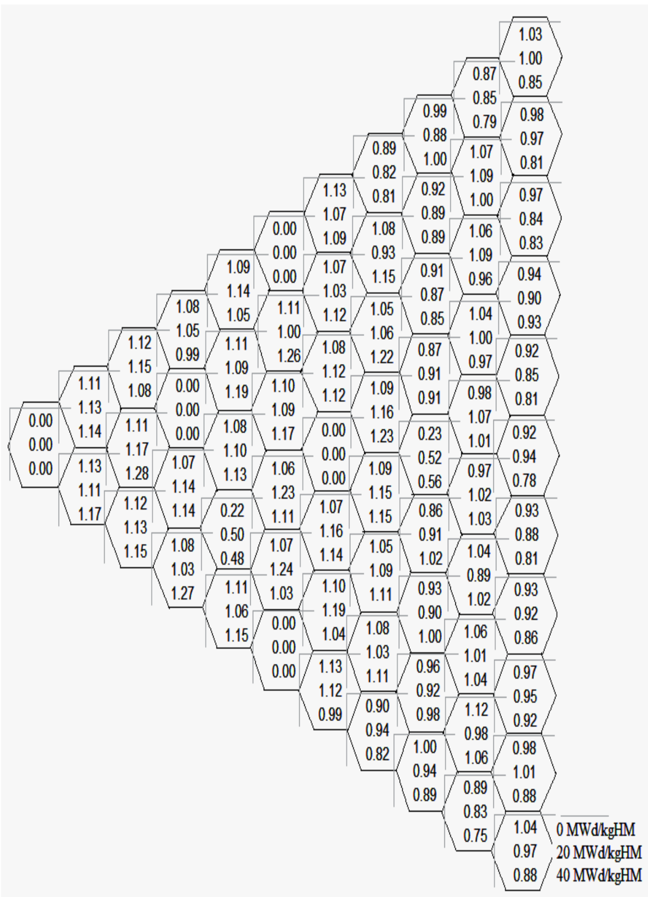

Fig.11: Pin-by-pin fission rate distributions for MOXGD variant at burnup = 0, 20 and 40 MWD/kgHM for state S5)

Table 4: Relative deviation from mean values for UGD variant at zero burnup

UGD Variant	S2			S3			S4			S5		
PIN NO.	MEAN	MCNPX	div%	MEAN	MCNPX	div%	MEAN	MCNPX	div%	MEAN	MCNPX	div%
1	1.15	1.15	0.44	1.16	1.16	0.32	1.16	1.13	2.47	1.20	1.22	1.39
2	1.12	1.11	0.87	1.13	1.13	0.13	1.13	1.10	2.80	1.15	1.17	1.10
3	1.08	1.07	0.81	1.08	1.05	2.18	1.08	1.07	0.81	1.08	1.08	0.43
4	1.11	1.09	1.35	1.11	1.10	0.61	1.11	1.10	0.73	1.13	1.15	1.82
5	1.05	1.05	0.58	1.06	1.05	0.91	1.06	1.04	1.21	1.05	1.04	1.20
6	1.03	1.01	2.45	1.03	1.04	1.03	1.03	1.02	1.44	1.02	1.00	1.95
7	1.09	1.08	1.29	1.09	1.07	1.38	1.09	1.06	2.73	1.11	1.09	2.05
8	1.04	1.03	0.35	1.04	1.03	0.55	1.04	1.03	1.07	1.03	1.00	2.65
9	1.02	1.02	0.25	1.02	1.00	1.99	1.02	1.01	0.40	1.01	0.98	2.52
10	1.01	1.02	0.48	1.01	1.01	0.77	1.01	0.98	3.21	1.00	1.01	1.25
11	1.07	1.09	2.32	1.07	1.06	0.70	1.07	1.05	2.27	1.09	1.05	3.92
12	1.01	1.03	1.73	1.01	1.00	0.64	1.01	1.01	0.05	1.00	0.99	1.36
13	1.00	0.99	0.76	1.00	0.99	0.95	1.00	0.99	0.61	0.98	0.98	0.21
14	1.01	0.99	1.21	1.01	0.99	1.97	1.01	0.99	1.43	1.00	0.98	1.70
15	1.03	1.02	1.24	1.03	1.02	1.29	1.03	1.02	1.46	1.04	1.04	0.51
16	1.06	1.05	0.28	1.06	1.04	1.83	1.06	1.06	0.19	1.08	1.07	0.99
17	0.96	0.93	2.27	0.96	0.93	2.94	0.96	0.96	0.50	0.94	0.94	0.39
18	0.94	0.94	0.43	0.94	0.96	1.79	0.94	0.93	1.30	0.92	0.93	0.88
19	0.99	1.01	2.07	0.99	1.00	1.26	0.99	0.98	0.99	0.98	0.99	1.09
20	1.02	1.01	0.65	1.02	1.03	1.16	1.02	1.02	0.32	1.03	1.03	0.26
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	1.07	1.06	0.44	1.07	1.07	0.06	1.07	1.05	1.95	1.09	1.11	1.71
23	0.96	0.96	0.17	0.96	0.96	0.77	0.95	0.94	1.17	0.94	0.92	2.45
24	0.33	0.34	5.62	0.32	0.34	5.91	0.31	0.33	6.66	0.22	0.23	5.44
25	0.96	0.95	0.79	0.96	0.94	1.90	0.96	0.96	0.06	0.95	0.97	1.28
26	1.00	1.00	0.29	1.00	1.01	1.04	1.00	1.00	0.45	1.01	1.01	0.69
27	0.97	0.97	0.47	0.97	0.96	0.93	0.97	0.96	1.29	0.97	0.96	1.07
28	0.97	0.98	0.93	0.97	0.98	0.72	0.97	0.98	1.03	0.97	0.96	0.84
29	1.09	1.07	1.62	1.09	1.09	0.20	1.09	1.10	0.38	1.11	1.11	0.40
30	1.01	1.00	1.27	1.01	1.01	0.24	1.01	1.01	0.24	1.01	1.01	0.67
31	0.94	0.92	2.14	0.94	0.94	0.55	0.94	0.95	1.01	0.92	0.93	1.46
32	0.96	0.95	0.96	0.96	0.95	1.43	0.96	0.93	2.87	0.96	0.95	0.41
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	0.97	0.97	0.01	0.97	0.97	0.18	0.97	0.97	0.53	0.97	0.94	2.95
35	0.32	0.35	8.02	0.32	0.35	9.42	0.31	0.33	6.40	0.22	0.23	3.98
36	0.97	0.97	0.31	0.97	0.99	1.28	0.97	0.98	0.33	0.97	0.98	0.87
37	1.11	1.11	0.22	1.11	1.11	0.09	1.11	1.11	0.17	1.13	1.14	0.86
38	1.04	1.03	0.58	1.04	1.04	0.70	1.04	1.05	1.42	1.03	1.03	0.65
39	1.00	0.99	0.95	1.00	1.00	0.43	1.00	0.99	0.38	0.99	0.98	0.26
40	0.99	0.99	0.46	0.99	0.98	1.15	0.99	0.98	1.14	0.98	0.98	0.09
41	1.02	1.01	0.83	1.02	1.01	1.16	1.02	1.01	1.44	1.03	1.02	0.77
42	1.02	1.03	0.71	1.02	1.00	1.59	1.02	1.01	1.25	1.03	1.04	0.83
43	0.97	0.97	0.50	0.97	0.97	0.35	0.97	0.97	0.02	0.97	0.96	1.32
44	0.98	0.98	0.09	0.98	0.98	0.43	0.98	0.98	0.24	0.98	0.97	1.34
45	1.03	1.04	0.21	1.03	1.04	0.77	1.04	1.04	0.65	1.04	1.03	1.25
46	1.13	1.09	2.85	1.13	1.12	0.52	1.13	1.12	1.44	1.16	1.15	0.27
47	1.06	1.03	2.91	1.06	1.05	0.59	1.06	1.06	0.49	1.05	1.05	0.20
48	1.02	1.02	0.31	1.02	1.01	0.44	1.02	1.05	2.90	1.00	0.98	2.30
49	1.01	1.00	0.68	1.01	1.00	1.23	1.01	1.00	0.86	1.00	0.99	0.55
50	1.03	1.05	1.25	1.04	1.03	0.66	1.03	1.02	1.22	1.05	1.05	0.40
51	1.03	1.03	0.43	1.03	1.00	2.90	1.03	1.01	1.65	1.05	1.05	0.93
52	1.02	1.00	1.68	1.01	1.01	0.88	1.01	1.01	0.50	1.03	1.01	1.42
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	1.05	1.04	0.56	1.04	1.05	0.95	1.04	1.06	1.33	1.06	1.05	0.77
55	1.07	1.05	1.78	1.07	1.05	1.23	1.06	1.08	1.05	1.08	1.08	0.38
56	1.16	1.17	0.98	1.16	1.15	0.44	1.16	1.15	1.00	1.20	1.20	0.13
57	1.08	1.08	0.41	1.08	1.08	0.16	1.08	1.11	2.97	1.08	1.07	0.63
58	1.03	1.03	0.41	1.03	1.02	0.93	1.03	1.02	1.09	1.02	1.00	2.41
59	1.02	0.99	2.43	1.02	1.01	0.37	1.02	1.03	0.88	1.00	0.97	3.31
60	1.03	1.03	0.20	1.04	1.04	0.42	1.03	1.03	0.20	1.04	1.03	0.76
61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	0.98	0.97	1.06	0.98	0.97	0.86	0.98	0.97	0.72	0.98	0.98	0.27
63	0.98	0.97	1.29	0.98	0.96	1.92	0.98	0.98	0.02	0.99	0.96	3.21
64	1.04	1.04	0.10	1.04	1.04	0.44	1.04	1.05	0.65	1.05	1.06	0.56
65	1.06	1.07	0.77	1.07	1.04	2.83	1.07	1.07	0.40	1.08	1.08	0.11
66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.Div%			8.02			9.42			6.66			5.44

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 9, September 2016

Table 5: Relative deviation from mean values for MOXGD variant at zero burnup

MOXGD	S2			S3			S4			S5		
PIN NO.	MEAN	mcnpx	div%	MEAN	mcnpx	div%	MEAN	mcnpx	div%	MEAN	mcnpx	div%
1	0.99	1.00	0.47	0.99	1.00	1.36	1.00	1.01	0.68	1.04	1.04	0.25
2	0.95	0.94	0.17	0.95	0.96	0.94	0.95	0.96	0.82	0.98	0.98	0.34
3	0.87	0.86	0.56	0.87	0.86	0.42	0.87	0.87	0.77	0.88	0.89	0.63
4	0.92	0.91	0.99	0.92	0.91	1.36	0.92	0.93	0.82	0.95	0.97	2.58
5	1.07	1.04	2.88	1.07	1.07	0.07	1.08	1.09	1.05	1.08	1.12	3.48
6	1.00	1.00	0.44	1.00	1.00	0.28	1.01	1.02	1.56	1.00	1.00	0.06
7	0.90	0.89	1.56	0.90	0.91	1.46	0.91	0.89	1.62	0.93	0.93	0.44
8	1.04	1.04	0.63	1.04	1.06	1.91	1.04	1.05	0.23	1.05	1.06	0.97
9	0.96	0.96	0.15	0.96	0.97	1.43	0.96	0.98	1.58	0.96	0.96	0.46
10	0.92	0.93	0.38	0.92	0.89	3.00	0.92	0.94	2.44	0.92	0.90	1.94
11	0.89	0.89	0.25	0.89	0.90	0.64	0.90	0.89	1.03	0.92	0.93	1.16
12	1.02	1.05	2.96	1.02	0.99	2.88	1.02	1.01	1.09	1.02	1.04	2.09
13	0.94	0.91	2.77	0.93	0.94	0.92	0.93	0.93	0.88	0.93	0.93	0.18
14	1.10	1.08	1.59	1.10	1.13	3.10	1.10	1.08	1.94	1.09	1.08	0.61
15	1.13	1.11	1.21	1.13	1.09	3.23	1.12	1.12	0.02	1.12	1.13	0.54
16	0.89	0.88	1.14	0.89	0.89	0.07	0.89	0.87	2.26	0.91	0.92	1.43
17	0.99	0.96	3.29	1.00	1.00	0.52	0.99	0.98	1.28	0.99	0.97	2.61
18	0.91	0.89	1.84	0.91	0.90	0.60	0.91	0.89	2.03	0.90	0.86	3.58
19	1.08	1.07	0.97	1.09	1.10	1.34	1.08	1.09	0.56	1.07	1.05	1.29
20	1.11	1.11	0.80	1.11	1.11	0.52	1.11	1.11	0.41	1.11	1.10	0.73
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.89	0.90	0.64	0.89	0.89	0.24	0.89	0.89	0.14	0.92	0.92	0.82
23	0.99	1.01	1.06	0.99	0.99	0.46	0.99	0.97	2.01	0.99	0.98	1.08
24	0.31	0.31	0.17	0.31	0.32	2.51	0.30	0.30	0.32	0.23	0.23	1.31
25	1.10	1.10	0.11	1.10	1.13	2.58	1.10	1.11	0.78	1.09	1.09	0.28
26	1.11	1.08	2.17	1.11	1.14	3.06	1.11	1.11	0.20	1.11	1.07	2.87
27	1.09	1.09	0.46	1.09	1.07	1.55	1.09	1.06	2.18	1.08	1.07	1.20
28	1.09	1.10	0.70	1.09	1.09	0.30	1.08	1.08	0.29	1.08	1.11	2.47
29	0.90	0.93	3.54	0.90	0.90	0.67	0.91	0.90	0.91	0.93	0.94	1.94
30	1.02	1.06	4.19	1.02	1.02	0.44	1.02	1.03	0.54	1.02	1.04	1.84
31	0.91	0.88	3.01	0.91	0.91	0.29	0.91	0.89	1.46	0.89	0.87	2.88
32	1.11	1.10	0.05	1.11	1.09	1.68	1.10	1.10	0.09	1.09	1.09	0.08
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	1.09	1.12	2.17	1.09	1.10	0.77	1.09	1.07	1.74	1.08	1.06	1.98
35	0.30	0.31	1.04	0.30	0.30	1.24	0.30	0.29	1.46	0.23	0.22	0.96
36	1.09	1.10	1.71	1.09	1.08	0.34	1.08	1.05	2.74	1.07	1.08	0.95
37	0.92	0.92	0.72	0.92	0.91	1.32	0.92	0.93	0.91	0.95	0.97	2.24
38	1.04	1.03	0.37	1.04	1.03	0.46	1.04	1.04	0.54	1.05	1.06	0.82
39	0.94	0.92	1.20	0.94	0.94	0.43	0.93	0.93	0.68	0.93	0.91	1.61
40	1.09	1.07	1.31	1.09	1.09	0.09	1.08	1.09	0.48	1.07	1.05	1.68
41	1.12	1.11	0.88	1.12	1.11	0.19	1.11	1.10	1.06	1.11	1.08	3.45
42	1.11	1.09	2.47	1.12	1.10	1.37	1.11	1.10	1.28	1.11	1.10	0.93
43	1.09	1.09	0.57	1.09	1.09	0.05	1.09	1.10	0.81	1.08	1.08	0.21
44	1.09	1.09	0.71	1.09	1.08	1.54	1.09	1.08	1.09	1.08	1.07	0.78
45	1.12	1.12	0.57	1.11	1.10	0.68	1.11	1.12	0.72	1.11	1.12	0.28
46	0.95	0.96	1.52	0.95	0.94	0.48	0.95	0.94	1.22	0.98	0.98	0.40
47	1.07	1.07	0.43	1.07	1.05	2.35	1.08	1.09	0.71	1.08	1.07	1.22
48	0.96	0.96	0.50	0.96	0.93	3.06	0.96	0.97	0.96	0.96	0.92	4.15
49	1.10	1.11	0.65	1.10	1.09	0.85	1.10	1.11	1.10	1.09	1.08	0.55
50	1.12	1.13	1.06	1.12	1.11	0.63	1.11	1.11	0.18	1.12	1.07	3.96
51	1.12	1.12	0.02	1.12	1.10	1.83	1.11	1.11	0.32	1.12	1.11	1.00
52	1.11	1.10	1.32	1.11	1.09	1.77	1.11	1.10	0.42	1.11	1.11	0.24
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	1.12	1.11	1.02	1.12	1.09	2.63	1.12	1.10	2.05	1.13	1.11	1.55
55	1.13	1.12	1.30	1.13	1.12	1.18	1.13	1.13	0.06	1.14	1.13	0.59
56	0.99	0.98	1.22	0.99	0.99	0.12	1.00	1.03	2.46	1.04	1.03	0.59
57	0.87	0.85	1.83	0.87	0.86	1.02	0.87	0.88	0.94	0.89	0.87	1.49
58	1.00	1.03	2.36	1.00	0.98	1.97	1.01	1.02	0.78	1.00	0.99	1.96
59	0.92	0.95	2.87	0.92	0.90	1.65	0.92	0.93	1.46	0.91	0.89	2.35
60	1.13	1.10	2.35	1.13	1.15	1.80	1.12	1.10	1.58	1.12	1.13	0.79
61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	1.10	1.06	3.02	1.10	1.08	1.20	1.09	1.07	1.67	1.09	1.09	0.28
63	1.10	1.07	3.31	1.10	1.09	0.88	1.10	1.07	2.37	1.09	1.08	1.48
64	1.13	1.10	2.24	1.12	1.11	1.59	1.12	1.10	1.91	1.13	1.12	0.40
65	1.13	1.13	0.28	1.13	1.12	1.24	1.13	1.09	3.38	1.14	1.11	2.09
66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.Div%			4.19			3.23			3.38			4.15

From table 4 we noticed that the maximum relative deviations of fission rate distributions from the benchmark mean value within 4% for all fuel pins, but for uranium gadolinium pin the discrepancies increased to reach about 8%. The pin with maximum deviation was uranium gadolinium pin and is located at pin location 35 for state s2 and s3 while is located at pin location 24 for s4 and s5. We can say that a very good agreement with the benchmark mean results for UGD variant was observed.

From table 5 we show the maximum deviation from benchmark mean results not exceed than 4% for all pins in MOXGD variant. A very good agreement with the benchmark mean results was observed in all MCNPX code results.

The previous tables make it possible to conclude that the pin-by-pin fission rate distribution calculations with MCNPX code show very good agreement with the benchmark mean results. So we can say that the presented results in this work is accurate and can be used as a reference values for LEU and MOX assemblies for VVER reactor.

III. CONCLUSIONS

In the present paper the computational benchmarks of UGD and MOXGD variants fuel assemblies for VVER-1000 have been calculated by the Monte Carlo code (version MCNPX 2.7) and ENDEF-VII.1 nuclear data library. Four calculational states have performed for depletion calculations at three burnup points (0, 20 and 40 MWd/kgHM). The obtained results of the K-inf and the pin-by-pin fission rate distributions with respect to burnup were performed. The results have been compared with the benchmark mean results of other codes presented in the benchmark. The MCNPX results of the k_{inf} values versus burnup show an excellent agreement.

The pin-by-pin fission rate distribution calculations with MCNPX code show very good agreement with the benchmark mean results. The maximum relative deviations for UGD and MOXGD assemblies were within 4% for all fuel pins, but for uranium gadolinium pin the discrepancies increased to reach about 8% in UGD assembly. These deviations are due the enhanced modeling and computational capacity of the MCNPX code over the other codes were used in benchmark as well as the utilization of more accurate evaluated data in the ENDFB-VII.1 library.

So we can say that the presented results in this work is accurate and can be used as a reference values for LEU and MOX assemblies for VVER reactor.

REFERENCES

[1] S. Chen, B. Mulgrew, and P. M. Grant, “A clustering technique for NEA/NSC/DOC 10, 2002. A VVER-1000 LEU and MOX Assembly Computational Benchmark. Nuclear Energy Agency, Organization for Economic Co-operation and Development.

[2] MCNPX User's Manual. Version 2.7.0, Los Alamos National Laboratory, LA-CP-11-00438, - 2011.

[3] M.B. Chadwick, et.al, ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariance, Fission Product Yields and Decay Data, 2011.