Trends and Results in In-Core Fuel Management for the Kozloduy NPP WWER-440 Reactors

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1. Introduction

This paper presents the experience gained during the design and operation of the last fuel cycles of the four WWER-440/V-230 NPP units at Kozloduy NPP.

Subject of the presentation are the activities on reactor fuel in-core management, including calculations and analyses for reloading scheme design, comparisons with results of operational measurements, fuel cycle efficiency estimation, etc.

The main principles and methods applied during these activities are focused on attainment of higher efficiency and economy of the fuel utilization obeying the nuclear safety criteria and requirements and using the up-to-date achievements of the computer codes and equipment.

The main stages of the implementation of advanced fuel assemblies in the Kozloduy NPP WWER-440 reactors and fuel cycles design development are described.

The results, obtained during this activity related to the discharged fuel assemblies number and burnup are presented.

The fuel cycle planning strategies are considered based on improved fuel utilization and decreasing spent fuel amount. Most important fuel cycle characteristics and features are demonstrated.

2. Stage-Wise Introduction of Advanced Fuel and Fuel Cycle Improvements

Since the more than 26-year operational practice, a series of fuel assemblies design and fuel cycle improvements have been introduced, which contribute to the Kozloduy NPP WWER-440 reactors economical efficiency and safety enhancement. Characteristic feature of in-core fuel management in WWER-440 of Kozloduy NPP is that new advanced types of assemblies are being put in operation in stages.

The most important previous fuel improvements, implemented at the Kozloduy NPP, are the following:

- Fuel pellet design and fabrication quality optimization;
- Fuel rod initial (filling) gas (helium) pressure increase, 0.4-0.75 MPa;
- Assembly shroud thickness decrease, from 2.1 to 1.5 mm, etc.

The fuel improvements have been implemented after the completion of comprehensive neutron-physical, thermohydraulic and thermomechanical analyses [6,9,10-12]. The schematic consequence of the neutron-physical calculations process and the computer codes used, are shown in Figure 2.

Through the stage-wise improvement of the fuel design characteristics, a real average assembly burnup increase has been achieved: from 31 MWd/kgU at the beginning, to 35-37 MWd/kgU at the present. Thanks to the implementation of low-leakage reloading schemes, at all Units 1-4 with or without dummy assemblies, decrease of the fresh working fuel assemblies number in

Table 1. Discharged assemblies burnup during last four cycles of Units 1-4

Average burnup, [MWd/kgU]		Enrichment, [%]		
Unit №	Cycle №	1.6	2.4	3.6
1	18			
	19			
	20			
	21	20.7	28.8	35.9
2	18	-	26.5	33.1
	19	-	31.5	34.7
	20	-	21.0	31.1
	21	-	27.5	34.3
	22	-	30.7	36.2
3	13	-	25.0	35.9
	14	-	30.1	35.6
	15	-	22.7	34.4
	16	-	26.6	36.2
4	12	-	23.6	36.6
	13	-	26.1	37.4
	14	-	-	36.8
	15	24.4	27.5	36.6
Total Units 1-4		12-14	28-30	32-36
Maximum Burnup		24.4	37	42

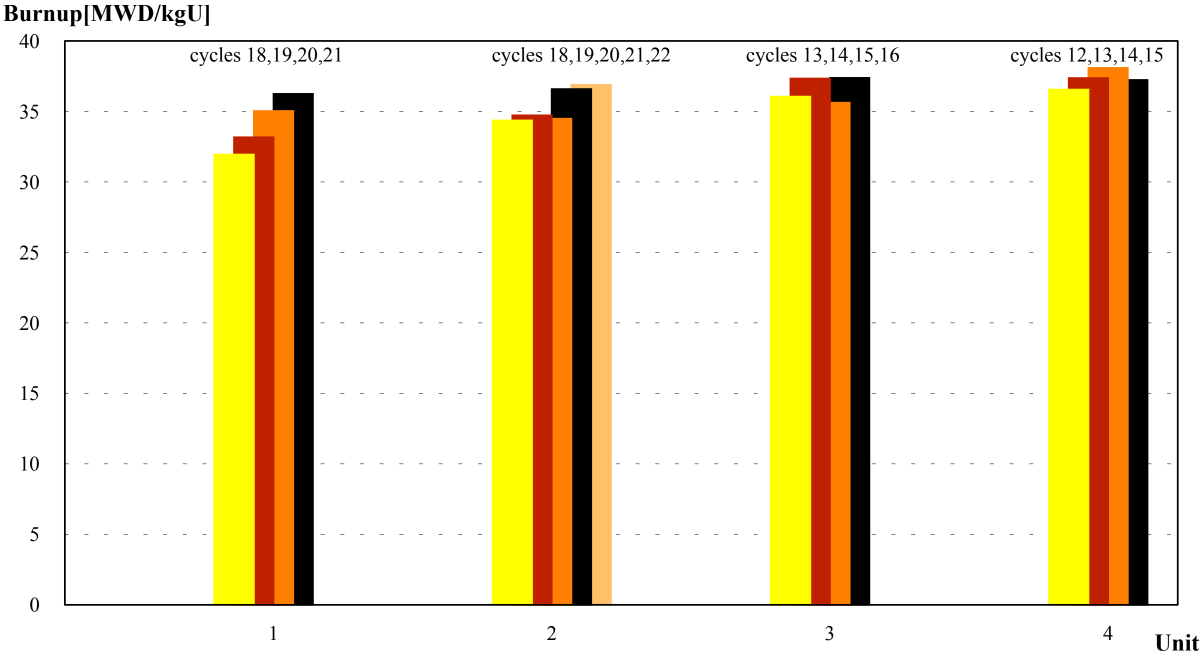


Figure 1. Discharged assemblies average burnup distribution for Units 1-4 during last four cycles

average from 102 to 90 (84-96) has been achieved without decreasing cycle length (about 280-300 FPD). These results are demonstrated in Table 1 and Figure 1. The results, shown in Figure 1, are an attempt to demonstrate visually the achievements regarding the discharged fuel burnup increasing, in the process of the fuel cycle characteristics improvement.

2.1. Advanced Fuel with Zr Spacer Grids Implementation in WWER-440 Reactors of Kozloduy NPP, Units 1-4

The most important fuel assembly improvements, implemented nowadays at the Kozloduy NPP, Units 1-4, are the following:

- Design enrichment increase from 1.6% and 2.4% to 3.6% of the control assemblies fuel part;
- Replacement of the stainless steel with Zirconium spacer grids;
- Introduction of working fuel assemblies with optimized mechanical design (vibration resistant assemblies) in Unit 2.

After successful operation of 12 advanced assemblies with Zr spacer grids during 13-th fuel cycle of Unit 4 this type of assemblies were introduced in next core loadings of the Units 1-4. The step-wise introduction process of fresh assemblies with Zr spacer grids in the Units 1-4 reactor core is presented in Table 2. As is shown in Table 3 at present time about 80% of all assemblies loaded into Units 1 to 4 are with Zr spacer grids. Significant operational experience is gained with new type assemblies with Zr spacer grids. The measured values of neutron physics core parameter are compared with calculated ones and the results show that the most important core characteristics are predicted with an acceptable level of accuracy. Main results of comparisons between calculated and measured assembly-wise relative power

Table 2. Implementaition process of fresh advanced assemblies with Zr spacer grids in the reactor cores of Units 1-4

Unit	Cycle №	Length	Assemblies with Zr grids	
			Working ass.	Control ass.
1	20	288.5	78	-
	21	293.4	84	13
	*22	280.4	78	3
2	21	294.6	90	-
	22	279.7	93	12
	*23	255.5	66	12
3	15	279.3	76	-
	16	305.9	79	3
	*17	287.0	78	12
4	13	358.7	12	-
	14	295.6	96	-
	15	333.7	80	-
	16	324.0	84	13

* - current cycle

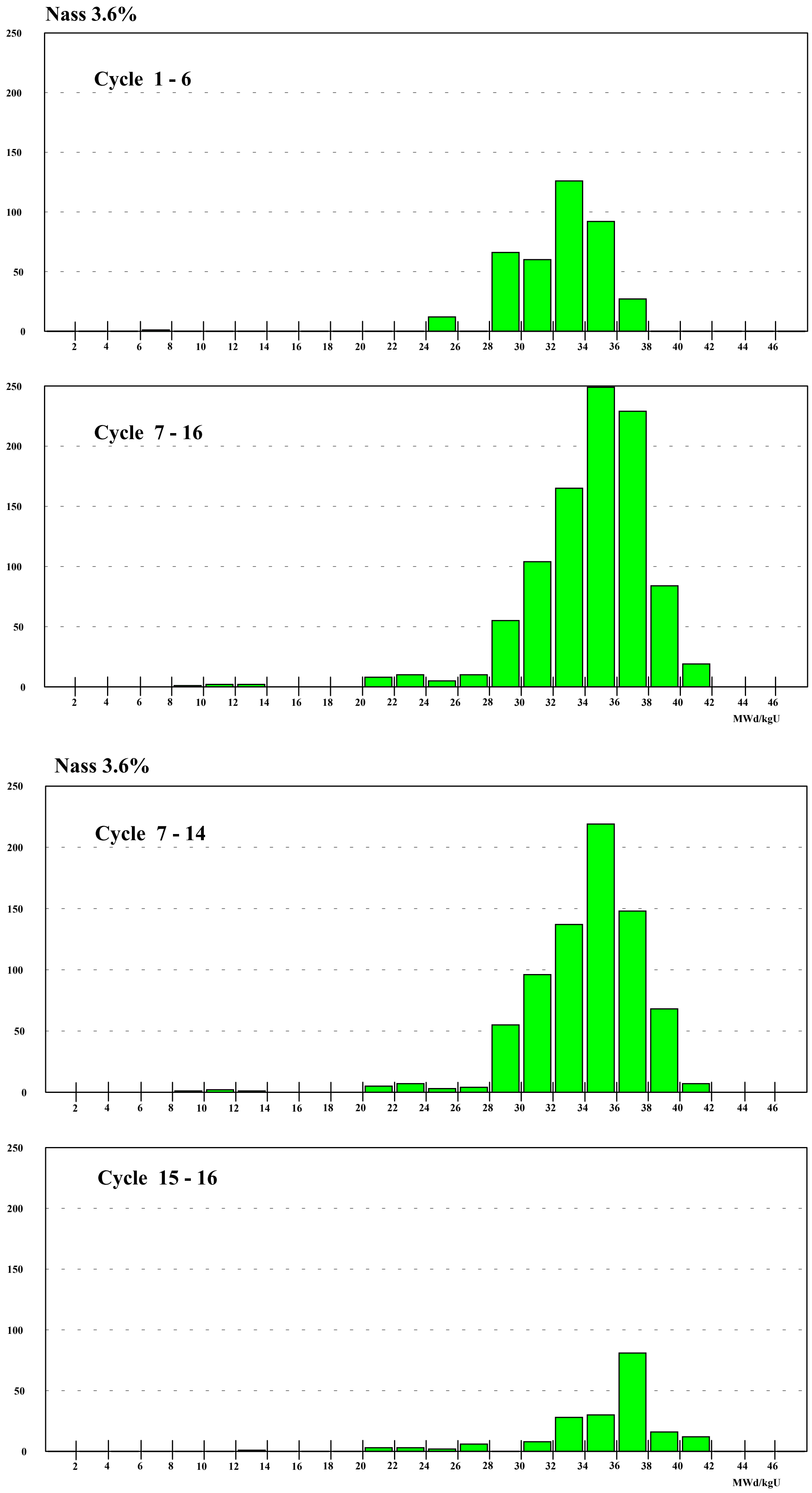
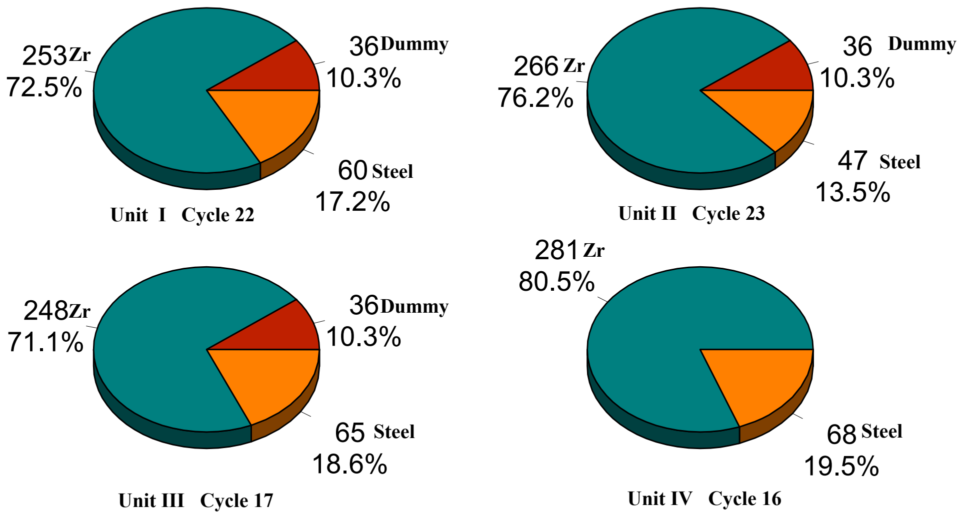


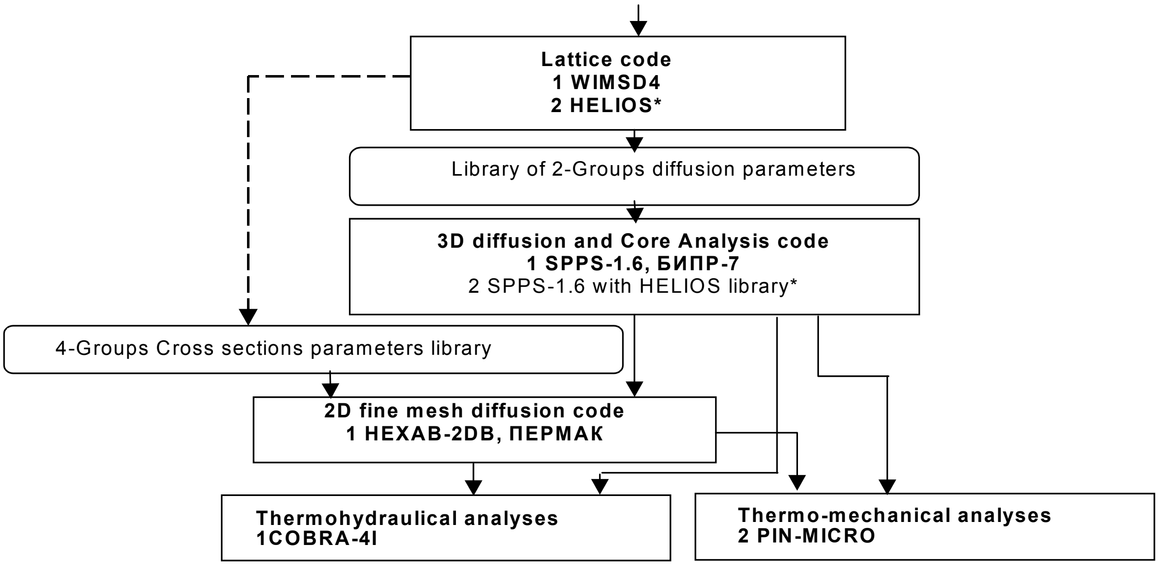
Figure 2. Relationship between assemblies burnup distribution and fuel cycle performance Improvements of Kozloduy NPP, Unit 3

Table 3.

Unit		WA							CA				Total	%
1	Type	1G	2G	3G				Total	1K	2K	2L	Total		
	Number	78	84	75				237	3	12	1	16	253	72.5
2	Type	1G	2G	3G	2H			Total	1K	2K		Total		
	Number	66*	84*	84	9			242	12	12		24	266	76.2
3	Type	1G	2G	3G	2H			Total	1J	2J		Total		
	Number	78	78	76	1			233	12	3		15	248	71.1
4	Type	1G	2G	3G	4G	2H	3H	Total	1J	1K		Total		
	Number	84	74	86	12	6	6	268	12	1		13	281	80.5



Number of loaded assemblies with Zr spacer grids for current fuel cycles of Units 1-4



* The next step of development of the used computer code complex

Figure 3. WWER-440 reactor computer codes at Kozloduy NPP

Table 4. Main results of SPPS-1.6 calculations, compared with the measured assembly-wise relative power distributions $K_q(N_{ass})$ for different moments during the 16-th cycle of Unit 3; $\Delta=(K_q^{calc}-K_q^{exp,ave})*100[\%]$ – error; N_{ass} – assembly location number in 360°sector in the core

Time, FPD/Reactor core conditions	4.1/H_{VI}=198 cm T_{in}=265.4°C; N_T=95%	78.5/H_{VI}=190 cm T_{in}=265°C; N_T=98%	146.9/H_{VI}=196 cm T_{in}=265.6°C; N_T=98%
Parameters	$C_{H_3BO_3}$=5.89 g/kg	$C_{H_3BO_3}$=4.09 g/kg	$C_{H_3BO_3}$=2.60 g/kg
K_{eff}	1.00299	1.00143	1.00068
ΔK_{eff} - critical state calculation err., [%]	0.299	0.143	0.068
Maximal values K_q $K_q^{ave.meas}/K_q^{calc}$ (N_{ass})	1.256/1.236(190)	1.244/1.227(190)	1.242/1.220(190)
Δ^+ maximal positive error	3.4	4.1	4.3
N_{ass} (type)	32(1G)	301(1G)	301(IG)
Δ^- maximal negative error	-6.8	-9.3	-9.7
N_{ass} (type)	30(4D)	307(4E)	307(4E)
σ mean-square error	2.5	2.9	3.2
Δ mean error 2D (7)	-0.5	-0.2	0.0
Δ mean error 3D (84)	-1.2	-0.4	0.0
Δ mean error 4D (23)	-4.4	-6.3	-7.9
Δ mean error 1G (78)	2.6	2.7	2.7
Δ mean error 2G (76)	0.0	-0.3	-0.3
Δ mean error 1F (4)	1.2	-0.3	1.3
Δ mean error in peripheral assemblies	-0.8	-1.6	-2.5

Table 5. Main results of SPPS-1.6 calculations, compared with the measured assembly-wise relative power distributions $K_q/N_{ass}/$ for different moments during the 17-th cycle of Unit 3; $\Delta=(K_q^{calc}-K_q^{exp,ave})*100[\%]$ – error; N_{ass} – assembly location number in 360° sector in the core

Time, FPD/Reactor core conditions	10.2/H_{VI}=197 cm T_{in}=264.0°C; N_T=95%	78.5/H_{VI}=200 cm T_{in}=264.7°C; N_T=98%	78.5/H_{VI}=190 cm T_{in}=264.2°C; N_T=98%
Parameters	$C_{H_3BO_3}$=5.53 g/kg	$C_{H_3BO_3}$=5.52 g/kg	$C_{H_3BO_3}$=4.09 g/kg
K_{eff}	1.00842	1.00475	0.99940
ΔK_{eff} - critical state calculation err., [%]	0.842	0.475	-0.060
Maximal values K_q $K_q^{ave.meas}/K_q^{calc}$ (N_{ass})	1.254/1.237(263)	1.251/1.210(123)	1.241/1.194(230)
Δ^+ maximal positive error	4.6	4.2	4.3
N_{ass} (type)	121(1E)	121(1E)	293(1G)
Δ^- maximal negative error	-4.0	-5.0	-4.7
N_{ass} (type)	203(4D)	203(4D)	117(2G)
σ mean-square error	2.1	2.2	2.1
Δ mean error 3D (5)	-0.7	-0.7	-1.3
Δ mean error 4D (26)	-2.1	-2.8	-0.4
Δ mean error 1E (4)	4.6	4.2	1.9
Δ mean error 1G (78)	1.2	1.0	2.1
Δ mean error 2G (78)	-0.1	0.2	-1.1
Δ mean error 3G (76)	-0.7	-0.6	-1.1
Δ mean error 1F (4)	-0.2	0.3	0.5
Δ mean error in peripheral assemblies		-1.4	0.9

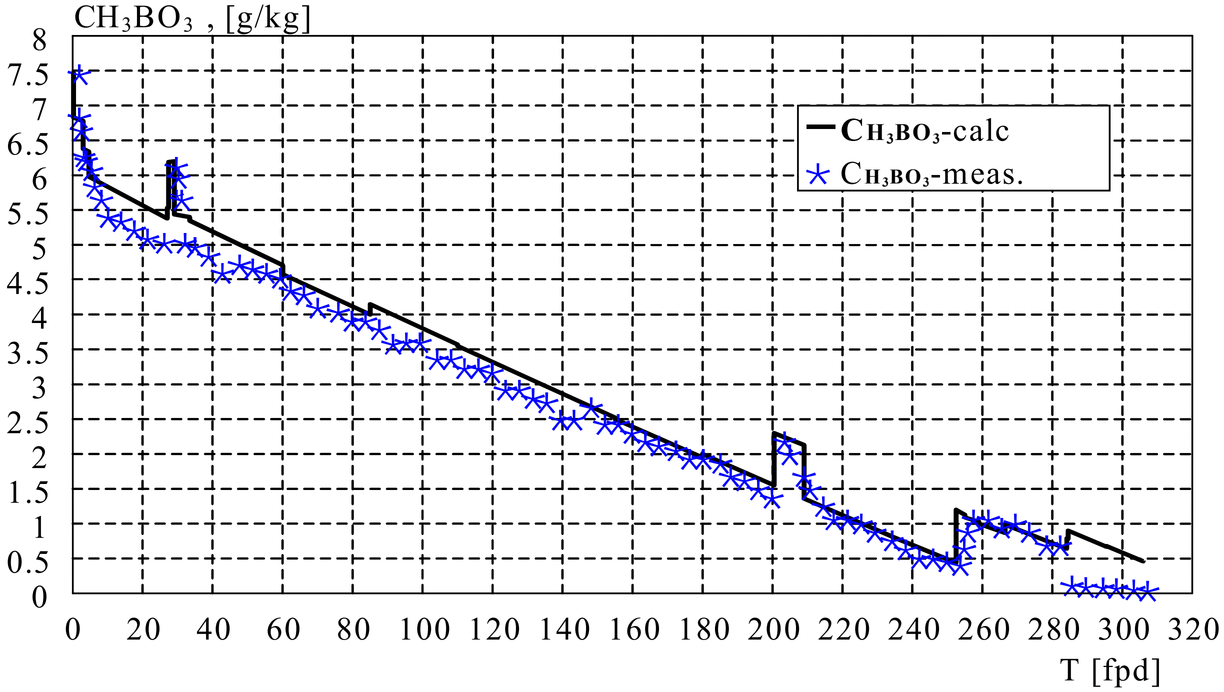


Figure 3. Calculated and measured Boric acid concentration changes during the 16-th cycle of Unit 3

distributions are presented in Tables 4 and 5 for Unit 3, fuel cycles 15 and 16 respectively. Results of comparisons between measured and calculated boron acid concentration values during 16-th fuel cycle of Unit 3 are given in Figure 3.

At the same time the expected burnup of discharged assemblies with Zr spacer grids is calculated about 35-36 MWd/kgU. The first assemblies with Zr spacer grids operated in the Unit 4 during 3 and 4 cycles were discharged recently.

2.2. Introduction of Working Fuel Assemblies with Optimized Mechanical Design (Vibration Resistant Assemblies) in Unit 2

Together with the demonstrated considerable positive results regarding the WWER-440 fuel utilization at the Kozloduy NPP, during the last years, a tendency of increase of the assemblies number identified as leaking has been observed. The causes for the increased number of leaking assemblies might be of different origin. In order to avoid the fuel failures a systematic approach has been developed and will be implemented at Kozloduy NPP. The goal is consequently to reveal and to eliminate the possible failure causes, to introduce fuel with enhanced mechanical stability, to exclude abrupt power changes during operation and movements of the 6-th group of control assemblies, etc. Up to now, 150 working fuel assemblies with enhanced vibration resistance and Zr spacer grids, are placed into the Unit 2 core during cycles 22 and 23, aiming significant decrease of the fuel failures.

3. Further Fuel Cycle Improvements

The reactors of Kozloduy NPP are currently operated in fuel cycles with the length about 270-300 full power days. Lately series of investigations and calculations are carried out for substantiation of the possibilities of improvement WWER-440 fuel cycles and fuel utilisation efficiency increasing. A general task is to increase the burnup of the reloaded fuel assemblies and to decrease the amount of the spent fuel assemblies. Due to a great number of relatively small-sized fuel assemblies in the core of WWER-440 reactors it is possible to vary the fuel cycle characteristics within wide range. Several fuel cycle strategies are under study now aiming to achieve optimal fuel cycle length and number of fresh and discharged assemblies.

Results of calculations and preliminary analyses of fuel cycles with different characteristics are given in this paper. Some calculated results by means of SPPS-1.6 code [1-4] and library of two groups diffusion parameters prepared by HELIOS [8] code regarding to three types of possible fuel cycles with the use standard 3.6% enriched working assemblies, with subsequently introduction of advanced 3.82% profiled assemblies operated respectively 4 and partially 5 years are considered. The main neutron-physics characteristics of four -year fuel cycle with the use of standard 3.6% enriched control (CA) and working (WA) assemblies and low leakage loading patterns (LLLP) are presented in Table 6. Table 7 demonstrates the main neutron-physics characteristics of four-year fuel cycle with the use of profiled working assemblies

Table 6. Neutron-physics characteristics of four year fuel cycle with the use of 3.6% enriched control (CA) and working (WA) assemblies and LLLP

Cycle №	Number of fresh assemblies	T, [FPD]	$C_b^{crit.}$	ρ_{Bu}^{mean}, [MWd/kgU]	Number ass. for cycle 4	Discharged assemblies burnup
1	1J(3.6%CA) - 12 1G(3.6%WA)- 84	300.2	1.035	25.3	48 42-3.6% 6-2.4%	60 (3.6%) - 37.5 18 (2.4%) - 32.8 12CA (3.6%) - 33.2
2	1J - 12 1G - 78	314.7	1.102	26.4	66 60-3.6% 6-2.4%	72 (3.6%) - 38.3 6 (2.4%) - 37.9 12CA (3.6%) - 34.2 1CA - 2.4% - 26.3
3	1J - 12 1K(2.4%CA) - 1 1G - 78	308.6	1.090	26.8	72-3.6%	78 (3.6%) - 39.0 12CA (3.6%) - 32.4
4	1J - 12 1G - 78	291.9	1.010	26.6	78-3.6%	78 (3.6%) - 39.5 12CA (3.6%) - 29.8
5	1J - 12 1G - 78	307.2	1.072	26.8	78-3.6%	78 (3.6%) - 40.3 12CA (3.6%) - 35.6 1CA (2.4%) - 26.8
6	1J -12 1K - 1 1G -78	311.2	1.090	26.8	78-3.6%	78 (3.6%) - 40.0 12CA (3.6%) - 29.2
7	1J -12 1G - 78	301.0	1.043	26.7	78-3.6%	78 (3.6%) - 39.2 12CA (3.6%) - 32.0

Table 7. Neutron-physics characteristics of four year fuel cycle with the use of profiled working assemblies with 3.82% average fuel enrichment and LLLP

Cycle №	Number of fresh assemblies	T, [FPD]	$C_b^{crit.}$	$\rho_{Bu.}^{mean}$, [MWd/kgU]	Number ass. for cycle 4	Discharged assemblies burnup
1	1J(3.6%CA) - 12 1G(3.6%WA)- 84	300.2	1.035	25.3	48 42-3.6% 6-2.4%	60 (3.6%) - 37.5 18 (2.4%) - 32.8 12CA (3.6%) - 33.2
2	1J - 12 1M (3.82%WA)-78	325.6	1.143	26.8	66 60-3.6% 6-2.4%	72 (3.6%) - 38.5 6 (2.4%) - 37.8 12CA (3.6%) - 34.5 1CA (2.4%) - 26.6
3	1J - 12 1K(2.4%CA) - 1 1M - 78	324.9	1.146	27.6	72-3.6%	78 (3.6%) - 39.5 12CA (3.6%) - 33.1
4	1J - 12 1M - 78	309.0	1.069	27.8	78-3.6%	78 (3.6%) - 40.6 12CA (3.6%) - 30.8
5	1J - 12 1M - 78	327.1	1.129	28.5	78-3.82%	78 (3.82%) - 42.5 12CA (3.6%) - 37.1 1CA (2.4%) - 28.3
6	1J -12 1K - 1 1M -78	330.0	1.144	28.5	78-3.82%	78 (3.82%) - 42.5 12CA (3.6%) - 30.5
7	1J -12 1M - 78	319.9	1.099	28.5	78-3.82%	78 (3.82%) - 41.7 12CA (3.6%) - 33.5

Table 8. Neutron-physics characteristics of partly five-year fuel cycle with profiled working assemblies with 3.82% average fuel enrichment and LLLP

Cycle №	Number of fresh assemblies	T, [FPD]	$C_b^{crit.}$	$\rho_{Bu.}^{mean}$, [MWd/kgU]	Number ass. used		Discharged assemblies burnup
					Cycle 4	Cycle 5	
1	1J(3.6%CA) - 12 1G(3.6%WA)- 84	300.2	1.035	25.3	48 42-3.6% 6-2.4%		60 (3.6%) - 37.5 18 (2.4%) - 32.8 12CA (3.6%) - 33.2
2	1J - 12 1M(3.82%WA)-78	325.6	1.143	26.8	66 60-3.6% 6-2.4%		72 (3.6%) - 38.5 6 (2.4%) - 37.8 12CA (3.6%) - 34.5 1CA (2.4%) - 26.6
3	1J - 12 1K (2.4%CA) - 1 1M - 78	324.9	1.146	27.6	72-3.6%		78(3.6%) - 39.5 12CA (3.6%) - 33.1
4	1J - 12 1M - 78	309.0	1.069	27.8	78-3.6%		78 (3.6%) - 40.6 12CA (3.6%) - 30.8
5	1J - 12 1M - 78	327.1	1.129	28.5	78-3.82%		72(3.82%) - 42.7 12CA (3.6%) - 37.1 1CA (2.4%) - 28.3
6	1J -12 1K - 1 1M - 72	312.3	1.072	28.6	78-3.82%	6-3.82%	72 (3.82%) -42.9 12CA (3.6%) - 30.2
7	1J -12 1M - 72	299.8	1.026	28.6	72-3.82%	12-3.82%	72 (3.82%) -43.1 12CA (3.6%) - 32.9
8	1J -12 1M - 72	302.0	1.032	28.5	72-3.82%	18-3.82%	72 (3.82%) - 43.0 12CA(3.6%) -32.0
9	1J -12 1M - 72	305.1	1.037	28.6	72-3.82%	24-3.82%	72 (3.82%) - 43.2 12CA (3.6%) - 31.7 1CA (2.4%) - 35.0

Table 9. Neutron-physics characteristics of core fuel loads with the re-use of partially burned assemblies from different unit with WWER-440 reactor

Type	Cycle №	Number of fresh assemblies	T, [FPD]	$C_b^{crit.}$	$\rho_{Bu.}^{mean.}$, [MWd/kgU]	Number ass. for cycle 4	Discharged assemblies burnup
1	17	1J(3.6%CA)-12 1G(3.6%WA)-84 1E(2.4%WA) - 6	286.7	1.111	24.1	26-3.6%	77(3.6%) - 35.9 1 (2.4%) - 29.0 6(2.4%) - 19.6 12CA(3.6%) - 31.5
	18	1J - 12 1G - 84	302.7	1.161	24.7	30-3.6%	78(3.6%) - 36.7 12CA(3.6%) - 33.9 1CA (2.4%) - 32.5
	19	1J - 12 1K(2.4%CA) - 1 1G - 78	287.7	1.094	24.7	30-3.6%	78(3.6%) - 36.4 6 (2.4%) - 32.3 12CA (3.6%) - 32.4
	20	1J - 12 1G - 78 1H(2.4%WA) - 6	298.5	1.142	24.8	30-3.6%	84(3.6%) - 37.2 12CA (3.6%)- 30.4
2	19*	1J - 12 1K(2.4%CA) - 1 1G - 78	287.7	1.094	24.7	30-3.6%	90(3.6%) - 36.3 6 (2.4%) - 32.3 12CA (3.6%) - 32.4
	20*	1J - 12 1G - 66 2G* - 30	302.3	1.144	24.5	18-3.6%	90(3.6%) - 35.6 12CA (3.6%) - 31.8
3	19**	1J - 12 1K(2.4%CA) - 1 1G - 78	287.7	1.094	24.7	30-3.6%	78(3.6%) - 36.4 6(2.4%) - 32.3 12CA(3.6%) - 32.4
	20**	1J - 12 1G - 54 2G * - 30	273.3	1.025	24.8	30-3.6%	90(3.6%) - 36.8 12CA (3.6%) - 29.7

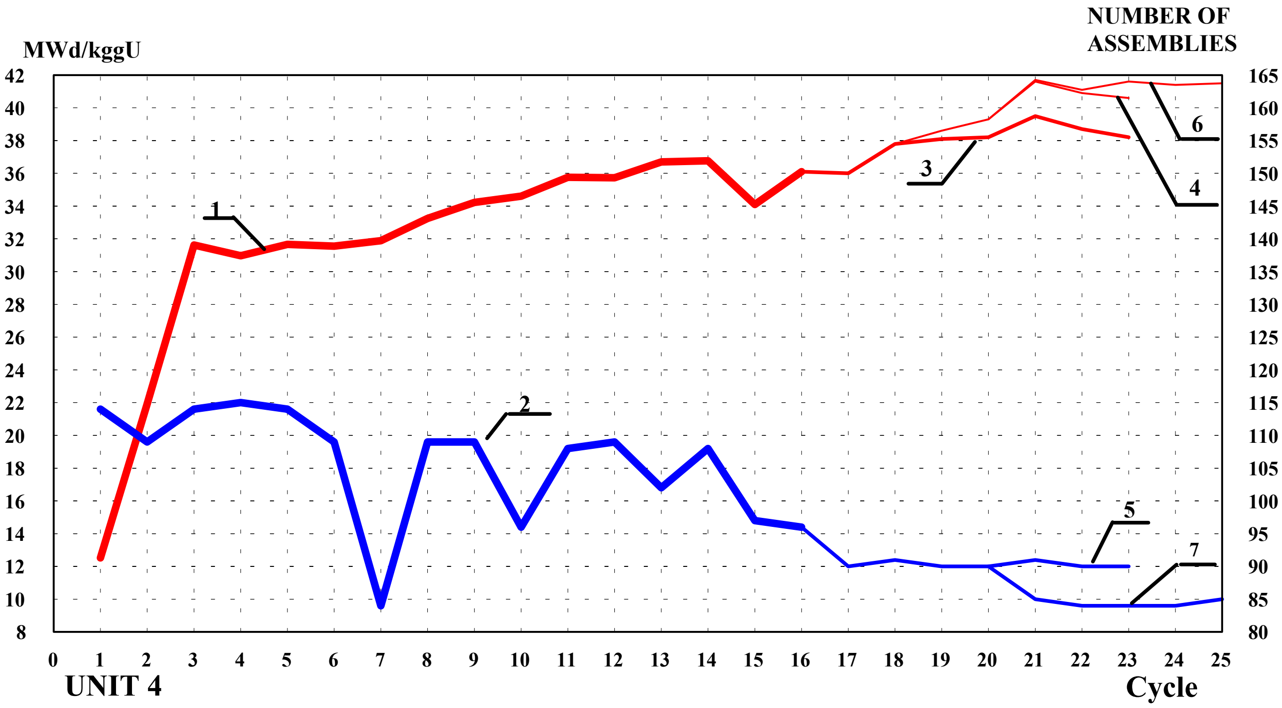


Figure 4. Trend of discharged assemblies number reduction and their average burnup increase: 1. Burnup; 2. Number of discharged assembles; 3. Expected burnup cycle type 1; 4. Expected burnup cycle type 2; 5. Expected number of discharged assembles; 6. Expected burnup cycle type 3; 7. Expected number of discharged assembles cycle type 3

with 3.82% average fuel enrichment and LLLP. The main neutron-physics characteristics of partly five-year fuel cycle with profiled working assemblies with 3.82% average fuel enrichment and LLLP are given in Table 8.

The tendency of the discharged assembly number decrease and the increase of the gained average burnup is demonstrated in Figure 4, based upon the completed up to now fuel cycles of Unit 4 and the considered above possible in the future three types of fuel cycles.

Different fuel cycle strategy is developed and investigated in the case of core fuel loadings, with the re-use of partially burned assemblies from spent fuel pond or partially burned fuel taken out from some other unit (for example after decommissioning of unit one). Again three types of loadings are considered, based on the possible next fuel cycles of Unit 3. Type 1 is an example of core loading for 20-th fuel cycle of Unit 3 with use of standard number of fresh fuel assemblies without using partially burned assemblies. Type 2 is an example of core loading for 20 fuel cycle of Unit 3 with use of reduced number (66) of fresh fuel assemblies and with the use of the 30 partially burned assemblies and 18 3.6% enriched assemblies operated 4 cycles. Type 3 is an example of core loading for 20 fuel cycle of Unit 3 with use of reduced number (54) of fresh fuel assemblies, with the use of the 30 partially burned assemblies and 30 assemblies operated during 4 cycles.

The main neutron-physics characteristics of the described types of fuel cycles are demonstrated in Table 9. The loading patterns of described three types of fuel core arrangements are presented in Charts 1, 2 and 3. The obtained results show that it is possible to achieve acceptable fuel cycle length together with decreasing of number of fresh assemblies in case of re-use of partially burned assemblies.

4. Conclusions

A series of calculations and analyses, related to the advanced fuel assemblies introduction and fuel cycle characteristics improvement has been carried out during the last years of WWER-440 operation at the Kozloduy NPP. The investigations are in progress now. After comprehensive analysis and evaluation, the most significant of obtained results will be implemented into practice.

References

[1] P. Petkov. SPPS-1.6. Phisics-Matematical Model and Users Guide. Contracts №653, 654: INRNE – BAS and Kozloduy NPP, 1. Sofia, 1994 (in Bulgarian).

[2] P. Petkov. SPPS-1.6 – A 3D Diffusion Code for Neutronics Calculations of the VVER-440 Reactors. Proc. 4-th Symposium of AER,

Sozopol, 10-15 Oct., 1994.

[3] P. Petkov. Generirane na efektivni malogrupovi parametri i granichni uslovia za difuzionni presmiatania na reaktorite VVER-440. NTS, Matematicheski modeli v iadrenata bezopasnost I radiacionnata zashtita, Sofia, 7-8 April 1993 (in Bulgarian).

[4] J. Askew, F. Fayers, P. Kemshel. A General Description of the Lattice Code WIMS.J.BNES, Oct., 1966.

[5] P. Petkov, I. Georgieva. HEXAB-2DB - Programma dlja operativnyh raschetov koeficientov neravnomernosti moshtnosti po tvelam v aktivnoj zone WWER-440. 16-th Symp. WWER Physics, Moscow, 1987 (in Russian).

[6] A. Novikov, V. Pshenin, M. Lizorkin, V. Saprykin, V. Sidorenko, A. Suslov. Code Package for WWER Cores Analysis and Some Aspects of Fuel Cycles Improving, RRC KI, УДК 621.039.5.

[7] Kozloduy-II NPP, Technical Project, Part IX. Moscow, 1973 (in Russian).

[8] J. Casal, R. Stamm'ler, E. Villarino, A. Ferri. HELIOS: Geometric Capabilities of a New Fuel-Assembly Program. International Topical Meeting on Advances in Mathematics, Computations and Reactor Physics, Pittsbirgh, 2, 10.2.1 1-13, 1991.

[9] K. Lassmann. TRANSURANUS: A Fuel Rod Analysis Code Ready for Use. Journal of Nuclear Materials, 188, 295-302, 1992.

[10] R. Pazdera, M. Valach, P. Strijov, K. Dubrovin, V. Murashov, A. Senkin, V. Yakovlev. User's Guide for the Computer Code PIN-micro. UJV 9515–T. Rez, CSFR, November, 1991.

[11] C. Wheeler, C. Stewart et al. COBRA-NI: An Interim Version of COBRA for thermal – Hydraulic Analysis of Rod Bundle Nuclear Fuel Elements and Cores. BNWL – 1962, UC-32, March, 1976.

[12] Programa za subkanalen termohidravlichen analiz COBRA-4I; Verifikacia na programata. Rep., INRNE-BAS, March, 1996 (in Bulgarian).

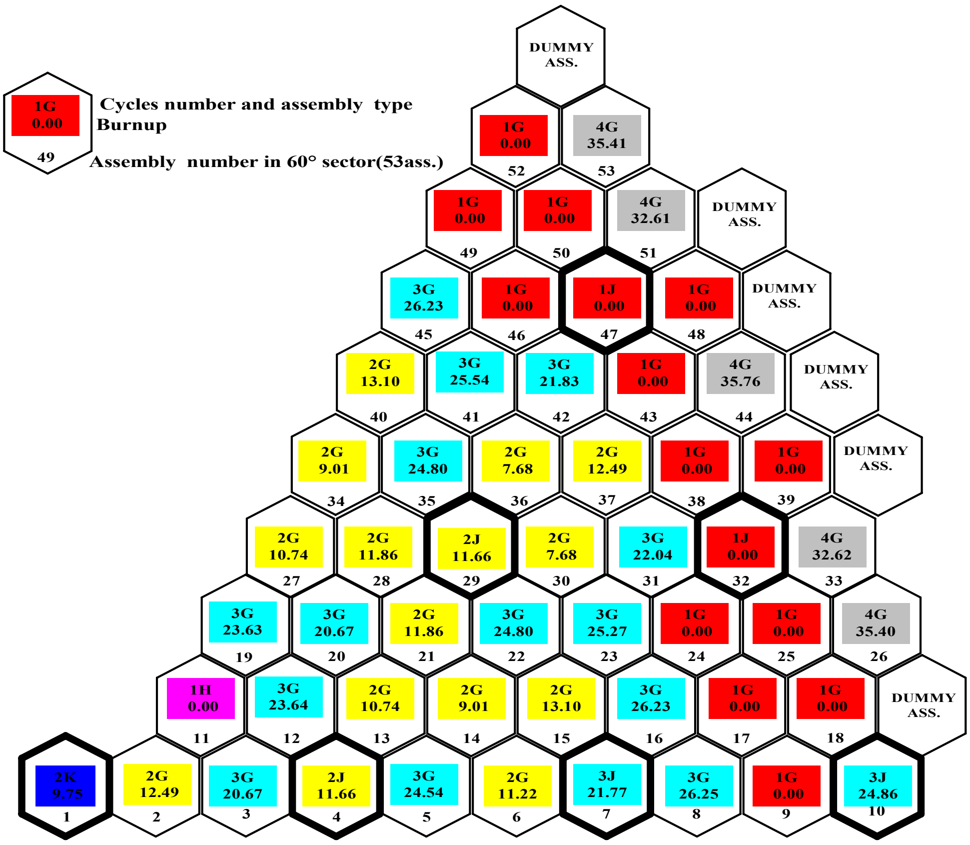


Chart.1. Core Loading pattern for 20 fuel cycle of Unit 3- Type 1.

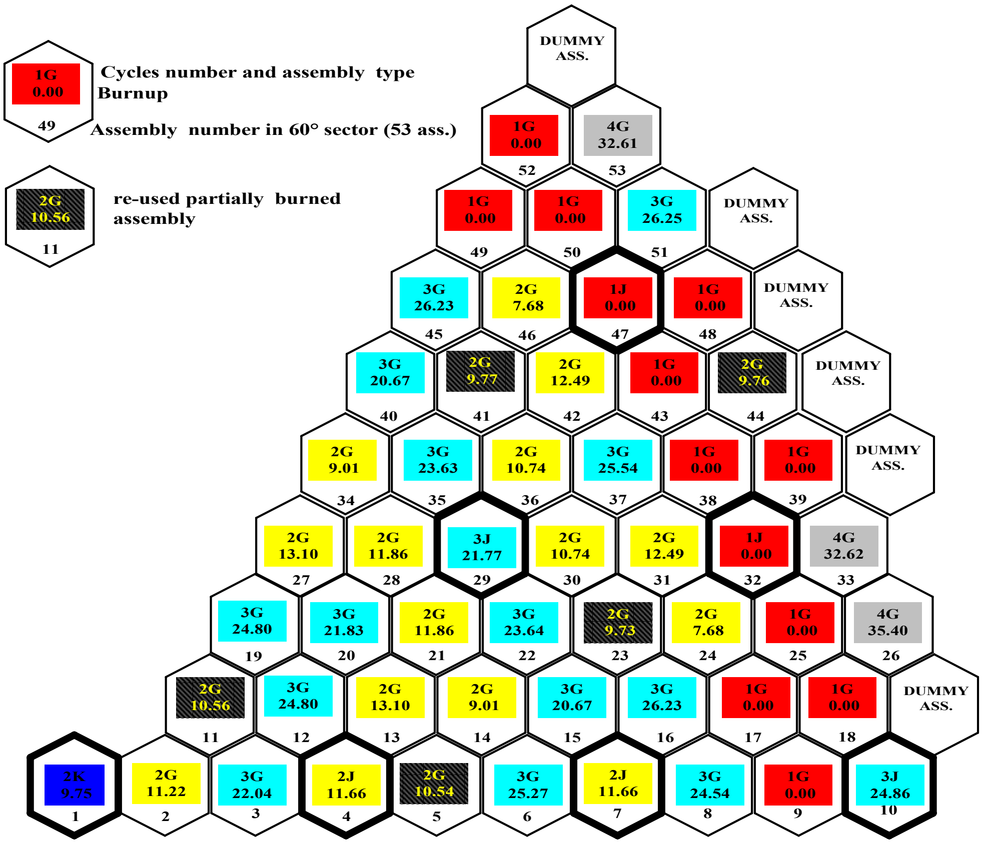


Chart.2. Core Loading pattern for 20 fuel cycle of Unit 3-Type 2.

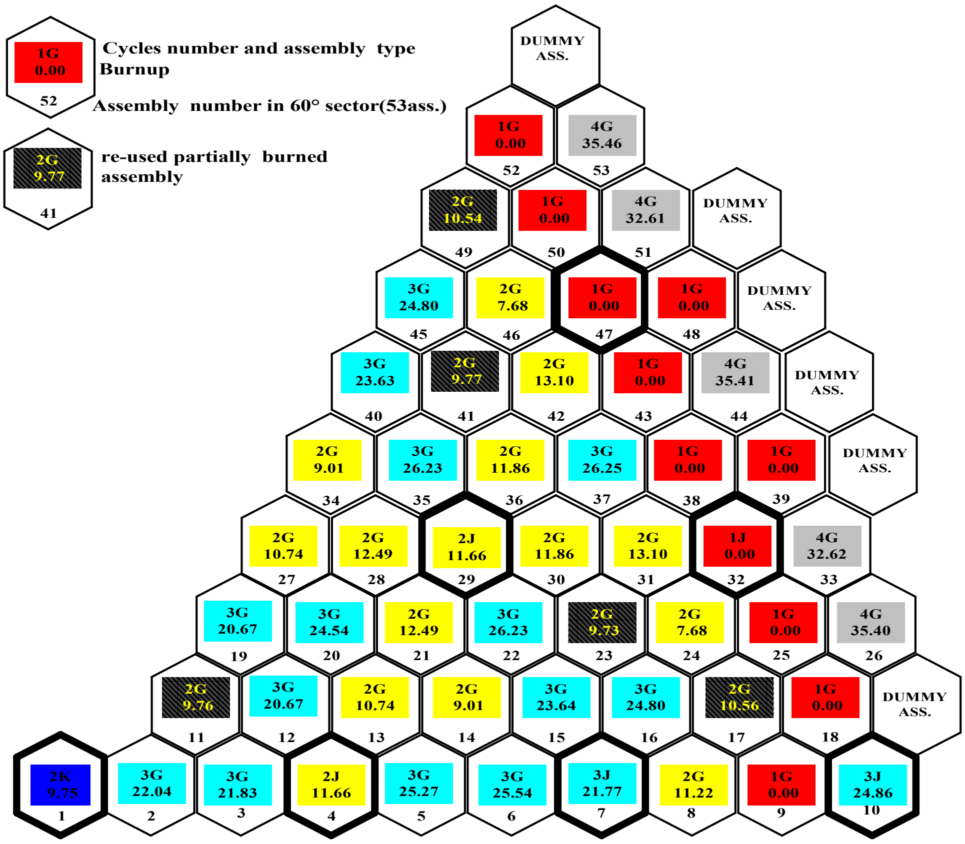


Chart.3. Core Loading pattern for 20 fuel cycle of Unit 3-Type 3.