Development of the Temperature Field at the WWER-440 Core Outlet Monitoring System and Application of the Data Analyses Methods

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On-line internal reactor monitoring by 216 thermal couples located at the reactor core outlet, is carried out during power operation WWER-440 (Chart 1-4).

Automatic monitoring of technology processes is performed by ИВ-500МА, which collects and performs initial data processing (discrediting and conversion of analogue signals into digital mode).

By means of design changes on the computer information system at Kozloduy NPP, Units 1&2 restoring the ИВ500-МА functions, additional hard disks are installed as well as software, preserving archive files every day during the fuel cycle.

Similar design changes for Kozloduy NPP, Units 3&4 are under way. The archive file contains the main reactor coolant system and secondary side parameters for a period of 24 hours at a frequency of 1 minute. Each archive file comprises 1440 records representing the unit status and allows 24-hours monitoring of the reactor core behavior during the fuel cycle, as it is specified in a previous report [1].

By statistical methods, it is possible to find out cyclic and random changes also to determine trends.

This presentation aims to present and analyze the results of power distribution monitoring during the past 21-th and current 22-th fuel cycle at Kozloduy NPP, Unit 1 by using archiving system capacity and related software.

The software capabilities of retrieval, processing and automatically data preparation, to comparison with computational results are demonstrated.

Comparing the neutron-physical calculation results with reactor coolant system parameters it is possible to perform operational assessment and analysis of power distribution in the reactor core in each point of the fuel cycle.

The following codes are used for such comparison and analysis:

- WDATA – retrieves data from archive file. The code to performs:
    - Basic statistic processing and average value determination, for a specified time interval;
    - Calculation and/or correction registering of temperatures at the assemblies' outlet in the reactor core;
    - Calculation of the reactor power by enthalpy at the inlet and outlet of the reactor core and core coolant flow by characteristics of the reactor coolant pumps;
- TOFTE – processes many of charts (possibly averaged) and presents basic and statistical information for each of them;
- SPPS 1.6 – coarse-mash 3D diffusion code simulates the operational mode, comparisons are performed between test and reference (calculated) results for power distribution by assemblies [2,3].

The results of data processing from archive files and comparison with calculations performed are present in Tables 1-4 and Figures 1-14.

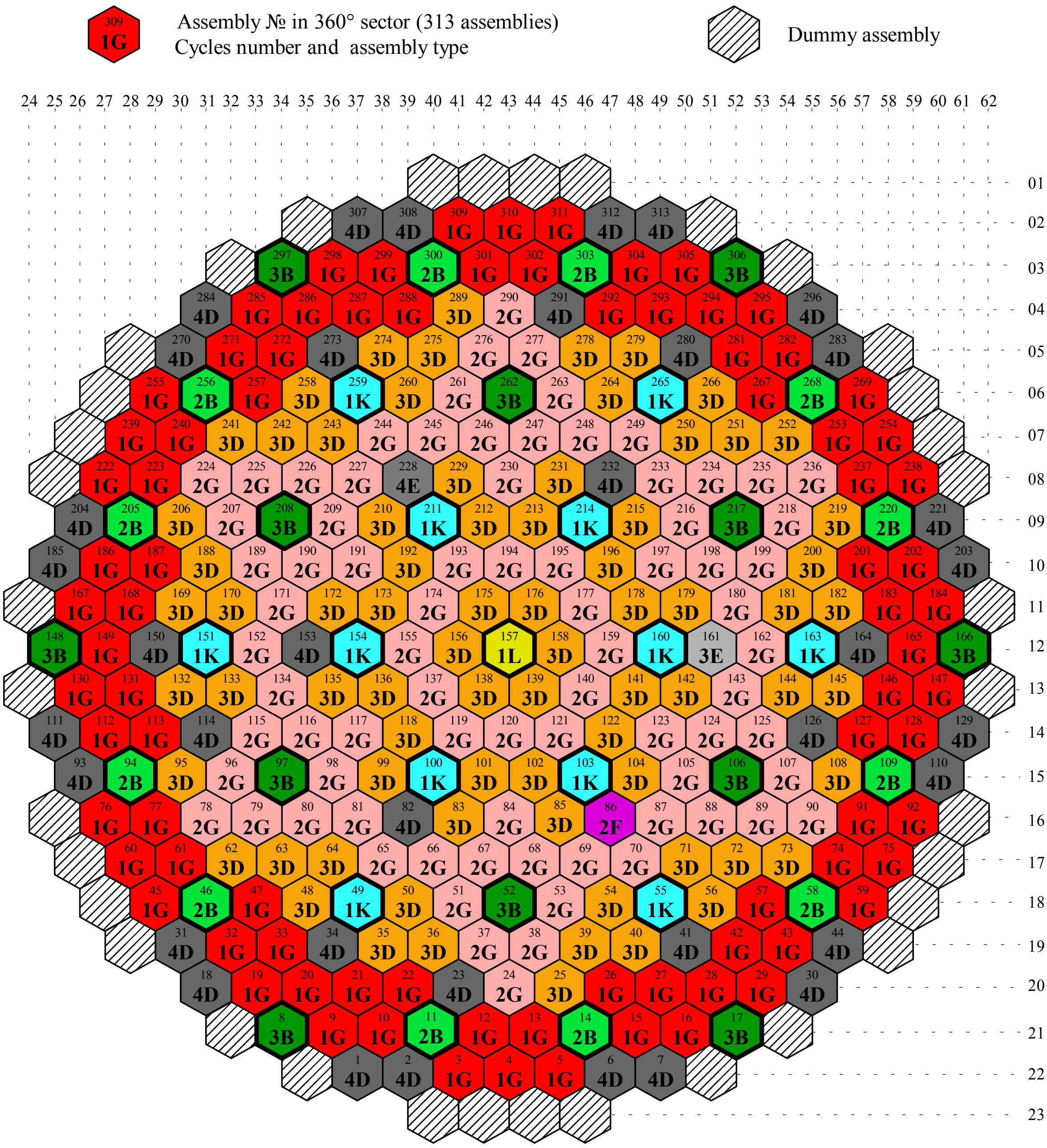
The processing and analysis of accumulated significant amount of data in the archive files increases accuracy and reliability of power distribution monitoring in the reactor core in each moment of the fuel cycles of WWER-440 reactors at Kozloduy NPP.

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 October, 1994.

[3] P. Petkov, T. Simeonov, P. Iontchev, G. Nanev. Statistical Analysis of the Temperature Field at the WWER-440 Core Otlet. Proc. 3-rd Seminar of WWER Fuel Performance, Modelling and Experimental Support, Pamporovo, 04-08 October, 1999.



B - 2.4% wall thickness 2.1mm

D - 3.6% wall thickness 1.5mm

E - 2.4% wall thickness 1.5mm

F - 1.6% wall thickness 1.5mm

G - 3.6% wall thickness 1.5mm and Zr spacer grids

K - 2.4% wall thickness 2.0mm and Zr spacer grids

L - 1.6% wall thickness 2.0mm and Zr spacer grids

Ghart 1. Chart of 21 - th core fuel loading of Unit 1

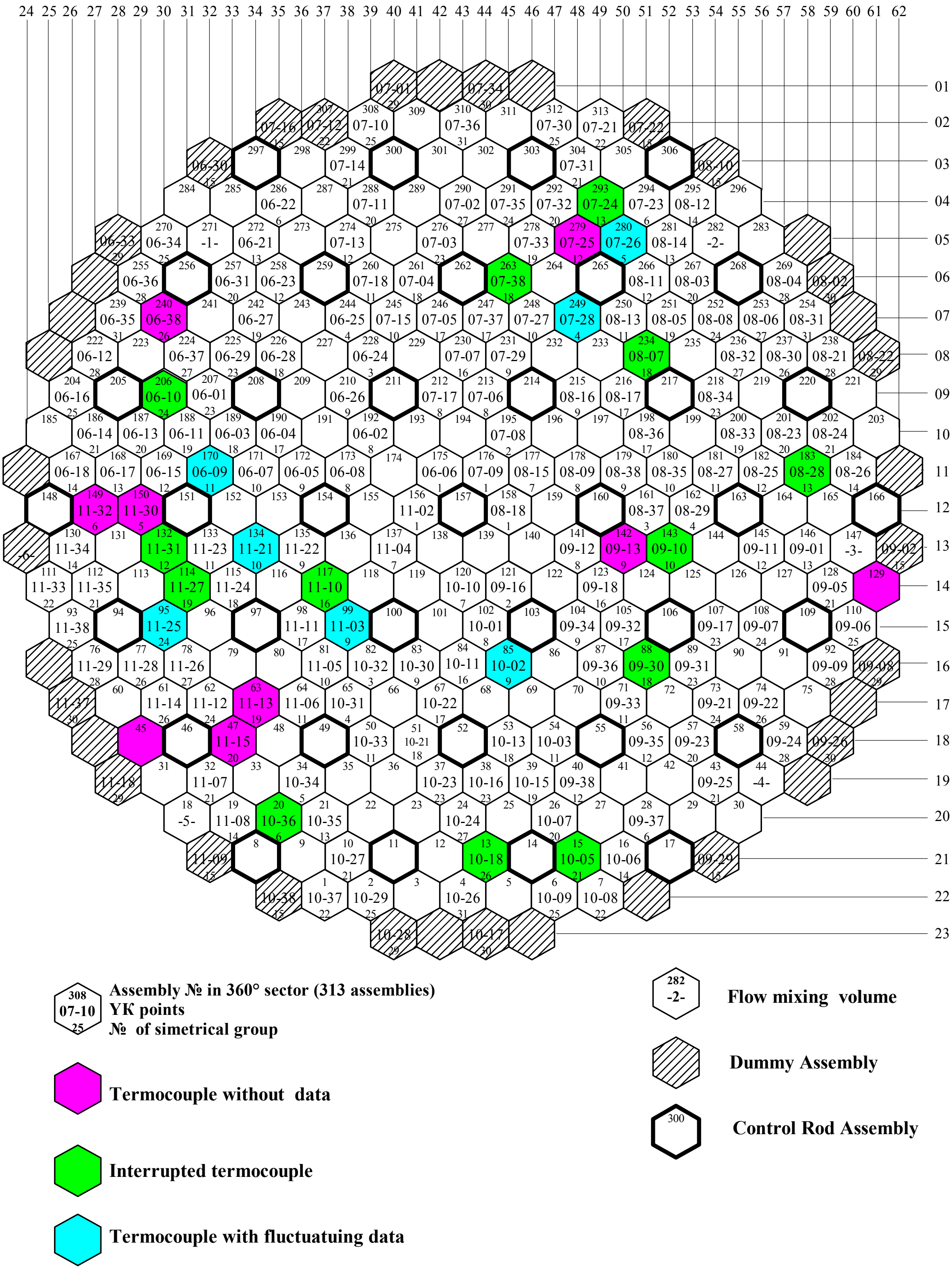
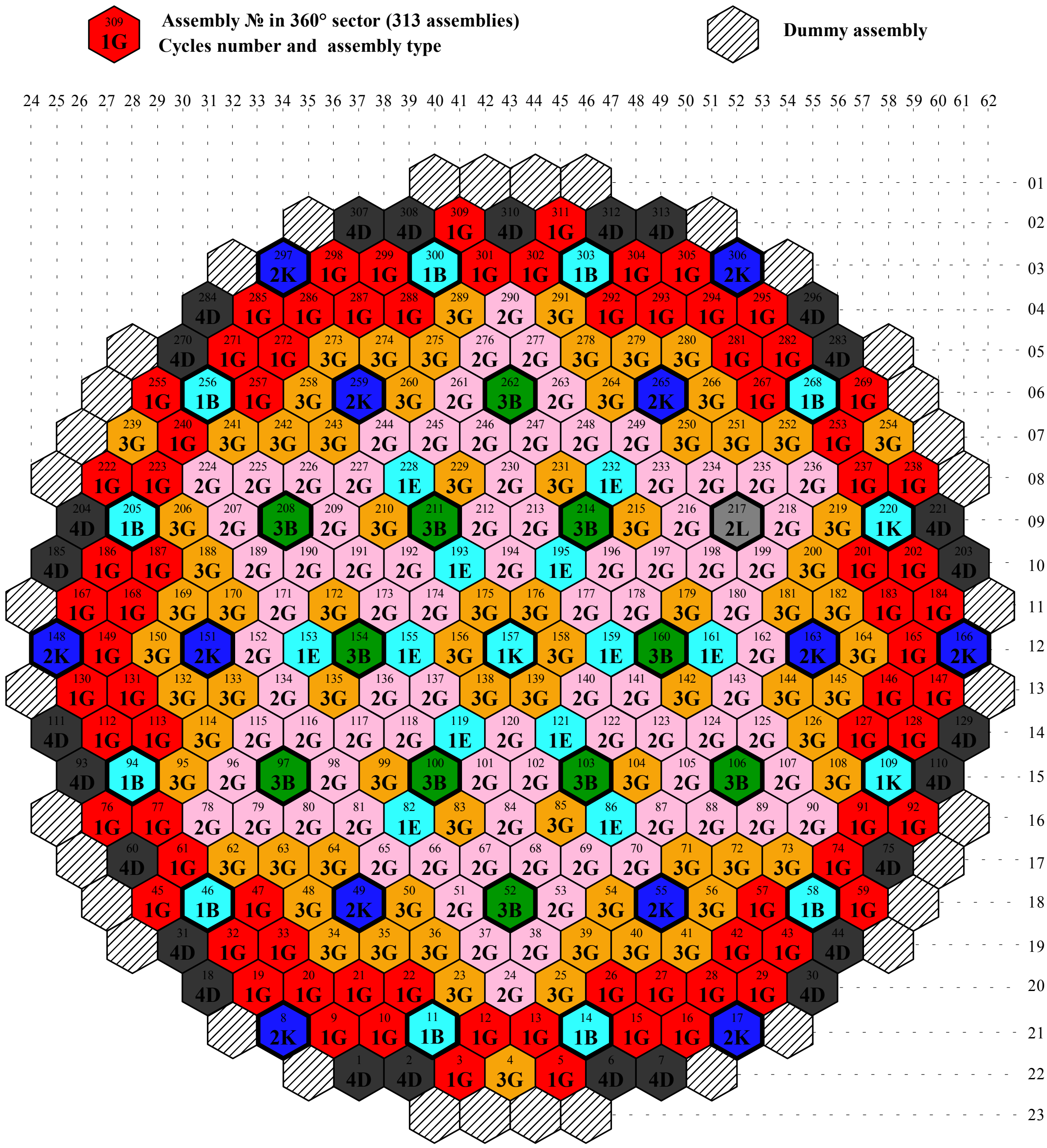


Chart 2. Distribution of termal couples by points in YK end simmetrical groups in the reactor core (Kozloduy NPP, Nnit 1, fuel cycle 21)



B - 2.4% wall thickness 2.1mm

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G - 3.6% wall thickness 1.5mm and Zr spacer grids

K - 2.4% wall thickness 2.0mm and Zr spacer grids

L - 1.6% wall thickness 2.0mm and Zr spacer grids

Ghart 3. Chart of 22 - th core fuel loading of Unit 1

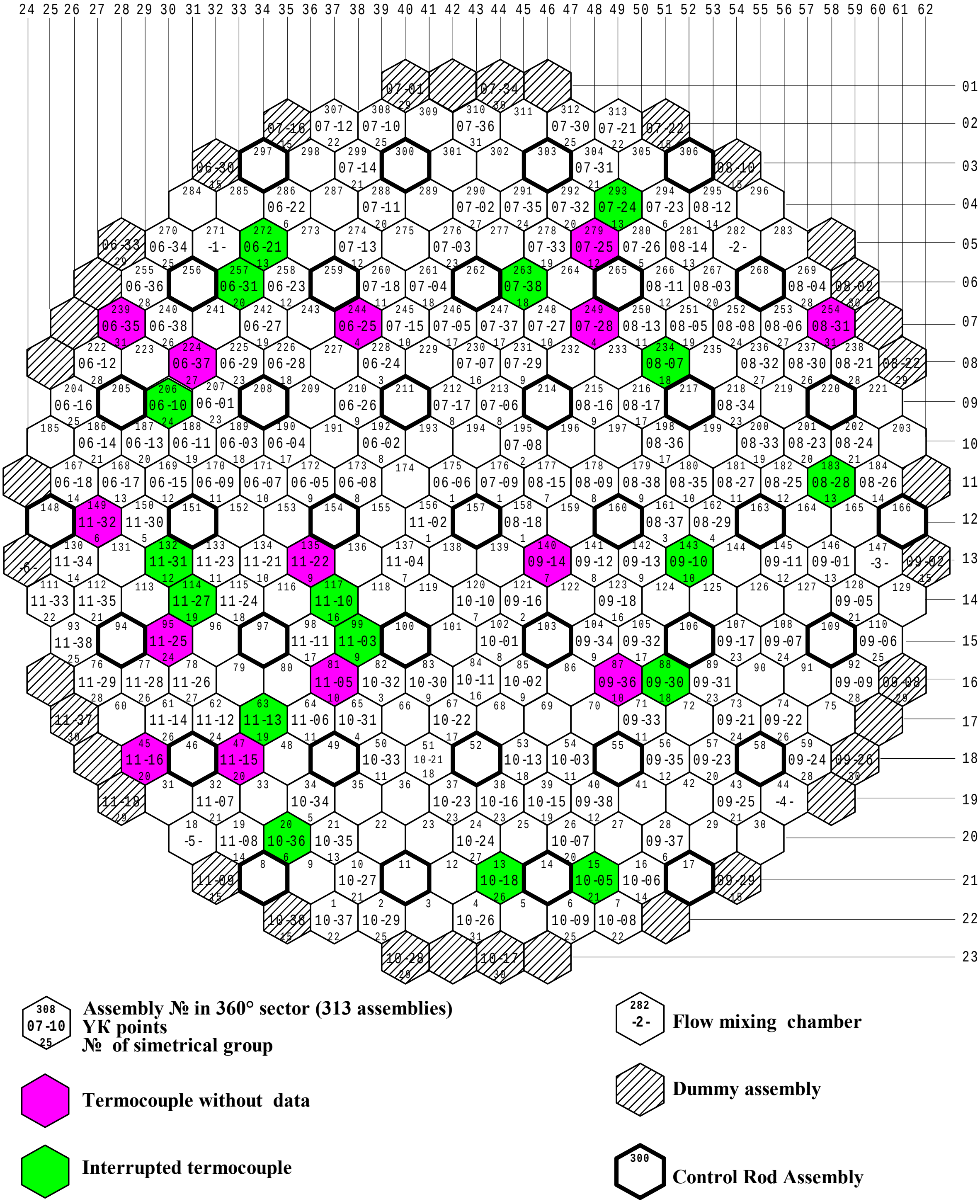

Chart 4. Distribution of termal couples by points in YK end simmetrical groups in the reactor core (Kozloduy NPP, Nnit 1, fuel cycle 22)

Table 1. Main results of SPPS-1.6 calculations, compared with the measured assembly-wise relative power distributions K_q /Nass/ for different moments [FPD] during 21-th cycle of Unit 1. $\Delta=(K_q^{calc}$(Nass) – $K_q^{ave,meas}$(Nass))*100 [%] – error

FPD	Power, [%]	T_{in}, [°C]	H_{VI}, [cm]	$C_{H_3BO_3}$, [g/kg]	K_{eff}	Std. Div.	Max+	№ ass.	Enrich.	Max-	№ ass.	Enrich.	$K_{q\text{-}ave}$	$K_{q\text{-}cal}$	№ ass.	$K_{q\text{-}cal}$	$K_{q\text{-}ave}$	№ ass.	Erad
51.6	96	263.8	198	4.96	0.99216	2.1	5.2	57	G1	-4.4	4	G1	1.249	1.216	67	1.267	1.215	57	-0.8
73.9	97	264	199	3.59	1.0045	2	4.1	238	G1	-3.7	244	G2	1.245	1.263	57	1.263	1.245	57	0
112.7	54	260.5	195	3.59	1.00372	3	5.2	236	G2	-8.9	82	D4	1.267	1.262	235	1.263	1.236	57	-0.2
167.7	96	263.9	197	1.67	1.00164	2.2	4	57	G1	-4.8	246	G2	1.251	1.203	68	1.243	1.204	57	0.9
223.4	95	264.4	194	0.52	1.00045	2.7	6.4	59	G1	-7	4	G1	1.246	1.202	68	1.236	1.219	89	-0.2
256.2	94	265.3	216	0.02	0.99961	2.8	6.8	59	G1	-5.7	246	G2	1.25	1.193	68	1.223	1.191	57	0.1
266.5	90	264.2	241	0.02	1.00019	2.5	4.8	59	G1	-6.1	191	G2	1.238	1.177	84	1.22	1.178	57	0.9
270.3	84	264.4	240	0.02	1.00045	3	7.2	224	G2	-6.3	244	G2	1.242	1.179	70	1.22	1.185	57	0.3

Table 2. Main results of SPPS-1.6 calculations, compared with the measured assembly-wise relative power distributions K_q /Nass/ for different moments [FPD] during 21-th cycle of Unit 1. $\Delta=(K_q^{calc}$(Nass) – $K_q^{ave,meas}$(Nass))*100 [%] – error

FPD	Power, [%]	T_{in}, [°C]	H_{VI}, [cm]	$C_{H_3BO_3}$, [g/kg]	Δ (G1)	Δ (G2)	Δ (D3)	Δ (D4)	Δ (E3)	Δ (E4)	Δ (F2)
51.6	96	263.8	198	4.96	1.2	-0.6	0	-1.5	0.2	0.2	0.2
73.9	97	264	199	3.59	1	-0.7	0.3	-1.3	0	-0.1	0
112.7	54	260.5	195	3.59	1	-1.4	0.8	-0.1	-8.8	-8.8	-8.8
167.7	96	263.9	197	1.67	1.5	-1.5	0.1	-0.3	-1.6	-1.7	-1.6
223.4	95	264.4	194	0.52	1.3	-1.3	0.2	-0.6	-0.8	-0.9	-0.8
256.2	94	265.3	216	0.02	1.9	-1.6	0.2	-1.4	-0.7	-0.7	-0.7
266.5	90	264.2	241	0.02	1.6	-2.2	0.3	0.3	0	0	0
270.3	84	264.4	240	0.02	0.5	-1.9	1	1	0.2	0.2	0.2

Table 3. Main results of SPPS-1.6 calculations, compared with the measured assembly-wise relative power distributions K_q /Nass/ for different moments [FPD] during 22-th cycle of Unit 1.$\Delta=(K_q^{calc}$(Nass) - $K_q^{ave,meas}$(Nass))*100 [%] - error

FPD	Power, [%]	T_{in}, [°C]	H_{VI}, [cm]	$C_{H_3BO_3}$, [g/kg]	K_{eff}	Std. Div.	Max+	№ ass.	Enrich.	Max-	№ ass.	Enrich.	K_{q-ave}	K_{q-cal}	№ ass.	K_{q-cal}	K_{q-ave}	№ ass.	Erad
13.4	95	264.1	197	1.014	0.9997	2.2	4.2	236	G2	-5.6	185	D4	1.255	1.241	88	1.268	1.239	201	-0.5
20	95	264.2	193	0.995	0.99851	2.4	4.5	236	G2	-5	175	G3	1.251	1.239	88	1.269	1.245	201	0.4
26.6	95	263.3	191	0.921	1.00255	2.6	4.7	140	G2	-6.2	185	D4	1.26	1.236	125	1.271	1.244	201	-0.5
33.2	97	263.9	202	0.921	1.00064	2.3	4.4	236	G2	-4.2	175	G3	1.242	1.232	88	1.268	1.241	201	0.3
40.1	98	265.7	188	0.899	0.99841	2.4	5.6	269	G1	-4.4	70	G2	1.264	1.232	125	1.27	1.256	201	2.9
46.9	98	266	189	0.878	0.99786	2.9	6.7	236	G2	-4.8	121	E1	1.264	1.23	125	1.269	1.238	201	3.1
53.8	98	265.9	195	0.848	0.99854	2.9	6.3	236	G2	-5.1	121	E1	1.267	1.228	199	1.268	1.23	201	3
73.1	98	265.4	196	0.78	0.9979	2.9	6.1	201	G1	-5.3	175	G3	1.245	1.224	199	1.266	1.205	201	1.9
86	98	264.5	202	0.745	0.99721	2.9	6.2	236	G2	-6	185	D4	1.244	1.222	199	1.262	1.212	201	0.1
97.6	97	265.1	196	0.675	0.99866	2.9	5	201	G1	-5.7	175	G3	1.246	1.222	199	1.262	1.211	201	0.9

Table 4. Main results of SPPS-1.6 calculations, compared with the measured assembly-wise relative power distributions K_q /Nass/ for different moments [FPD] during 22-th cycle of Unit 1.$\Delta=(K_q^{calc}$(Nass) - $K_q^{ave,meas}$(Nass))*100 [%] - error

FPD	Power, [%]	T_{in}, [°C]	H_{VI}, [cm]	$C_{H_3BO_3}$, [g/kg]	Δ (G1)	Δ (G2)	Δ (G3)	Δ (D4)	Δ (E1)
13.4	95	264.1	197	1.014	2.2	0.4	-1.4	-3	-1.2
20	95	264.2	193	0.995	2.5	-0.2	-1.5	-1.9	-1.3
26.6	95	263.3	191	0.921	2	0.9	-1.5	-3.2	-2.4
33.2	97	263.9	202	0.921	2.5	0.1	-1.7	-2	-1.7
40.1	98	265.7	188	0.899	2.3	-1	-1.1	1.3	-4.1
46.9	98	266	189	0.878	2.5	-0.8	-1.6	1.4	-4
53.8	98	265.9	195	0.848	2.5	-0.8	-1.6	1.5	-3.8
73.1	98	265.4	196	0.78	3.4	-1.4	-1.2	-0.7	-3.5
86	98	264.5	202	0.745	3	-0.5	-1.3	-3.2	-0.6
97.6	97	265.1	196	0.675	3.4	-1.3	-1.2	-2.2	-0.7

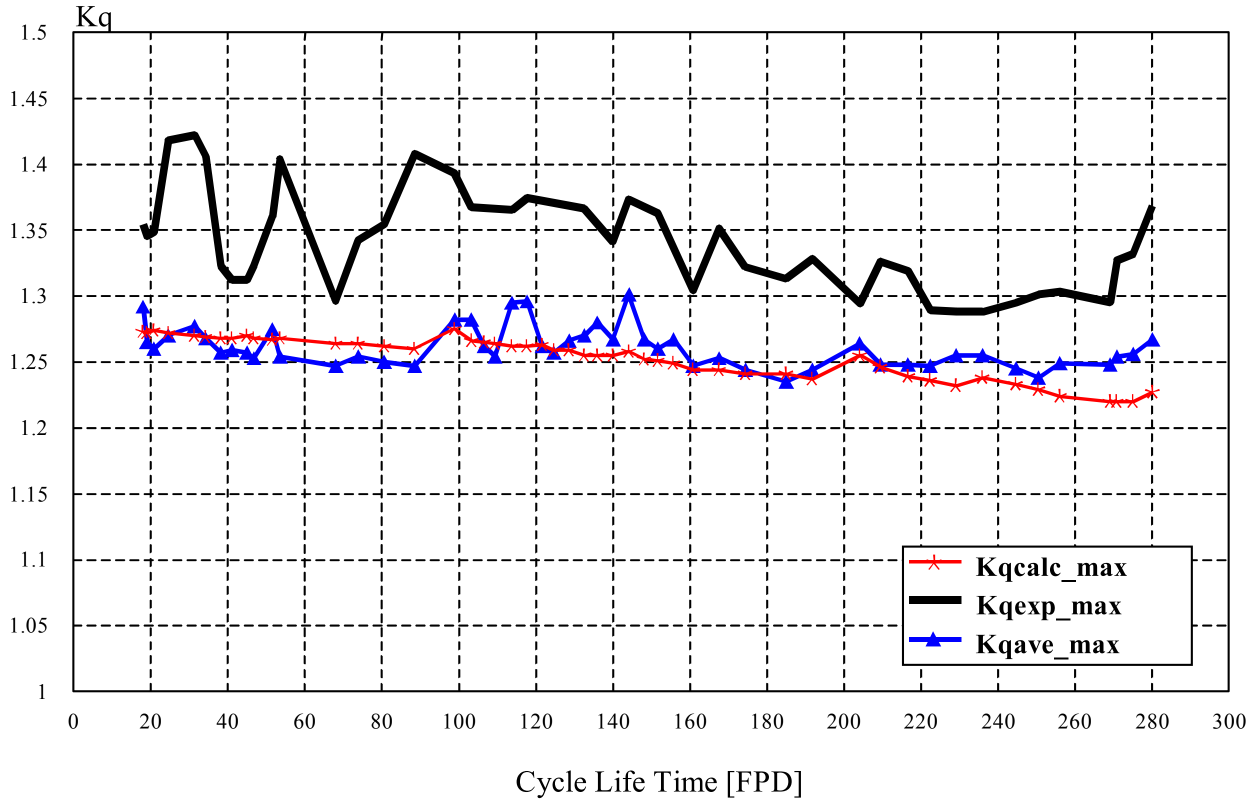

Figure 1. Trends of the maximum radial power peaking factors during 21 fuel cycle, Kozloduy NPP, Unit 1

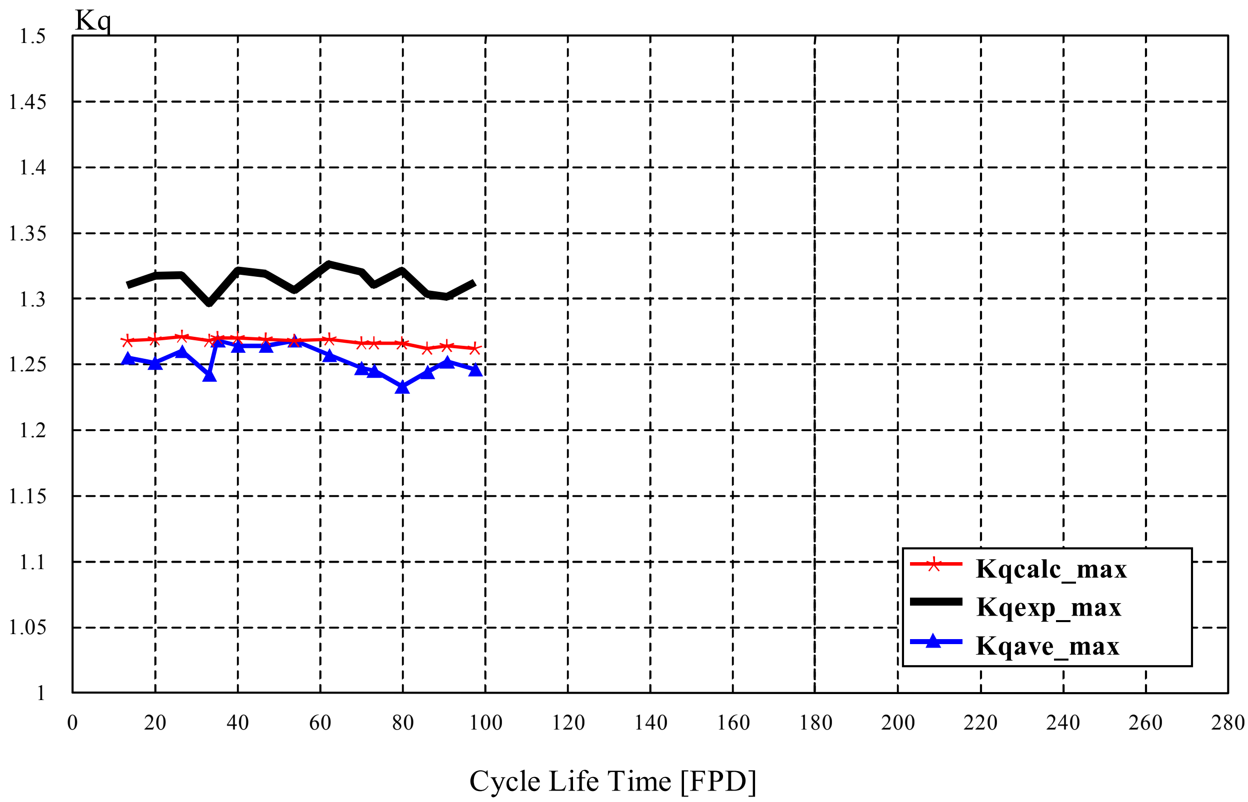

Figure 2. Trends of the maximum radial power peaking factors during 22 fuel cycle, Kozloduy NPP, Unit 1

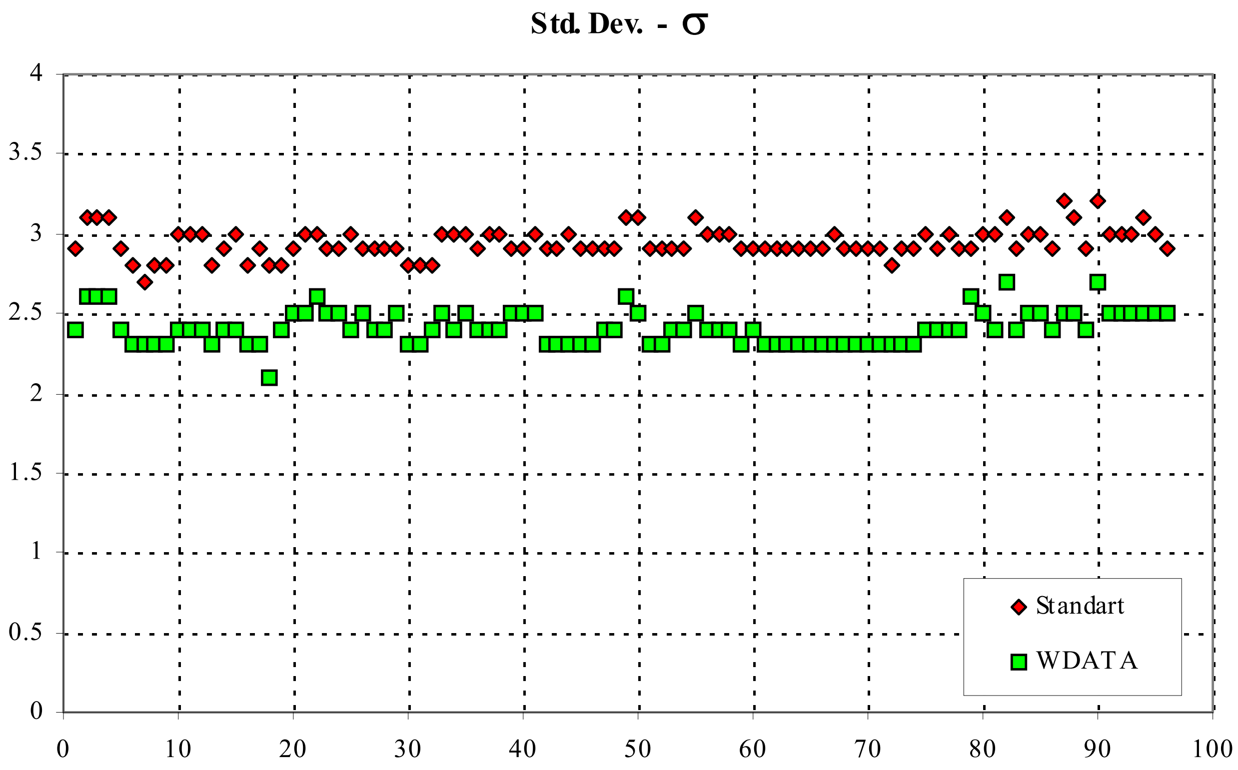

Figure 3. Stdandard deviation of the assemblies radial power peaking factors

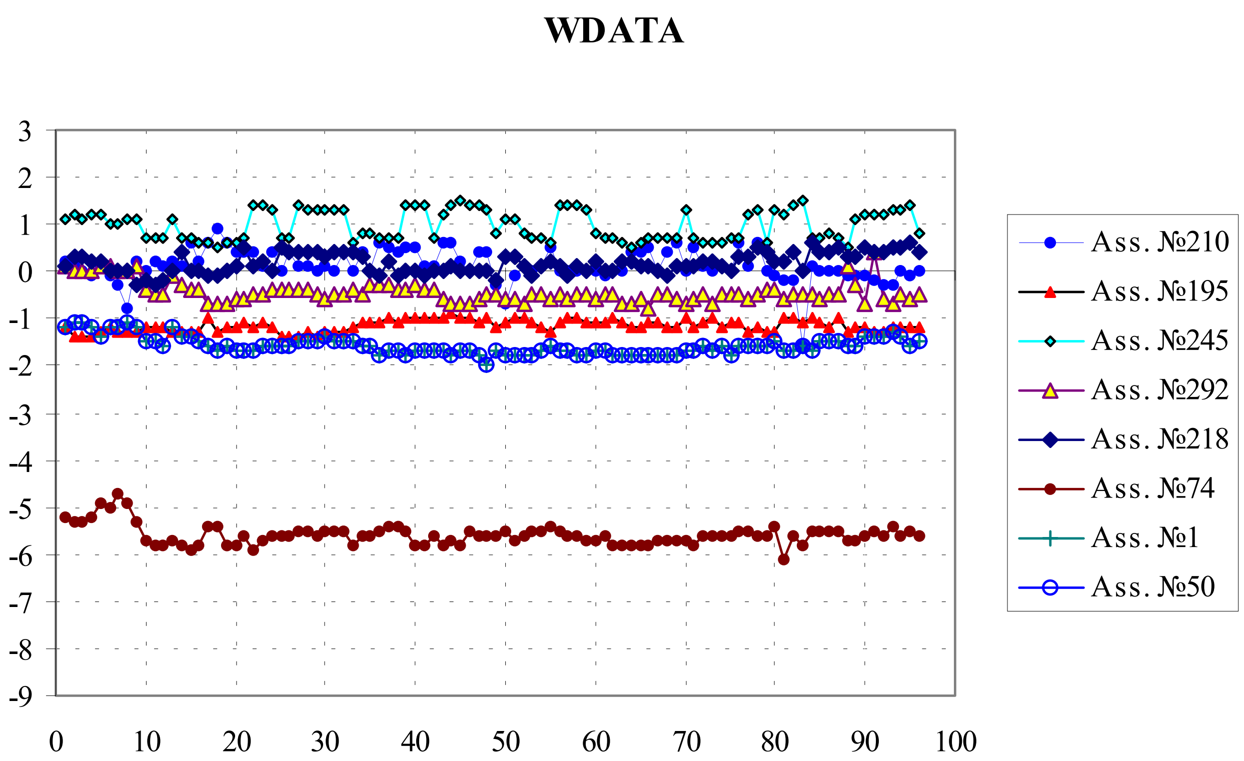

Figure 4. Temperature deviation (T_{exp} – T_{ave} sim.gr.) of the assemblies without determinated corrections

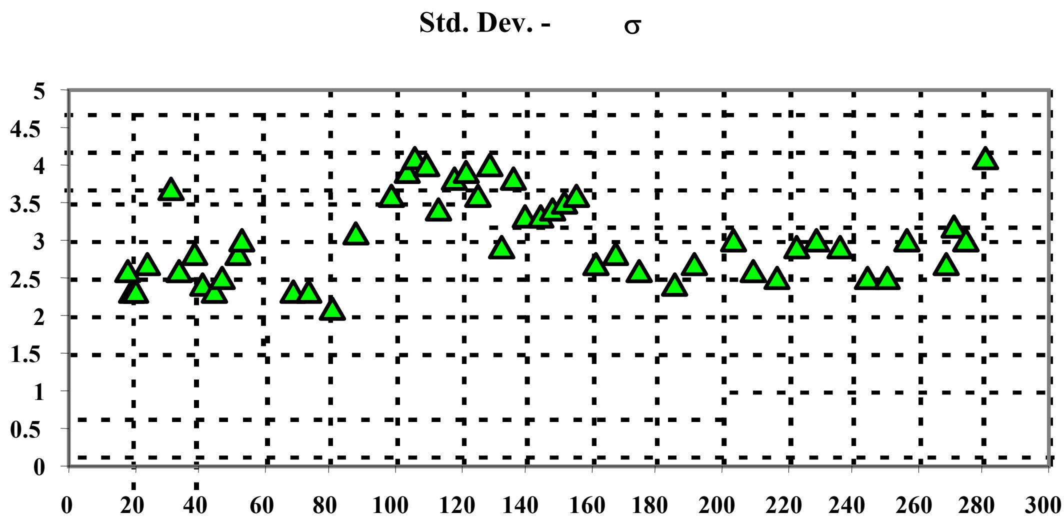

Figure 5. Stdandard deviation of the assemblies radial power peaking factors during 21 fuel cycle, Kozloduy NPP, Unit 1

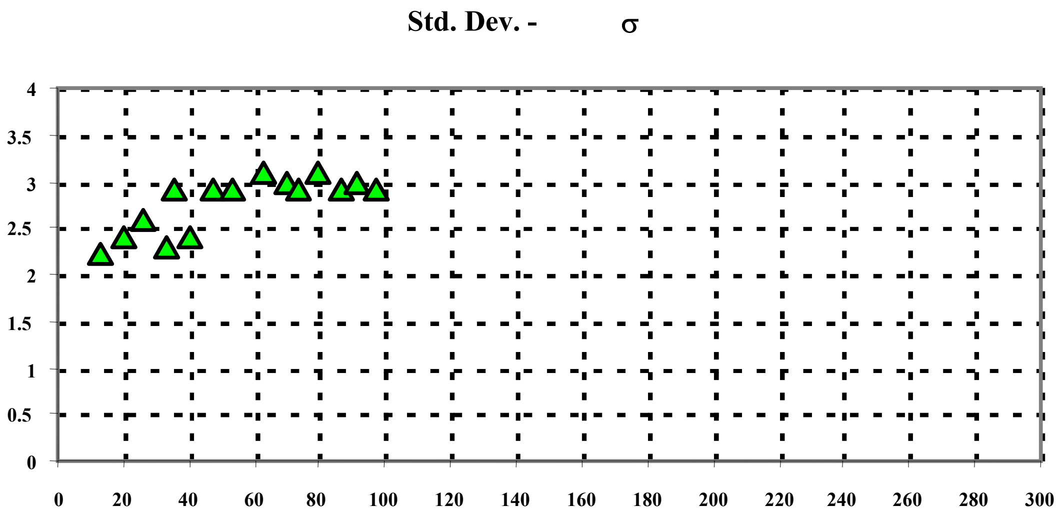

Figure 6. Stdandard deviation of the assemblies radial power peaking factors during 22 fuel cycle, Kozloduy NPP, Unit 1

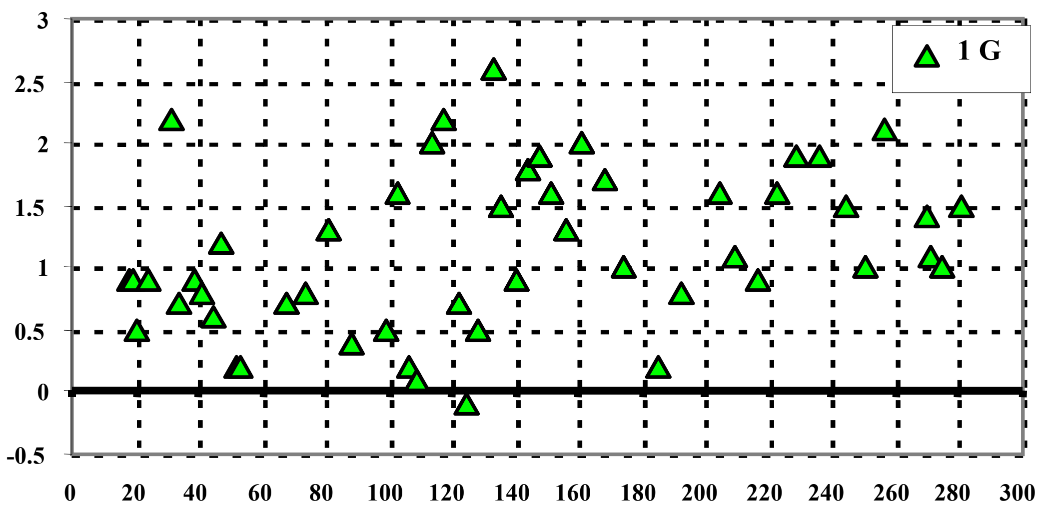

Figure 7. Absolute errors of the 1G assemblies during 21 fuel cycle, Kozloduy NPP, Unit 1

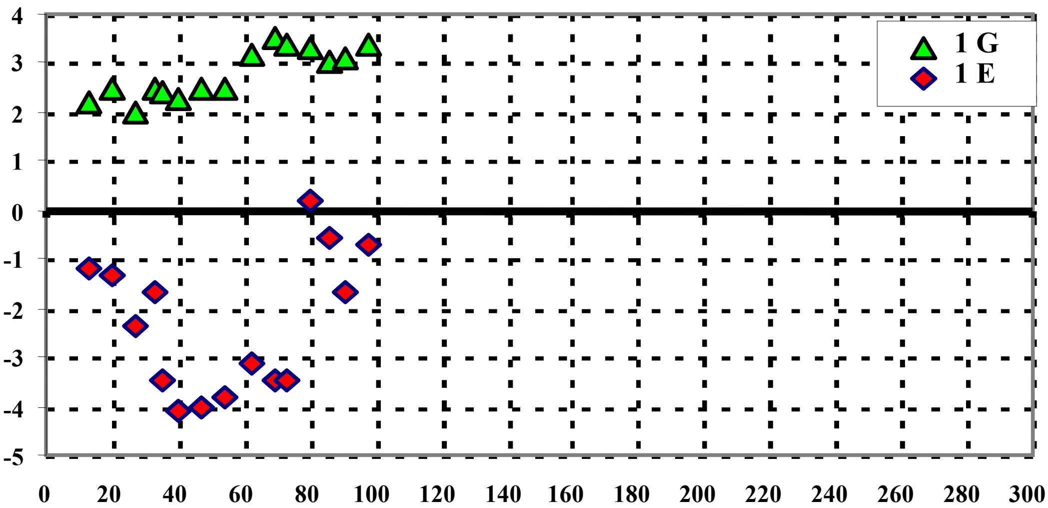

Figure 8. Absolute errors of the 1G&1E assemblies during 22 fuel cycle, Kozloduy NPP, Unit 1

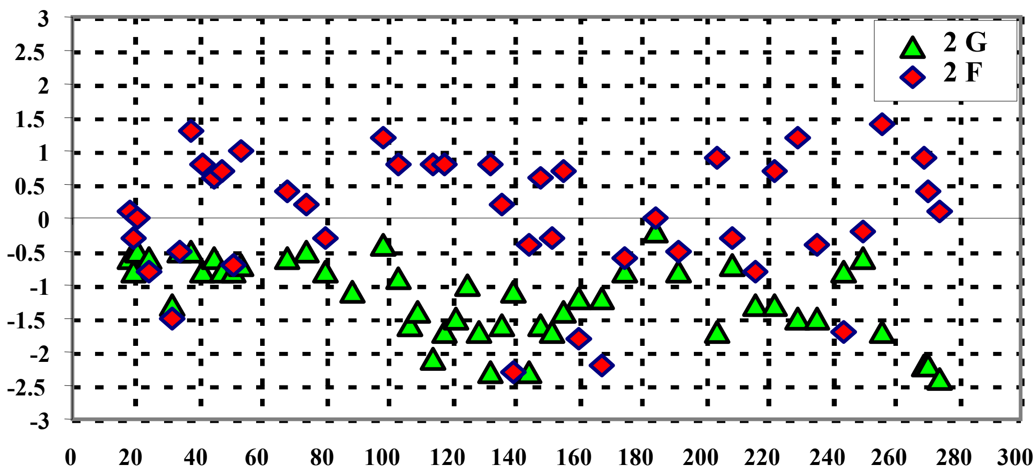

Figure 9. Absolute errors of the 2G&2F assemblies during 21 fuel cycle, Kozloduy NPP, Unit 1

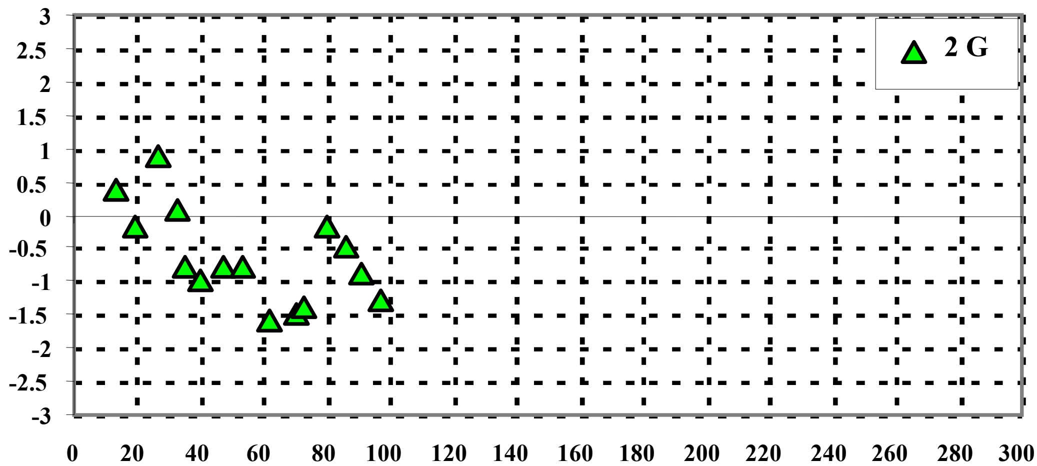

Figure 10. Absolute errors of the 2G assemblies during 22 fue cycle, Kozloduy NPP, Unit 1

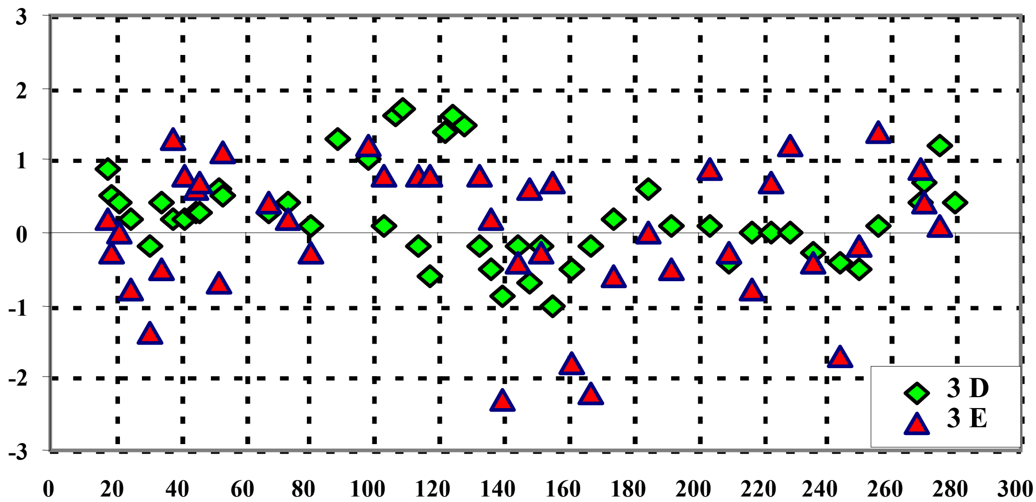

Figure 11. Absolute errors of the 3D&3E assemblies during 21 fuel cycle, Kozloduy NPP, Unit 1

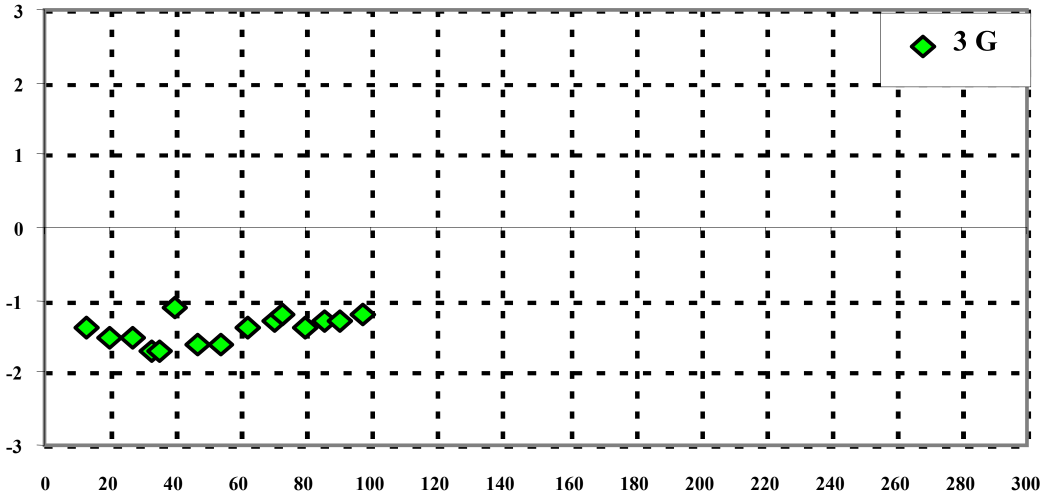

Figure 12. Absolute errors of the 3G assemblies during 22 fuel cycle, Kozloduy NPP, Unit 1

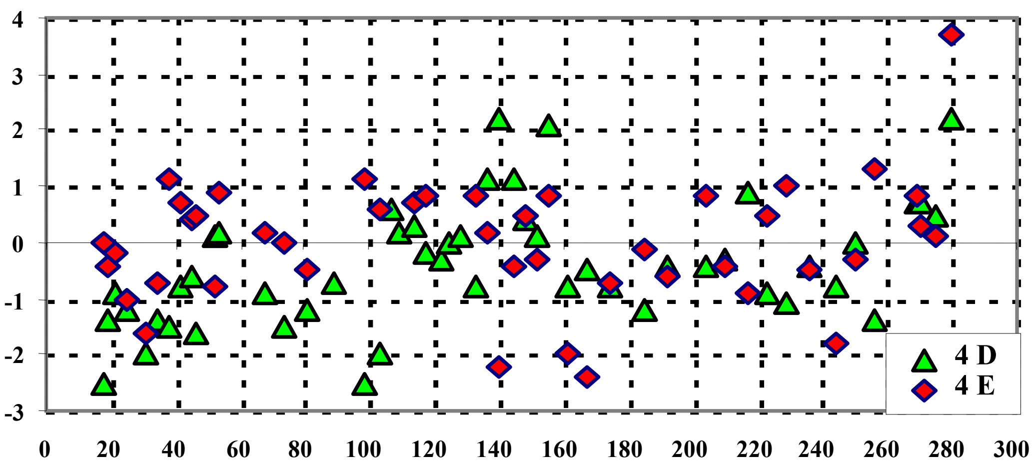

Figure 13. Absolute errors of the 4D&4E assemblies during 21 fuel cycle, Kozloduy NPP, Unit 1

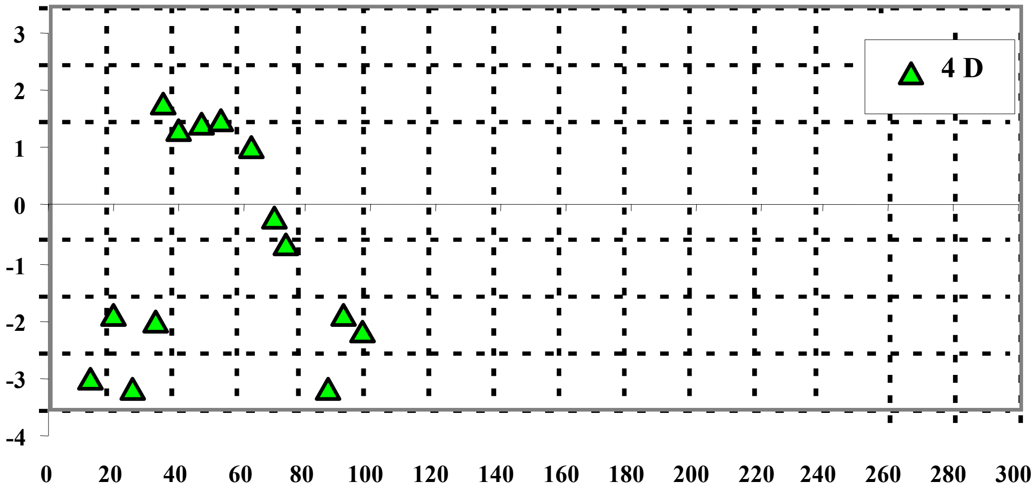

Figure 14. Absolute errors of the 4D assemblies during 22 fuel cycle, Kozloduy NPP, Unit 1