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Neutron-Physical parameters used for WWER-440s analyses at NPP Kozloduy

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Main goal of reactor physics calculations and analysis at Kozloduy NPP is core fuel loading design to be done in such a way, that to assure safe and reliable reactor performance during the entire period of a definite fuel cycle.

To achieve this, have to be considered such core design features as power density and coolant temperature distribution, coolant boron concentration, reactivity coefficients, scram effectiveness and fuel burn-up distribution.

Core safety requires not too heavy thermal loads on the fuel at any part of reactor core area. This means. that limits for maximum fuel rod linear power and the burn-up, should not be exceeded.

Another aspect of power density distribution (mainly the power peaking factor) is the requirement. that water temperature must remain below the boiling point at each subchanel outlet.

The values of reactivity coefficients are important to mitigate the consequences of possible accidents and also to make sure that the reactor is behaving well under normal operational conditions.

The scram function should be quick, liable and effective, so that the reactor will be shut-down in a safe manner in anticipated transient and emergency conditions.

When designing the fuel cycle at Kozloduy NPP's WWER - 440s, all above mentioned matters should be considered. This includes the requirement of core fuel loading basic parameters to be within the permitted limits of variation. These admissible limiting conditions were available in the report of the safety technical validity and the general documentation of the designer.

The fuel cycles design of WWER - 440 reactors are done by the use of physical codes SPPS-1.6 and HEXAB-2DB. /1,2,4/

SPPS-1.6 is a three dimensional two-group neutron diffusion code for hexagonal fuel assemblies. The nodal equations are derived by expansion of the group fluxes in terms of the two eigensolutions of the diffusion equation on each space element. The library of two group diffusion parameters is generated by the well known WIMS - D4 code. /5/

A comparison of calculated and experimental values of critical boron concentration for different reactors and over broad range of moderator temperatures and control assemblies' positions are presented in Table (1). The deviations are within ±0.2g/kg which illustrates the adequate prediction of the reactivity effects, such as boron acid concentration effect, control assemblies effectiveness and moderator temperature effect.

The sum of Doppler and xenon poisoning effects is also predicted adequately as well as the good accuracy of the predicted boron acid concentration at full power states. These are illustrated in Table (3).

The comparison between predicted and experimental assembly-wise power distribution for many fuel cycles of different reactors have shown good agreement (Ref.1, 2)

Results on similar comparisons concerning temperature reactivity coefficients are presented in Table 2. Practically received deviations are within ±3pcm.

The results in Table 3 present the good accuracy of the predicted boron acid concentration during the first 44 FPD of operation at NPP Paks. These results confirm that the sum of the Doppler and xenon poisoning effects is adequately described. This conclusion is also based on the good accuracy of the critical boron concentration both for zero power and full power states.

The calculated values of power reactivity coefficients seem to be more positive than the experimental ones, but the adequate prediction of the total power effect, inclu-ding xenon poisoning is of greater importance. This approach assures a more conservative design prediction of fuel loading.

For fuel rods power distribution calculation at Kozloduy NPP is used a two-dimensional four-group fine-mesh diffusion code HEXAB-2DB. The code solves the equation of neutron transport in the 30° sector of symmetry and considers the neutron physics characteristics of fuel rods and the radial reflector. The SPPS-1.6 code is used for the purpose of HEXAB-2DB axial dimension accounting.

The neutron-physical studies on assessment of core design loading patterns involve the following 3 stages:

- appropriation of the number and the enrichment of the fresh assemblies, loading pattern and cycle life time optimisation, in order to achieve the objective of a high thermal power availability factor within the limits set for reactor's safe operation;
- assessment of compliance with all nuclear safety criteria and requirements, concerning the chosen fuel cycle loading;
- basic neutron-physical characteristics calculations on fuel cycle loading in compliance with all reactor operating conditions and preparation of the final nuclear design report.

For the first stage, numerous calculations are done in order to obtain a loading pattern optimisation and information on power distributions, cycle lifetimes, local assemblies' burnup etc. During the design work , national energy system requirements, other cycle constrains and utility requirements are taken into account.

Figures 1 and 2 present the core loading patterns for 60° symmetry sector of Unit 3, the 11-th cycle and Unit 4, the 12-th cycle respectively. The WWER-440s of units 1,2 and 3 at Kozloduy NPP are operated at reduced core. 36 dummy assemblies have been located at core periphery in the period 1987-1988, in order to reduce fast neutron

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flux to the reactor pressure vessel. Since the 4-th fuel cycle of Unit 4, low leakage core loading patterns have been used by placing high burn-up assemblies in core periphery with the same purpose.

The second stage is the most important. The refuelling scheme will not be valid before to be met all the requirements and criteria concerning nuclear safety. This stage is based on 3 main criteria:

1. Assessment of the negative power and moderator temperature coefficients of reactivity over the whole range of variation of the reactor parameters at its start and operation.
2. Following the limit values for the maximum power peaking factors in the core, which determine the maximum heat loading of the fuel rods in the assemblies.
3. Providing an appropriate to the requirements of safe shut-down margins.

In order to prevent destroying of the fuel rod claddings, a comparison was made between the admissible limit values of the power peaking factors in the core and the calculated ones.

The last stage in these reload management computations consists of the demand for the operation during the designed cycle and the neutron-physical characteristics, which include:

- critical boron concentration in the coolant and boron concentration in coolant, which provides the respective subcriticalilty at shutdown;
- position of the working control group of assemblies (WCA) during operation and control groups ACA worths;
- differential reactivity coefficients (moderator temperature, Doppler);
- assembly-wise power distribution in the core , etc.

The results of the predicted neutron-physical calculations are checked by carrying out a series of reactor-physical experiments at the time of the start-up after the reloading of the unit. The positive results of this verification guaranteed the observance of the requirements for nuclear safety during the planned operation.

The results of the neutron-physical calculations and analysis concerning Unit 3, 13th fuel cycle, corresponding to the nuclear safety criteria, are presented in this paper. The core Nph parameters are compared to the nuclear safety limit values.

Table 4 presents general assemblies' characteristics of the 13th fuel cycle of Unit 3.

On Table 5 are shown the major operational parameters of the 13th cycle, Unit 3 reactor core: nominal thermal reactor power, coolant mass flow-rate, linear power density, inlet temperature, reactor core average temperature at nominal power, coolant flaw by-pass factor. The maximal linear power density does not exceed the limit value 325 W/cm .

On Table 6 are presented the maximal values of the reactor core power peaking factors, which have been calculated at nominal reactor core parameters. It is obvious, that they are lower than the corresponding limits.

The reactivity coefficients and their limit values are shown on Table 7. The comparison proves their correspondence to the limit values.

Table 8 includes the assessment of the ACA groups ability to provide the required subcriticality for the reactor shut-down state. The provided subcriticality at the 13th cycle end is calculated to be at least of 3 % in hot (t=260°C) condition at zero power, even in case the most effective absorber from an automatic control assemblies is stuck at the upper reactor core level,

Table 9 concerns;

- effective fraction of delayed neutrons at the beginning and at the end of the 13th cycle -βeff;
- differential worth of boron concentration at the beginning and at the end of the 13th cycle, including the cold zero power conditions (t=20°C, zero power rate) and the hot zero power conditions.

It is obvious, that the maximum rate of the insertion of positive reactivity at uncontrolled withdrawal of ACA at a speed of 2 cm/s is considerably lower than 0.07xβeff, so there is no increasing of the power over the admissible one.

In addition to the above mentioned results it could be explained that the maximum burn-up (37.6 MWd/kgU) is much lower than the permitted limit value of 42MWd/kgU.

The reactor subcriticality at cold zero power condition at the 13-th cycle beginning (boric acid concentration 12g/kg, all ACA withdrawn) is -3.8%, while the limit value is $\leq$ -2.0%.

At the beginning of the cycles at NPP-Kozloduy a set of physical experiments is carried out. The comparison between the calculated and the experimental data is made regarding: the critical concentration of boric acid in the coolant at zero power, the isothermal temperature reactivity coefficient, the integral and differential worths of the working control assemblies group and etc.

The results of physical tests and comparisons with the corresponding calculated parameters are represented for the 13-th cycle of Unit 3 on Tables 10,11 and Figures 3,4.

The conclusions, which can be drown are:

1) regarding the initial critical concentration of boric acid, the deviation is less than 0.2g/kg;

2) the measured isothermal temperature reactivity coefficient in the interval [250°C - 260°C] is negative and the results are in satisfying coincidence with the calculated ones;

3) the experimental integral and differential worths of the working ACA group are higher than the calculated ones, but the difference is within the test criterion.

The results of simulation of the reactor operation at the beginning of the 13-th cycle are shown at table 12.

The last two columns include: C_{H3BO3}^{crit} - critical boric acid concentration, calcu-lated for the operational parameters and calculation's accuracy $\Delta C_{H3BO3} = C_{H3BO3} - C_{H3BO3}^{crit}$.

The very good accuracy of simulation is obvious for the power gaining transient processes.

The results on Table 12 show that the SPPS-1.6 version for reactor core transients simulation describes Them in an adequate way.

It is obvious, that the systematic comparisons between measured and calculated distributions of relative assembly wise power Kq^{exp} and Kq^{calc} are carried out through the fuel cycles of NPP Kozloduy reactors.

Finally it may be concluded, that the described methodology for reactor core safety assessment at Kozldouy NPP could be subjected to further development and improvement.

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Table 1

Unit	Cycle	Hi [cm]	t [°C]	C_{H3BO3} -exp [g/kg]	SPPS-1.6		
					C_{H3BO3}	δ	$\partial\rho/\partial C_{H3BO3}$
L-1	1	H5= 50	122±1	6.14±0.05	6.30	+0.16	-2.26
L-1	1	H5=200	122±1	6.20±0.05	6.35	+0.15	-2.29
L-1	1	H6= 50	122±1	6.23±0.05	6.38	+0.15	-2.29
L-1	1	H6=100	122±1	6.36±0.05	6.50	+0.14	-2.31
L-1	1	H6=150	122±1	6.53±0.05	6.67	+0.14	-2.33
						+0.15	-2.30
L-1	1	H5= 50	260±1	5.59±0.05	5.72	+0.13	-2.03
L-1	1	H5=200	260±1	5.80±0.05	5.91	+0.11	-2.08
L-1	1	H6= 50	260±1	5.89±0.05	5.98	+0.09	-2.09
L-1	1	H6=100	260±1	6.14±0.05	6.22	+0.08	-2.10
L-1	1	H6=150	260±1	6.42±0.05	6.51	+0.09	-2.11
L-1	1	H6=200	260±1	6.58±0.05	6.68	+0.10	-2.11
						+0.10	-2.10
B-3	1	H4= 51	200.1	5.32±0.11	5.18	-0.14	-2.20
B-3	1	H6=110	200.0	6.54±0.09	6.42	-0.12	-2.22
B-3	1	H6=178	198.0	6.74±0.16	6.68	-0.06	-2.24
						-0.11	-2.22
B-3	1	H4= 76	256.0	4.96±0.05	4.91	-0.05	-2.09
B-3	1	H5=122	257.0	5.85±0.08	5.81	-0.04	-2.05
B-3	1	H6=160	260.0	6.65±0.10	6.55	-0.10	-2.11
B-3	1	H6=202	259.5	6.74±0.10	6.68	-0.06	-2.11
						-0.06	-2.09
L-1	11	H6=175	260.0	10.66±0.17	10.49	-0.17	-1.38
L-2	8	H6=200	261.0	11.11±0.09			
						-0.17	
D-1	1	H4= 55	200.1	6.50±0.11	6.41	-0.09	-2.01
D-1	1	H6=130	203.1	7.95±0.09	7.82	-0.13	-2.04
D-1	1	H6=195	202.0	8.15±0.16	8.05	-0.10	-2.04
						-0.11	-2.03
D-1	1	H4= 65	260.5	6.07±0.05	6.02	-0.05	-1.90
D-1	1	H5=104	260.5	7.04±0.08	7.03	-0.01	-1.87
D-1	1	H6=154	260.5	7.99±0.10	7.89	-0.10	-1.93
D-1	1	H6=209	260.4	8.12±0.10	8.08	-0.04	-1.93
						+0.05	-1.91
B-2	1	H4= 50	115.0	6.69±0.11	6.75	+0.06	-2.12
B-2	1	H6=178	123.0	7.95±0.09	8.03	+0.08	-2.14
B-2	1	H6=195	119.0	7.94±0.16	8.07	+0.13	-2.15
						+0.09	-2.14
B-2	1	H4= 0	260.0	6.02±0.10	5.88	-0.14	-1.90
B-2	1	H4= 65	260.0	6.24±0.10	6.03	-0.21	-1.90
B-2	1	H6= 24	261.0	7.33±0.08	7.25	-0.08	-1.92
B-2	1	H6=190	261.0	8.00±0.05	8.05	+0.05	-1.94
B-2	1	H6=209	258.0	8.09±0.10	8.08	-0.01	-1.94
						-0.08	-1.92

Critical boric acid concentration [g/kg] and differential boric acid worth [%kg/g].

Table 2

Unit	Cycle	Teff [fpd]	N [%]	Hi [cm]	t [°C]	$C_{H_3BO_3}$ [g/kg]	$\partial\rho/\partial t_{H_2O}$	
							Exp	SPPS-1.6
L-1	1	0	0	H6=175	260	6.52	-5.5±1	-3.6
L-1	1	0	0	H6= 80	260	6.03	-10.5±1	-8.5
L-1	1	25	95	H6=200	264	4.20	-17.1±2	-12.1
L-1	3	330	90	H6=250	260	0.00	-49.4±4	-45.7
L-1	11	0	0	H6=175	255	10.66	-5.3±1	-3.4
L-2	8	0	0	H6=200	255	11.11	-4.1±1	
B-2	1	0	0	H5=175	245	7.42	-5.9±0.6	-7.9
B-2	1	0	0	H5=225	245	7.42	-5.9±0.6	-7.0
B-2	1	0	0	H5=175	260	7.42	-5.9±0.6	-9.2
B-2	1	0	0	H5=225	260	7.42	-5.9±0.6	-8.2
B-2	1	0	0	H4= 50	250	6.18	-16.9±0.2	-17.2
B-2	1	0	0	H4= 65	250	6.18	-16.9±0.2	-17.0
B-2	1	0	0	H4= 50	260	6.18	-16.9±0.2	-19.0
B-2	1	0	0	H4= 65	260	6.18	-16.9±0.2	-18.8
B-1	1	0	0	H6= 51	250	7.30	-4.4±0.9	-6.9
B-1	1	0	0	H6= 51	260	7.30	-4.4±0.9	-7.7
K-3	1	0	0	H3= 50	125	5.30	-9.8	-10.4
K-3	1	0	0	H6=110	264	7.30	-4.9	-5.2
K-3	1	0	0	H6= 90	264	7.30	-4.9	-6.4
K-2	4	0	0	H6=168	257	7.80	-6.8	-9.9
K-2	4	0	0	H6=168	271	7.80	-6.8	-13.1
K-2	7	0	0	H6=106	260	7.57	-16.8	-13.9

Temperature reactivity coefficients [pcm/°C]

Table 3

Teff [fpd]	N [%]	H6 [cm]	tav. [°C]	$C_{H_3BO_3}$ [g/kg]		
				Exp.	SPPS-1.6	δ
2.0	23.8	173.0	264	6.68±0.06	6.72	+0.04
2.8	33.8	178.5	268	6.40±0.06	6.52	+0.12
9.7	53.5	170.3	272	6.02±0.06	5.99	-0.03
17.0	54.8	162.5	272	5.88±0.06	5.90	-0.02
21.5	71.9	179.0	276	5.76±0.06	5.70	-0.06
33.4	84.1	177.5	278	5.45±0.06	5.43	-0.02
41.4	96.8	187.0	280	5.48±0.06	5.24	-0.24
44.2	98.0	177.0	280	5.10±0.06	5.13	+0.03

Critical boric acid concentration at start-up of Unit 1 , Packsh.

Table 4

Type Characteristics	Automatic Control Assemblies				Working Fuel Assemblies						
	2B	3B	1A	2A	Assem.wall thick.2.1mm			Assem. wall thickness 1.5mm			
					2A	3A	2B	1D	2D	3D	1E
Number of assemblies	7	6	12	12	15	21	7	96	72	62	3
Initial U-235 enrichment [%wt]	2.4	2.4	3.6	3.6	3.6	3.6	2.4	3.6	3.6	3.6	2.4
Average fuel burnup at beginning of the 13-th cycle [MWd/kgU]	12.95	22.66	0.0	13.01	11.74	25.52	13.60	0.0	12.86	25.76	0.0
Outer diameter of fuel rods cladding [mm]	9.1										
Thickness of the fuel rod cladding [mm]	0.65										
Diameter of the fuel pellets central hole [mm]:	1.2÷2.0										
Initial helium pressure in the fuel rod [MPa]	0.1÷0.2 0.4÷0.75										
Outer fuel pellet diameter at cold condition [mm]	7.55										
Initial density of UO2 fuel at cold condition [g/cm^3]	10.2÷10.4										
Fuel supplier	ВВО “Техснабэкспорт“ , Москва , Русия										

Characteristics of the 13-th fuel loading, Unit 3, NPP "Kozloduy"
Preceding 12-th cycle lifetime : 327 Full Power Days [FPD]
Number of assemblies in the core: 276 fuel working assemblies(FWA),
37 ACA(automatic control assemblies) and 36 dummy assemblies (shield assemblies)

Table 5

General parameters	**Values,related to safety assessment**
Nominal reactor thermal power rate[MW]:	1375
Linear power density of the fuel rod [W/cm]:	
- maximum for the 13-th cycle	304.3
- average	142.9
- permissible linear rate	325
Primary circuit coolant flow [kg/h]	35000 x 10^3
Assemblies coolant flow bypass fraction [%]	10
Average coolant temperature at the core inlet [°C]:	
- at zero power (N_T = 0%)	260
- at nominal power (N_T = 100%)	263
Average coolant temperature in the core at nominal power [°C] :	278.5
Reactor vessel nominal pressure [MPa]:	12.26

General operational parameters

Design 13-th cycle lifetime - 277 FPD

Table 6

Parameters	**Limit values**	**13-th cycle values**
1. Core power peaking factors:		
1.1. Fuel assemblies radial peaking factor Kq	< 1.29	
BOC, if H_{Vl} = 200 cm		≤ 1.277
EOC, if H_{Vl} = 250 cm		≤ 1.232
1.2. Fuel rod radial power peaking factors (relative power of the maximum loaded fuel rod)		
Kμ = Kq.Kkk ,where Kkk is the peaking factor of the fuel rods in the assembly	< 1.48	≤ 1.44
1.3. Core volume peaking factor Kv:	< 1.81	
BOC, if H_{Vl} = 200cm		≤ 1.632
EOC, if H_{Vl} = 250cm		≤ 1.428
1.4. Power peaking factor Ko (total): Ko = Kv.Kkk = Kq.Kz.Kkk	< 1.93	≤ 1.86

Distribution of the power peaking factors values
in the core for the 13-th cycle, Unit 3

Table 7

Parameters	Limit values	13-th cycle values
Moderator temperature reactivity coefficient $\partial\rho/\partial t_{H2O}$ [pcm/°C]		
Upper limit (BOC, zero power, all ACA** are withdrawn in upper position 250 cm, t = 260°C)	< 0	- 2.5
Lower limit (EOC, zero power, all ACA are inserted in the core 0 cm, t = 260°C)		- 40.2
For the end of 13-th cycle (EOC), nominal power, all ACA in upper position at 250 cm, t = 278.5°C	> - 64.0	- 42.5
Fuel temperature reactivity coefficient $\partial\rho/\partial t_U$ [pcm/°C] (BOC/EOC,zero power, t = 260°C, all ACA are in upper position 250 cm)		- 3.41 / - 3.65
Fuel temperature reactivity coefficient $\partial\rho/\partial t_U$ [pcm/°C] (BOC/EOC,at nominal power, t= 278.5°C)		- 2.69 / - 2.97
Power reactivity coefficient $\partial\rho/\partial N_T$[pcm/MW] (BOC, H_{VI} =200 cm, nominal power, t=278.5°C, C_B = 1.067 g/kg)	< 0	- 1.03
Power reactivity coefficient $\partial\rho/\partial N_T$[pcm/MW] (EOC, H_{VI} =250 cm, nominal power, t=278.5°C, C_B = 0.001 g/kg)	< 0	- 1.39

Reactivity coefficients for 13-th cycle, Unit 3

- moderator temperature reactivity coefficients

Table 8

Parameters	Limit values	13-th cycle values
1. Negative reactivity of ACA** [pcm]*		
1.1.Rods worth value of all ACA when 1 control assembly (the most effective one) is stuck at top position		7645
1.1.1. Reactivity calculations tolerance of 10%		- 764
1.1.2. Reactivity margin for the position of ACA 1%		- 76.4
1.1.3.Reactivity margin for the position of 6-th working control group		- 341
1.1.4.Negative reactivity of ACA		6463.6
2.Introduction of positive reactivity [pcm) Positive reactivity release in the core when the power changes from 100% to 0% due to effects:		
2.1.Doppler and temperature effects		2189
2.1.1.Calculations accuracy tolerance of 15%		328.3
2.2.Coolant density effect		100
2.2.1.Calculations accuracy tolerance of 10%		10
		2627.3
3.Shutdown reactivity margin [pcm]	> 3000	3836.3

Reactivity margin of shutdown at the end of design 13-th cycle Unit 3

*1pcm = 10^{-5}

**ACA - Automatic Control Assemblies

Table 9

Parameters	Limit values	13-th cycle values
Effective fraction of delayed neutrons from fission βeff [pcm]*:		
Upper limit (at the beginning of the 13-th cycle, nominal power, H_{VI} =200cm, t=278.5°C, C_B = 1.067g/kg)		621
Lower limit(at the end of the 13-th cycle, nominal power, H_{VI} = 250 cm, t = 278.5°C, C_B=0.001g/kg)		572
Maximal rate of positive reactivity introduction [pcm/s]:	< 0.7βeff	
Maximal rate of positive reactivity introduction when the 6-th working control group moves at operating velocity of 2cm/s [pcm/s]:	< 43.5	20.6
Differential boron worth $\partial p/\partial C_B$ [pcm/ppm]** at zero power, t = 20°C , BOC/EOC C_B - critical		-10.34/ -11.71
Differential boron worth $\partial p/\partial C_B$ [pcm/ppm] at zero power, t = 260°C , BOC/EOC C_B - critical		-8.10/ -9.11
Differential boron worth $\partial p/\partial C_B$ [pcm/ppm] at nominal power, t=278.5°C, BOC/EOC C_B - critical		-7.92/ -8.76
Critical boron concentration [ppm] at BOC, nominal power, H_{VI}=200cm , t = 278.5°C		1067
Differential boron worth $\partial p/\partial C_B$ [pcm/ppm] (t=20°C,zero power, C_B=2000ppm, all ACA inserted at 0 cm) BOC		-10.84
For the cold, zero power condition at BOC, all ACA*** withdrawn, C_B =2000ppm, t=20°C, the effective multiplication factor Keff value:	≤ 0.98	0.962
For the cold, zero power condition at BOC, all ACA*** inserted, C_B= 2000ppm, t = 20°C, the effective multiplication factor Keff value:		0.887

Neutron kinetic coefficients, boron effeciency and differential ACA worth during the design 13-th cycle

*1pcm = 10^{-5}

**1000 ppm = 1g/kg

***ACA - Automatic Control Assemblies

Table 10

Unit	Cycle	Measured critical parametres			Calculated	Deviation
		H_{VI}, cm	t °C	C_{H3BO3}, g/kg	C^{crit}_{H3BO3}, [g/kg]	ΔC_{H3BO3}, g/kg
3	13	200	258	9.04	9.09	-0.05
		210	259	8.98	9.12	-0.14
		193	256.6	9.04	9.07	-0.03
		207	250.2	9.05	9.13	-0.08
		59	253.6	8.31	8.24	0.07
		198	259.3	9.05	9.06	-0.01

Critical boric acid concentrations at start-up physical measurements

Table 11

Unit	Cycle	Measurements			Calculated	Deviation
		initial temperature °C	final temperature °C	$\partial\rho/\partial t$ [βeff/ °C]	$\partial\rho/\partial t$ [βeff/ °C]	[βeff/ °C]
3	13	256.6	258.3	-1.35	-0.954	-0.40
		258.3	259.7	-1.36	-0.998	-0.36

Isothermal reactivity coefficients at start-up physical measurements

Unit 3, Cycle 13, BOC

Table 12

Time to [h] after start up	Operational parametres				Calculated	
	N_T, %	H_{VI}, cm	t °C	C_{H3BO3}, g/kg	C^{crit}_{H3BO3}, [g/kg] by simulation	ΔC_{H3BO3}, g/kg
0	*HZPC	200	258	9.04	9.08	-0.04
0	HZPC	147	258	8.64	8.74	-0.10
7	30	175	266	8.49	8.47	0.02
16	30	171	268	7.92	7.92	0.0
23	50	193	268	7.68	7.64	0.04
25	50	190	269	7.44	7.56	-0.12
35	50	192	269	7.19	7.22	-0.03
57	55	185	267	6.85	6.94	-0.09
66	55	186	267	6.94	6.89	0.05

Simulation of the core operation at the beginning of Cycle 13 of Unit 3
*HZPC - Hot Zero Power Critical condition

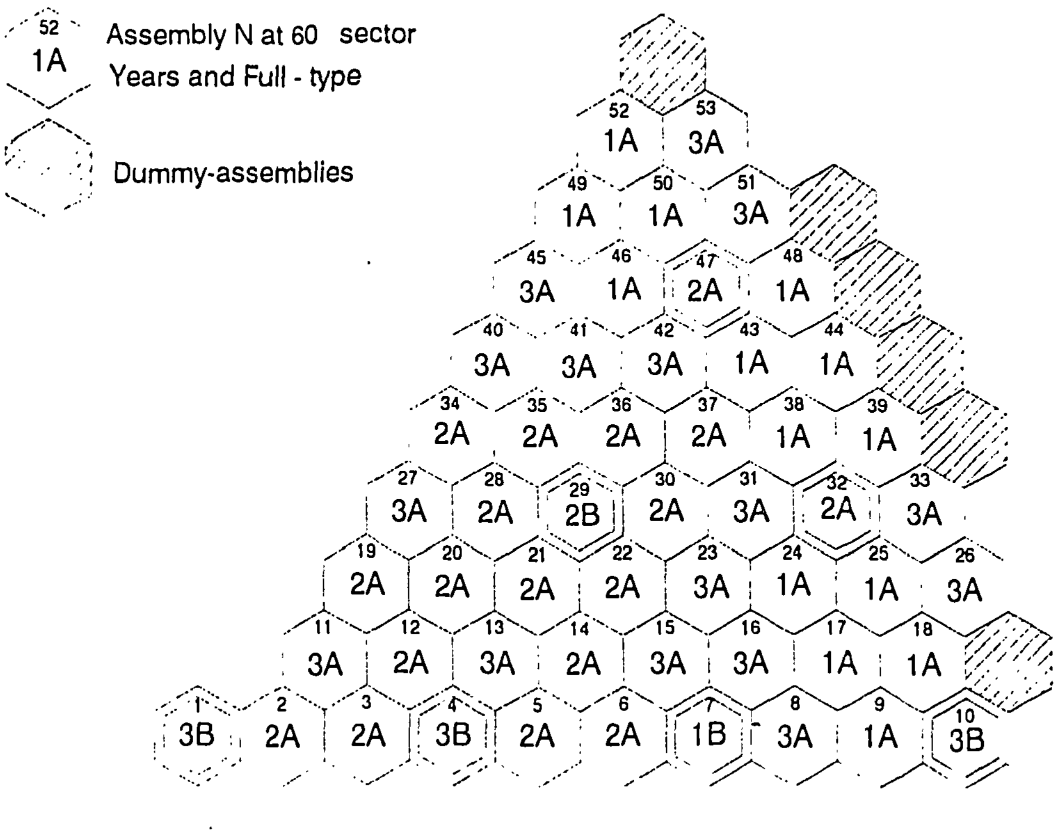


Fig.1. Unit 3 Cycle 11

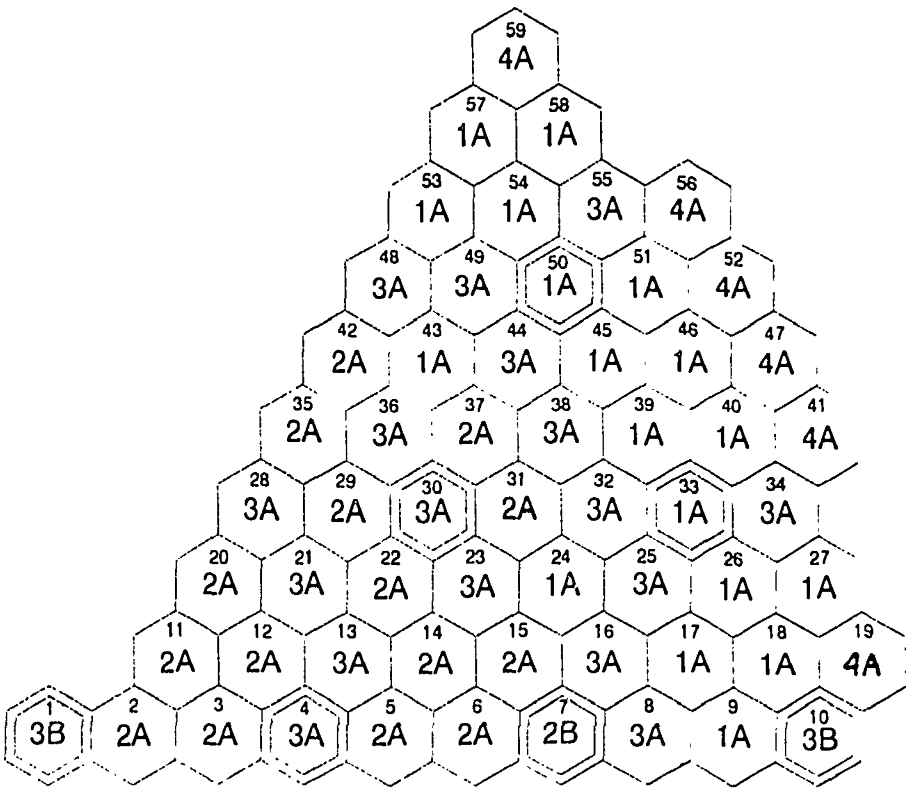
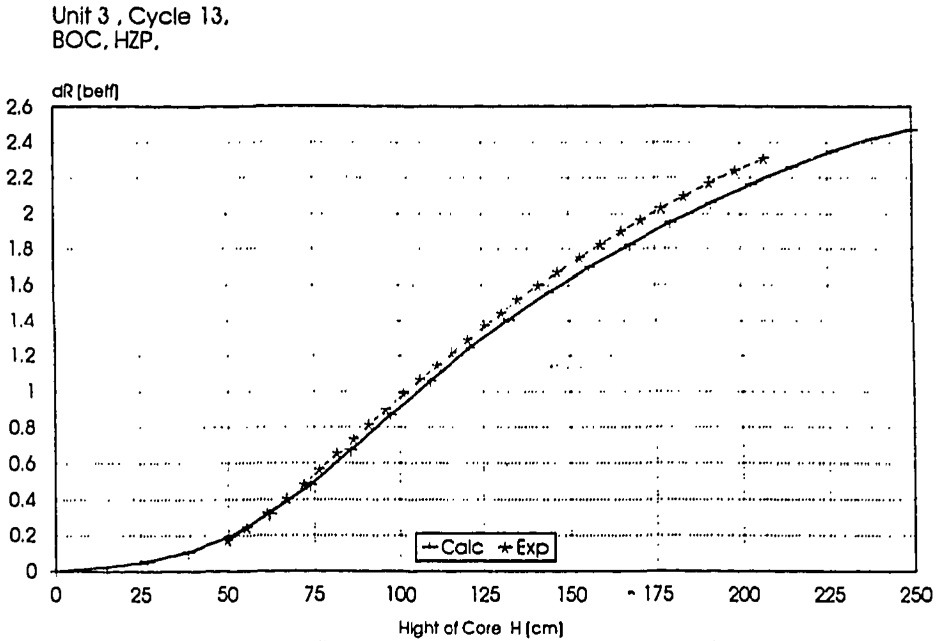
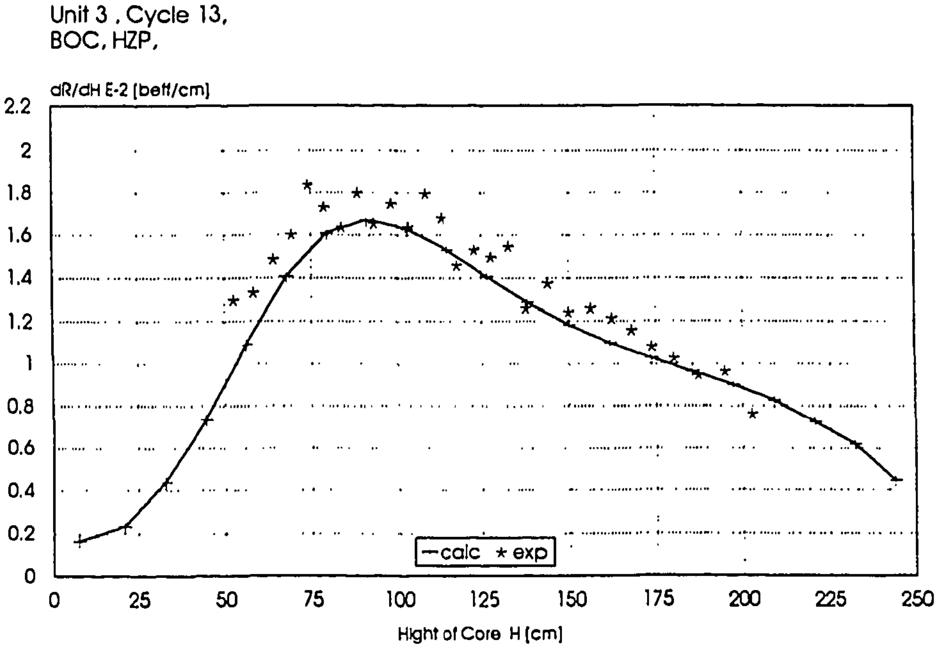


Fig.2. Unit 4 Cycle 12



Operating VI-th group ACA integral worth measured by insertion.

fig 3.



Operating VI-th group ACA differetial worth measured by insertion.

fig 4.