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About Reasonably Achievable Balance between Economy and Safety indices in WWERs

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Here I would like to emphasize how the permanent process of modifications of FAs, active core and fuel cycle in the WWERs intended first of all **for the total economy improvement** leads to inevitable some **worsening of safety** and even **economy** itself.

And what should help in this conflict of opposites to improve economy and maintain the necessary level of safety.

Safety vs. Economy

Build-up of engineering safety systems including their diversification leads not only to the Safety enhancement but also to the complexity and rise in price.

It was noted at the previous INPRO meeting DF7 which took place on 2012 year.

So here it should be achieved a reasonable balance between Economy and Safety.

What is the better combination for “Economy +Safety”

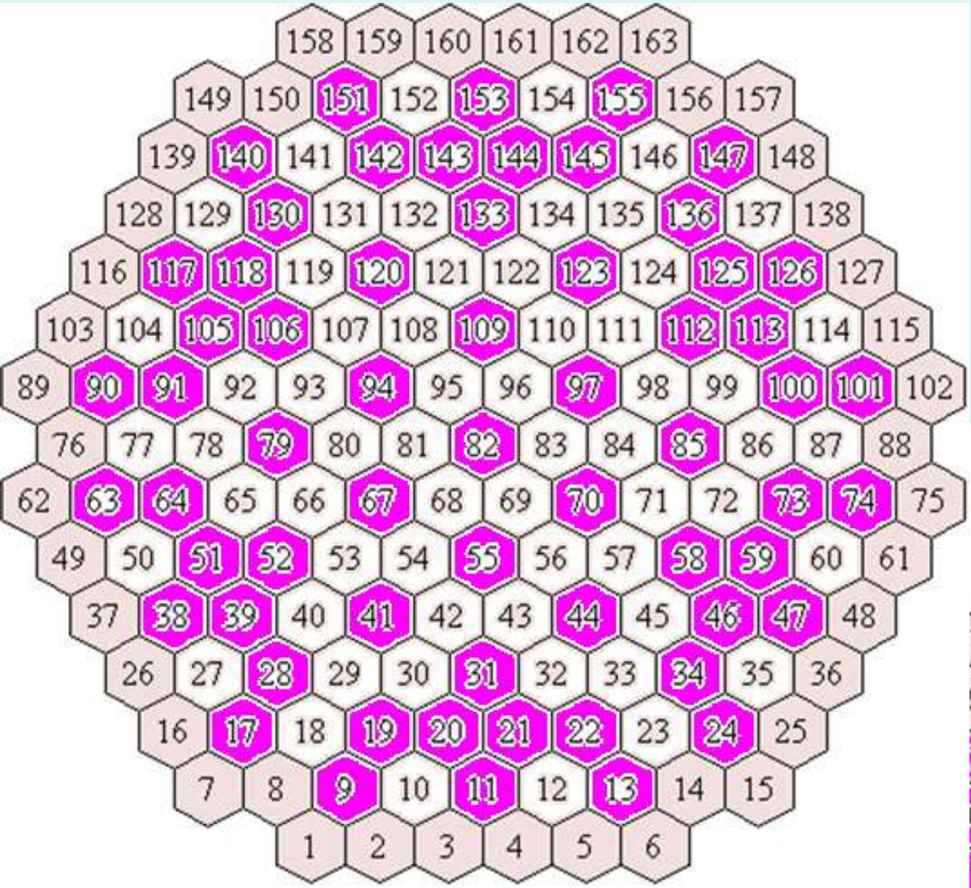
Frequently there is **not an unambiguous answer** for this question.

For example:

- much more CPS CRs (EP) in WWERs than in PWRs;

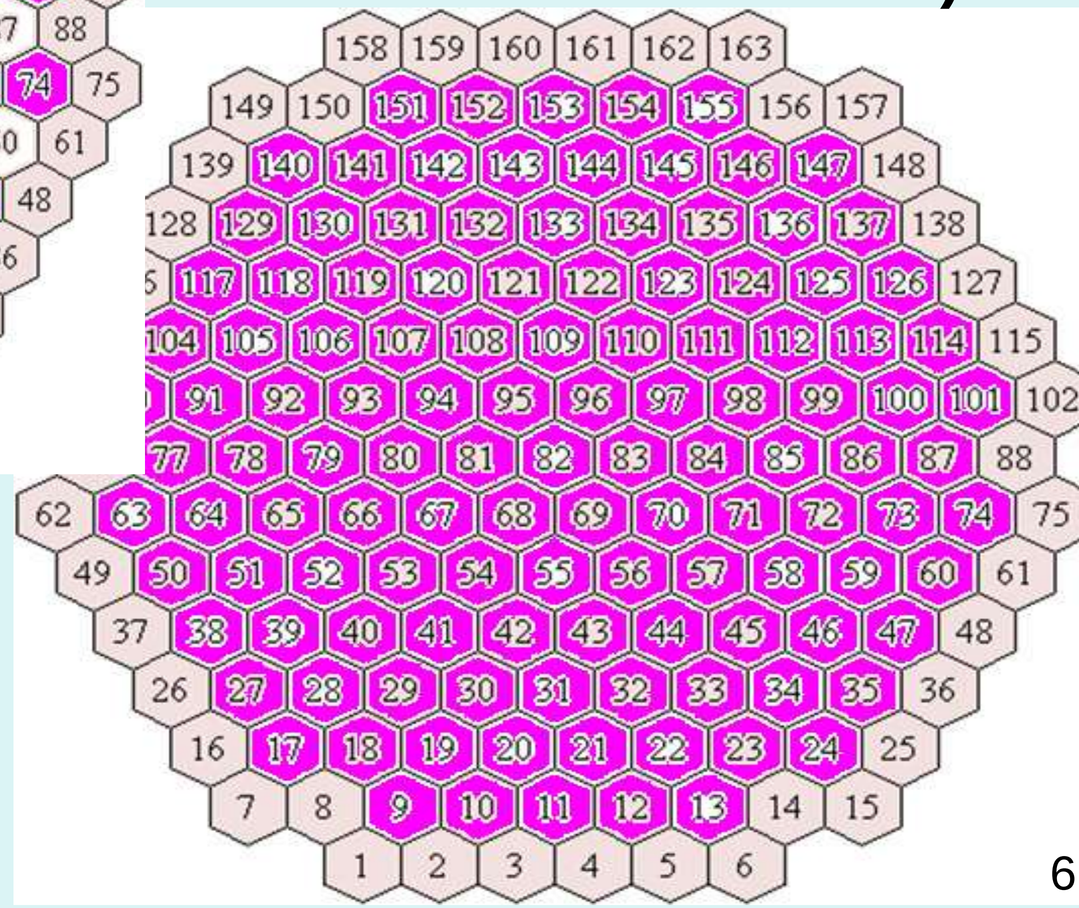
- in PWRs are used the **external** neutron source for more safe reactor start-up from the subcritical state, but in WWERs are not used;

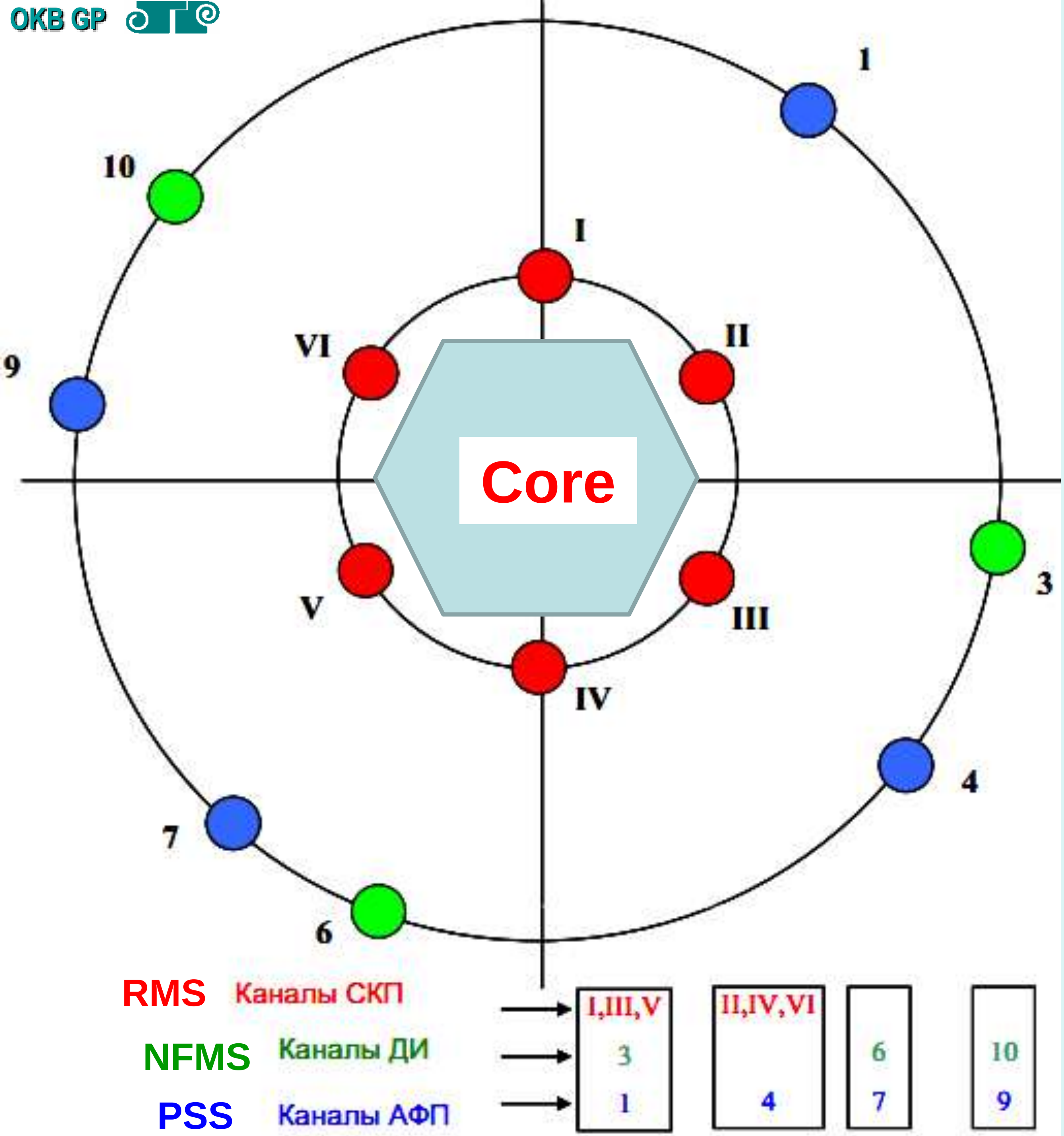
- much more SPND+TC for neutronics and thermal monitoring in WWERs than in PWRs.



EP with 61 CRs (Serial WWER-1000)

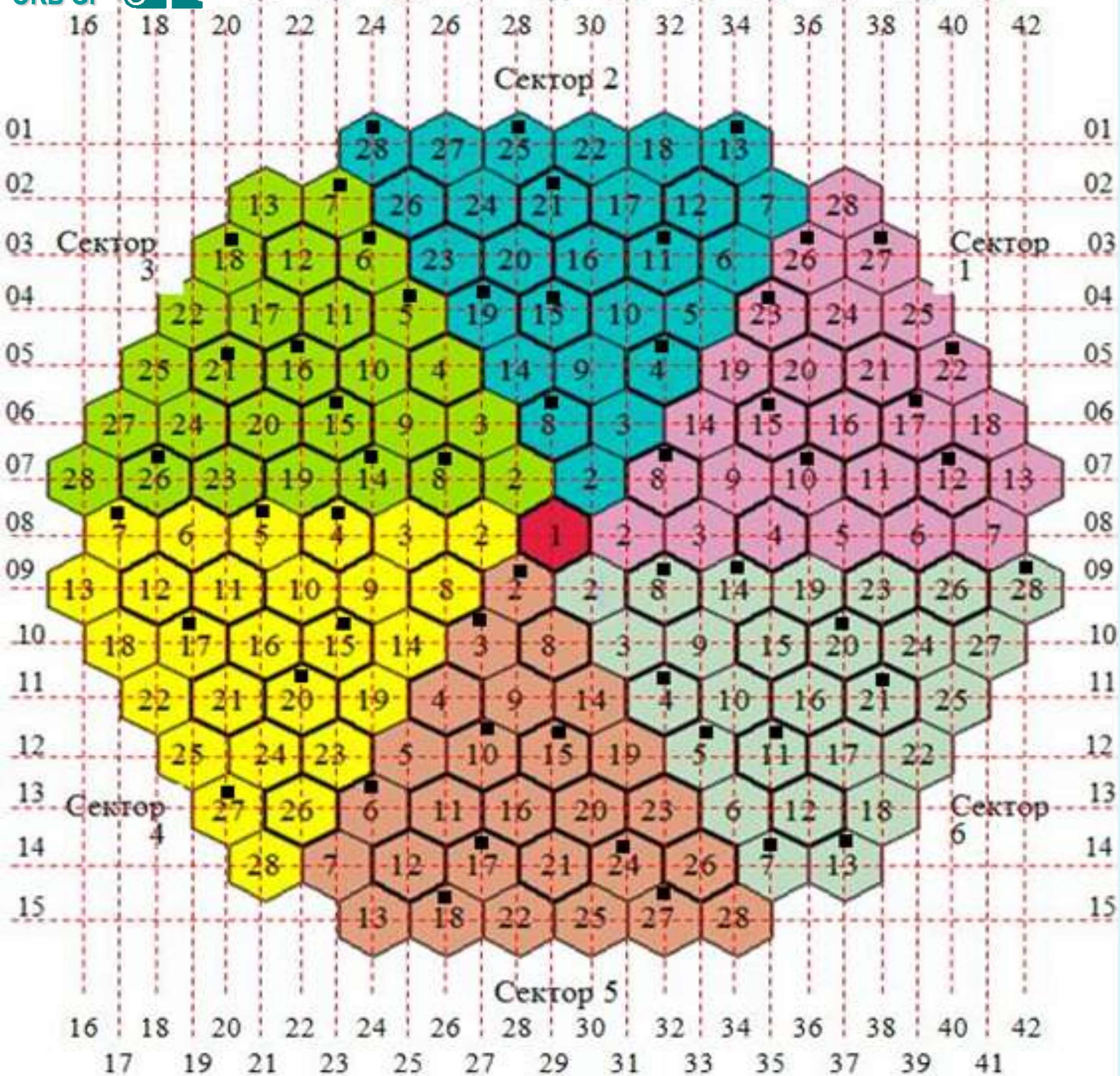
EP with 121 CRs (advanced WWER-1200)





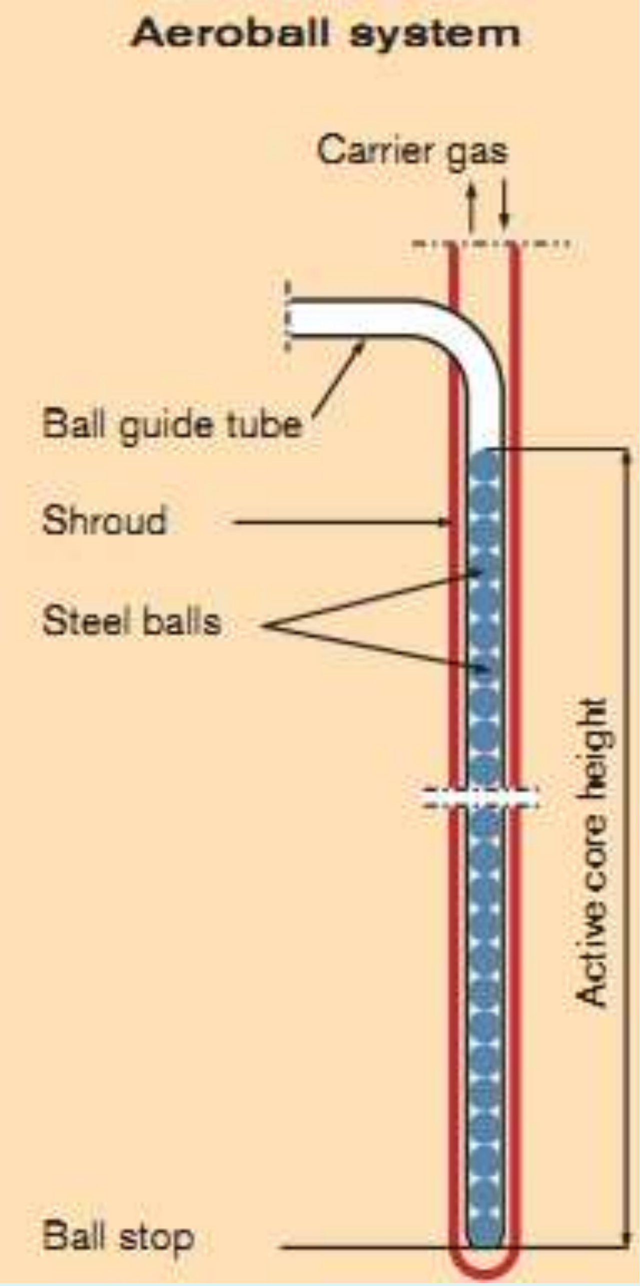
After filling by CB the monitoring is executed by **PSS** channels.
Then after return of **PSS** indications to “zero” values – by **RMS** channels.

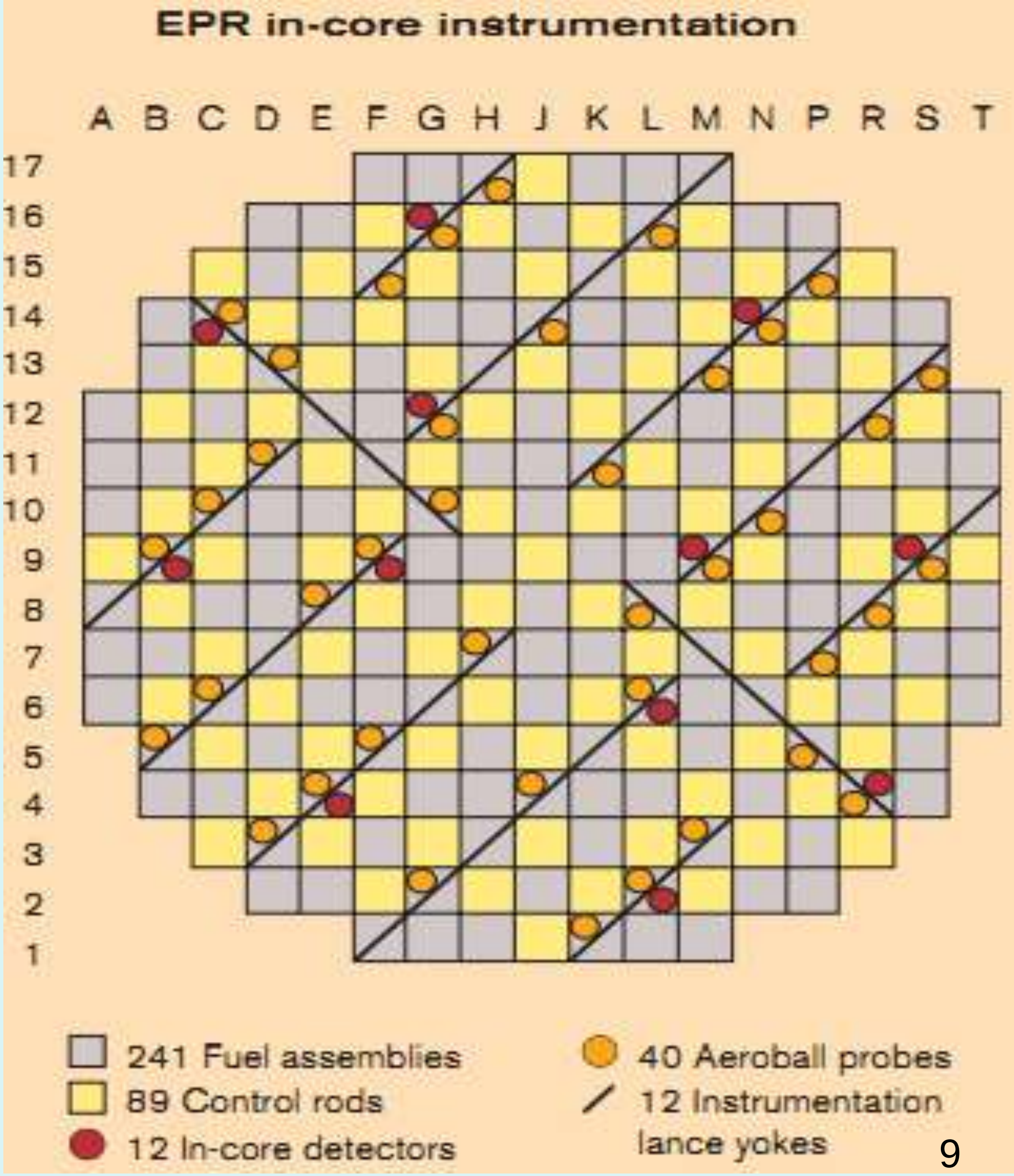
There is **not the necessity** to use the **external** neutron source.



54 NTMC (SPND+TC) in FAs of the “Bushehr” core.

SPND– 54 x 7 pcs. (by height).


Aeroball system
Carrier gas
Ball guide tube
Shroud
Steel balls
Active core height
Ball stop


EPR in-core instrumentation
A B C D E F G H J K L M N P R S T
17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
241 Fuel assemblies
89 Control rods
12 In-core detectors
40 Aeroball probes
12 Instrumentation lance yokes

Fuel efficiency in WWERs has been considerably increased during last 20 years particularly due to:

- replacement of steel elements in active part of Fuel Assemblies by Zr elements;

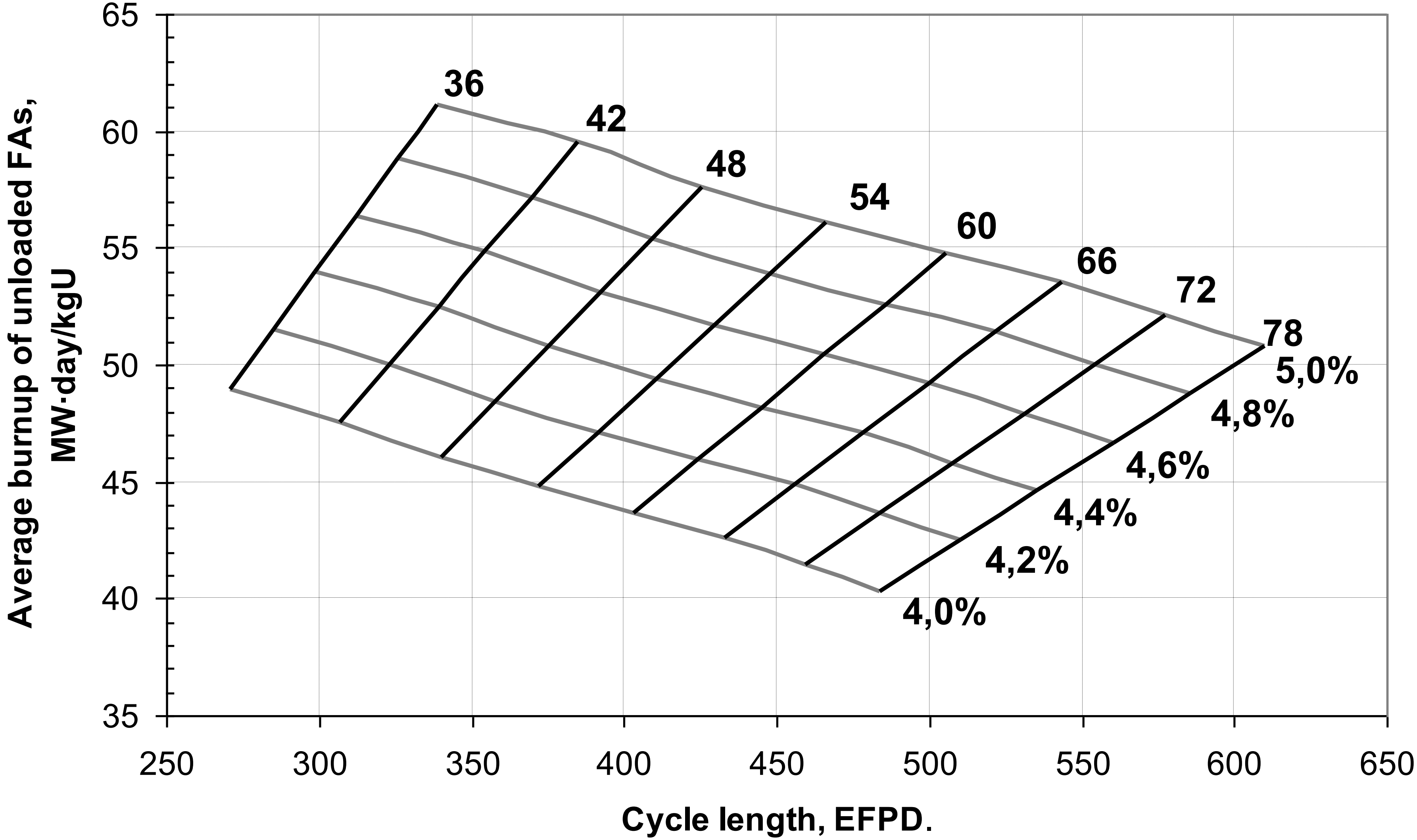
- transition from two-years fuel cycle to three, and then four-year cycle, and

- reduction of lateral neutron leakage (L3P). It promoted also the collateral increase the RPV **life time** (due to decrease FN Fluence) and increase of **EP effectiveness**.

However there is a competition in safety and economical parameters between different variants. Any implemented improvement has not only the positive influence but also the negative one.

For example the very favorable for safety and economy implementation of L3P loading scheme leads also to some disadvantages in safety – worsening of Power Peaking Factor (Kq) and Temperature Coefficient of Reactivity (TCR).

Another example is a competition between strategies of often reloadings (reactor campaign 6-12 months with maximal Burn-up) and rare ones (reactor campaign 18-24 months with maximal Load Factor).



Average burnup of unloaded FAs, MW·day/kgU
Cycle length, EFPD.
65
60
55
50
45
40
35
250
300
350
400
450
500
550
600
650
36
42
48
54
60
66
72
78
5,0%
4,8%
4,6%
4,4%
4,2%
4,0%

To improve economy and at the same time to maintain the necessary level of **safety** may help the following measures:

✓evolution of safety methodology to BE-approach and BE- codes,

✓the coupled simulation of 3D effects in the link NF/TG/HD,

✓harmonization of DSA and PSA,

✓ Risk- Informed Approach to decision making by the optimum balance of safety and efficiency in the RI projects and

✓optimization of NTD in the field of AE.

Characteristic	Times		
	Yesterday	Today	Tomorrow
Designation	**TVS-2**	**TVS-2M**	**TVS-4**
Fuel height, m	3.53	**3.68**	3.68
Diameter of fuel pellet, mm	7.57	**7.6**	**7.8**
Diameter of fuel pellet central hole, mm	1.4	**1.2**	**0**
Fuel mass, rel.	1.00	**1.06**	**1.15**

Base price parameters (approximate)

Cost of natural uranium USD / kg	26
Cost of Separating Work Unit USD / SWU	90

Economical profit due to implementation of the **axial profiling** of fuel **enrichment**

Reactor campaign (refueling)	Gain in the cycle length, %	Sum gain, %	Sum gain, 10^3 $/(year · unit)
Basic (ref. - no profiling)	0,0	0,0	0
First Transition	1,3	3,2 - 3,5	**470 - 510**
Second Transition	0,5	2,4 - 2,7	**350 - 390**
Third Transition	0,0	1,9 - 2,2	280 - 320
Forth….	-0,1	1,8 - 2,1	260 - 300
Equilibrium	0,0	1,9 - 2,2	280 - 320

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Gain – Decrease of "Natural U + enrichment" costs

Implemented:

Transition from **SS** elements to **ZR** in FAs **+** from **2 to 4** years campaign **+** **LLLP (in-in-..out)**

$ 4,5 · 10^6 /(year · unit)

Implemented partly:

Axial blankets

$0,32 · 10^6 / (year · unit) in equilibrium cycle

Implemented partly:

Fuel length increase + Axial blankets

$0,58·$10^6$ /(year ·unit) in equilibrium cycle

Will be soon Implemented:

Increase of **fuel mass** in FRs, decrease of **cladding thickness**

$1,0 · 10^6 / (year ·unit) in equilibrium cycle

Decrease of specific consumption of Natural U

Implemented:	*Implemented partly:*	*Implemented partly:*	*Will be soon Implemented:*
Transition from **SS** elements to **ZR** in FAs **+** from **2 to 4** years campaign **+ LLLP (in-in-..out)**	**Axial blankets**	**Fuel length increase + Axial blankets**	Increase of **fuel mass** in FRs, decrease of **cladding thickness**
30 %	2,2 %	4 %	4,8 %

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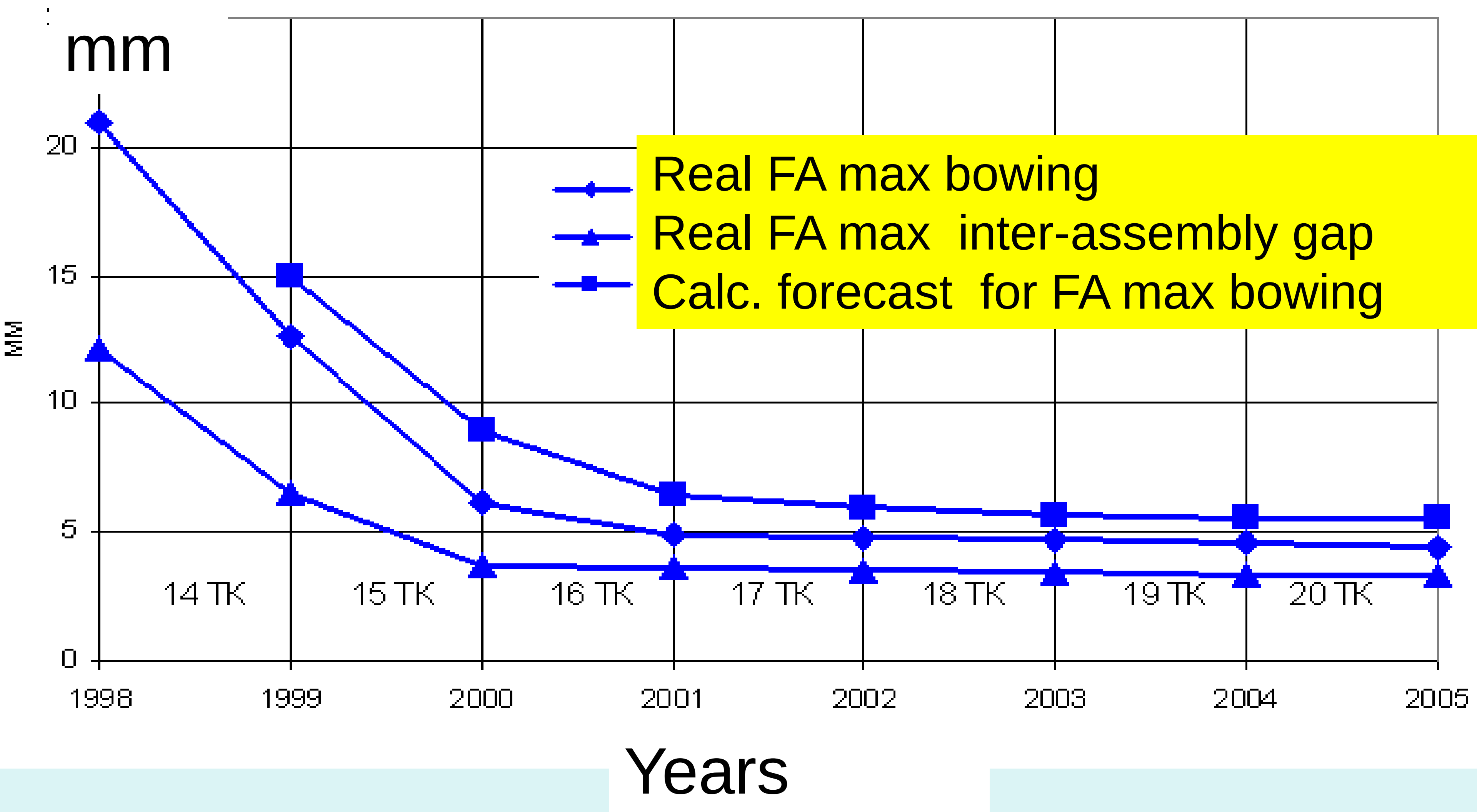
Fuel and Fuel Cycle Innovation	**Advantages**	**Possible Disadvantages**	Implemen-tation
Transition from st-steel to Zr in Spacer Grids and Guiding Tubes in FAs	Substantial increase of fuel utilization Efficiency due to removal of a parasitic steel absorber of neutrons	Rigidity lowering against FA bow. Increase of the degree of freedom on FA's **bow** due to increase of inter-assembly gaps at heating-up, **additional local power peaks**	PWR. WWER


mm
MM
20
15
10
5
0
Real FA max bowing
Real FA max inter-assembly gap
Calc. forecast for FA max bowing
14 TK
15 TK
16 TK
17 TK
18 TK
19 TK
20 TK
1998
1999
2000
2001
2002
2003
2004
2005
Years

But for the hexagonal FAs made by Westinghous (**W-FA**), namely for Temelin NPP (Chech Republic) and South-Ukrainian NPP (Ukraine) there is a problem with **W-FA**s bowing and even loss of their leak-tightness. This is a complex and money loosing task.

Therefore several years ago the Temelin NPP unloaded from the core all 163 **W-FA**s and loaded into the core all 163 fresh **FAs of Russian design**.

At the SU NPP a similar situation was with several trial **W-FA**s. Now a real dangerous may occur of irresponsible usage of such unreliable **W-FA**s on Ukrainian NPPs in the connection with certain events in the Ukraine.

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Fuel and Fuel Cycle Innovation	**Advantages**	**Possible Disadvantages**	Implemen-tation
Transition from discrete BAR to IFBA (tvegs)	Increase of fuel utilization due to better burn-up of integrated with fuel burnable absorber (IFBA). No spent burnable absorber rods (BARs). More flexibility for improving of TCR and power peaking factors in the FAs and core.	More strict limitations and acceptance criteria for IFBA (due to less thermal conductivity and less melting temperature).	PWR. WWER

Fuel and Fuel Cycle Innovation	**Advantages**	**Possible Disadvantages**	Implementation
Decrease (up to Zero) of the central hole diameter in the fuel pellet. **Fuel-fullness of the Core**	Increase of fuel usage Efficiency. Increase of the loading Fuel mass.	Decrease of the free volume. Potential aggravation of safety margin in accidents	PWR. WWER - in progress

Fuel and Fuel Cycle Innovation	**Advantages**	**Possible Disadvantages**	Implemen-tation
Decrease of the cladding thickness in the fuel rods (the inner diameter of claddings is increased via decreasing the minimal wall thickness to 0,54 mm)	Increase of fuel usage Efficiency. Improve of the Fuel rods cooling	Decrease of the mechanical strength of the cladding	PWR. WWER - in progress **(It requires to decrease the tolerances at fabrication of Fuel Rods)**

Fuel and Fuel Cycle Innovation	**Advantages**	**Possible Disadvantages**	Implemen-tation
Increase of fuel pellet diameter and decrease of gas gap between pellet and cladding. **Fuel-fullness of the Core**	Improving of fuel usage. Increase of the loading Fuel mass	Decrease of the free volume. Potential aggravation of safety margin in accidents	PWR. WWER- in progress **(It requires to decrease the tolerances at fabrication of Fuel Rods)**

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Fuel and Fuel Cycle Innovation	Advantages	Possible Disadvantages	Implemen-tation
Increase of the fuel Burn-up. Fuel cycle flexibility and long reactor campaigns up to 18-24 months	Total increase of economical indices in spite of the worsen of fuel usage	Decrease of the mechanical strength of fuel rods and FA's structure. FA's deformation, additional local power peaks. Worsen of the Temper. Coeff. of Reactivity	PWR. WWER-in progress

Fuel and Fuel Cycle Innovation	**Advantages**	**Possible Disadvantages**	Implemen-tation
Increase of the fuel Burn-up. More of the fuel refuelings (from 2-years to 3-4-5-6-years fuel campaign	Improve of the fuel utilization	Decrease of the mechanical strength of fuel rods and FA's structure. FA's deformation, Many outages due to refuelings	PWR. WWER-in progress

Fuel and Fuel Cycle Innovation	Advantages	Possible Disadvantages	Implemen-tation
Reduction of radial leakage of neutrons from the core. **In-in…-out** or **Low Leakage Loading Patterns**	Improve of the fuel utilization. Increase of EP efficiency. Reduction of fluence of FN on RPV	Worsen of the radial power peaking factor. Worsen of the Temper. Coeff. of Reactivity	PWR. WWER

Fuel and Fuel Cycle Innovation	Advantages	Possible Disadvantages	Implemen-tation
Reduction of axial leakage of neutrons from the core (axial fuel blankets)	Improve of the fuel utilization.	Worsen of the axial power peaking factor. Local worsen of differential eff. of WG. Increase of max. burn-up of pellets	Some PWR. WWER-in progress

Fuel and Fuel Cycle Innovation	Advantages	Possible Disadvantages	Implemen-tation
Implement. of the axial profiling of the fuel rods enrichment and of the BA's concentratio ns	Improve of the axial power peaking factor. Improve of the fuel utilization. Lowering of the power jumps after fuel refuellig	Worsen of the stability index on Xenon ocsill.	Some PWR. WWER- is suitable

Thanks for your attention