**SIXTH INTERNATIONAL CONFERENCE ON
WWER FUEL PERFORMANCE, MODELLING
AND EXPERIMENTAL SUPPORT**

.

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Evolution of Fuel Cycles for NPP with VVER-440. Status and Prospects

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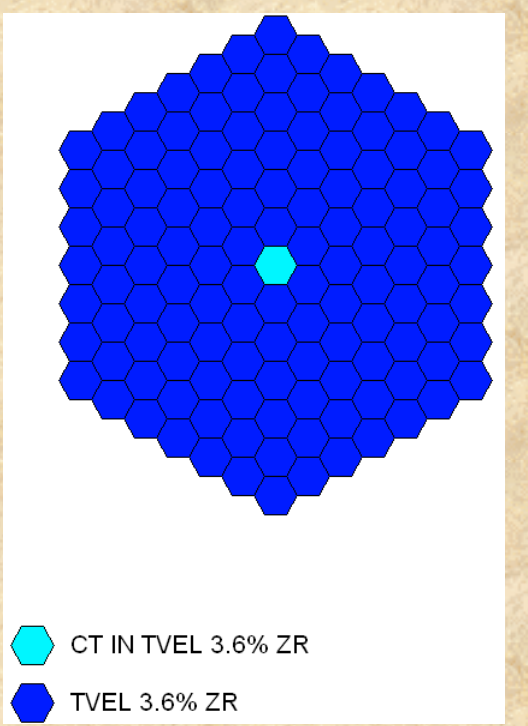
Main ways of improving VVER-440 fuel assemblies (FAs)

- Extended list of manufactured operational FA types Expansion the nomenclature of different types FAs
- Improved FA construction
- Increased fuel column height in assemblies
- Increased fuel rod lattice pitch
- Reduced neutron absorption in FA construction materials (reduced hafnium (Hf) contents)
- Reduced FA shroud thickness
- Improved construction of the control rod assembly's coupler part

Basic parameters of VVER-440 FA designs

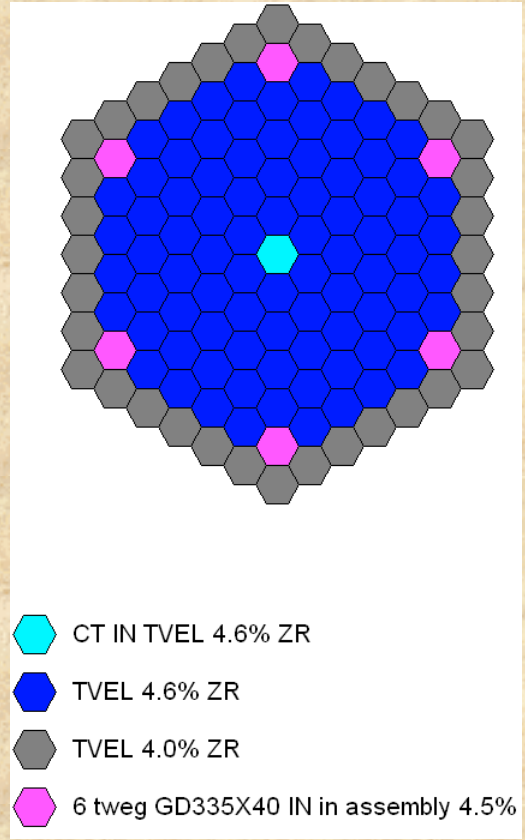
Parameter	Initial fuel cycle	Current fuel cycle	Projection 2010 г
Construction materials Cover FA	Zr(Hf≤0.05%) Zr(Hf≤0.05%)	Zr(Hf≤0.05%) Zr (Hf=0.01%)	Zr (Hf≤0.01%) NO
Burnable absorber	-	UO_2-Gd_2O_3	UO_2-Gd_2O_3
Profiled FA average enrichment in horizontal section in axial section	 YES NO	 YES NO	 YES YES
Weight of uranium in FA (rel.) Axial hole Diameter, rel. /Height fuel , rel. Fuel rod lattice pitch, rel./ Fuel rod diameter, rel.	1.00 1.00/1.00 1.00/1.00	1.05 0.86/1.02 1.01/0.99	1.15 0.0/1.02 1.03/0.97
The maximal enrichment of fuel (%)	4.40	4.25	4.65
The maximum admissible FA burn-up (MWd/kg HM)	53.9	57.5	62.0
The maximum admissible FA energy production (rel.)	1.00	1.12	1.32

Typical FA pattern of the for VVER-440

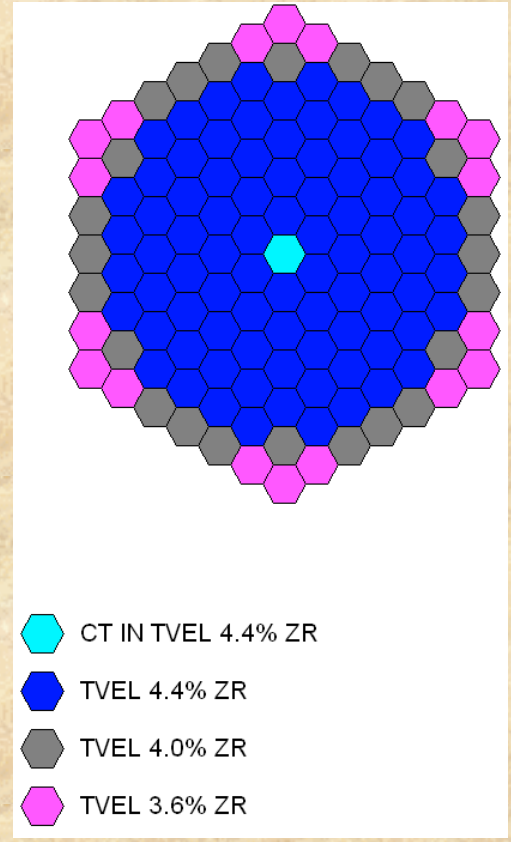


Standard FA

fuel enrichment
1.6%, 2.4%, 3.6%, 4.4%



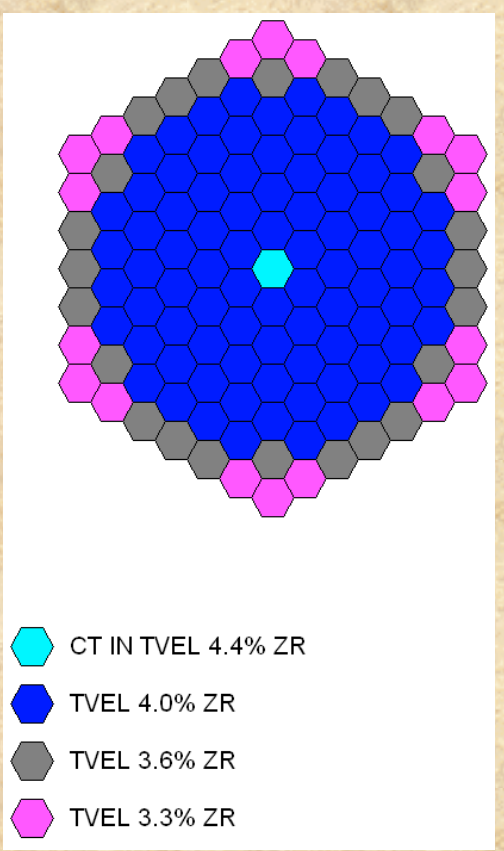
fuel enrichment 4.41%
with (Gd_2O_3)



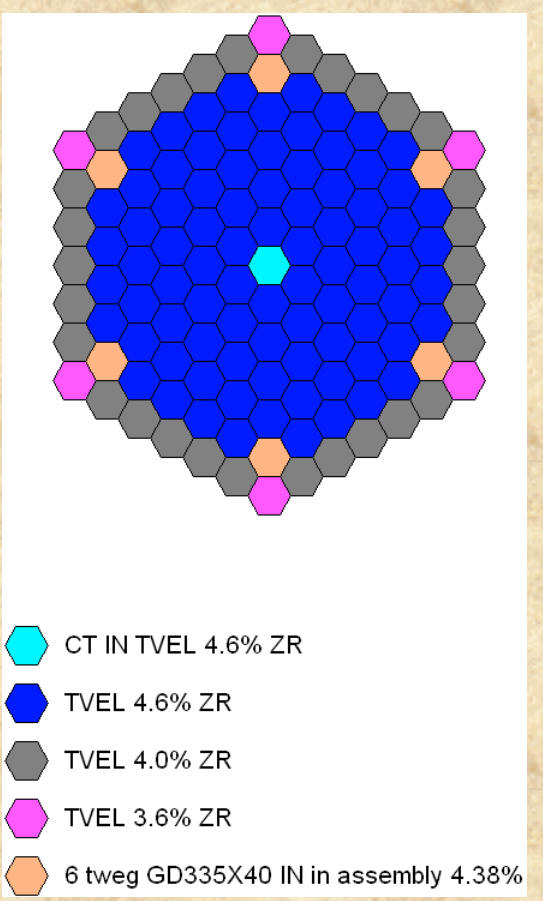
fuel enrichment 4.21%

Standard FA (only for Kola NPP unit 4)

Present-day FA pattern of the for VVER-440

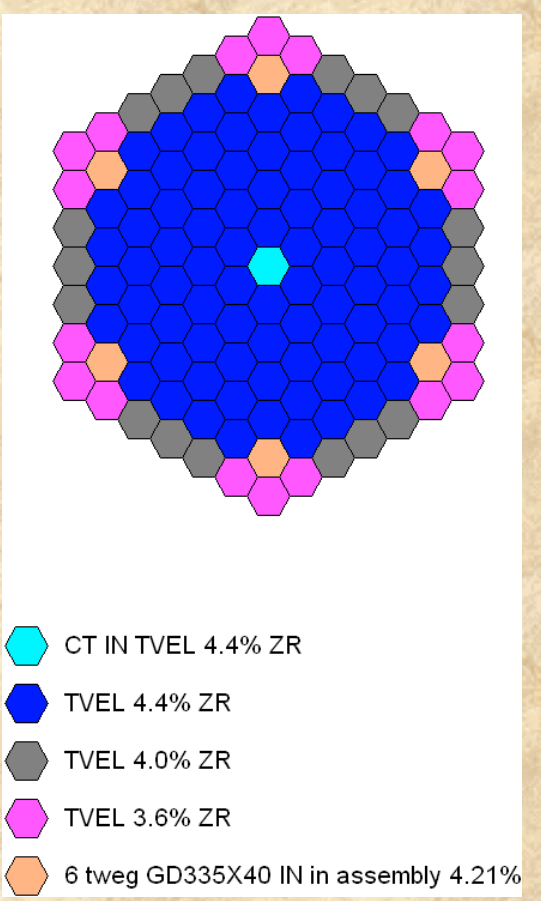


fuel enrichment 3.82%



fuel enrichment 4.38%

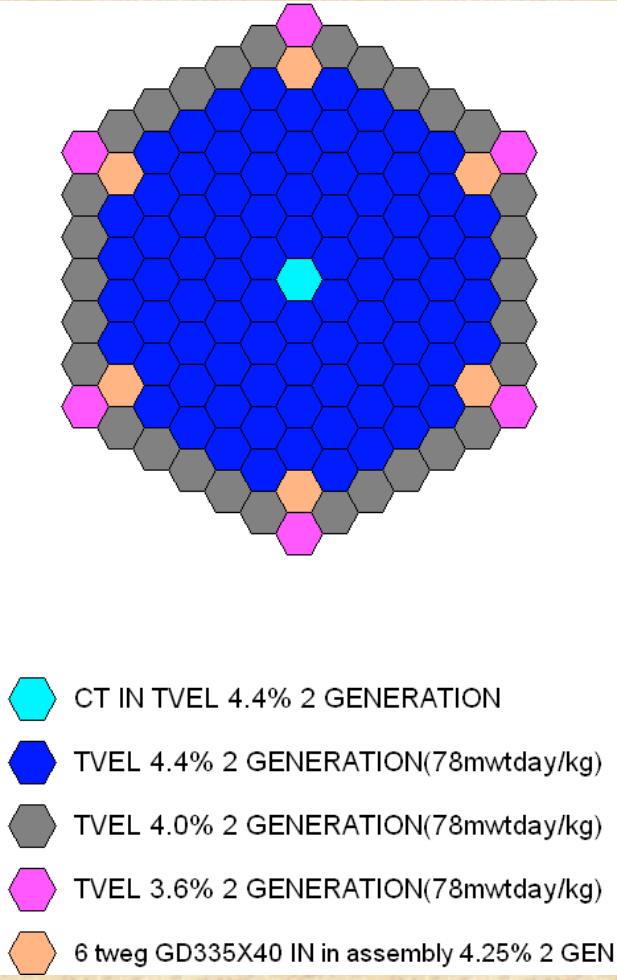
with (Gd_2O_3)



fuel enrichment 4.21%

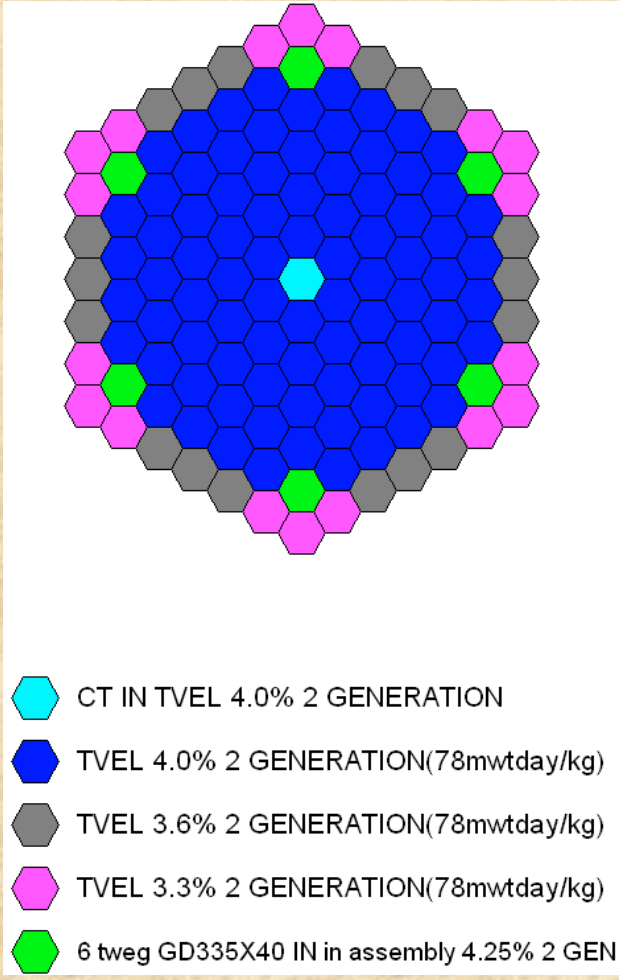
with (Gd_2O_3)

Advanced FA pattern of the for VVER-440 (second generation)



fuel enrichment 4.25%

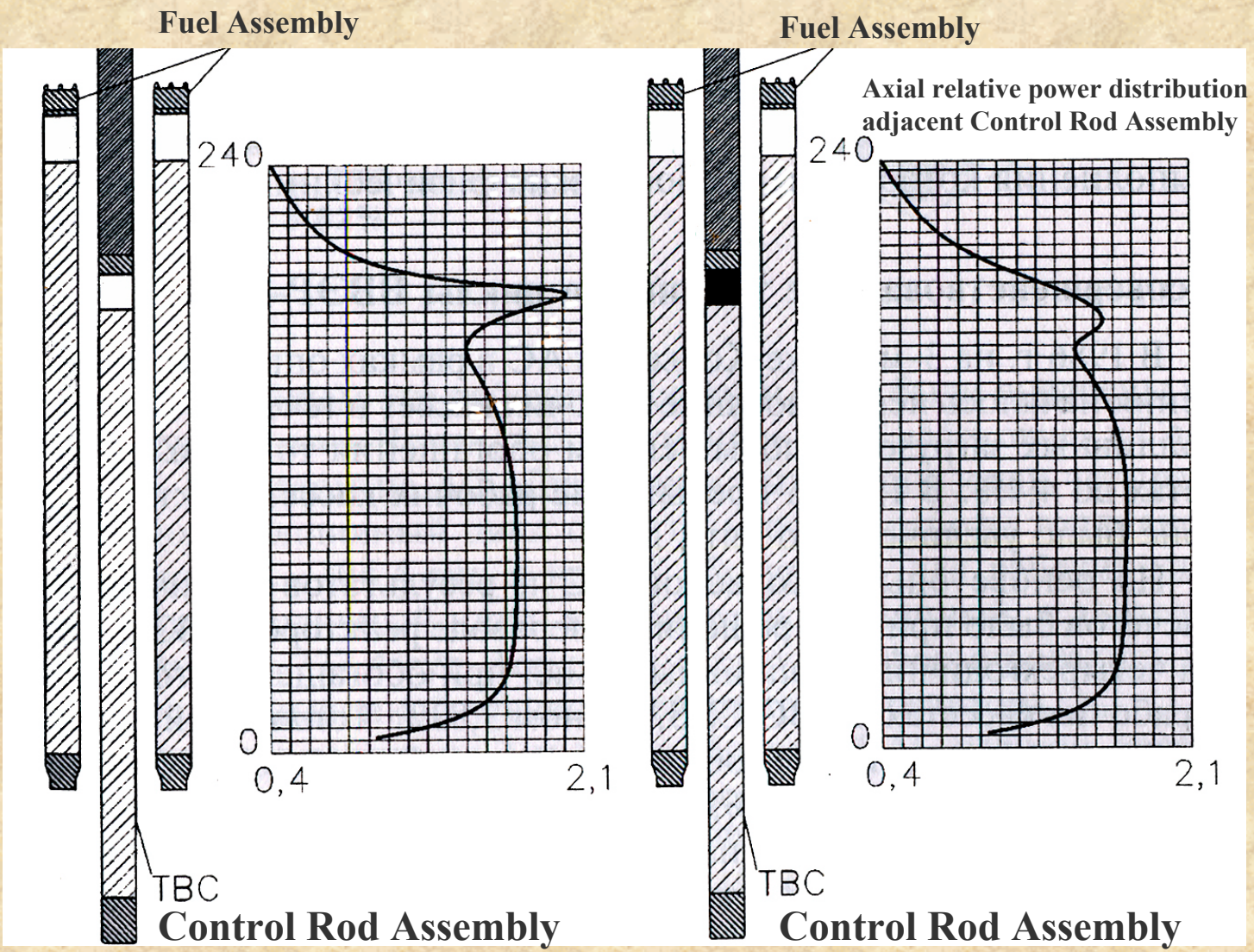
with (Gd_2O_3)



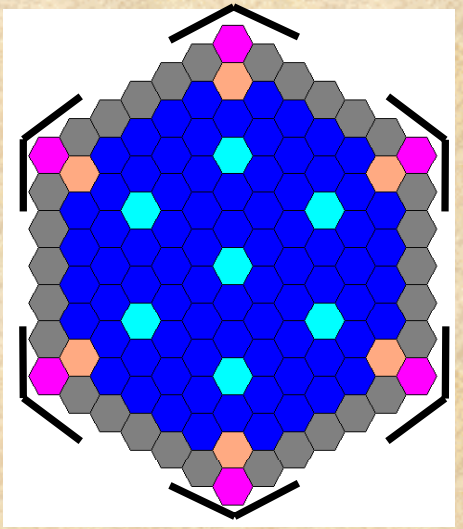
fuel enrichment 3.84%

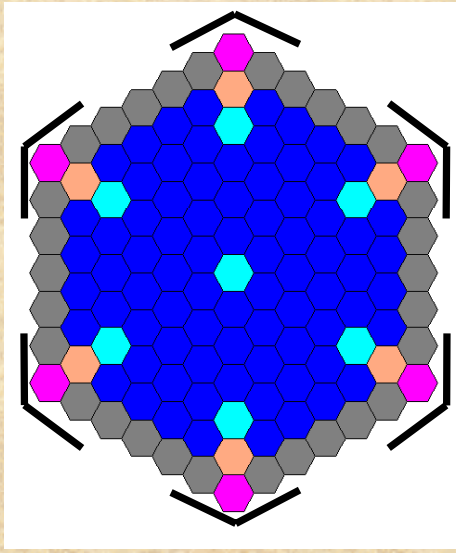
with (Gd_2O_3)

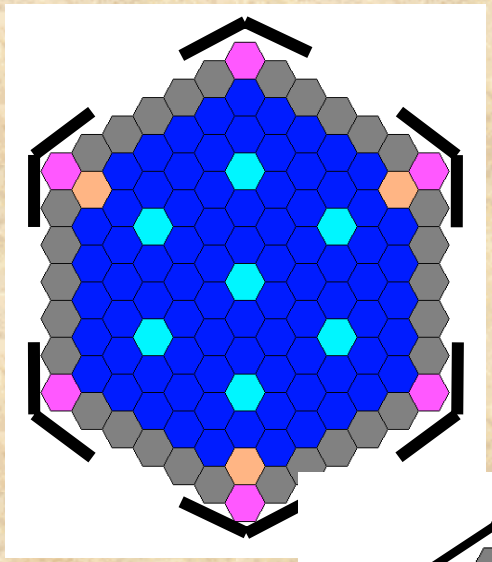
Control Rod Assembly (Hf shielding) coupler part Improvement design

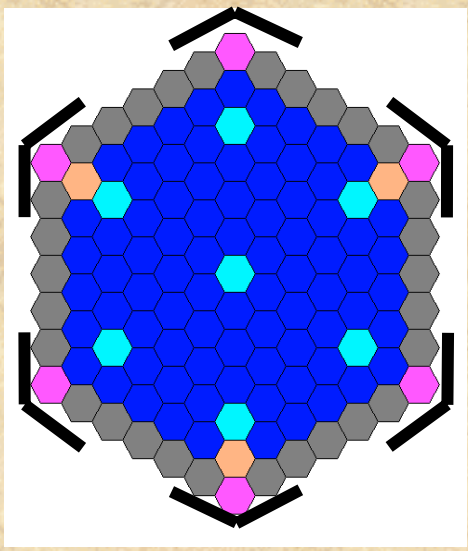


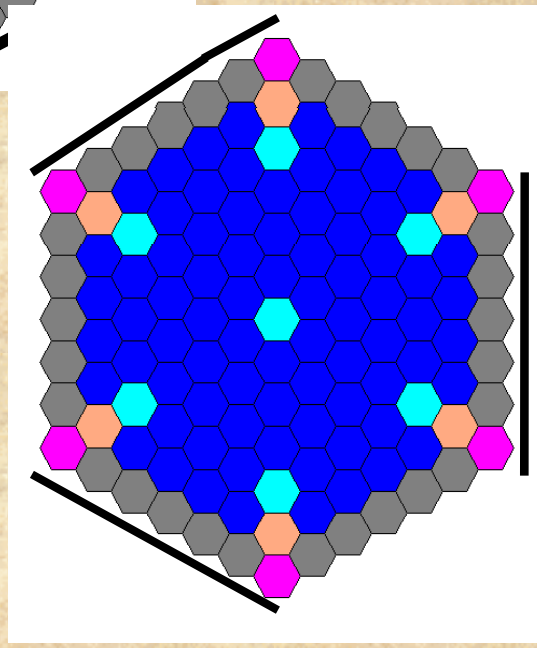
Perspective FA pattern of the for VVER-440









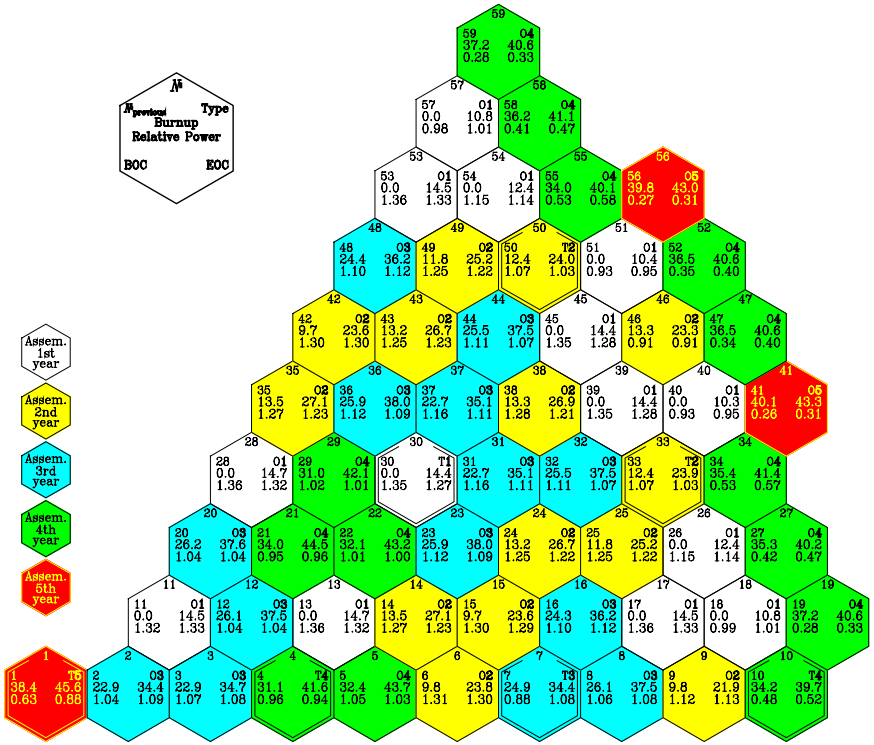


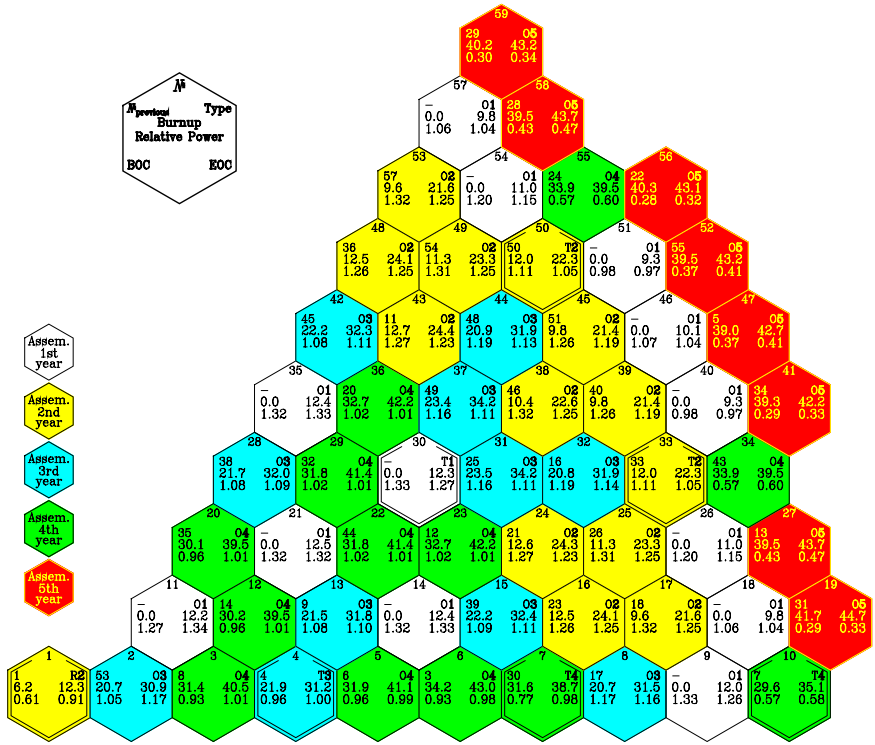
- Zr tube with H_2O
- FUEL ROD 4.8%
- FUEL ROD 4.4%
- FUEL ROD 4.0%
- FUEL ROD - 4.0 (3.35 Gd_2O_3)

Main ways of improving VVER-440 fuel cycle

- Increased initial fuel enrichment and reduced share of reloaded fuel
- Use of fuel refueling patterns with lower neutron leakage
- Increased FA operational period (from 3-4 to 5-6 years)
- Increased fuel burn-up (from 30-40 to 50-60 MW·day/kg)
- Decrease in conservatism of substantiation of fuel cycle

ADVANCED FOUR-YEAR FUEL CYCLE
with 3.82% FA PROFILED AVERAGE ENRICHMENT





Number of loaded FAs, 84 pcs
Cycle length, 307 FPD

Period average FA operation 4.14 year

Average burnup, 44.61 MWd/kg

→ **fuel economy** →

Number of loaded FAs, 78 pcs
Cycle length, 286 FPD

Period average FA operation 4.58 year

Average burnup, 44.91 MWd/kg

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Further improvement of VVER-440 fuel utilization efficiency and safety

Modern 5-year fuel cycles using uranium-gadolinium fuel

√Using burnable absorbers integrated with fuel

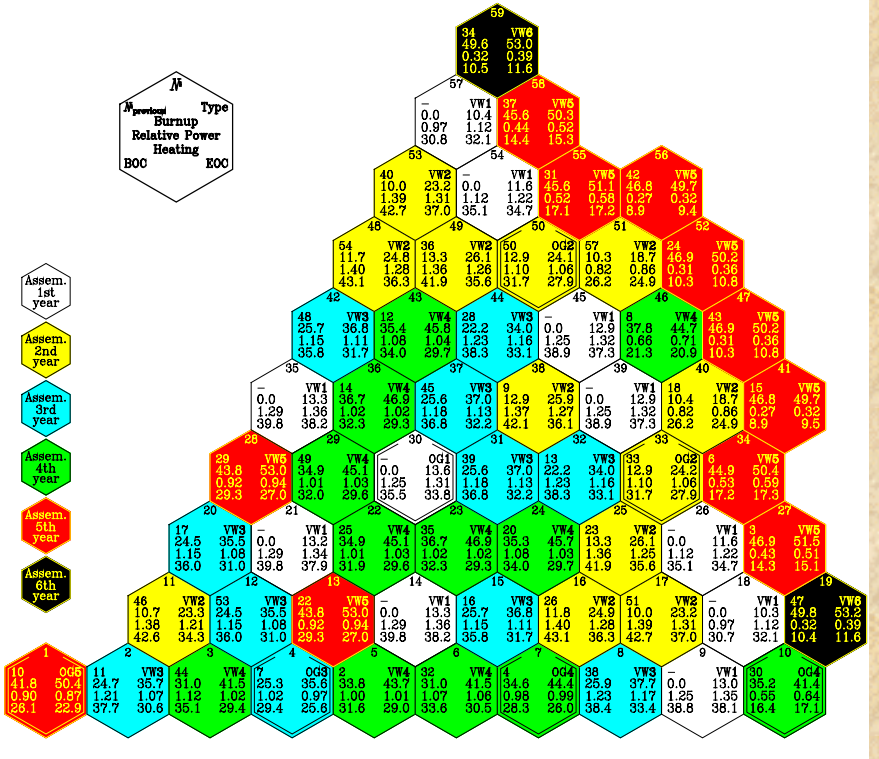
√Ensuring fuel cycle flexibility

√No need of changing NPP fresh fuel handling instructions at the moment of second-generation assemblies' introduction

√Developing fuel cycles providing for excess power reactor operation (105-110%)

√Developing fuel cycles with account of maneuvering reactor operation modes

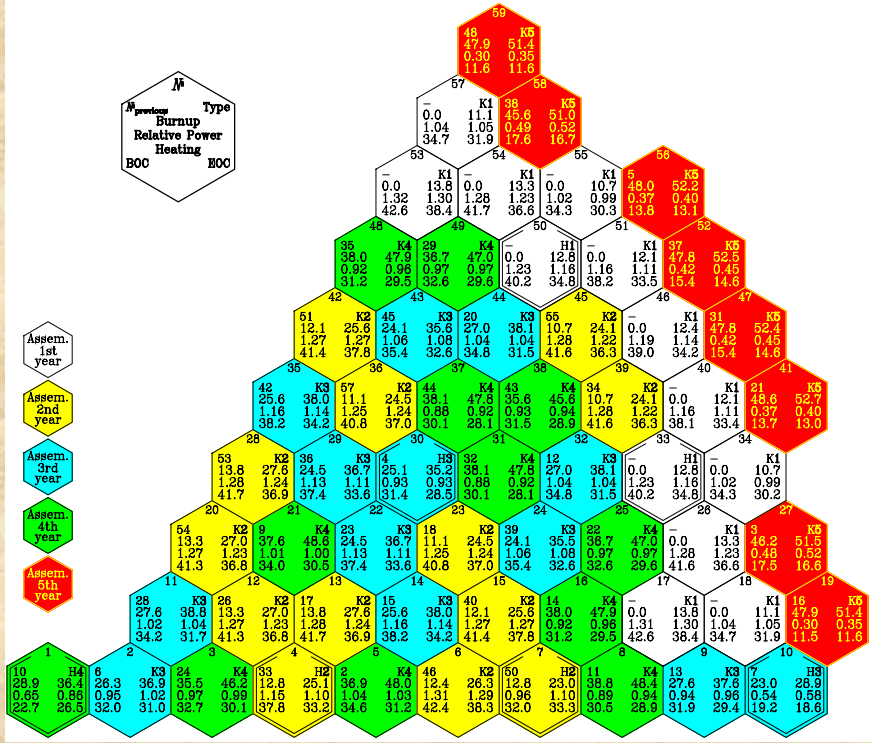
EQUILIBRIUM 5-YEAR FUEL CYCLE with 4.25% FA PROFILED AVERAGE ENRICHMENT with (Gd_2O_3)



Number of loaded FAs, 66 pcs

Refueling pattern IN-IN-IN-OUT

EQUILIBRIUM 5-YEAR FUEL CYCLE with FA 4.4% ENRICHMENT



Number of loaded FAs, 78 pcs

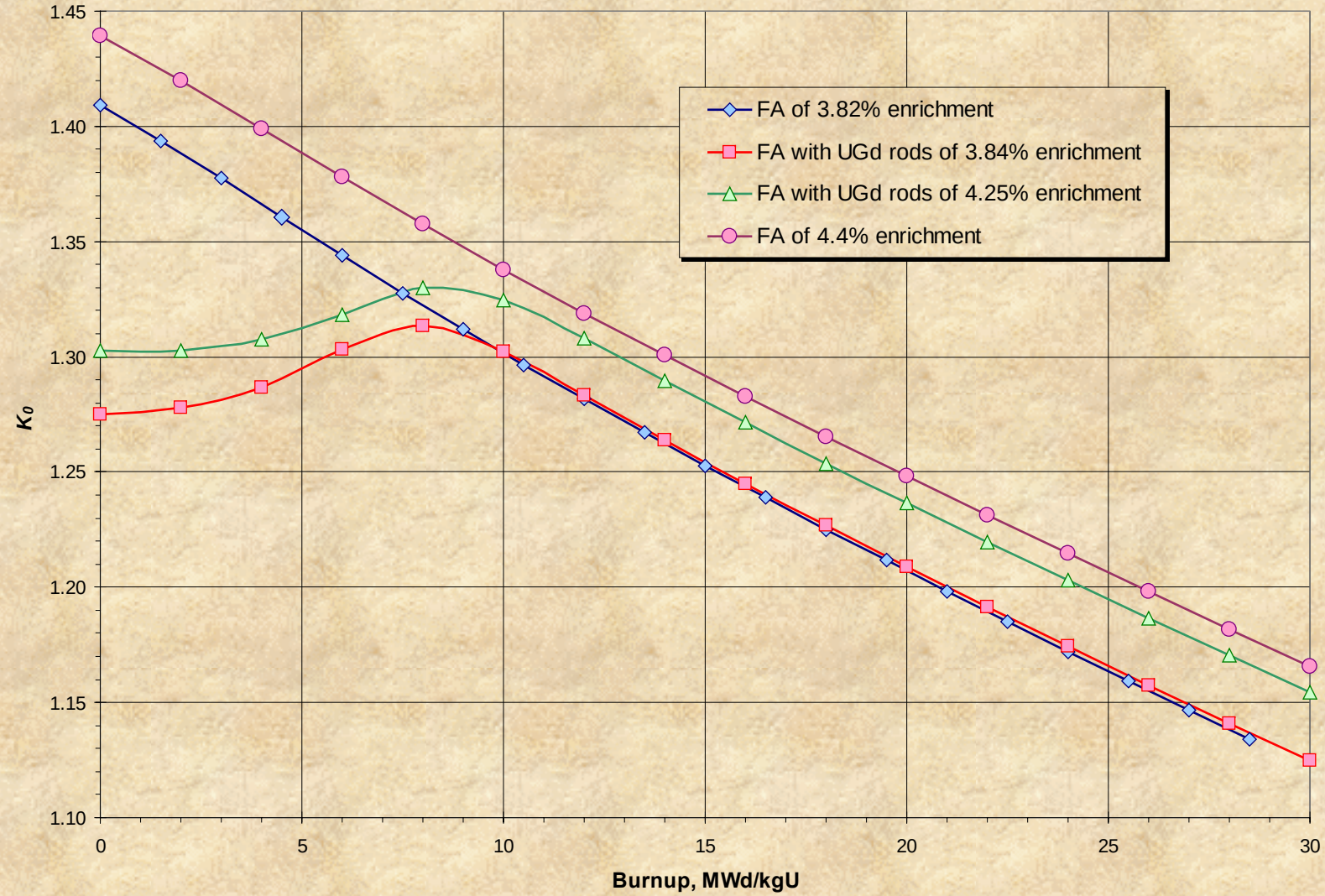
Refueling pattern WITH A LOW NEUTRON LEAK

Main Neutron Physics Parameters of Equilibrium Fuel Cycles

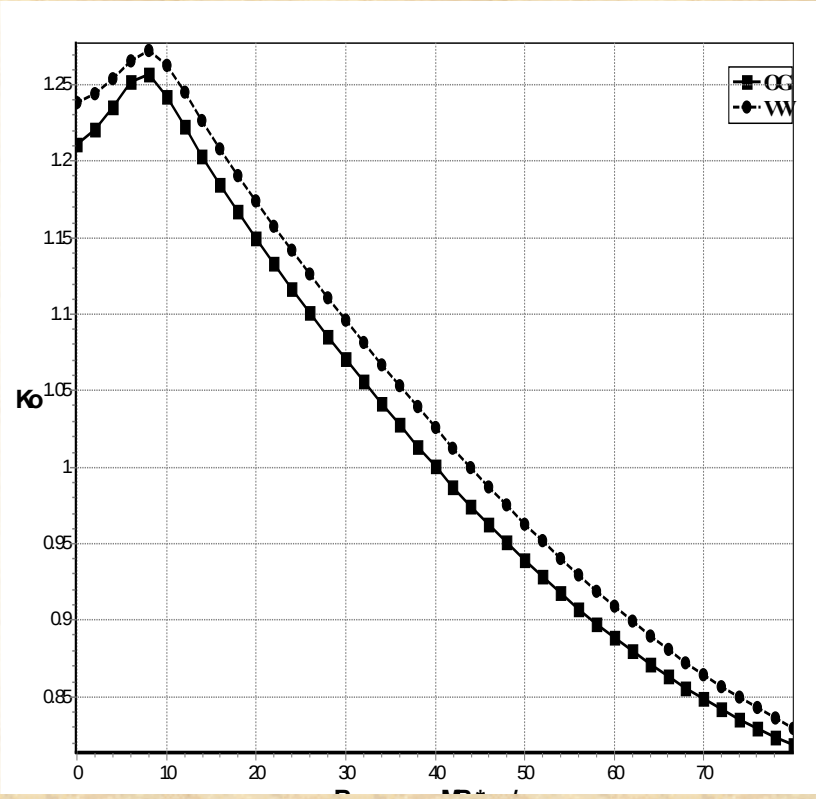
Name of cycle		4.25% UGBA	4.4%
Amount of loaded FAs, pcs		66	78
Average enrichment of fresh FAs, %		4.25	4.4
Burnable absorber type		Gd_2O_3	Not used
Time of FA operation average lifetime, year		5.01	4.47
Cycle length, EFPD		314	327
Unloaded fuel Burn-up, MWd/kgU	Average	49.9	47.9
	Maximum	53.0	52.7
Maximal relative power of fuel rods in the core		1.55	1.57
Critical concentration of boric acid, g/kg		4.13	6.15
Coefficient of reactivity on coolant temperature (BOC, hot T_M=200 °C, zero power,all control rods out), pcm/°C		<0 -0.42	>0 2.56
Repeat criticality temperature, °C (End of Cycle)		144	141
Maximal Linear Heat Rate of Fuel Rod, W/ см		233.7	253.6

Ratio of generation and absorption reaction rates depending on average fuel assembly burnup

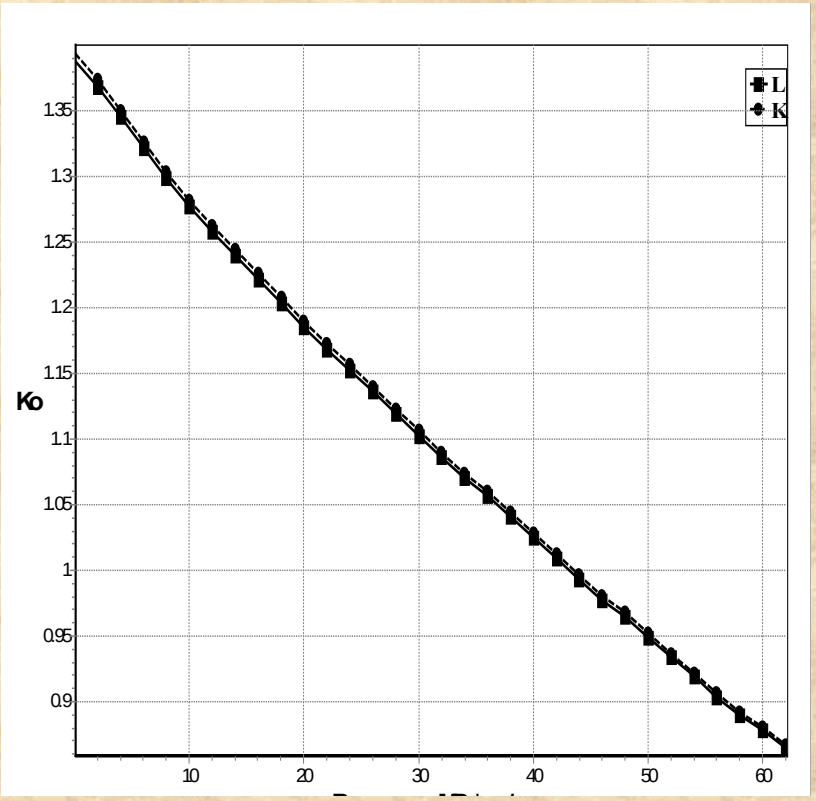
Cold State, T_M=27°C, Zero Boric Acid Concentration



EQUILIBRIUM 5-YEAR FUEL CYCLE with 4.25% FA PROFILED AVERAGE ENRICHMENT with (Gd_2O_3)

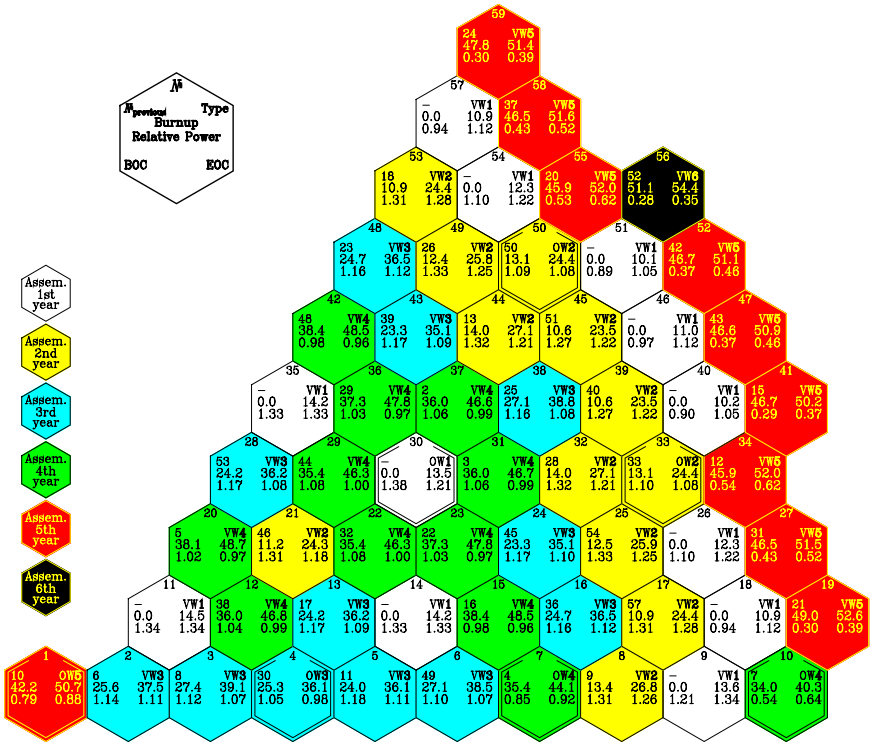


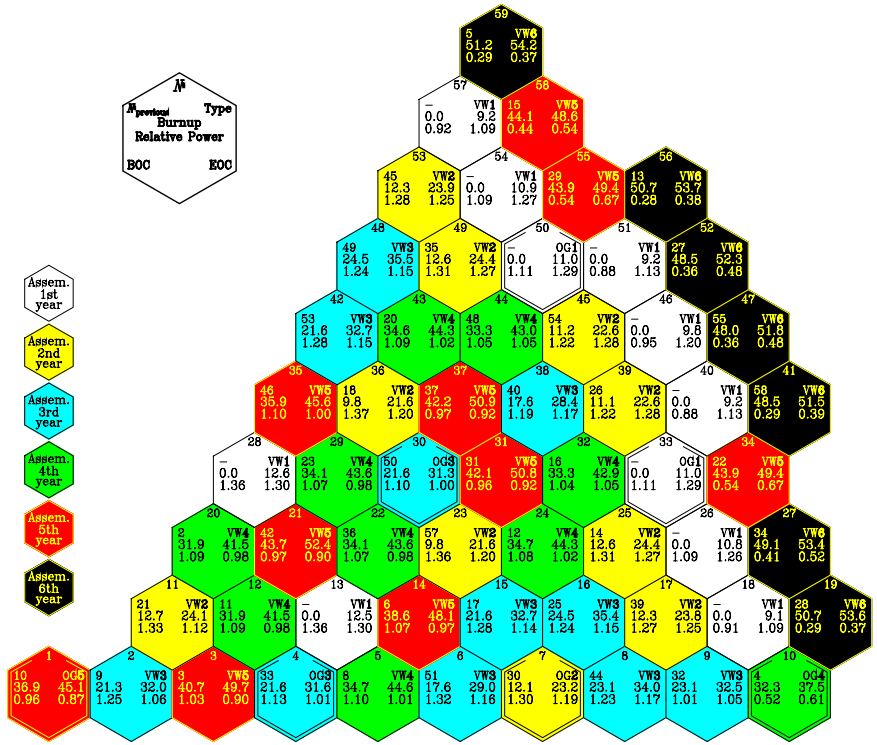
EQUILIBRIUM 5-YEAR FUEL CYCLE with 4.4% FA ENRICHMENT



K0 – Ratio of generation and absorption reaction rates in the system
HOT Zero Power State
Zero concentration of boric acid

ADVANCED EQUILIBRIUM FIVE-YEAR FUEL CYCLE
with 4.25% FA PROFILED AVERAGE ENRICHMENT with (Gd_2O_3)





Number of loaded FAs, 72 pcs
Cycle length, 303 FPD
Time of FA operation
average 4.93 year
Average Burnup, 52.40 MWd/kg

→ **fuel economy** →

Number of loaded FAs, 66 pcs
Cycle length, 292 FPD
Time of FA operation
average 5.12 year
Average Burnup, 54.22 MWd/kg

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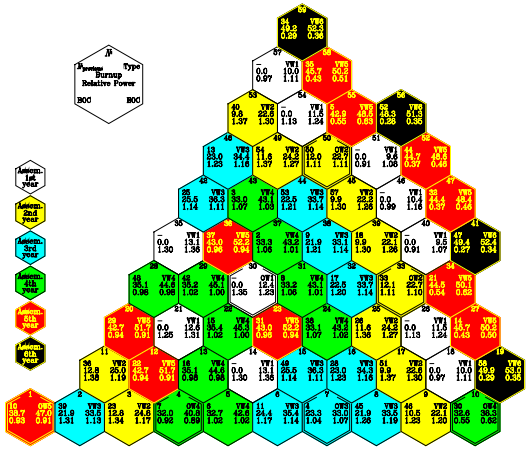
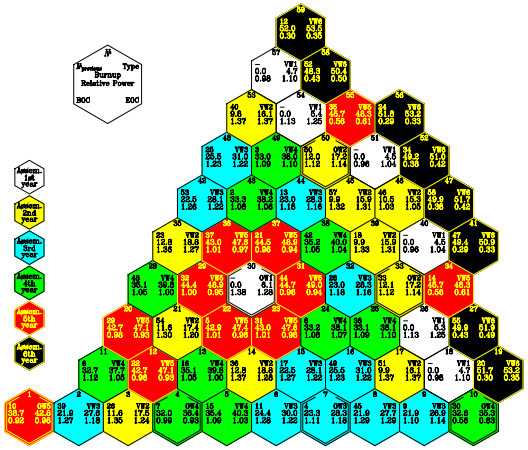
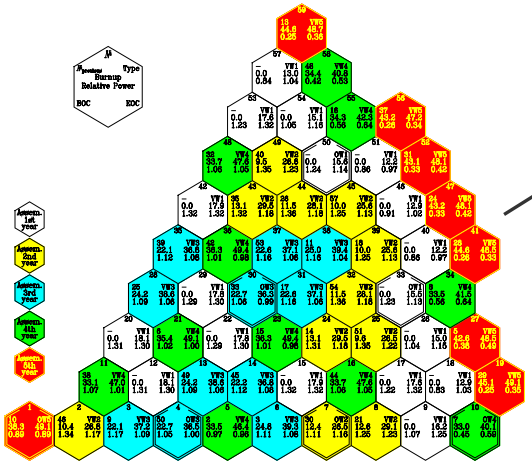
Flexibility of Fuel Cycle with Second Generation FAs



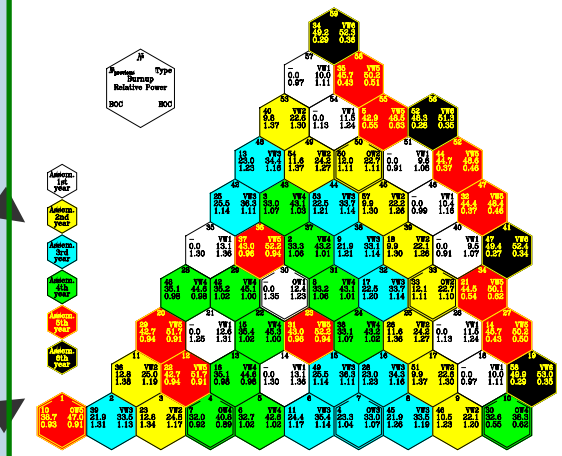
Equilibrium Fuel Cycles
Cycle length, 309 FPD
Amount of loaded FAs, 66 pcs



Cycle length, 146 FPD
Amount of loaded FAs, 42 pcs



Cycle length, 430 FPD
Amount of loaded FAs, 108 pcs



Equilibrium Fuel Cycles
Cycle length, 309 FPD
Amount of loaded FAs, 66 pcs

ADVANCED FIVE-YEAR FUEL CYCLE

with 4.25% FA PROFILED AVERAGE ENRICHMENT with (Gd_2O_3)

Power to increase by 5%-10% of power rating

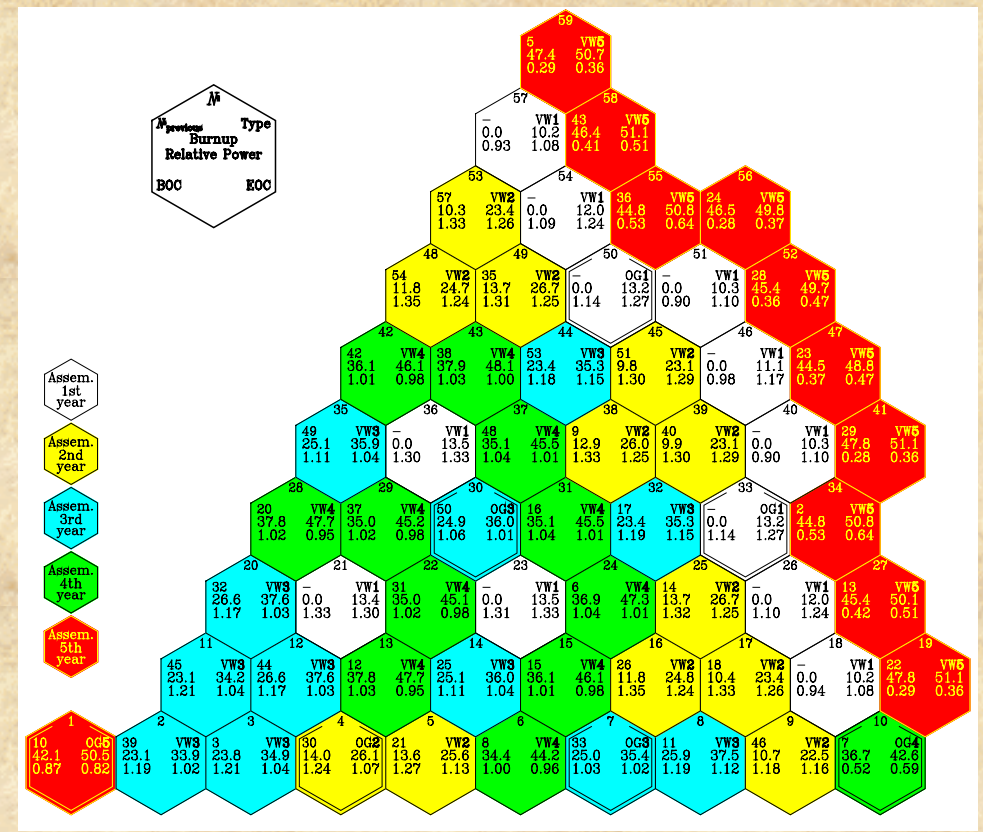
Equilibrium Fuel Cycles

Reactor thermal power 1444 MW

Cycle length, 306 FPD

Amount of loaded FAs, 72 pcs

Max. relative power of FA	**1.36 (Kq_{max})**
Max. relative power of fuel rods	**1.50 (Kr_{max})**
Maximal value of fuel rods linear heat rate, 280.0 W/cm	



Power Maneuvering VVER-440

Power 100%? 50%

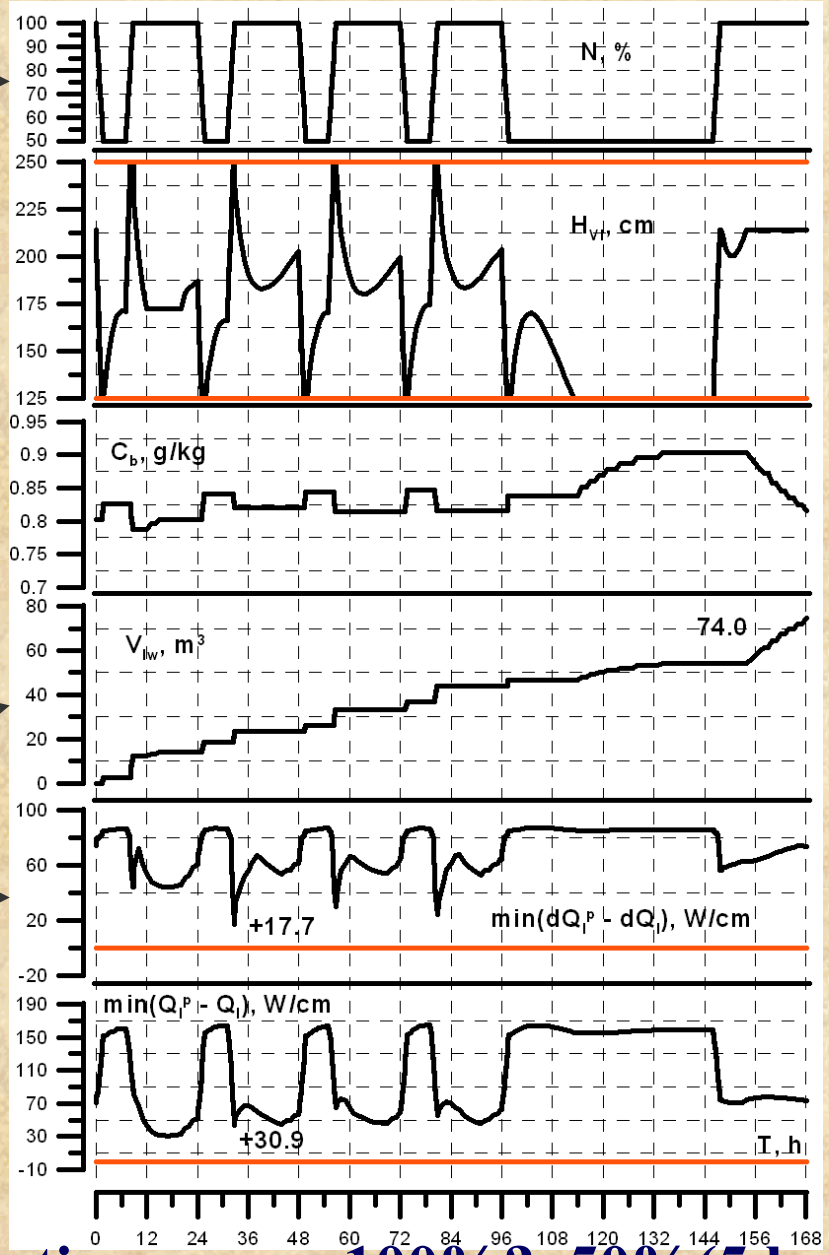
Height of control rod group

Boric acid concenration

Liquid radioactive wastes

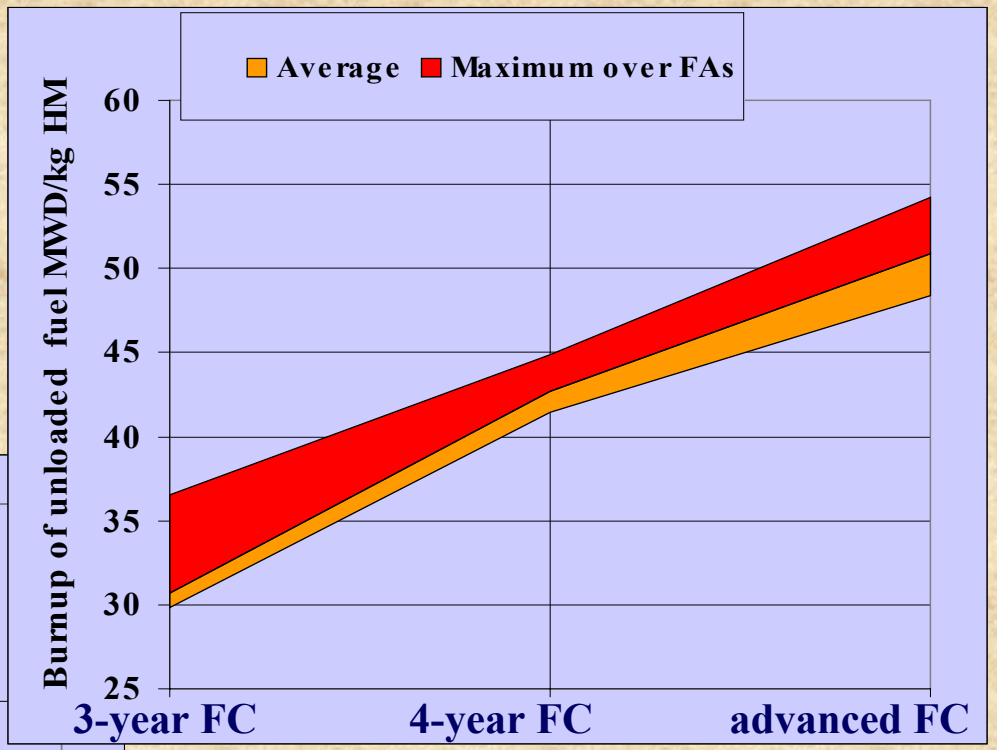
Local linear heat rate ramps

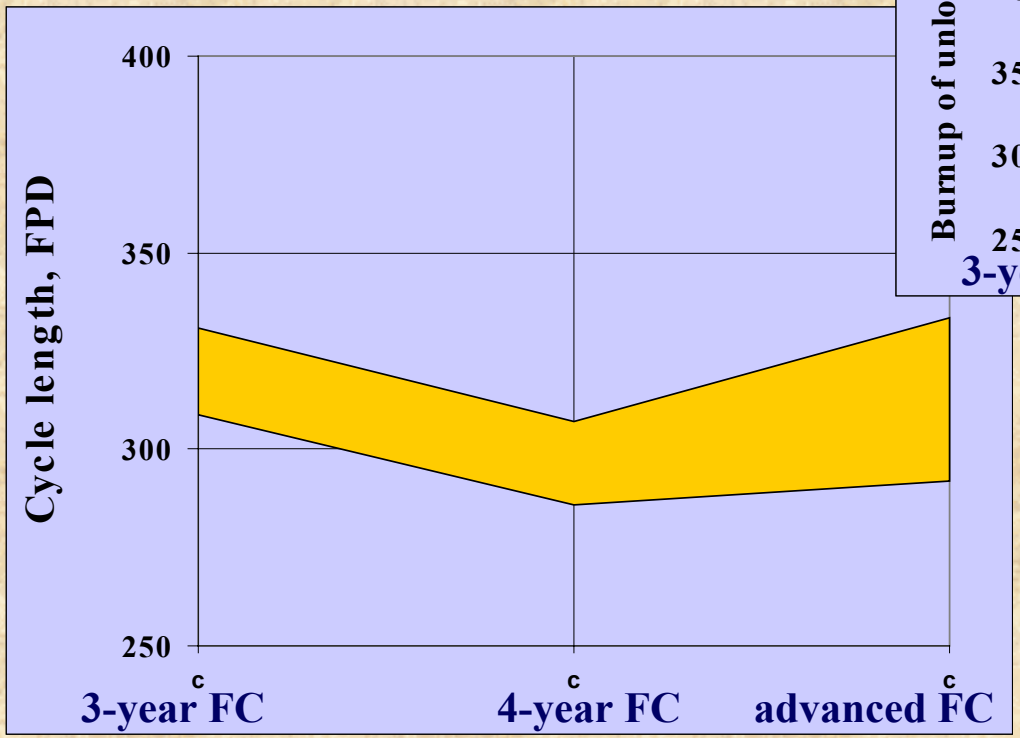
Linear heat rate



Mode of operation power 100%? 50%(5 hours)? 100%

Some equilibrium fuel load parameters' variation during VVER-440 fuel cycles improvement





CONCLUSION

- Operational reliability of this new fuel has the same level, as traditional fuel.
- Technical solutions laid in the design of second-generation fuel assemblies, were proven and confirmed by the results of trial and commercial operation.
- Development of a technical proposal on a third-generation fuel assembly is currently underway.

CONCLUSION

- **Profiled fuel with burnable absorber based on gadolinium makes it possible to realize full-scale 5-year fuel cycles with average fuel enrichment reduced from 4.4-4.38% to 4.25% (in second-generation assemblies).**

- **Present-day fuel cycles for VVER-440 developed on the base of new FA constructions (second-generation fuel) ensure considerable increase of nuclear fuel utilization efficiency.**

- **Present-day fuel cycles for VVER-440 make it possible to realize various operational fuel load lifetimes. This allows optimal adapting of the unit's electricity production to the specific energy system requirements.**

- **Fuel cycles for VVER-440 using modernized construction of fuel were developed. These cycles make it possible to work at excess reactor power of up to 105-110%.**

- **In case the modernized fuel is used, present-day fuel cycles for VVER-440 also make it possible to realize the maneuvering reactor operation mode, when the reactor power varies in wide frames during a short time period.**