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Nuclear Fuel Cycle and Power Up-rate

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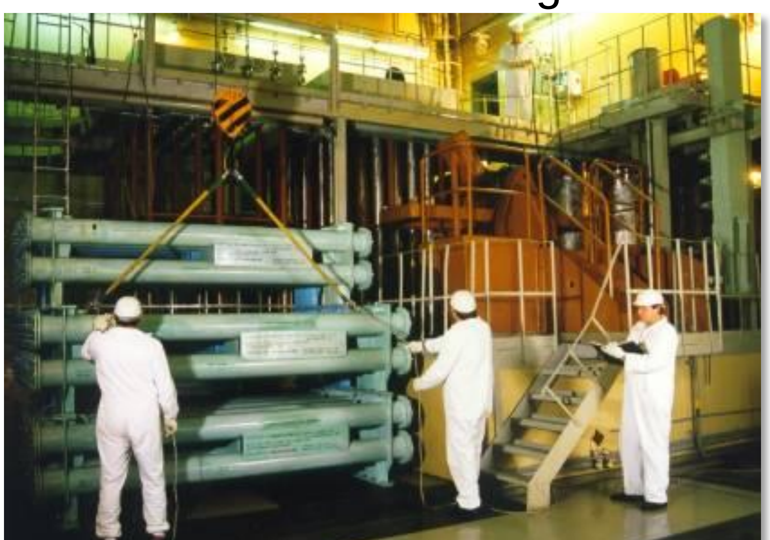
Four VVER-440/V-213 type reactor units

VVER Fuel

- All units operated exclusively with VVER440 fuel
- Vendor: JSC TVEL (and predecessors)
- Long term fuel supply contract since 1994
- Good operational experience with high quality fuel
- Excellent fuel reliability allows continuously high load factors for the units
- Flexibility in meeting the needs of the plant operator
- Continuous modernization in order to achieve more efficient fuel management
- Growth of the average and maximum discharge fuel burn-up

Maximal calculated burnups :

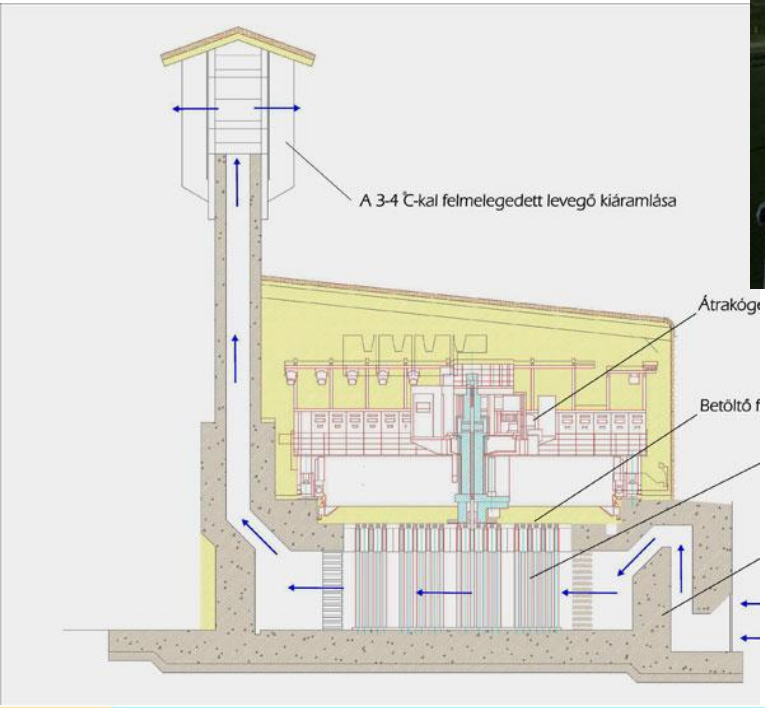
Assembly	51 MWd/kgU
Pin	53 MWd/kgU
Pellet	61 MWd/kgU



Spent fuel policy

- First step: at reactor storage during 3-5 years (spent fuel pool)
- Second step in the past (until1998): spent fuel reprocessing at Mayak without sending back the HLW – 2331 FA
- Second step at the present: Interim Spent Fuel Storage Facility (storage duration: appr. 50 years) – 7027 FA
- Third step, long term solution is uncertain; present reference scenario is: direct disposal in a Hungarian deep geological formation

Interim Spent Fuel Storage



- modular vault type facility
- fuel assemblies are each stored in vertically installed airtight sealed heavy storage tubes
- cooling system based on natural air draught

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History of fuel cycle

	1984-1994	1995-2001	2002-2004	2005-2009	2009-2015	2015-
				fuel used for power up-rate		
FA type	conventional	conventional	conventional	conventional (welded Hf plate)	2nd generation	2nd generation
type of bundle	non-profiled	non-profiled	profiled	profiled	profiled 3 Gd rods	profiled 6 Gd rods
enrichment WFA CFA	3.6%, 2.4% 2.4%	3.6%	3.82%	3.82%	4.2%	4.7%, 4.2%
№ WFA № CFA	90+12 12	90 12	78 12	90 12	72 (78) 12 (6)	66+24 12
Fuel cycle	3 year	3.5 year	4 year	3.5 year	> 4 year	4x 15 month
Rod pich	12.2 mm	12.2 mm	12.2 mm	12.3 mm	12.3 mm	12.3 mm
Rated power	100 % 1375 MW	100 % 1375 MW	100 % 1375 MW	108 % 1485 MW	108 % 1485 MW	108 % 1485 MW

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Motivation of the power up-rate

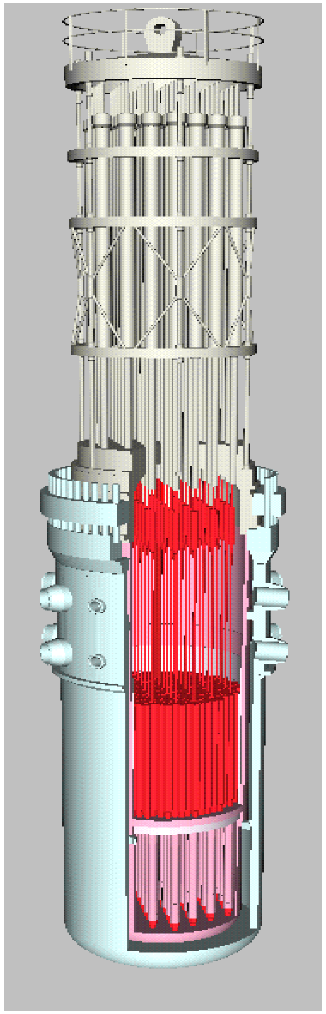
- an ambitious safety upgrading program completed, the safety level is now comparable to those of the Western plants of similar age
- early phase of the power up-rate: unit power was increased by enhancement of thermal efficiency with modifications in secondary circuit
  - replacement of turbine condensers (introduce the high pH water regime)
  - replacement of separators
  - replacement of high pressure pre-heaters
  - reconstruction of turbines
  - the rated power is 470 MW (designed power was 440 MW)
- recent phase of the power up-rate: increase with 8% of the reactor thermal power
- general electrical output for units exceed 500 MWe; response to the market challenges
- engineering studies supported the feasibility of the power up-rate and defined the necessary modifications

Necessary modifications

Three major reasons for modifications:

PT	process technology,
OL	keeping operational limits,
SM	preserving safety margins

1.	Introduction of the new fuel type	OL
2.	Reconstruction of primary pressure control system	OL
3.	Modernization of in-core monitoring system	OL
4.	Up scaling some of the trip signals	SM
5.	Change of the parameters of the hydro-accumulator	SM
6.	Replacement of the MCP impellers at Unit 2	OL, SM
7.	Boron concentration in the primary circuit: 13.5 g/kg	SM
8.	Modernisation of the electrical generators cooling	PT
9.	Replacement of turbine inlet wheel	PT



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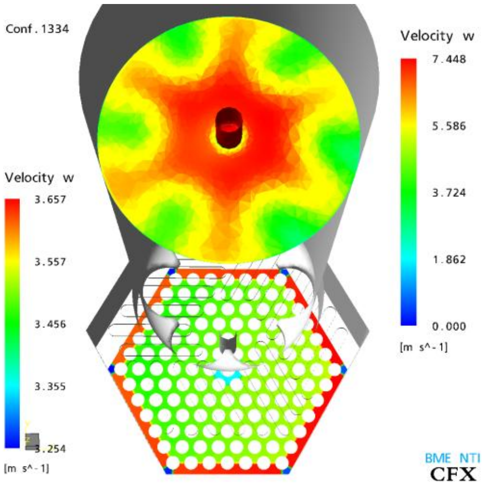
Sources for reactor thermal power uprate

To increase of the reactor thermal power by 8 % means +**5°C** ΔT coolant heatup in the core sub-channels

The ultimate core limitations remained unchanged



<u>Main sources of higher coolant heat-up</u>

- Fuel modification (increased lattice pitch) – 1,5°C
- Stabilization of the primary pressure
  (narrowing the allowed pressure range) – 1,5-2°C
- Better in-core monitoring and measurement – 1,5°C

<u>Other sources</u> Total ~ 1°C

- Conservative core design
- Lower secondary pressure
- Better coolant mixing in the sub-channel outlet

extra margins for increased reactor power would be gained by further flattening the core power distribution. This would have required a change from the full low-leakage loading pattern back towards the out-in-in loading pattern

however, the low leakage loading pattern with 4th cycle fuel at the core peripheral locations has been kept as a boundary condition to minimize the pressure vessel fluence and preserve the safety margin on the embrittlement characteristics

Introduction of new fuel for power up-rate

<u>Step 1</u> (small modification for power up-rate)

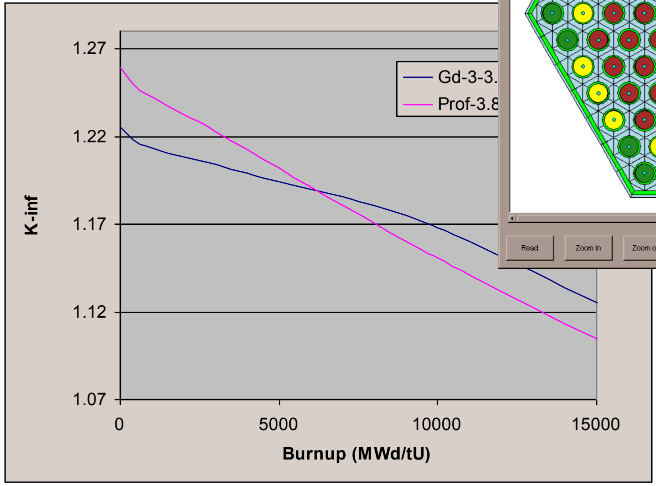
- Increasing fuel pitch: 12.2 mm -> 12.3 mm
- Welded Hf absorption plate inside the upper section of the follower head for better neutron flux distribution
- Reload of more (90->)102 fuel assemblies
- Same enrichment (3,82% U-235), pin-wise and sub-channel-wise limits, linear power, sub-channel outlet temperature, slight increase of max assembly power

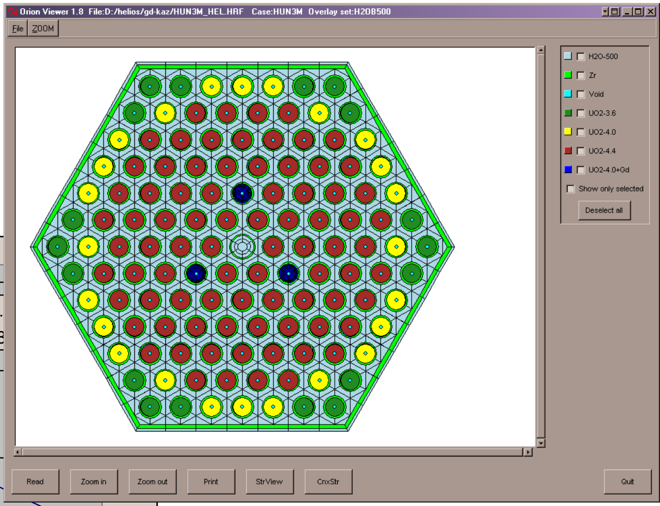
This fuel was sufficient to reach the 108% reactor power level, but did not allow the optimum fuel economy, it mildly 4-5% deteriorated

> need more economic fuel!

<u>Step 2</u> (Generation-2 fuel for optimization)

- Higher average enrichment in the assemblies: 4,20% U-235
- 3 rods with burnable poison Gd
- Saving appr. 6 % fuel cost (reload of 102->84 fresh FA)





Commissioning of Unit 4

The 108 % of reactor power was achieved on 28.09.2006.

100%

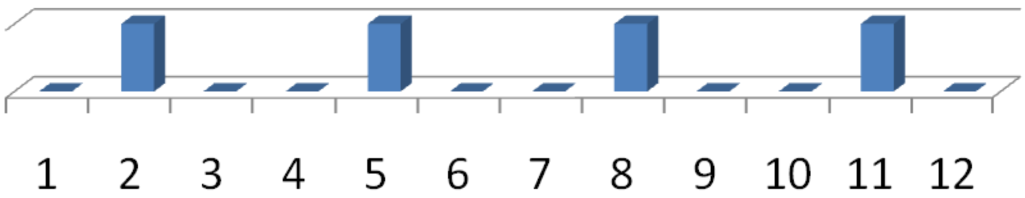
108%

- regulatory approval of the principal design for all units – 2005
- regulatory approval of the operation with increased power level for Unit 4 – 2006

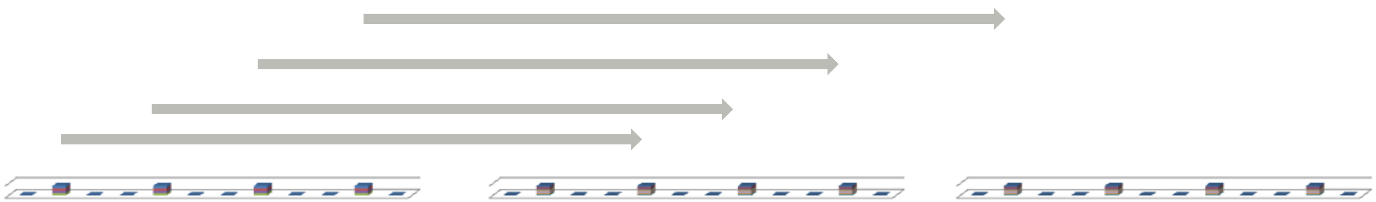
15m cycle option

Outages:

February, May, August, November



Cycle length : ~ 415-425 fpd.



During 5 year: 5 x 12 = (5 x (11 + 1)= (4 x (14 +1)

- 4 outages/unit
- +25 day/year production (4 units)
- reduction of the maintenance cost

Problems to solve to reach 15m cycle

For longer cycle higher enriched fuel is needed

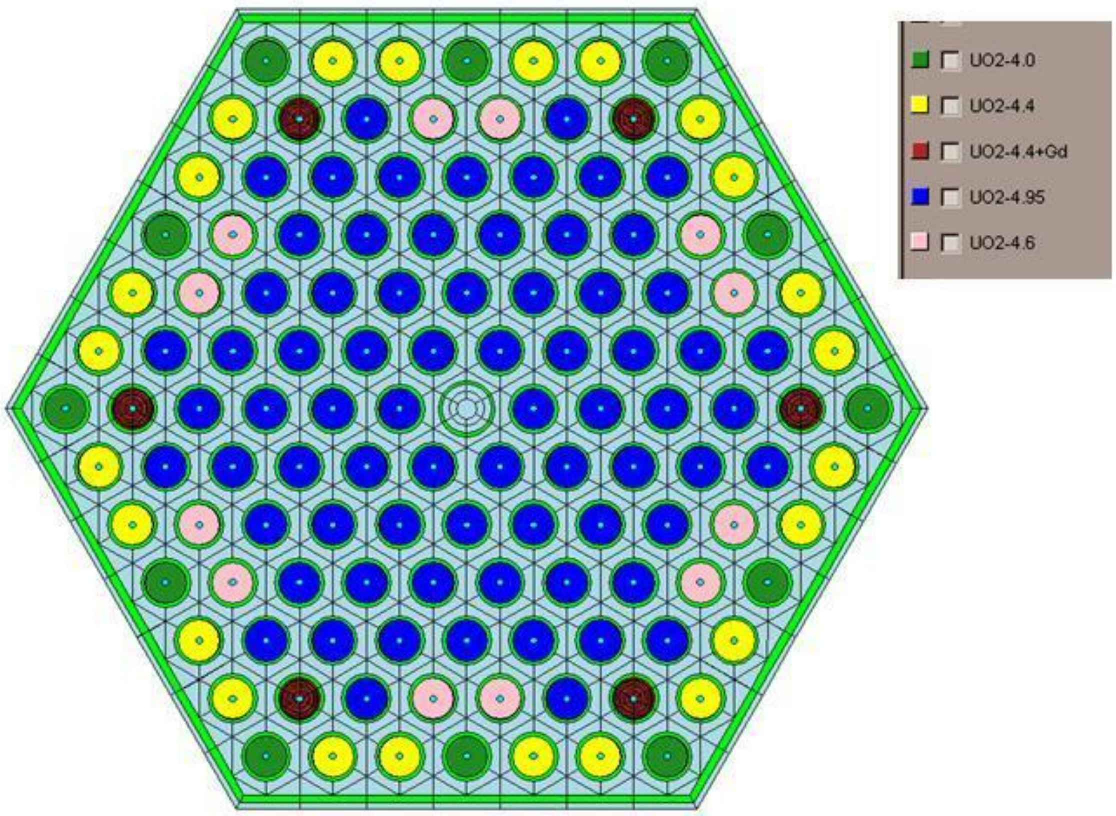
- Possibilities for cycles from 415- to 425+ fpd
- Safety limits for reactor physical parameters have to be fulfilled in transient and in equilibrium cycles as well
- We have to be able to realize the needed transient cycles
- Usage of the recent 4.2% enriched Fas during the transition
- Use up all the reserved 4.2% enriched Fas

How did we choose the appropriate FA?

- Fuel supplier gave us the possible assortment of enrichments of U-pin, U-Gd pin and Gd-content
- Calculation of possible versions (4.87-4.65 %) with HELIOS-program: 16+ versions (pp-max,pp-gd)
- Sub-channel outlet temperature calculation of chosen FAs with VERONA TH: 8 versions (tsub-max)
- Calculation of few-group cross sections for 4 versions (HELIOS)
- Calculation of equilibrium cycles (model EGYS)
- Calculation of transient cycles (C-PORCA 7.0)

The chosen FA (4.7%)

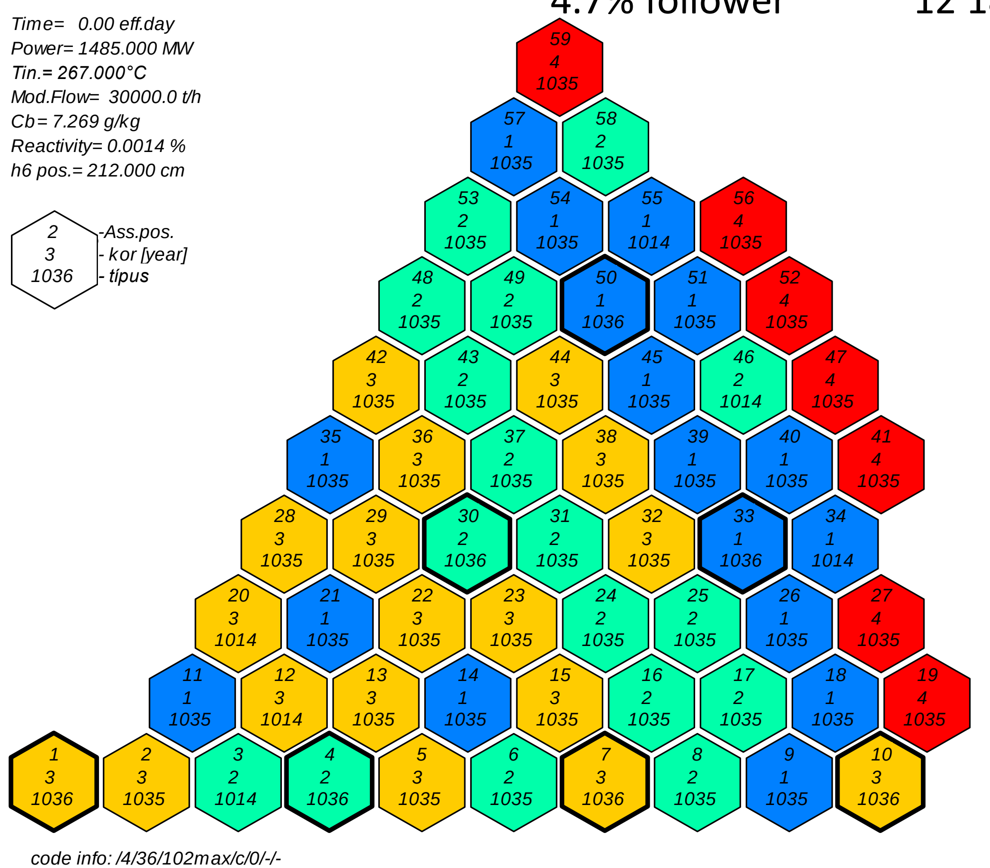
Profilisation of fuel assemblies,
type: 1035, 1036
(Average enrichment of FAs: 4,7%)



Reload for 15 months cycle

FUEL CONTENT/AVERAGE BURNUP(MWD/KGU) :

FUEL DESCRIPTION	1ST C.	2ND C.	3RD C.	4TH C.
4.7% fixed	78 16.64	78 32.83	78 47.43	42 51.77
4.2% fixed	12 12.25	12 27.15	12 41.82	0 0.00
4.7% follower	12 18.65	12 35.22	13 46.47	0 0.00



1014, 1015 :
4.2%, actually used

1035 , 1036 :
4.7% fixed and follower

- Fuel development at the supplier has already started
- Supporting safety analyses are in progress
- Unit 3 was selected to be the base of SA for 15m cycle analyses
- Transient cycles for Unit 3 from 12m to 15m cycles have been calculated
- 2012-13 year reloads: everything according to original (12m) plan
- Implementation would be possible from 2015

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Thank you for your attention!