International Forum Atomexpo 2018

Safety and efficiency go hand in hand at MVM Paks NPP

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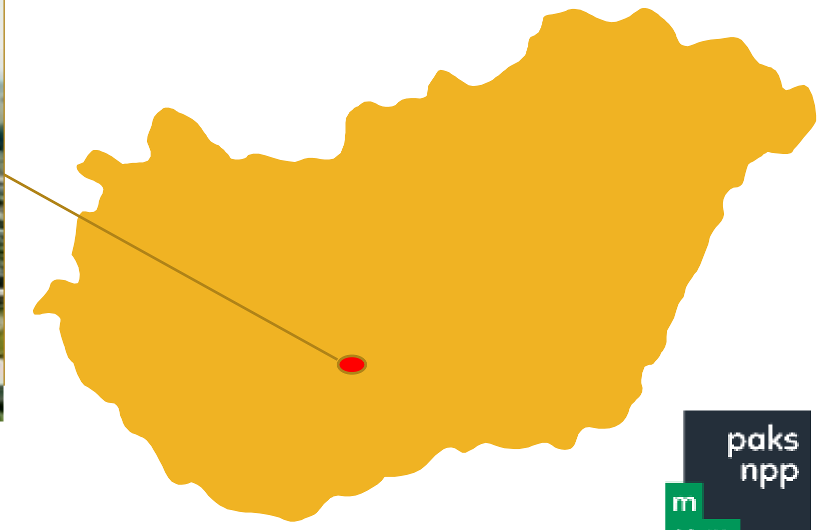
	Start up of the unit	Power up-rate	30-year life time	50-year life time
Unit 1	14/12/1982	19/07/2007	2012	2032 - licenced
Unit 2	26/08/1984	05/12/2008	2014	2034 - licenced
Unit 3	15/09/1986	13/11/2009	2016	2036 - licenced
Unit 4	09/08/1987	28/09/2006	2017	2037 - licenced

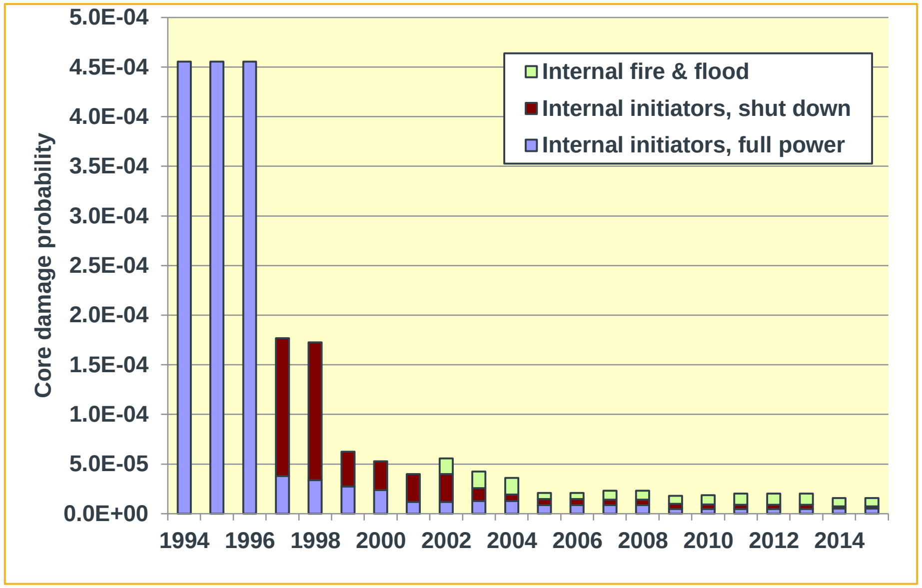
Electricity production (2017): 16 097 GWh

MVM Paks Nuclear Power Plant

- the only nuclear power plant in Hungary
- belongs to the MVM Hungarian Electricity Company Ltd.
- designed in the 70's, commissioned in the 80's
- 4 x VVER440/V213 reactors
- 30 years originally designed lifetime
- the largest and cheapest domestic source



Continuous safety enhancement



The enhancement of nuclear safety had been started in Paks already before the commissioning of Unit 4 in 1987

1991 – 1994 AGNES Report *(Advanced General and New Evaluation of Safety)*

1996 – 2002 Safety Enhancement Measures – design basis related

1993 – 2002 Review of seismic hazards, plant reinforcement

1993 – 2004 Reactor Protection System Reconstruction

Addressed all the feasible modifications and improvements that could provide capability to cope with the design basis accidents (including seismic events)

2008 – 2014 Severe Accident Management

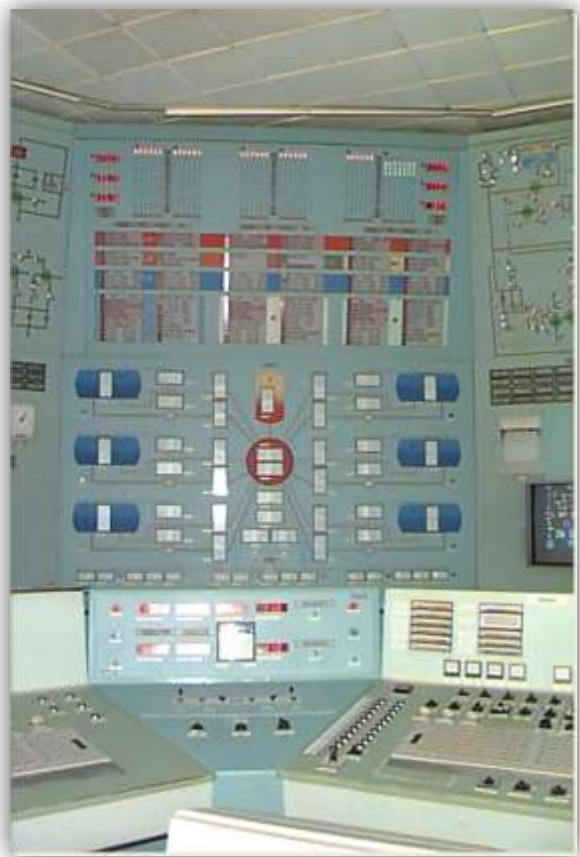
To ensure long term goals (power up-rate and plant life extension of the units) the utility was willing to step forward to a higher level of defense

2011 – 2018 Targeted Safety Review *(TSR)* **and corrective measures**

Technical modifications

Protected sump strainers

Fully digital reactor protection system with additional functionalities



Relocation of the emergency feedwater system into a protected building

Seismic reinforcement

Qualification and upgrades	Volume of work
High energy pipelines of primary circuit and equipment	250 fixes (GERB damper)
Building structure of the turbine and reactor hall	1360 t steel structure
Supporting frames (reactor building, localization towers)	300 t steel structure
Other classified pipelines of primary circuit and the equipment	760 fixes
Classified pipelines and equipment of secondary circuit, fixes of supporting steel structures in the turbine building	160 t steel structure 1500 fixes
Electrical and I&C equipment (batteries replaced, seismic instrumentation added)	450 t steel structure

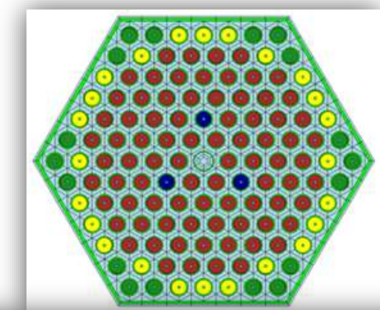
108 % reactor power up-rate

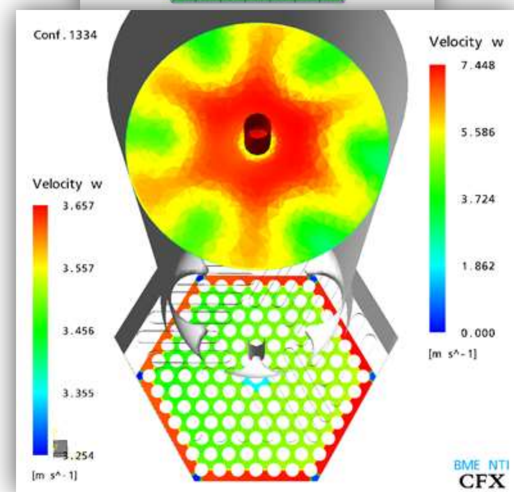
- ambitious safety upgrading program was completed, the safety level of the plant was recognized as high
- thermal efficiency of the secondary side was increased
- increase of the reactor thermal power as a response to the market challenges

Unit 4, 28. September 2006

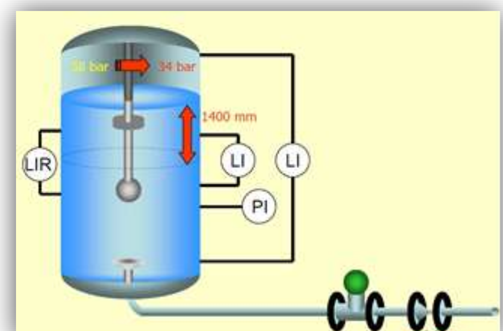
Plant modifications for power up-rate

- no significant reduction of any safety margins,
- no relaxation of any acceptance criteria or operational limits
- benefit shall be based on the advances in calculation and evaluation methods, and experience from more than 70 reactor years of operation



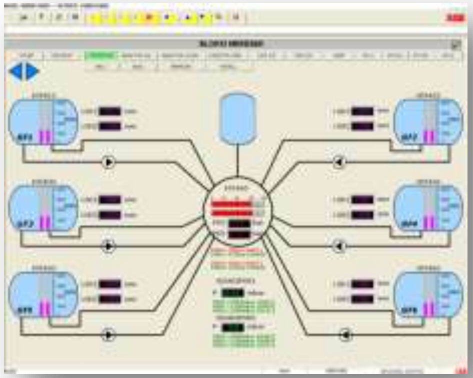


1.	Introduction of the new fuel type	OL
2.	Reconstruction of primary pressure control system	OL
3.	Modernization of in-core monitoring system	OL
4.	Up scaling some of the trip signals	SM
5.	Change of the parameters of the hydro-accumulators	SM
6.	Boron concentration in the primary circuit: 13.5 g/kg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



Severe accident management -1

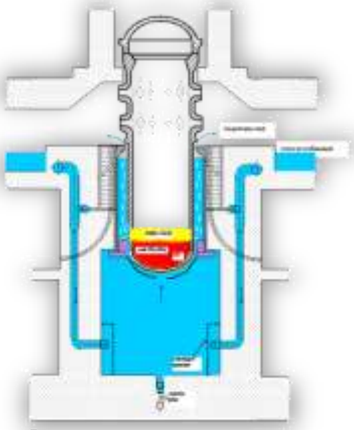
- SAM Safety Goal for the operating reactors of the Paks NPP:
  - Demonstrate that containment failure is physically unreasonable for accident classes which cannot be screened out based on probabilistic arguments.
  - Cumulative frequency of „large radioactive releases” shall be lower than 10^{-5} per reactor year.
- The key elements of the SAM are:
  - SAMG development and implementation.
  - SAM measurements and instrumentation.
  - Independent electrical back-up with outside connection points.
  - Specific hardware modifications to mitigate SA consequences.



Severe accident management -2

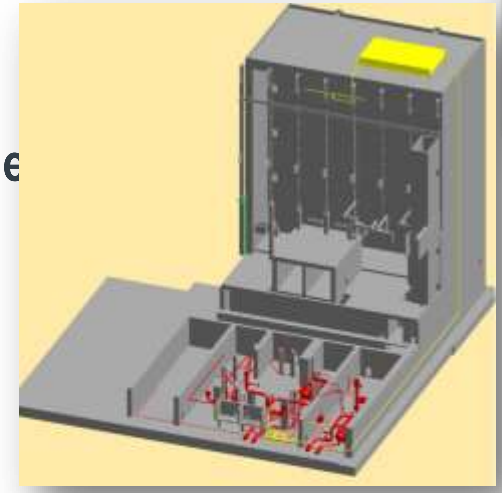
- Hardware modifications to ensure coolability and containment functions:

  - In-vessel retention of molten corium through external cooling of the reactor pressure vessel.



  - Hydrogen mitigation scheme including controlled removal of hydrogen by a set of PARs.

  - Mitigation of long-term pressurization of the containment through spraying.



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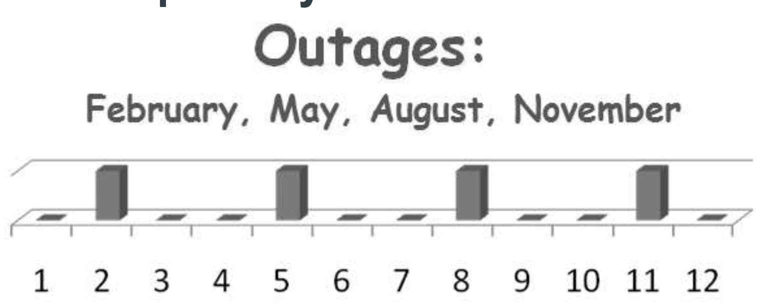
15 months fuel cycle

- Positive experience of the power uprate 500 MW, and 2nd generation 4.2 wt% fuel assembly
- From 2009 the fuel producer (TVEL) offered fuel assemblies containing a higher enrichment
- The use of more highly enriched fuel was investigated, with a view to introducing longer fuel cycles.
- According to preliminary estimations 18-month cycles are not feasible. The core is small, and the necessary fuel enrichment for a realistic and economic 18-month cycle would exceed 5wt%.
- 15 month fuel cycle is feasible, with combined use of 4.2 and 4.7 wt% fuel
- Refueling outages could be optimally scheduled for a 4 unit plants (4x12=4x15)



Long-term maintenance plan of Paks NPP

C12

Unit	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1	26	26	26	56	26	26	26	42	26	26	26	56	26	26	26	42	26
2	42	26	26	26	56	26	26	26	42	26	26	26	56	26	26	26	42
3	26	42	26	26	26	56	26	26	26	42	26	26	26	56	26	26	26
4	26	26	42	26	26	26	56	26	26	26	42	26	26	26	56	26	26
∑	***120***	***120***	***120***	***134***	***134***	***134***	***134***	***120***	***120***	***120***	***120***	***134***	***134***	***134***	***134***	***120***	***120***

C15

Unit	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1	26	56	26		26	26	42	26		26	26	56	26		26	26	42
2	42		26	26	26	56		26	26	26	42		26	26	26	56	
3		26	42	26	26		26	56	26	26		26	42	26	26		26
4	26	26		42	26	26	26		56	26	26	26		42	26	26	26
∑	***94***	***108***	***94***	***94***	***104***	***108***	***94***	***108***	***108***	***104***	***94***	***108***	***94***	***94***	***104***	***108***	***94***

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Δ	**26**	**12**	**26**	**40**	**30**	**26**	**40**	**12**	**12**	**16**	**26**	**26**	**40**	**40**	**30**	**12**	**26**

- **15-month cycle save 12-40 days outage on each year**
- **Load factor increase by 2%**

Key-elements of the C15 implementation

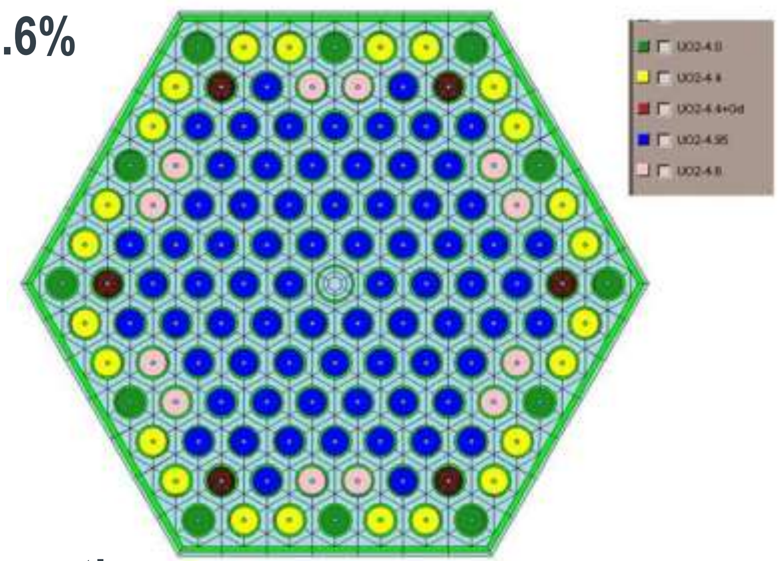
- To develop and introduce the higher enriched fuel
  - 4.2 wt% ⇨ 4.7 wt%
- Extended operating cycle
  - 11 months run + approx. 1 month refueling outage ⇨ 14 months run + approx. 1 month refueling outage
- Extended in-service inspection and maintenance periods
  - 8 years ⇨ 10 years (in case of critical components 8 years ⇨ 5 years) according to ASME BPVC XI and OM Code

Fuel for the recent, 15m cycle option

- VVER-440 standard 2nd generation fuel assemblies with a hexagonal shroud tube, central tube and 11 spacer grids
- 126 fuel rods with enrichments: 4.0%, 4.4%, 4.6% and 4.95%
- Average enrichment: 4.7%
- Six rods with UO_2-Gd_2O_3 pellets
- Enrichment profile is unique and optimized for our reactors to enable 15 months cycle
- None of the VVER units are operating with 15 months cycle
- Fuel cycle: 4 x 15 month; 102 assemblies/15 months

  (78 ass. with 4.7% and 24 ass. with 4.2%)

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



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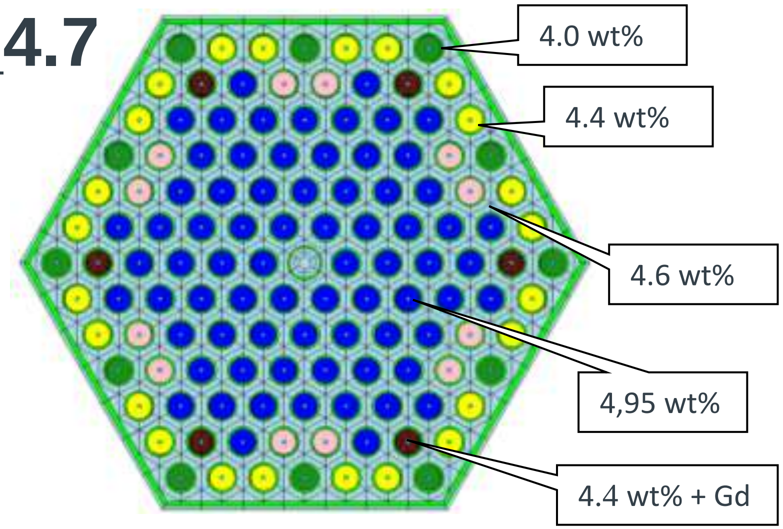
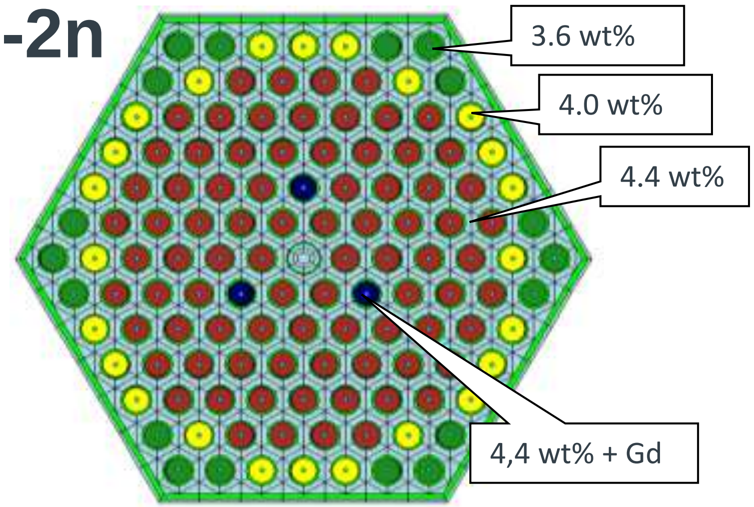
Fuel assembly

Gd-2_4.7



Gd-2n



C15 fuel assembly

	Enrichment	Amount	UO_2
	4%	12	48
	4,4%+Gd	30	132
	4,6%	12	55,2
	4,95%	72	356,4
∑	-	126	591,6
Avg.	-	**4.695%**	

C12 fuel assembly

	Enrichment	Amount	UO_2
	3,6%	18	64,8
	4,0%	24	96
	4,4%+Gd	84	369,6
∑	-	126	530,4
Avg.	-	**4.215%**	

Nuclear fuel management

C15 vs. **C12**

C15:

1. cycle: 102 assemblies
2. cycle: 102 assemblies
3. cycle: 102 assemblies
4. cycle: 102 assemblies

Total: 408 assemblies

5 years

C12:

1. cycle : 84 assemblies
2. cycle : 84 assemblies
3. cycle : 84 assemblies
4. cycle : 84 assemblies
5. cycle : 84 assemblies

Total: 420 assemblies

The number of spent fuel assemblies is decreasing:

- more economical use
- less spent fuel

15-month fuel cycle benefits

Deterministic influences:

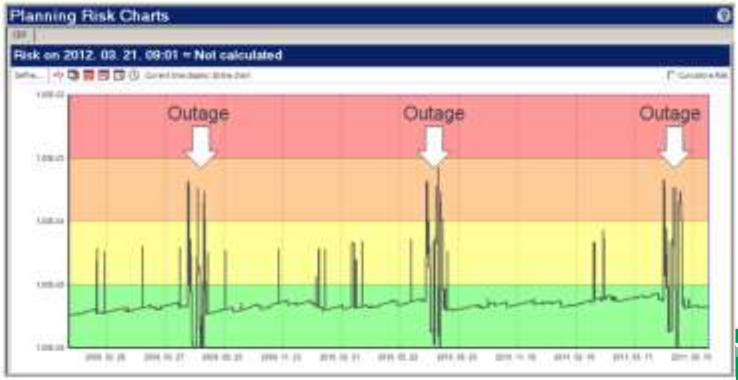
Electricity Production +2%	Non-radioctive Waste -5%	Stress transients -20%	Spent Fuel -3%
Periodic Work Volume -15%	Collective Dose -15%	Radioactive Waste -10%	Overtime HR Cost -10%

Probabilistic influences:

Core damage probability – decrease

Workplace accident probability - decrease

Maintenance work risk – decrease



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Summary

- **Continuous safety enhancement at the units**
  - Gen3 safety on a Gen2 plant
  - CDF decreased by more than an order of magnitude
- **Continuous performance and availability enhancement**
  - Safety margins should be preserved
  - Any negative safety effects should be compensated

	Electricity production, TWh	Load factor, %	Spent fuel assemblies
1988	13 445	85.67	448
2017	16 098	91.88	326
	+19.7%	**+ 7%**	**-27%**

- **Paks NPP is going to operate until 2037**

THANK YOU FOR YOUR ATTENTION!

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