ROSATOM

FUEL COMPANY OF ROSATOM TVEL 20 YEARS

STATE ATOMIC ENERGY CORPORATION ROSATOM

Improvement of economic efficiency of the fuel usage in NPP. The new types of nuclear fuel and the fuel cycles

Petr Lavrenyuk (JSC «TVEL»)

Eighth International Forum «Atomexpo»,
Moscow, Gostinyy Dvor, 31 May 2016

Nuclear fuel life cycle

The operation life time for Kola NPP Unit 4 was extended in 2014 by 25 years (until December 2039)
The commissioning of Mochovce NPP Units 3 and 4 is scheduled in late 2016 – early 2017. The design operation life time of these Units is 30 years (until 2047, not taking into account the operation life time extension)

The operation life time for Novovoronezh Unit 5 was extended by 25 years (until 2035)
The commissioning of Rostov NPP Unit 3 is scheduled in 2015. NVAES-2 and LAES-2 NPP with VVER-1200 reactors are being constructed (the design operation life time is 60 years)

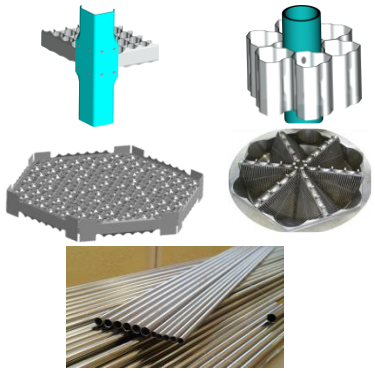
The NPP life time taking into account the construction and decommisioning is around 80 years, of which NPP generates electricity during around 60 years. During this period nuclear fuel is being regularly modernized, aiming at improving its technical and economical characteristics, performance and safety of operation.

Nuclear fuel design and manufacturing technology development

Customer's requirements to Nuclear Fuel

Safety

- Experiment-calculated justification of fuel safety in normal operation conditions and design accidents
- Innovative constructive and fuel materials development



Reliability

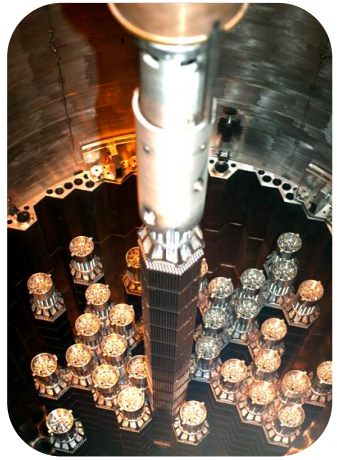
- Improvement of normative-methodological base for designing, manufacturing and operation of nuclear fuel
- Development of QMS
- Improvement of FA skeleton rigidity
- DF implementation
- AVG implementation
- Mixing grid implementation
- Improvement of constructive and fuel materials

Efficiency

- Increase in fuel burnup
- Increase in fuel lifetime
- Increase in fuel cycle length
  - Computer codes and fuel design methodology development
  - Change of fuel rod geometry in order to increase uranium mass
  - Higher enrichment level
- Substantial of fuel behavior in load-follow modes
- Substantial of fuel behavior at higher RP thermal power

Competitive price

- Unification of fuel design
- Improvement of conversion, enrichment and manufacturing technologies



Main types of nuclear fuel for Russian power reactors

VVER-440

Fuel assemblies of
1st,
2nd,
3rd
generations

VVER-1000

TVS-2M
TVSA-PLUS

VVER-1200

TVS-1200, NvAES-2, LAES-2, Belarusian NPP, «Hanhikivi» NPP, «Paks» NPP

RBMK-1000

FA with uranium-erbium fuel

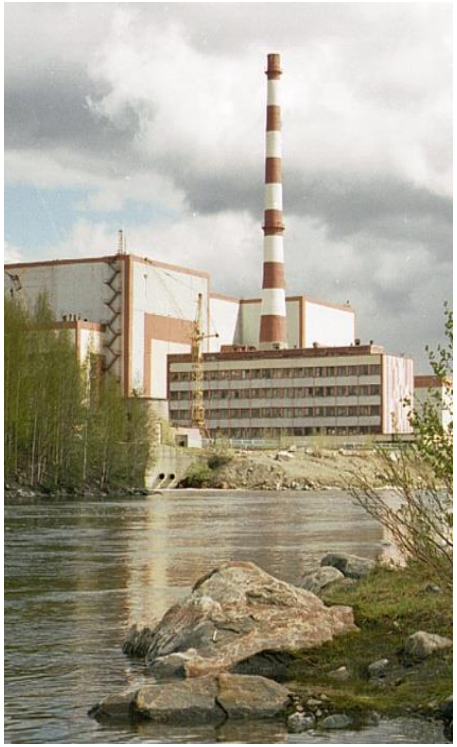
BN-600

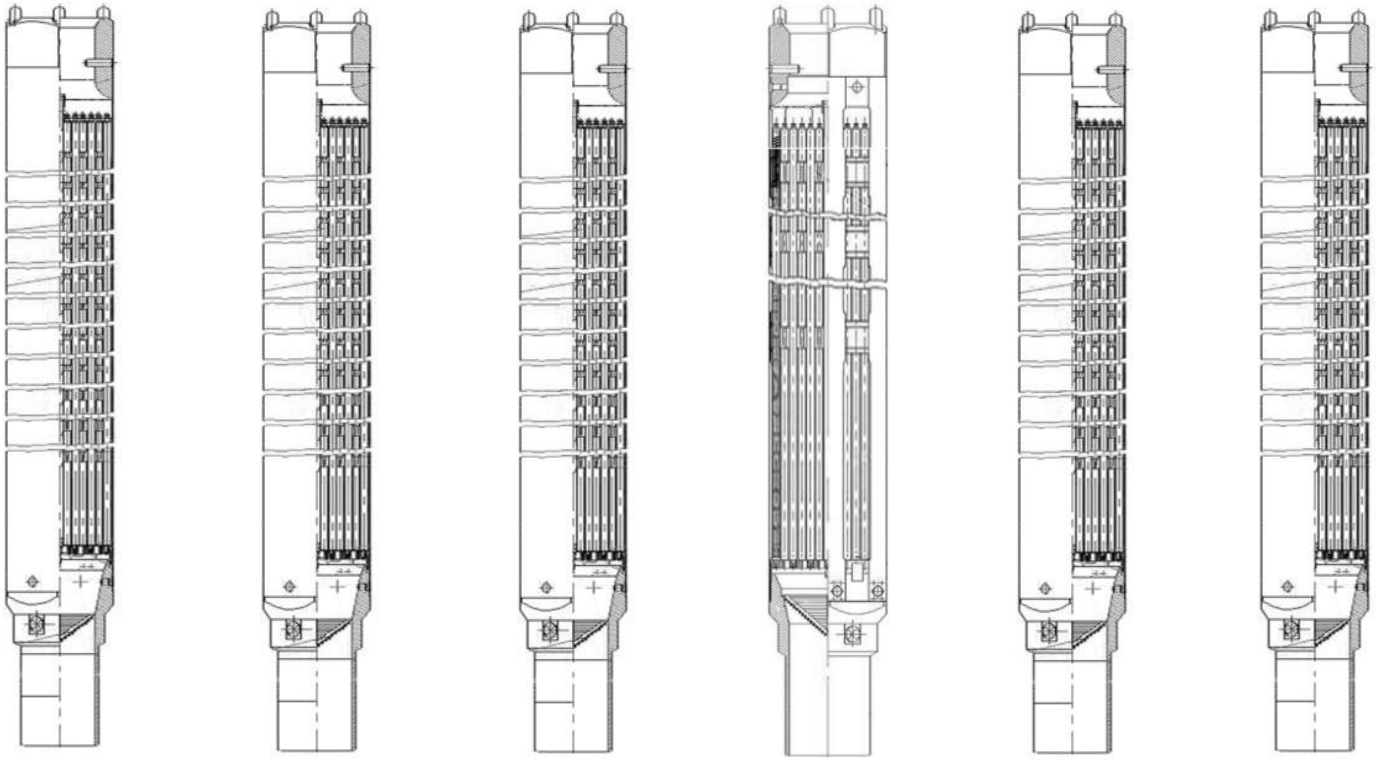
FA with the fuel made of UO_2

BN-800

FA with the fuel made of UO_2
FA with MOX fuel

Nuclear fuel for VVER-440





Operation duration, cycle×month	3x12	4x12	5x12	6x12	4x15
Burnup, MW×day/kgU	36	45	57	65	72
Core thermal power, MW	1375			1471	
Year	1971	1998	2003	2010	2014

Nuclear fuel for VVER-440

2nd generation nuclear fuel

Rovno NPP, Units 1,2
Kola NPP, Units 3,4
«Bohunice» NPP
«Dukovany» NPP
«Paks» NPP
«Loviisa» NPP

2+ generation nuclear fuel

«Dukovany» NPP (since 2014)

3rd generation nuclear fuel

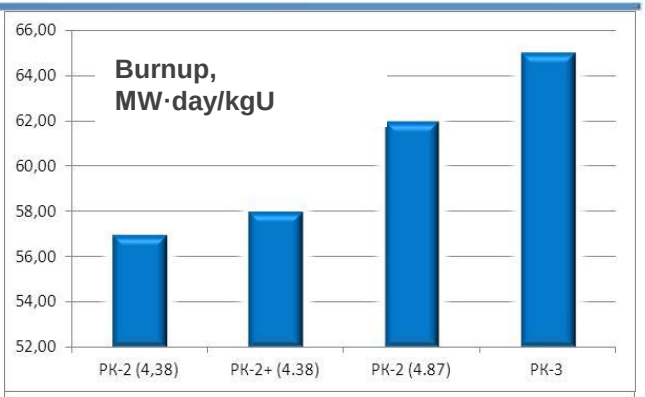
Kola NPP, Unit 4

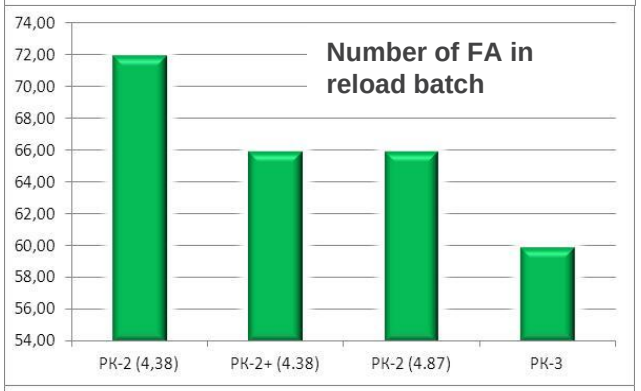
VVER-440 units power uprate

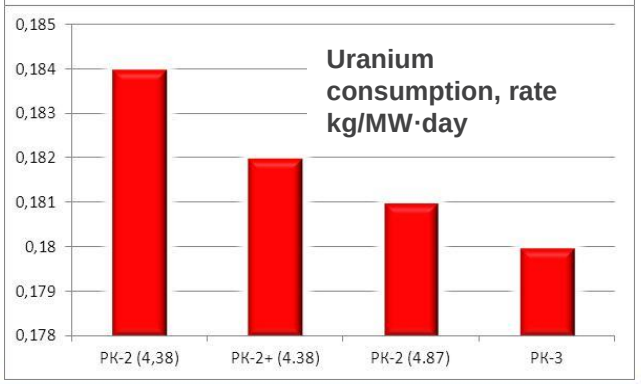
Kola NPP (3,4)	– 107%;
«Mochovce» NPP	– 107%;
«Bohunice» NPP	– 107%;
«Dukovany» NPP	– 105%;
«Paks» NPP	– 108%;
«Loviisa» NPP	– 109%.

Fuel cycles

«Paks» NPP – 15-month fuel cycle (since 2014)







VVER-440 nuclear fuel development

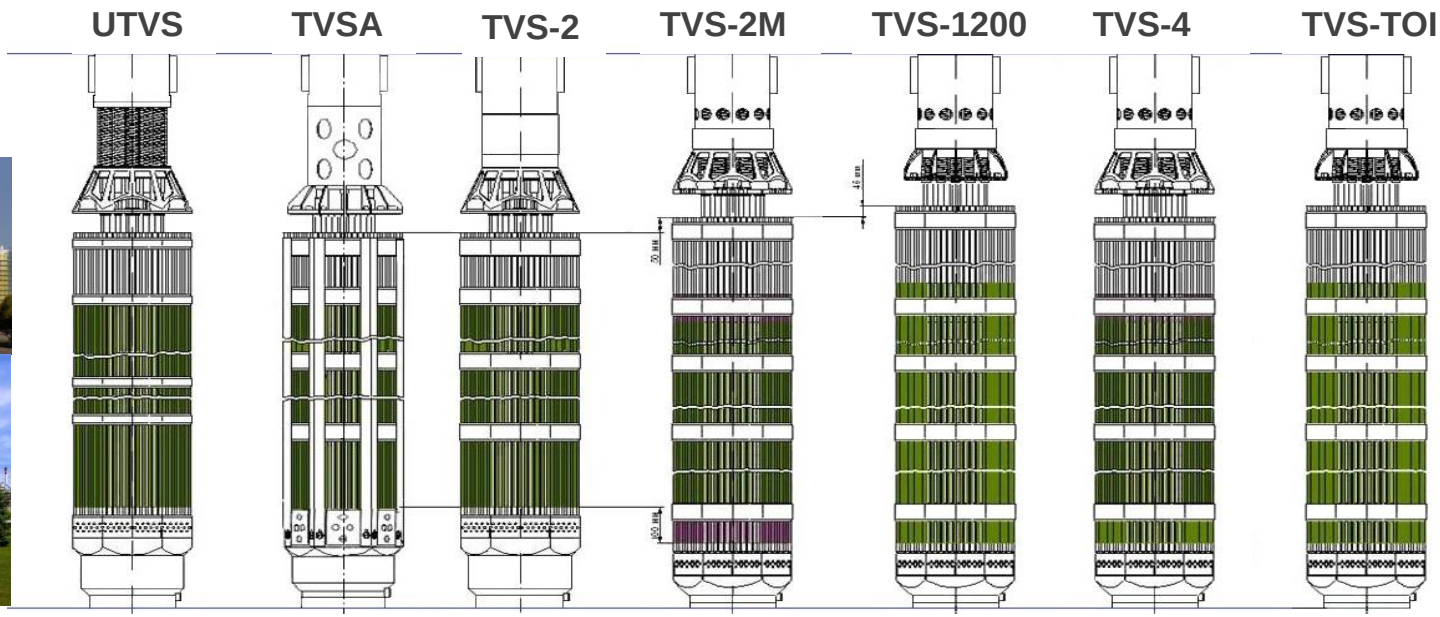
RK-3 design is shroudless, having a skeleton composed of stiffening angles and tubes. The fuel mass is increased by 4.5%, A rod-to-rod pitch in the bundle is increased from 12.3 to 12.6 mm.The fuel cycle duration is 6 years.
Effect from the RK-3 adoption – increase in fuel usage efficiency by around 10 % comparing to the RK-2 fuel having similar enrichment.

The pilot 12 RK-3 have been operated in Kola NPP Unit 4 since 2010. The outcome of their pilot operation is positive.
The RK-3 operation extension in Kola NPP – starting from 2016.
Starting from 2019 – a full reload batch will be loaded into the core.

VVER-440 nuclear fuel development

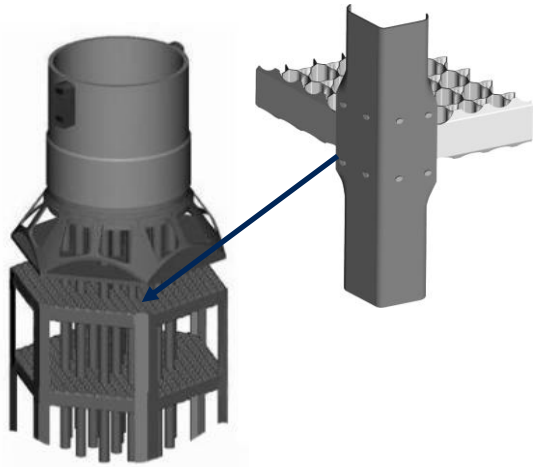
2nd generation fuel having a pellet 7.8/0	Implementation started in 2014 at Dukovany NPP, Unit 1. At first stage fuel enrichment is 4.38%. Implementation is going at all 4 units. At the second stage (since 2018) average enrichment of the fuel will be increased upto 4.76%. This will allow to reduce at 6 number of FA for reload batch.
RK-3 (shroudless design)	Implementation started in 2010 at kola NPP, Unit 4. In 2016 the second batch is loaded. RK-3 Full reload batch is expected in 2019.
FA having the fuel rods with less diameter 9.1→ 8.9 mm	2016 – feasibility study. Expected saving rate –5% increase in fuel cycle length. 2018 – Development Program. 2019 – licensing. 2020 – start of pilot operation.

Nuclear fuel for VVER-1000/1200



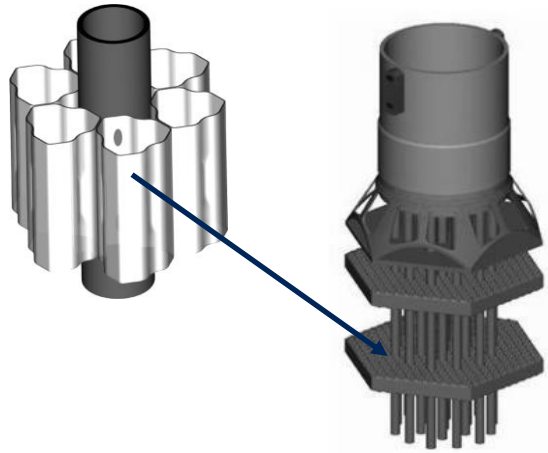
Operation duration, cycle×month	3x12		4x12		3x18	
Burnup, MW×day/kgU	54		65		72	
Core thermal power, MW	3000		3120		3200	3300
Year	1996	1998	2002	2006	2012	2017

Nuclear fuel for VVER-1000



Main outcome of the adoption

- ✓ FA bow is no more than 7 mm.
- ✓ RCCA drop time is less than 2.5 s.
- ✓ Decrease in the reloading time.
- ✓ Life time increase.
- ✓ Performance improvement.



Characteristics

- ✓ Fuel pellet stack length 3530 mm or 3680 mm.
- ✓ Maximum fuel rod burnup – upto 72 MW·day/kgU.
- ✓ Fuel cycle – 4x1 or 3x1.5.
- ✓ Unit power uprate upto 104-107%Nnom

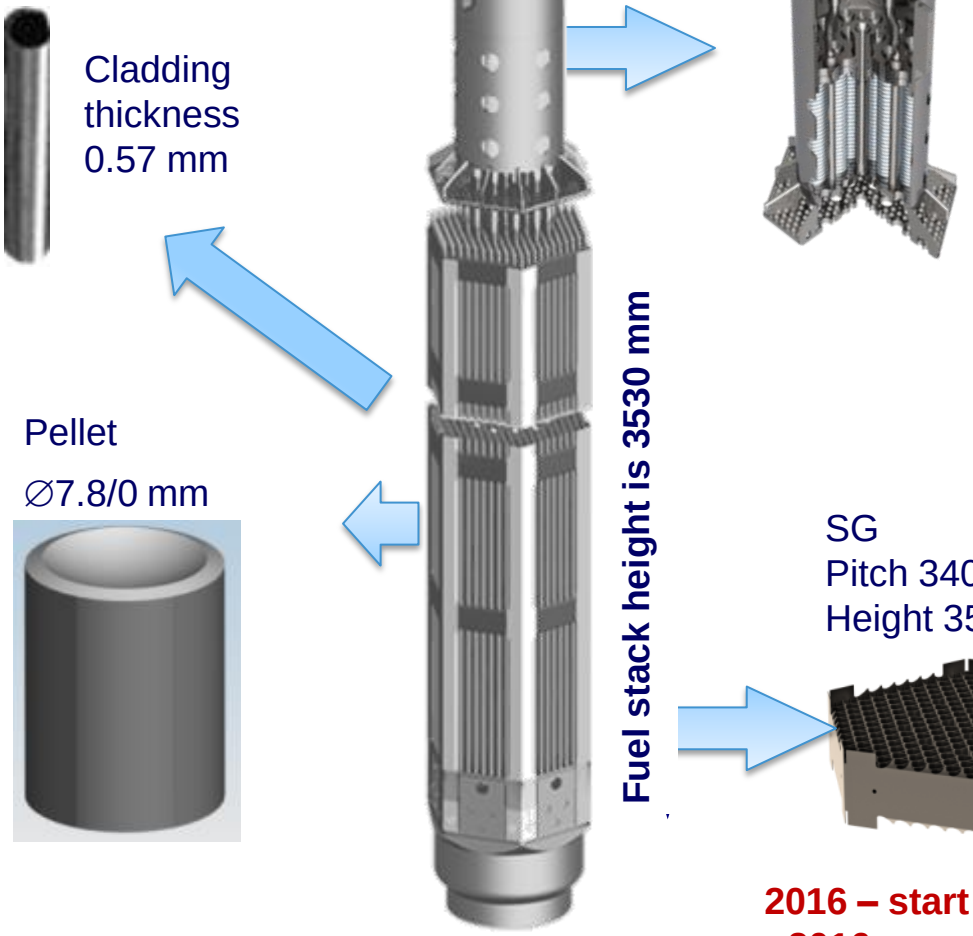
TVSA(TVSA-PLUS)

Since 1998
Kalinin NPP, Ukraine,
Bulgaria, Czech Republic

TVS-2 (TVS-2M)

Since 2003
Balakovo NPP, Rostov NPP, China
Transition at Kudankulam and Busher NPPs

Nuclear fuel for VVER-1000 TVSA-12



- ✓ Increased operational performance while at increased upto 546 kg uranium content
- ✓ For the operation in fuel cycles 4x1 or 5x1 year.
- ✓ Unified in components with the TVSA design to maximum possible extent.

TVSA-12 advantages over basic TVSA:

- ✓ **Increase in fuel cycle length from 300 to 320 EFPD**
- ✓ **reducing number of FA in an annual reload batch by 12 %,**
- ✓ **reducing amount of spent fuel, reducing the time for fuel handling;**
- ✓ **Decrease in effective rated consumption of natural uranium by 5 %.**

2016 – start of TVSA-12 operation at Kozloduy NPP.
2016 – continue licensing of TVSA-12 in Ukraine.

Nuclear fuel for VVER-1000
4-th generation FA

TVS-2M

12 SG, IFM, debris filter,

Fuel stack is 3680 mm,

Unified top nozzle

TVSA-PLUS

Debris filter,

Fuel stack is 3680 mm

TVSA-12

IFM, debris filter,

pellet Ø7.8/0 mm

4th generation FA

Unified SG span length – 340 mm

Unified top nozzle

12 SG, IFM, debris filter

Fuel stack is 3680 mm

Pellet Ø7.8/0 mm

UO_2 load – 568.4 kg

Fuel cycle 3x1.5 or 5x1 year

Extension of the campaign duration by 8 %

or

Decrease of the number of reload batch FA by 10%

or

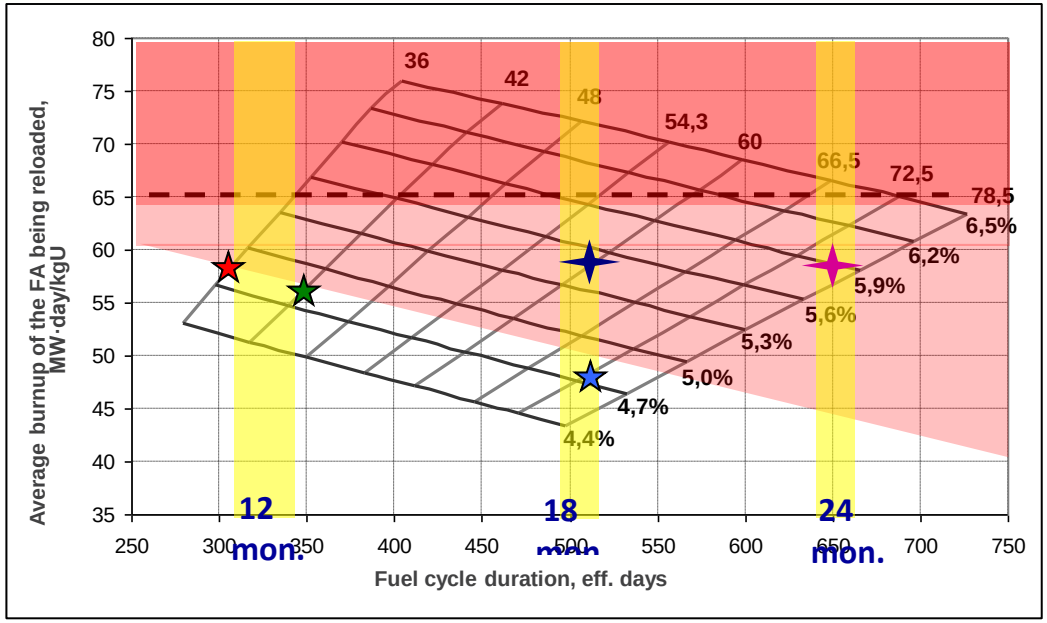
Decrease of reload batch's enrichment by 0.25% (U-235)

2018 – Initiation of the TVS-4 implementation at Rostov NPP unit 3

2018 – Initiation of the TVSA-T.mod.2 (TVSA-4) implementation at Temelin NPP

Prospective developments for VVER-1000/1200 designs

- ✓ **Utilization of the fuel having enrichment on uranium-235 up to 7%:**
  - Decrease of the number of reload batch FA by 20%,
  - Decrease of the fuel constituent in the electricity production cost in similar cycles by 5% (erbium) and 8% (gadolinium),
  - Possibility of 24-month fuel cycles realisation.



- ✓ **Utilization of the uranium-erbium fuel:**
  - Decreasing of the power distribution nonuniformity.
  - Increasing of the accuracy of the power distribution.

Feasibility study	Development Program	Licensing	Pilot operation
2016	2017-2018	2019	2020

Power maneuvering in VVER-1000

VVER-1000 FA is justified for the operation in the power maneuvering modes

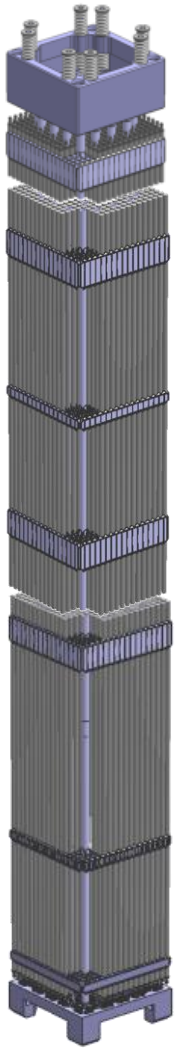
Primary power maneuvering in the range of ± 2 % Nnom
Daily power maneuvering in the range of 100-75-100 % Nel.
up to 200 cycles per year

2006: the pilot operation of Khmelnitsky NPP Unit 2 in the daily power maneuvering mode - 11 daily cycles

2015: the pilot operation continued - 21 daily cycles

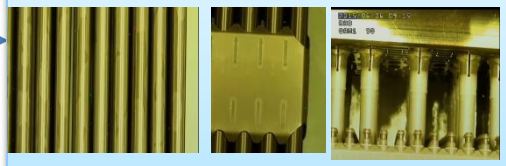
2017: the pilot operation will be continued - 50 daily cycles

Russian Nuclear Fuel for PWR
TVS-K project development



TVS-K design is developed and justified. The design is competitive to the modern designs RFA-2 and GAIA by technic and economic characteristics

Main results after 1st year of pilot operation at Ringhals-3



Oxide film | Spacer grid | Weldings

Signing the Consortium Agreement with GNF-A (USA).

TVS-K design for the US market

Operation experience

Fuel Vendor qualification

Agreement on the TVS-K LTA Program in the USA

Invitation to tender for fuel supply in Europe and USA

Specific features:

- usage of two alloys of Zr-Nb system;
- low level of corrosion and hydrating in PWR water chemistry;
- original design of SG eliminates GTRF;
- high rigidity of welded skeleton ensures low distortion;
- burnup up to 68 MW×day/kgU, 18-th months fuel cycle.

Conclusions

As a result of performed scope of activities:

- **The operation duration increase from 30,000 to 42,000 EFPH**
- **Fuel burnup increase from 49 to 68 MW×day/kgU**
- **Fuel cycles length from 12 to 18 months**
- **Core power uprate**
- **Load-follow modes of operation**

Together with our Customers JSC TVEL continue activities aimed at nuclear fuel development to increase its safety, reliability and economic efficiency.

Thank you for attention!