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Effective fuel solutions using SNF reprocessing

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Utilization of reprocessed uranium in power reactors

Long time operation and development of power reactors contemplates a closing of the fuel cycle: return of plutonium and reprocessed uranium (RepU) back to reactors for further use. The problem of return of uranium from spent fuel assemblies (SFA) in the NPP fuel cycle has a long history. Such process to a certain degree is already implemented in many countries. At present Russia is one of the few countries that have industrial experience in the utilization of RepU. About 20 years RepU from VVER-440, BN-600, research and propulsion reactors' fuel is used in loading RBMK reactors.

A characteristic feature of RepU is that it contains ^{234}U, ^{236}U and ^{232}U apart from traditional isotopes ^{235}U and ^{238}U. ^{234}U and ^{236}U provide fuel with little neutron absorption and ^{232}U as a result of radioactive decay produce thallium ^{208}Tl, that emits hard γ - rays. Operational experience of using pilot fuel assemblies in VVER-440, VVER-1000 reactors allowed to justify the use of RepU in light water reactors. According to calculations, residual content of ^{235}U in VVER-1000 burnup fuel is higher than that in natural uranium up to burnup of 60 MWt*days/kg.

The main problems of using RepU

- Compensation of ^{236}U and ^{234}U
- Technology and fabrication
- Presence of ^{232}U in the fuel
- Trail operation of RepU fuel

Compensation of ^{234}U and ^{236}U in FA with RepU

The influence of neutron absorption in ^{234}U and ^{236}U on breeding properties of fuel assemblies (FA) with RepU is considered in asymptotic approximation. To accomplish a task of compensation, calculations of eternal grids of similar FA with different content of ^{234}U, ^{235}U and ^{235}U was done. Calculations didn't include ^{234}U content in standard fuel.

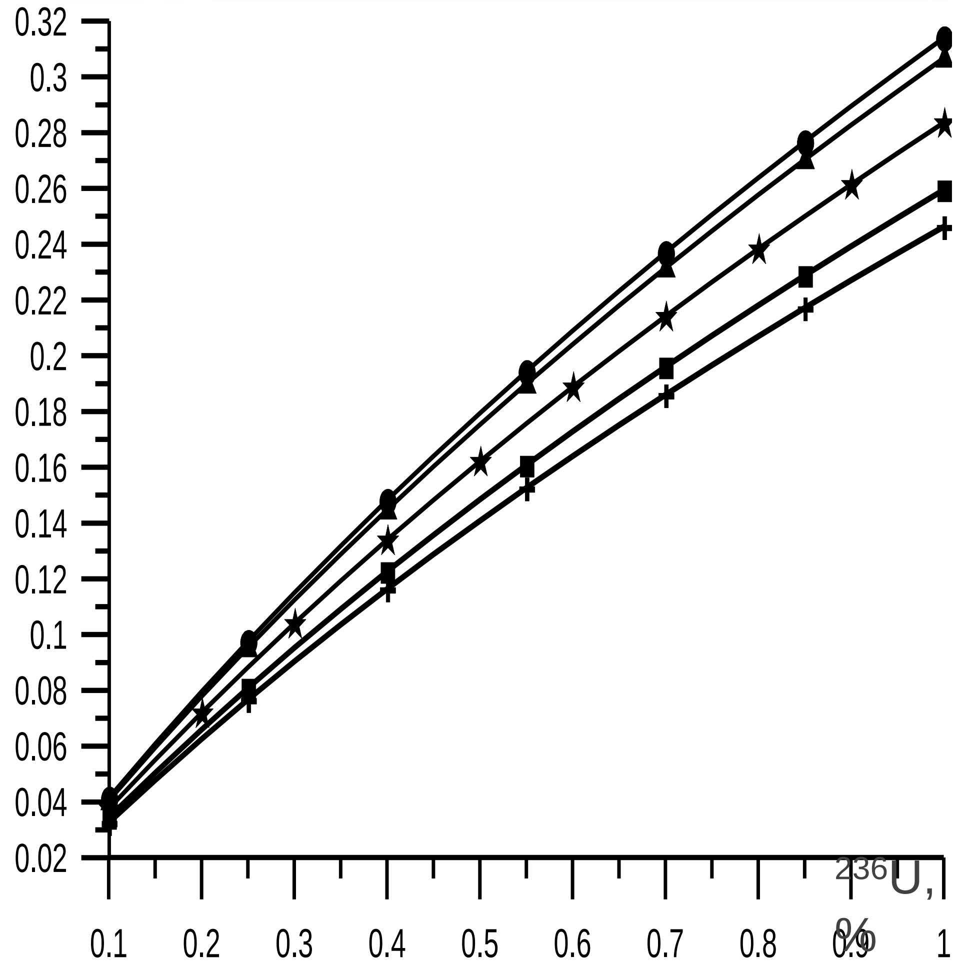
To calculate relative divergence and sensitivity ratio of the FA breeding ratio averaged per fuel cycle, received during disturbance of isotopic composition of standard fuel, FA burnup calculation have been carried out for the whole range of relative mass fraction of ^{236}U in RepU.

In practice a simplified dependence can be used which :

$$\Delta^{*} C_{^{235}U} \approx K_1 \cdot C_{^{236}U} + K_2$$

where K_1 and K_2 are compensating ratios.

Thus the value of compensating enrichment depends upon ^{236}U content in RepU.

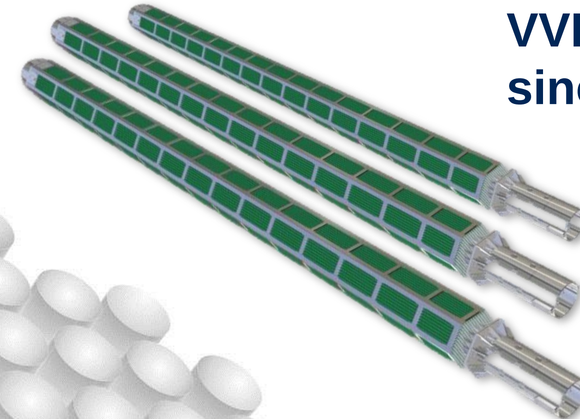


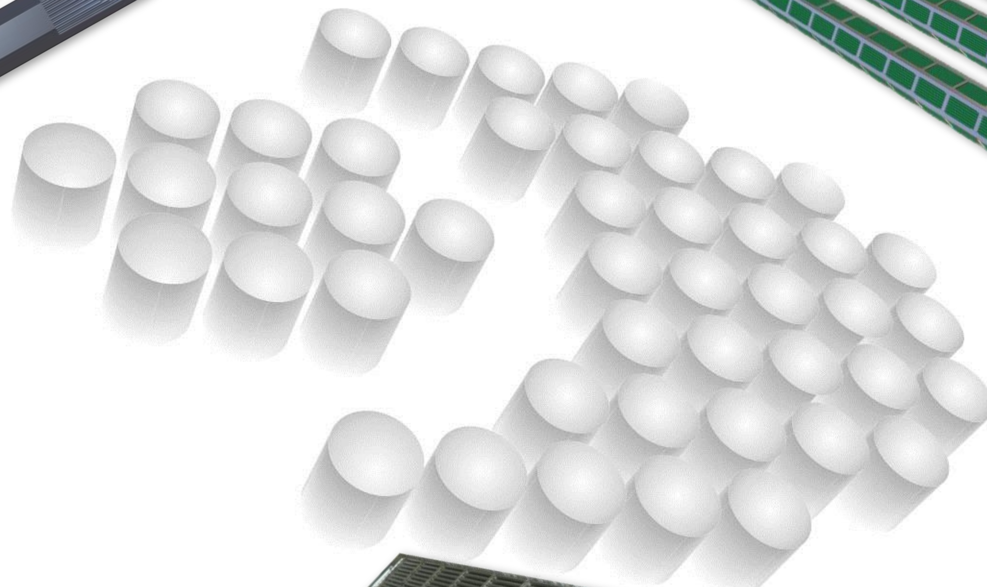
VVER fuel rods with efficient enrichment (%):
+ – 3.3; ■ – 3.6; ★ – 4.0; ▲ – 4.4; ● – 4.6

MSZ experience in fabrication of FA with RepU

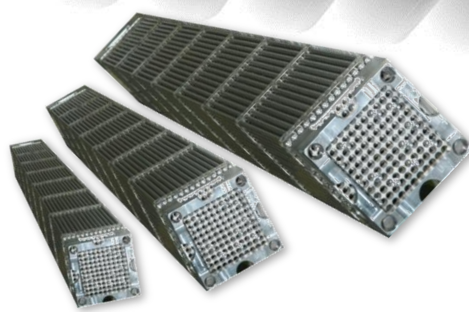
VVER-440 since 2002

VVER-1000 since 2002





Fast Breeder Reactors since 1996

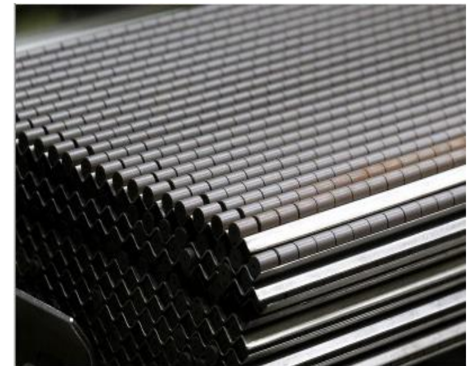


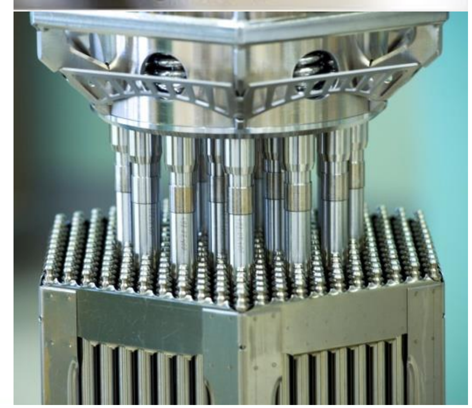
AREVA since 2000

RBMK since 2002

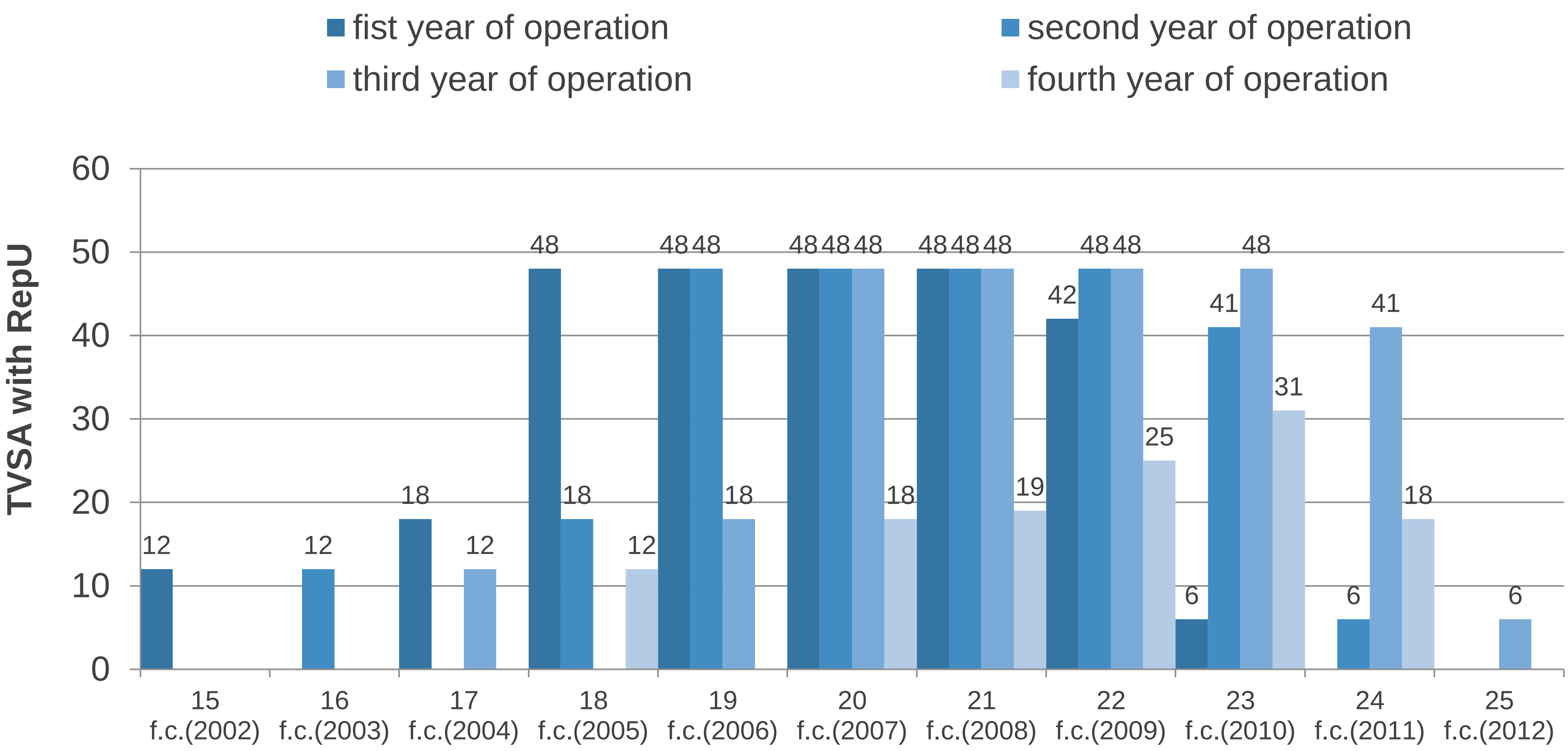
Fabrication of fuel with RepU

- Since 1996 MSZ produces fuel rods of RepU with a high content of reactor origin isotopes along with FR of the natural uranium
- At present MSZ has a license for processing nuclear materials based on RepU with ^{232}U content up to $5 \cdot 10^{-7}$ %.
- In total, the following products with RepU have been fabricated:
  - RBMK – 16096 FAs (including 150 FAs with a high content of even isotopes)
  - BN – 1998 FAs
  - VVER–440 - 728 working assembles and fuel follower assembles (Unit 2 of Kola NPP)
  - VVER–1000 – 246 FAs (Unit 2 of Kalinin NPP)
  - Fuel pellets for AREVA - 992 batches of FM raw material
- A set of engineering, radiation-protection and organizational measures was developed and implemented at MSZ to reduce the impact of radiation factors on the staff in the processing of RepU



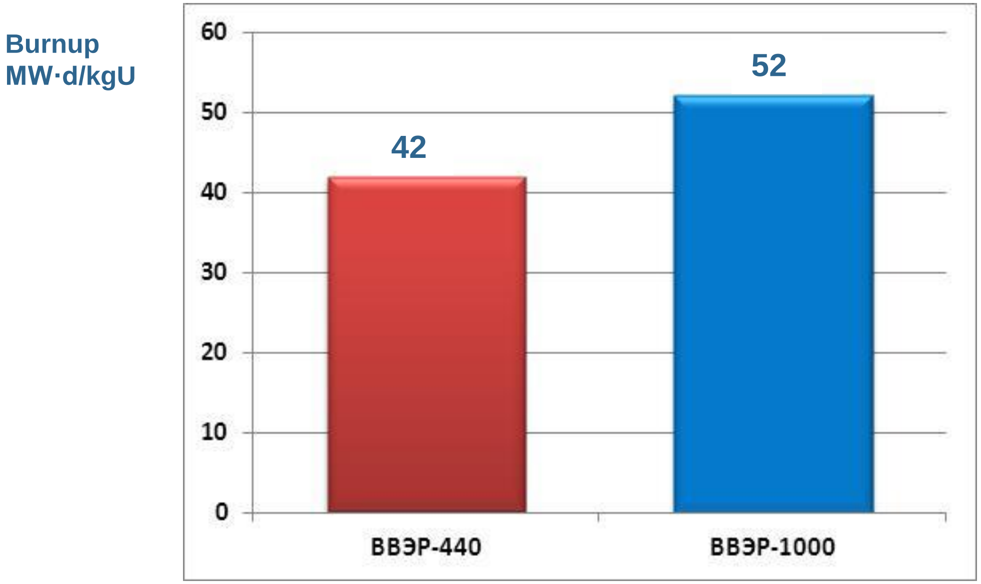


Operational experience: Kalinin NPP Unit 2



Introduction of TVSA with RepU at Kalinin NPP Unit 2

Achieved burnups and modern fuel cycles



Achieved RepU burnups in VVER type reactors

Dependence of enrichment via content of ^{236}U for VVER-1000

Max. enrichment/ ^{236}U,%	Cycle length, EFPD	FA reload batch, pcs.
4,95/до 0,1	510	67
5,2/0,55	510	67
5,37/1,0	510	67

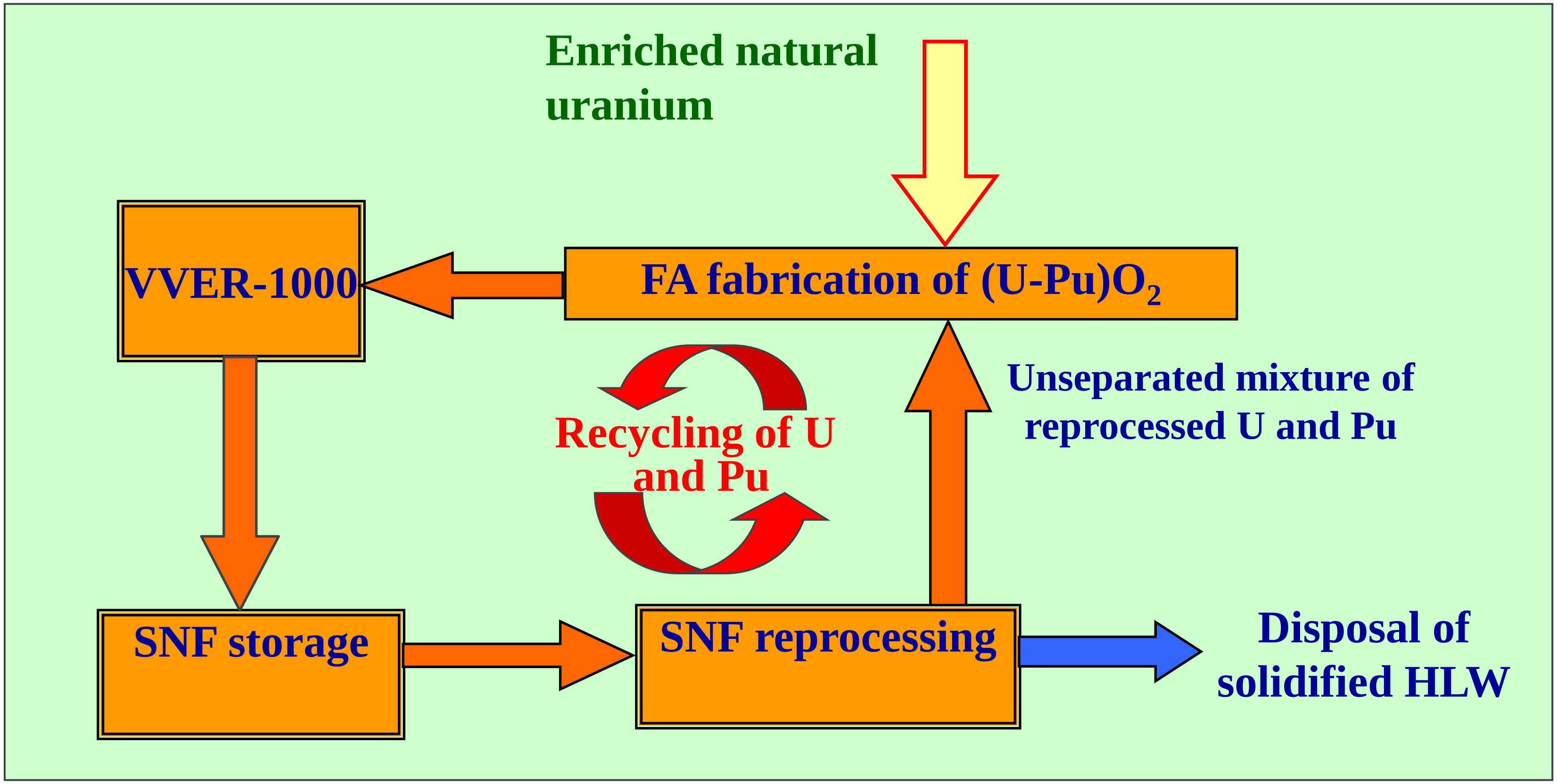
Characteristics of fuel cycles with RepU fuel for Hanhikivi-1 NPP

Parameter	Initial Cycle	Equilibrium Cycle
Types (number) of fresh loaded FAs	R27PA (48) R39PF (79) R50B6 (36)	R50B6 (24) R38F2 (12) R50A2 (12)
Average enrichment of fresh loaded FAs, % wt.	3.74	4.57
Fuel cycle length, EFPD	544	348
Fuel burnup: −average by FA −maximum by FA −maximum by U fuel rod −maximum by U-Gd fuel rod	 22.8 23.1 24.1 21.3	 49.4 54.7 62.4 50.2

Requirements for fuel pellets

Parameter	«N» specification	«RepU» specification
U-235 conditional mass fraction, %	From 0.16 ± 0.05 to 4.95 ± 0.05	From 2.00±0.05 to 4.95 ± 0.05
U-236 conditional mass fraction, %	<0,10	(0.0-0.7) ± 0.1
Maximum U-232 conditional mass fraction, %, less	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Oxygen ratio	2.000-2.010	2.000-2.010
Total boron equivalent, %, not more	0.00018	0.00018
Hydrogen mass fraction, %, not more	0.00006	0.00006
Density, g/cm^3	10.4 – 10.7	10.4 – 10.7

Recycling of RepU and plutonium in VVER-1000 reactors in the form of REMIX-fuel



Flowchart of Recycling of RepU and plutonium in VVER-1000 reactors in the form of REMIX-fuel

Neutron-physical characteristics

Neutron-physical characteristics of the reactor core with enriched natural U and REMIX fuel with burnup of 50 MW•d/kg. Fuel cycle duration 297 EFPD

Neutron-physical characteristics	U-fuel	REMIX recycle 1	REMIX B
Average enrichment of fresh loaded fuel ($^{235}U+^{239}Pu+^{241}Pu$), % wt.	4.33	4.79	5.08
Initial content of Pu in fuel, %	0	1.0	2.0
Reactivity coefficient for the coolant temperature, nominal power, start (end) of the fuel cycle, ($1/^{0}C \cdot 10^{-5}$)	- 31.8 (-68.1)	-36.6 (-68.7)	-40,1 (-68,4)
Reactivity coefficient for the reactor power (total), nominal power, start (end) of the fuel cycle, (1/MW) $\cdot 10^{-5}$	- 0.50 (- 0.71)	-0.56 (-0.73)	-0.59 (-0.74)
Effective part of the delayed fission neutron, nominal power, start (end) of the fuel cycle, %	0.63 (0.56)	0.58 (0.55)	0.55 (0.53)
Efficiency of rod cluster control assembly, nominal power, start (end) of the fuel cycle, % $\Delta\rho$	0.84 (0.80)	0.74 (0.73)	0.74 (0.75)
Efficiency of ECPS in the upper position jam of the most efficient rod cluster control assembly, nominal power, start (end) of the fuel cycle, %$\Delta\rho$	7.5 (7.3)	7.4 (7.3)	7.2 (7.3)

REMIX fuel allows repeatedly recycle the entire amount of uranium and plutonium from SNF at 100% load of the VVER-1000 core with such fuel

Design and experimental study of REMIX-fuel

In the framework of the 'Design and experimental study of REMIX-fuel' project in July 2015 the Decision was issued on the organization of work for the fabrication and trial operation of FRs with REMIX-fuel as part of a pilot FA at Unit 3 of Balakovo NPP

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

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П.И. Лавренюк
(Исх. № 4/03-25/10928 от 10.07.2015)

РЕШЕНИЕ
об организации работ по изготовлению и проведению опытной эксплуатации твэлов с РЕМИКС-топливом в составе КЭТВС на блоке №3 Балаковской АЭС

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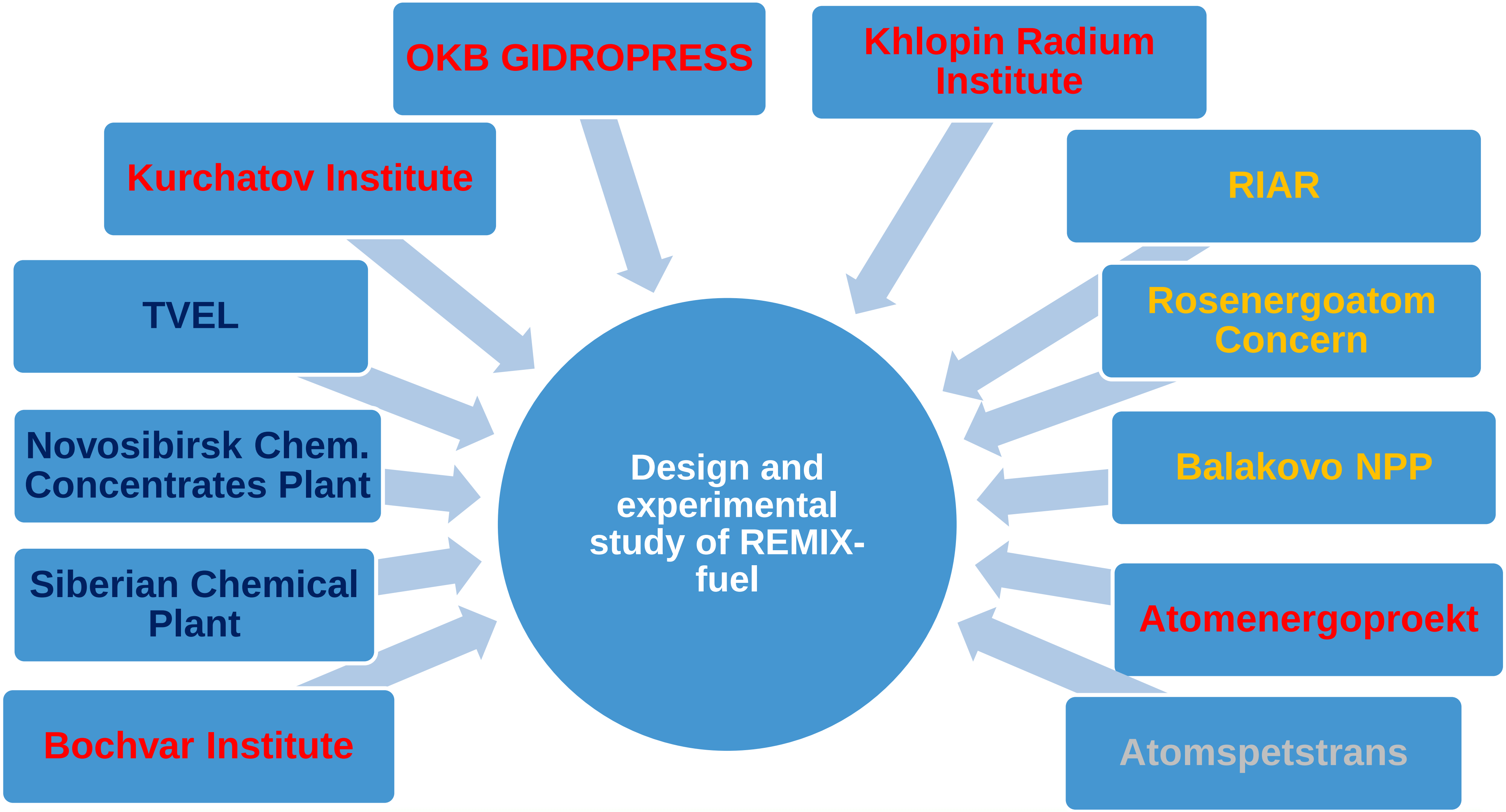
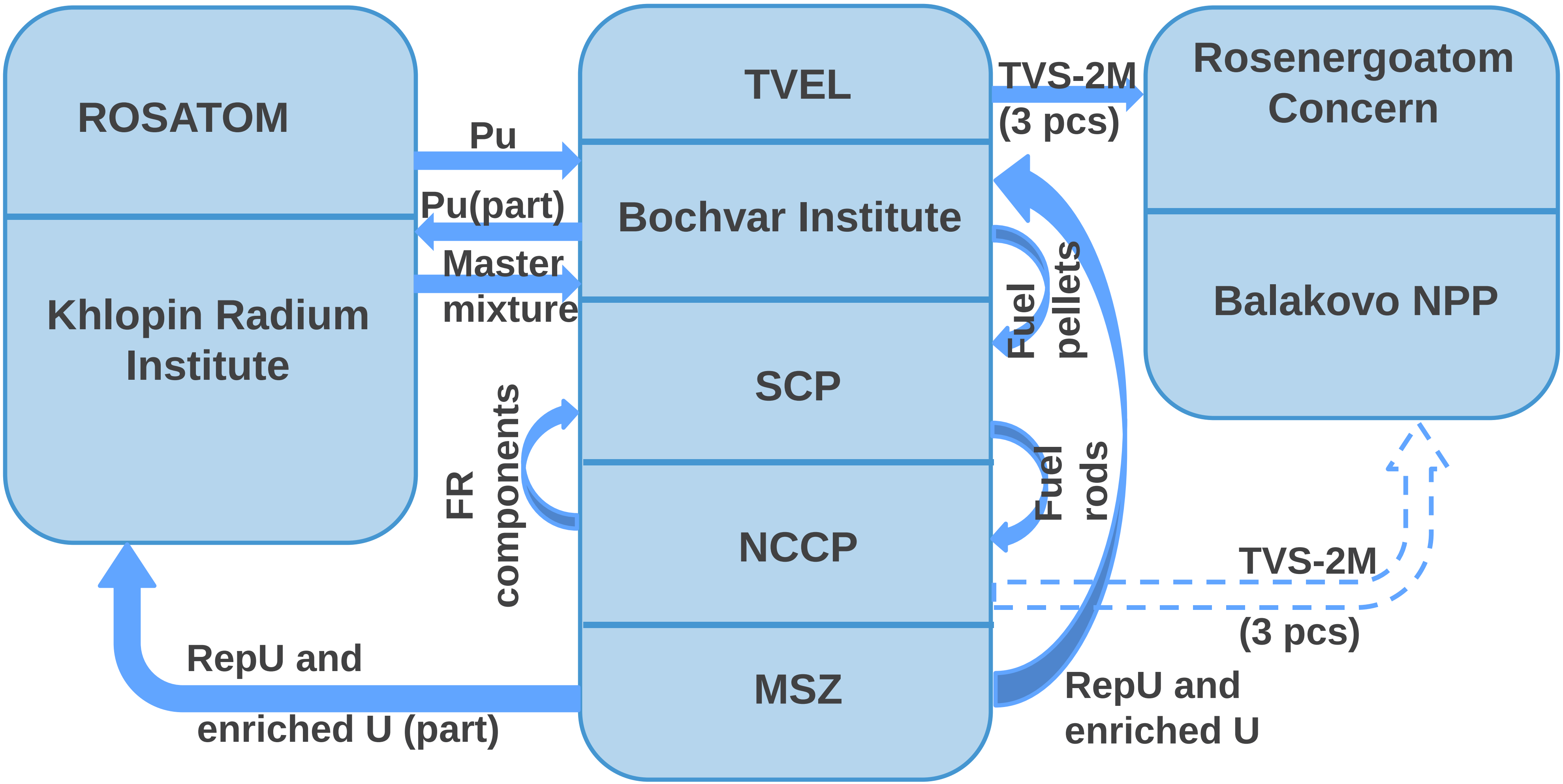
Cooperation of organizations



Flowchart of REMIX-fuel fabrication



Design and fabrication of FAs with REMIX-fuel and its components was carried out in strict accordance with the requirements of STK-5-2005 document

Conclusions

- The use of reprocessed uranium in fuel fabrication is fully mastered. Possibility of operation is confirmed for all types of power reactors in Russia.
- The full implementation of REMIX-fuel requires completion of reactor tests.
- Commercial development of the REMIX-fuel fabrication requires a revision of the feed streams and modernization of fabrication facilities in terms of the development of closed production lines.

THANK FOR YOUR ATTENTION!