ROSATOM

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Modern Russian Approaches in the Nuclear Fuel Cycle Development

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TENEX

Introduction

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To keep in pace with the global progress in energy technologies, nuclear generation should follow the trend of resource saving technologies.

Solution of the problem based on the national infrastructure is expensive even for the countries possessing a large fleet of civilian nuclear reactors.

Development and improvement of technologies results in reducing their costs, while uniting in international systems accelerates the process as a result of scale-up effect.

Content

POCATOM

1. Modern NFC trends
2. Russian proposal based on two-component nuclear power generation
3. Russian proposal based on REMIX technology
4. Russian proposal based on international NFC

Modern NFC trends which are implemented in commercial NPP have as positive as negative effects

РОСАТОМ

Some modern NFC trends	Advantages	Disadvantages
Increase of nuclear fuel burnup (from 35 GWt*day/tU to 65 GWt*day/tU)	The increase of reactor capacity factor (from 65% to 86-96%) and duration of micro companies (from 300 to 600 effective days)	The increase of exposure time for SNF storage. The increase of SNF reprocessing costs and amount of high level wastes.
«Dry» cask storage	Low costs in short term	Risk of underestimation of deferred costs and revaluation the impact of discounting. SNF "switches off" from из technological development.
SNF Reprocessing	«Fuel prize» from recovered nuclear material usage, possibility of finding the optimal scenario of SNF treatment. No responsibility on future generations.	High costs in short term.
Pu usage in NFC	«Fuel prize» from energy potential of Pu fissile isotopes.	Additional costs of nuclear fuel fabrication and its treatment at NPP.

The optimal solution with respect to national conditions may vary in time and based on the market situation

Comparison of SNF Management Options Worldwide

Open Nuclear Fuel Cycle

- \+ No need to immediately address the issues of final isolation of SNF
- − High cost of construction & maintenance of landfills & long-term storage sites
- \+ Low price of natural U at the current market situation (production exceeds the demand)
- − Low efficiency of using the energy potential of natural U
- − No solution regarding long-term isolation of radionuclides contained in SNF

Closed Nuclear Fuel Cycle

- − Needs improving technology of radiochemical reprocessing of SNF aimed at: (i) reducing the process costs, and (ii) mitigating the risks of proliferation of SNF reprocessing products
- \+ Zero dependence on sources of fuel resources and market situation
- \+ Return to the NFC of non-burnt out & reactor generated products of SNF reprocessing (U-235, Pu, MA) reduces the need for natural U
- \+ Minimizing activity, volume and mass of waste intended for final disposal

- Advantages of open NFC are of short-term nature
- Disadvantages of closed NFC can be eliminated

By the end of 2015 r. total accumulated ~ 285 thousand MT of SNF, and ~ 11 thousand MT of UNF unloaded from world reactor fleet annually

Russian infrastructure for handling SNF with the ultimate goal of closed NFC and new technologies to make it more cost-efficient

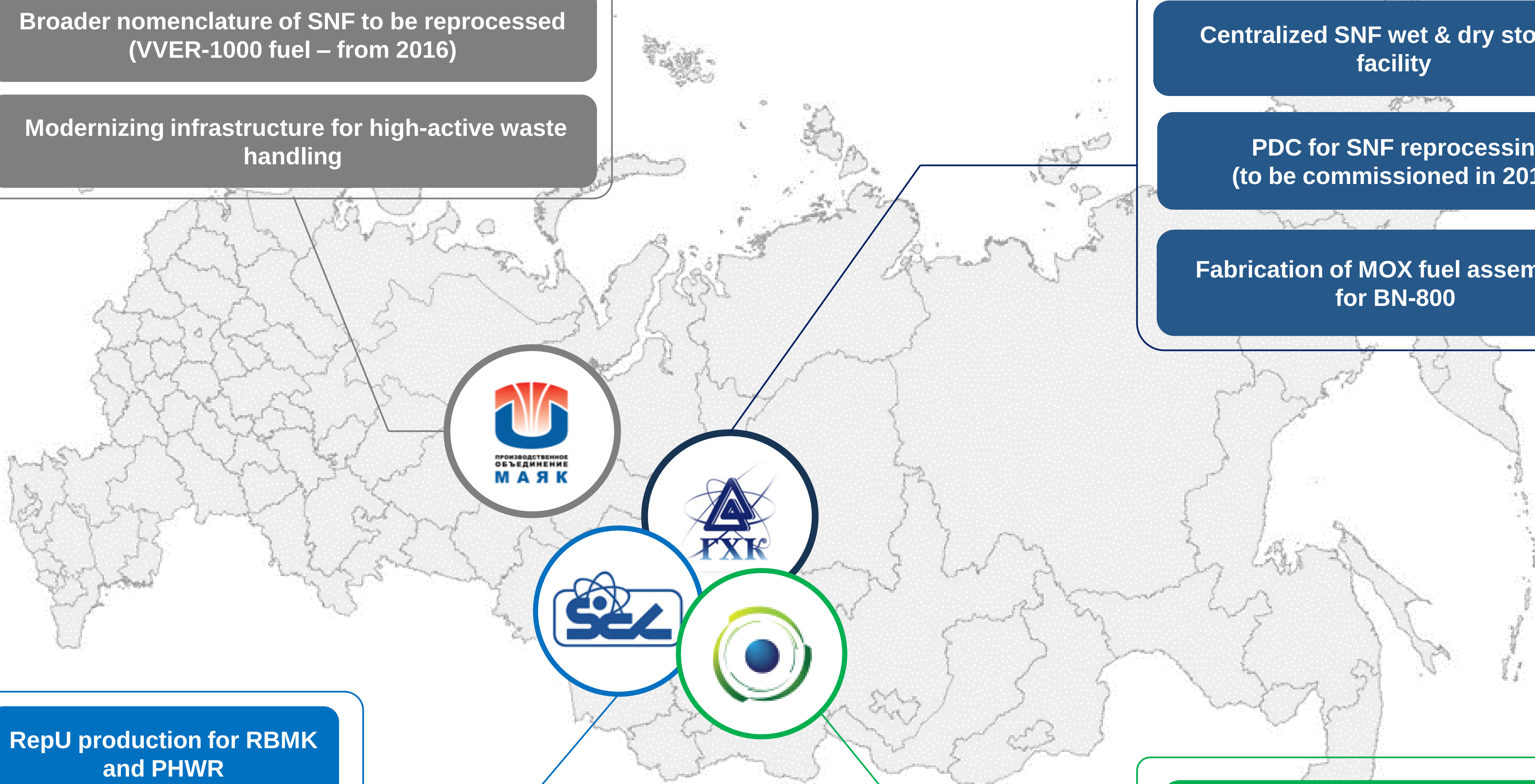
Broader nomenclature of SNF to be reprocessed (VVER-1000 fuel – from 2016)

Modernizing infrastructure for high-active waste handling

Centralized SNF wet & dry storage facility

PDC for SNF reprocessing (to be commissioned in 2019)

Fabrication of MOX fuel assemblies for BN-800



RepU production for RBMK and PHWR

Pu treatment

Final isolation of high-active waste in deep geological repository (to be commissioned in 2022)

Solutions for recycling SNF reprocessing products that could be used right now

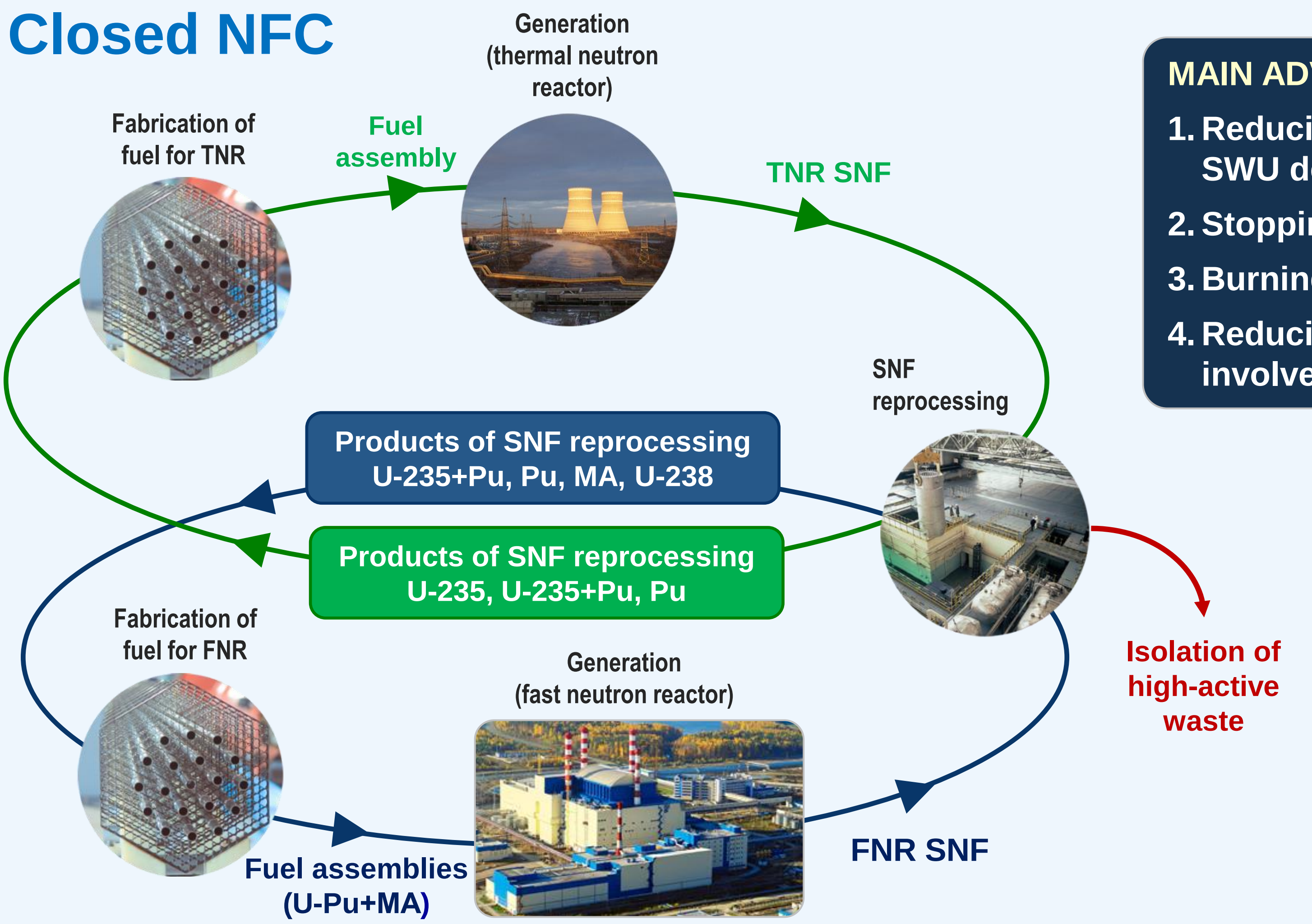
РОСАТОМ

Reprocessing Products	Technological Solution	Usage
RepU obtained during SNF reprocessing with burnup < 35 GW·day/tU	Enrichment at Siberian Chemical Plant (SCK)	Fuel supply for VVER-440/1000
RepU obtained during SNF reprocessing with burnup in the range 35-55 GW·day/tU	Enrichment at SCK with improved parameters as a result of mixing with natural or "slightly irradiated" component	Fuel supply for VVER-440/1000 or RBMK
RepU obtained during SNF reprocessing with burnup > 55 GW·day/tU	Production at Machine Building Plant of pellets through direct mixing of powder with variable enrichment	Fuel supply for RBMK or CANDU*
Energy Pu	Fabrication of MOX fuel assemblies for BN-800 Fabrication of REMIX fuel assemblies for VVER-1000/1200*	Pu utilization in BN-800 Fuel supply for VVER-1000/1200*

** Solutions are being currently developed*

Content

Principal Chart of Two Component Nuclear Power Generation
(System of Fast Neutron & Thermal Neutron Reactors)



MAIN ADVANTAGES:

1. Reducing natural uranium and SWU demand.
2. Stopping SNF accumulation.
3. Burning Minor Actinides (in FNR).
4. Reducing Pu amount by its involvement in NFC.

FNR – fast neutron reactor
TNR – thermal neutron reactor

Pilot Demonstration Center at MCC, Zheleznogorsk
New Generation of the Reprocessing Technology

Main characteristics

- a part of the SNF management unit at MCC (incl. SNF Storage, MOX Manufacturing)
- reprocessing of SNF VVER-1000, SNF BN-800, SNF RBMK;
- ecologically-advanced technology (no liquid RW);
- non-stop technology improvement in the incorporated research hot cells complex;
- start complex (research hot cells) was commissioned in 2015;
- **to be fully commissioned in 2019;**
- 250 tons of VVER-1000 SNF per year as designed capacity;
- first branch of the RT-2 Reprocessing Plant (950 tons of SNF per year in total);
- acceptable price (less than $1000 for 1kg of SNF);
- ready to deliver the demanded product (MOX, REMIX).

SNF Management Unit at MCC with the SNF Dry and Pool Storages (Grey) and the PDC (Colored)

A sketch of the Pilot Demonstration Center for the SNF Reprocessing, MCC site, Zheleznogorsk

Fractioning & After-Burning of Minor Actinides – Way to Reduce Time of High-Activity Radwaste Management

Today: SNF is recycled with no fractioning

- Rep U, Pu – useful products
- Vitrified high-active waste (MA, Sr, Cs)

~ 2 cub.m per 1 GW annual nuclear generation
Activity decay period = 10,000 years

Prospective: SNF reprocessing with fractioning

- Rep U, Pu – useful products
- Minor actinides (Np, Am) after-burning in fast neutron reactors
- Vitrified high-active waste (MA, Sr, Cs)

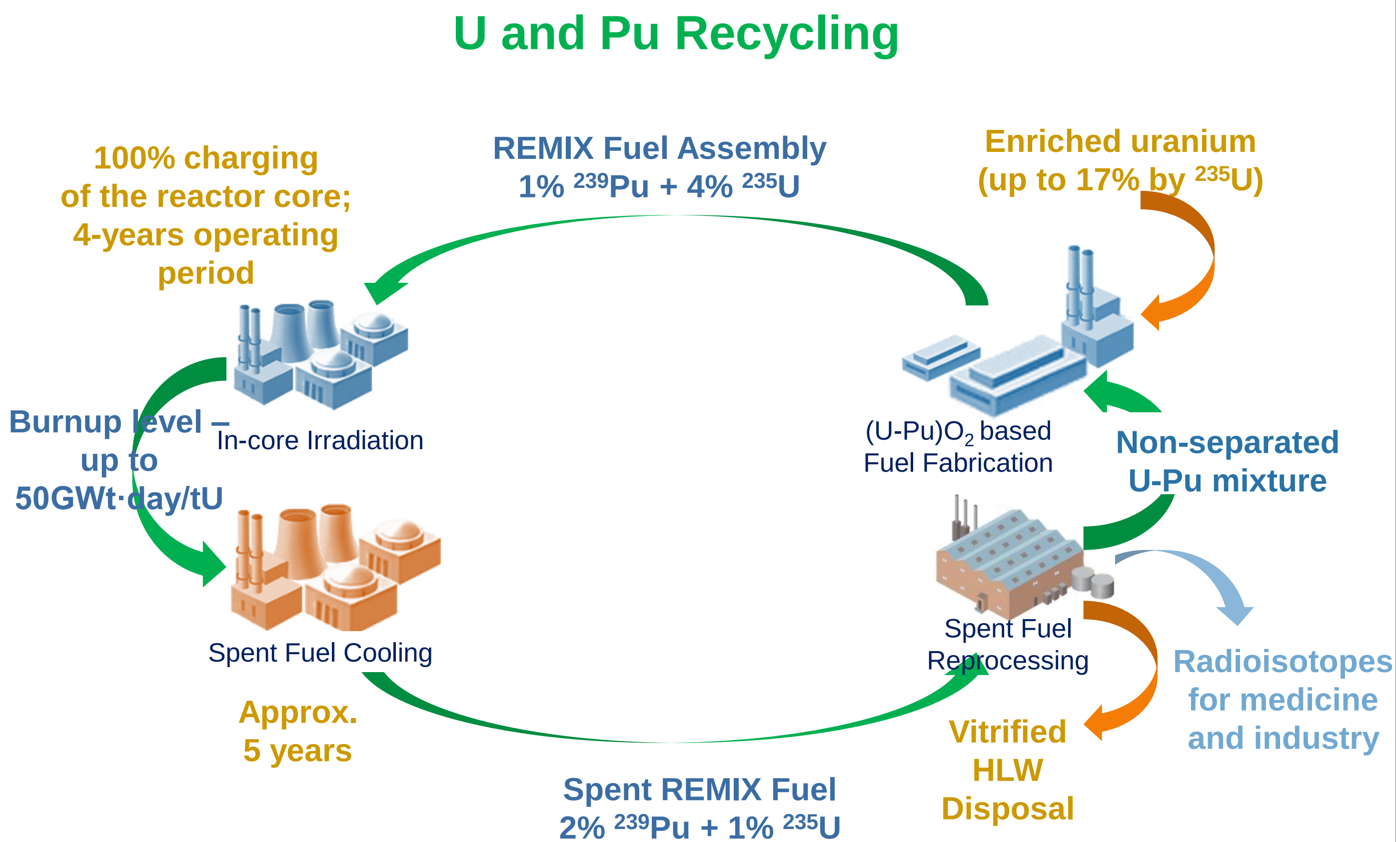
~ 2 cub.m per 1 GW annual nuclear generation
Activity decay period = 300 years

Current Steps in fast neutron reactors development in Russia

- In December 2015 the Beloyarsk NPP's BN-800 fast neutron reactor has been connected to the national grid.
- The reactor uses MOX fuel.
- For a one year of reactor's operation 1,84 t of plutonium is required. It is produced from 190 t of reprocessed SNF of thermal-neutron reactors.
- The separated from BN-800's SNF plutonium is to be reheated in VVER-1000 reactors.
- This will show significant improvement in fuel utilization effectiveness in nuclear energy.

Content

REMIX Nuclear Fuel Cycle
Nuclear Fuel Recycling



MAIN ADVANTAGES:

- The only waste from NPP in REMIX NFC is the vitrified fission products of uranium and minor actinides and operational radwaste. No SNF for storage and disposal.
- 5 REMIX cycles completely cover a 60-year lifetime of the reactor. Thus, the reactor can run on the same fuel (with minor recharge) for its whole lifetime.
- Reprocessing of SNF under the REMIX technology does not separate pure plutonium. There are no warehouses and no shipments of separated plutonium in the frame of REMIX NFC.
- REMIX fuel can be loaded in the entire core of reactor on thermal neutrons like PWR/VVER.
- For various national scenarios, there are various types of REMIX fuel: with the reprocessed uranium enrichment, with adding of extra plutonium, etc. Thus, REMIX Nuclear Fuel Cycle could be optimized to the certain parameters of the National NFC and the National Nuclear Industry.
- REMIX NFC seems to be cheaper than the open fuel cycle with the final disposal of SNF.

Implementation REMIX fuel in Russia

Works are underway already

- The first steps in confirmation of the REMIX vitality are already made in Russia: technology is mastered in laboratory, cost-effectiveness evaluated roughly, patent pending, program of the test FA fabrication is elaborated.
- First experimental REMIX fuel assemblies have been installed in VVER-1000 commercial reactor on summer 2016 (Balakovo NPP, Saratov).
- In parallel, irradiation of the test REMIX assemblies is starting in research reactor MR (RIAR, Dimitrovgrad).
- The yield on the large-scale application of REMIX-fuel in commercial reactors in Russia is expected in the mid-2020s.
- REMIX Nuclear Fuel Cycle could be realized internationally in more or less cooperation with the Russian facilities. Scale of cooperation to be discussed.

Prospective Russian Approaches turn SNF into a source of new fuel and valuable isotopes. Decreasing the SNF amount will ensure reducing of disposal costs

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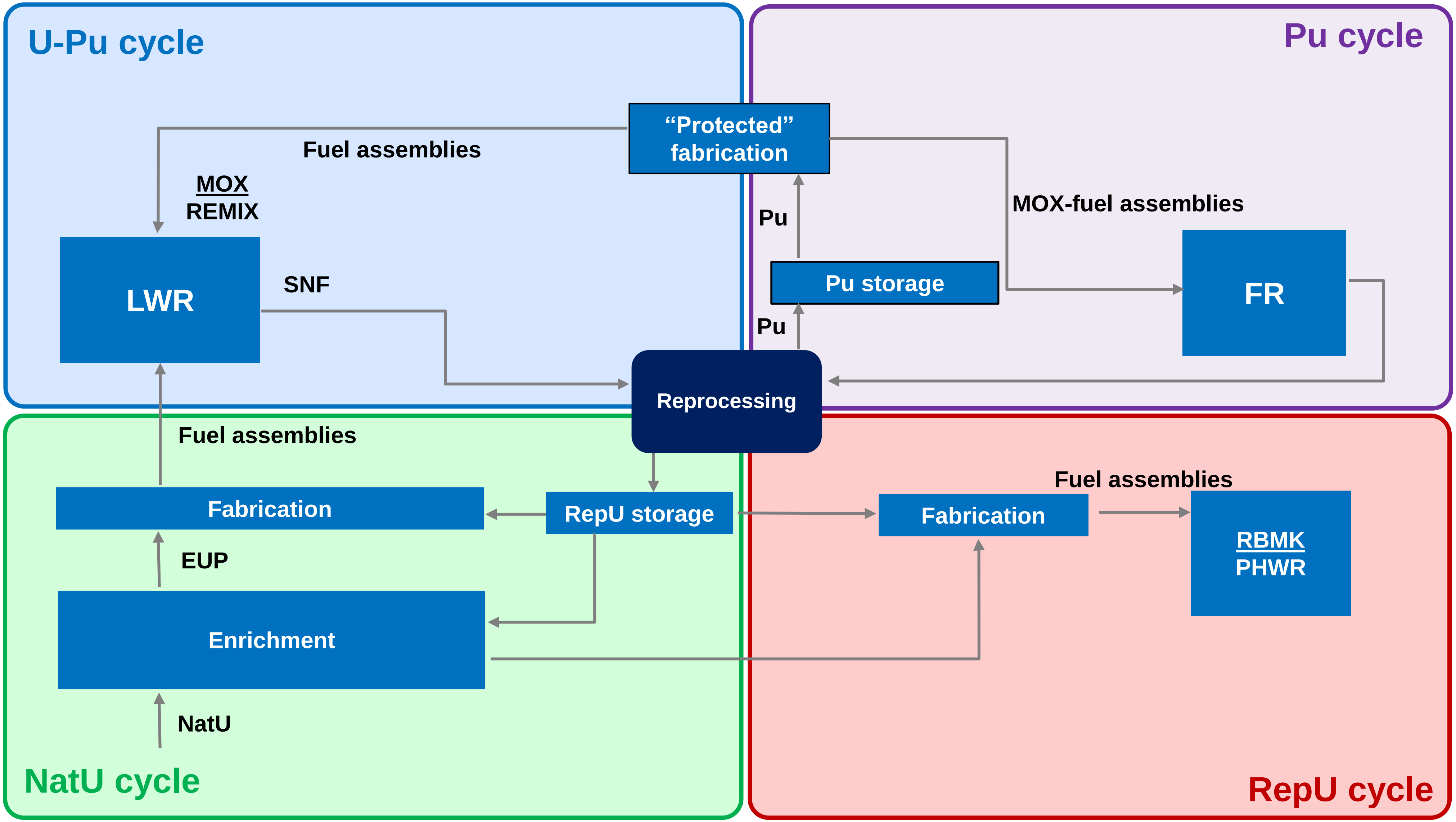
Pilot international NFC could be implemented in the period 2020-2030.
Concept



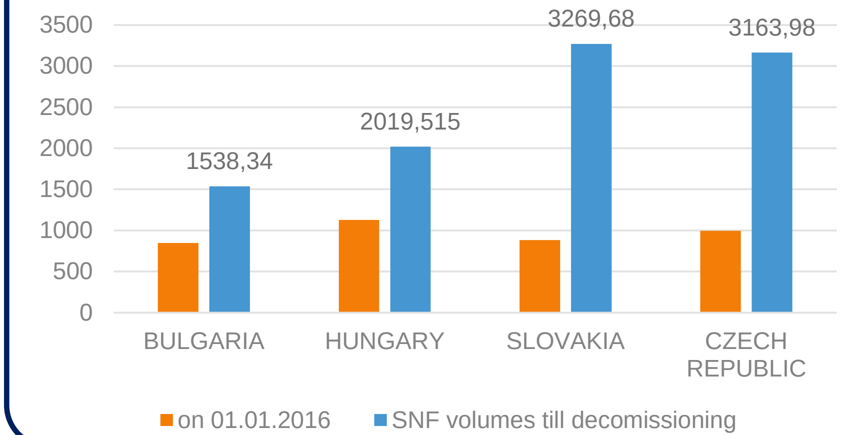
Potential volume of SNF and regenerated products of NPPs in Central and Eastern Europe (CEE)

РОСАТОМ

Existing and planned NPPs in CEE

	Existing NPP	Planned NPP
Hungary	4 VVER-440	2 VVER-1200
Bulgaria	2 VVER-1000	1 VVER-1200
Slovakia	4 VVER-440	2 VVER-440
Czech Republic	4 VVER-440 2 VVER-1000	2 VVER-1200

SNF volume accumulation of existing NPPs in CEE, TM



Total SNF volume of accumulation of existing NPPs in CEE:

~ 10 thousand tons

During reprocessing of **10 thousand tons** SNF will be generated :

~ 9 600 tons of RepU
~ 100 tons of Pu.

Generated during SNF reprocessing 10 thousand tons regenerated products have energy potential for fuel supply VVER-1200 reactor:

~ 60 reactor/year by Pu;
~ 60 reactor/year by RepU.

Two VVER-1200 type reactors can be provided fresh fuel, fabricated from regenerated materials from existing NPPs SNF for the whole life cycle

Evaluation of back-end cost based on existing technologies & national infrastructure capabilities

РОСАТОМ

NFC options	Main trends of development	NFC costs*
Open NFC of thermal reactor	Higher initial enrichment & burnup factor	< $7.0 /MW·h front end ~ $5.5 back end ~ $1.5
Thermal reactor with once-through cycle (PUREX/MOX)	Increasing Pu in fuel assemblies	~ $7.5 /MW·h front end ~ $4.5 back end ~ $3.0
Thermal reactor operating together with fast reactor balanced in closed NFC	Minimizing long-living high-active waste & replenishing the balance of fission nuclear materials	~ $8.0 /MW·h front end ~ $4.0 back end ~ $4.0

Our current capabilities:
< $6.5 /MW·h
front end < $4.5
back end < $2.0

Our future goal:
< $5.0 /MW·h
front end < $3.5
back end < $1.5

Russian estimates are taking in account the opportunities of existing and now creating infrastructure as well as the scale factor in the organization the international cooperation

* THE ECONOMICS OF THE BACK END OF THE NUCLEAR FUEL CYCLE, NEA No. 7061, © OECD 2013

Conclusion

The optimal solution for NFC NPP with VVER reactor – long-term cooperation based on SNF reprocessing.

- reprocessing of accumulated and accumulating SNF VVER
- consideration of RepU usage
- joint analysis of REMIX-NFC efficiency
- study of NFC as multireactor scheme

1 STEP **joint feasibility study of perspective NFC for current NPP**

Thank you for your attention!

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