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HOW TO OVERCOME THE CONSTRAINTS IN NUCLEAR FUEL CYCLE
ROSATOM' SOLUTION

Mikhail Baryshnikov
TENEX, Russia

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Keynote Speaker

Mikhail Baryshnikov

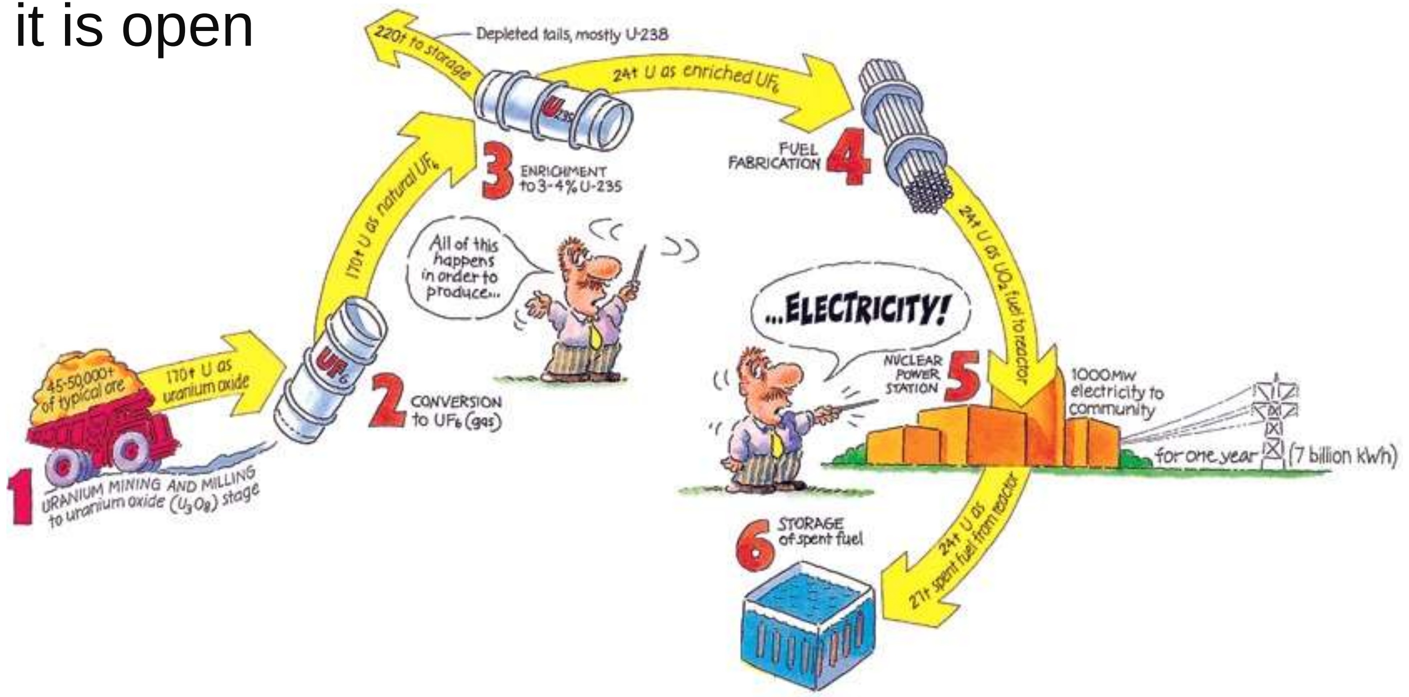
Director, Department for Innovations and Technologies,

TENEX

Russian Federation

- entered his career as a research scientist in Kurchatov institute, being engaged in the irradiated nuclear fuel exploring → has an academician experience
- worked as a nuclear fuel related project manager in engineering company SOSNY → has a business experience
- employed as a head of spent nuclear fuel project office in the Russian State Corporation ROSATOM → has an administrative experience
- currently represents ROSATOM’ subsidiary TENEX world-famous as a nuclear fuel cycle products supplier → specializes in prospective solutions in the field of nuclear fuel cycle
- chair of Sustainable Used Fuel Management working group of World Nuclear Association in 2017-2022; an experienced IAEA expert, member of the various professional societies, technical councils and international committees

What is Nuclear Fuel Cycle
when it is open



1 Uranium mining

2 Conversion U_3O_8 to UF_6

3 Enrichment by U-235

4 Fuel Assemblies fabrication

5 Fuel irradiation (electricity production)

6 Cooling of used fuel

The Main Constraints
in the Nuclear Fuel Cycle

Fresh Fuel:

- limited resources
- unavailability of resources
- technological limitations
- geopolitical protectionism

Non-secured supply

Spent Fuel:

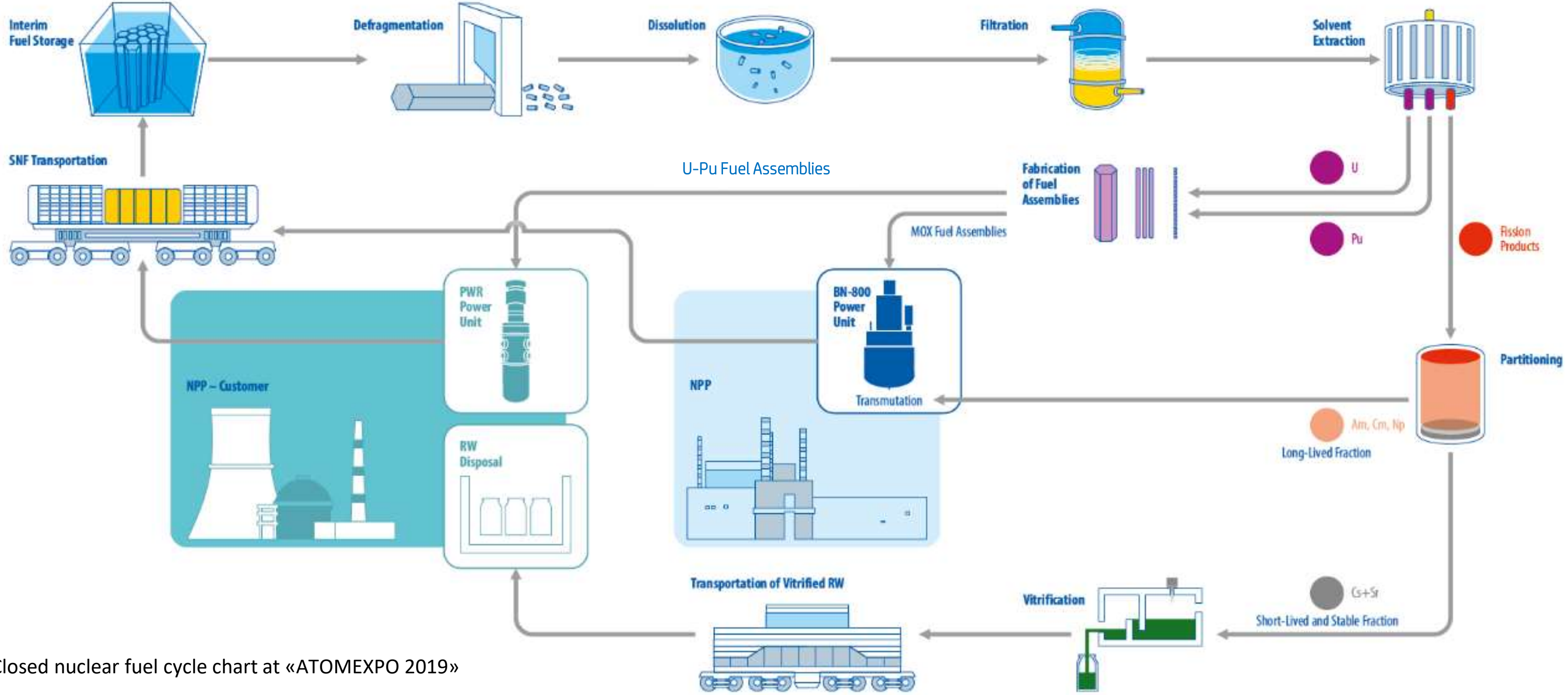
- long-term radioactivity and residual heat
- technological limitations
- Pu proliferation threat
- governmental (not only commercial) responsibility

Deferred decisions

What should an ideal **Nuclear Fuel Cycle** be like?

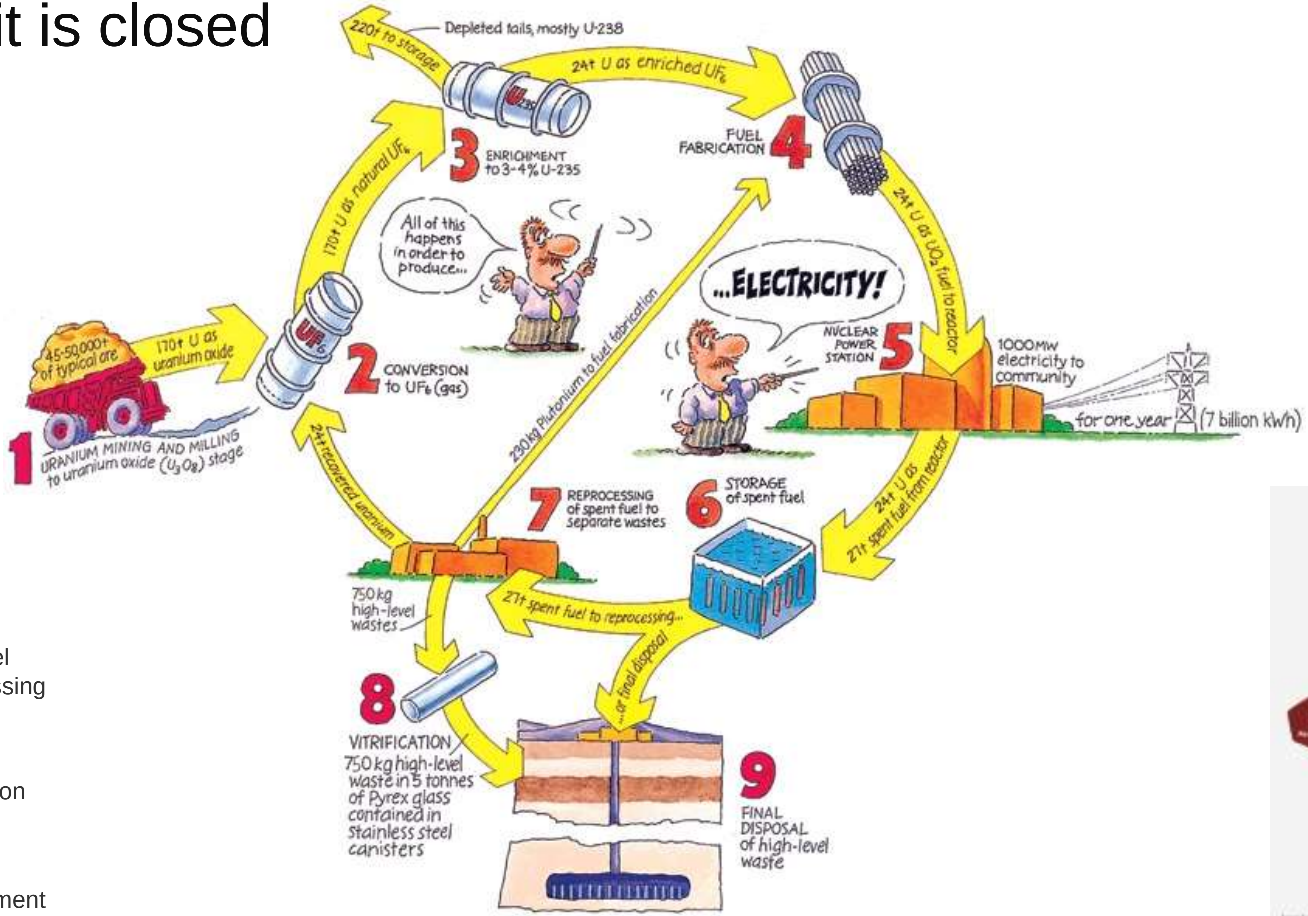
- minimize the volume of radioactive waste
- reduce the danger life of radioactive waste
- implement fuel recycling
- create sustainable partnerships
- ensure non-proliferation of critical nuclear materials

Dreams Come True
by the Best Available Technologies



Closed nuclear fuel cycle chart at «ATOMEXPO 2019»

What is Nuclear Fuel Cycle
when it is closed



7 Used fuel reprocessing

8 Waste vitrification

9 Waste entombment

Four Main Components
to make Nuclear Fuel Cycle **Sustainable**

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UNF Reprocessing & HLW Partitioning

- Radiochemical reprocessing of UNF in the Russian Federation with recovering of RepU and Pu
- Partitioning of the HLW for the purpose of "short-lived" fraction (Cs+Sr) separation and vitrification
- Return of the "short-lived" fraction to the Customer with adaptation of the Customer's infrastructure
- Storage in the Russian Federation of the "long-lived" fraction and temporarily unclaimed regenerated fissile materials, with their possible subsequent use, transmutation and conditioning for final disposal

Transport & Storage Systems for UNF and HLW

- Solutions in preparation and transportation of UNF to the Russian Federation and to return of HLW to the Customer: delivery of "turnover" casks, the interim storage for the purpose of the transport batch formation, temporary technology storage of UNF and HLW in the Russian Federation
- Development of infrastructure for HLW long-term storage and/or final isolation (geological disposal) at the Customer's site; includes delivery of “non-returnable" casks

U-Pu Fuel

- Fabrication of fresh fuel (MOX, REMIX, RepU) of the fissile materials recovered of the UNF
- Delivery to the Customer of the fuel made of RepU or U-Pu according to the program of fuel supply with replacement of natural uranium and with exception of accumulation of Pu, superfluous for development of the local nuclear industry
- Ensuring the maximum recycling of fissile materials in the existing reactor fleet

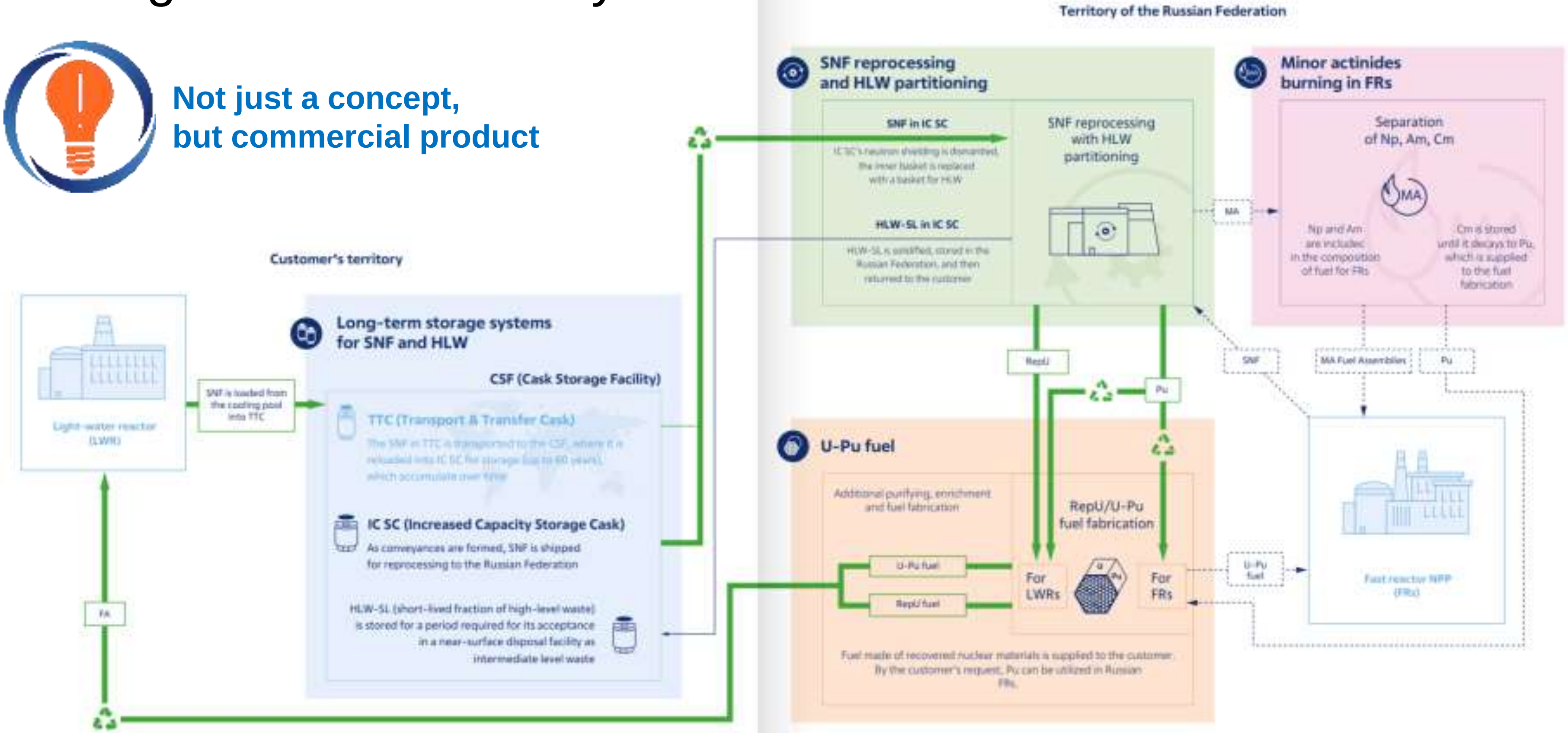
Minor Actinides Transmutation

- HLW partitioning with separation of americium, neptunium, curium.
- Fabrication of the fuel rods with Am and Cm in its matrix, placing the fuel rods in the fast neutron reactor core.
- Long-term storage of Cm for its transmutation to Pu
- Am- and Np-containing fuel irradiation in the fast neutron reactor during the standard campaign
- UNF reprocessing with minor actinides recycling and RW conditioning

Sustainable Nuclear Fuel Cycle

integrates all necessary solutions

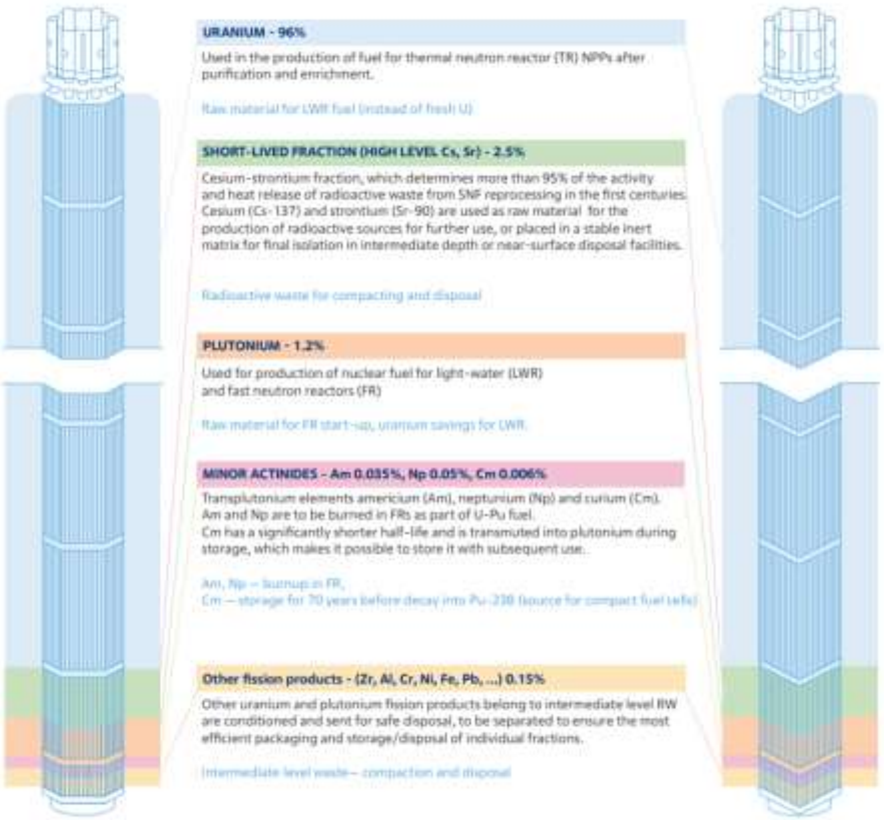
Not just a concept, but commercial product



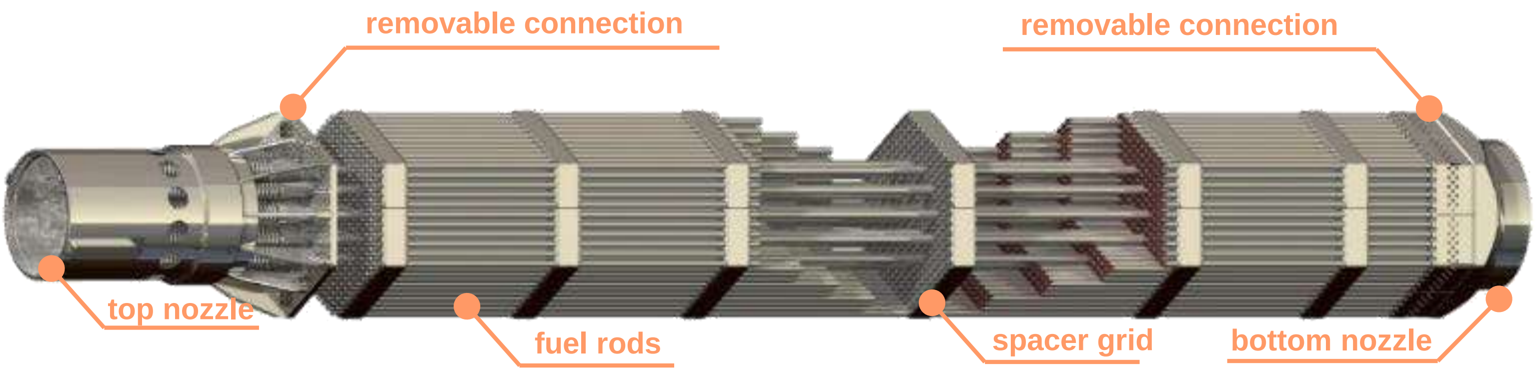
Releasing the full potential of Nuclear Energy

More than 97% of Used Nuclear Fuel could be used right now:

- Reprocessed Uranium: RBMK reactors, PWR reactors, CANDU reactors;
- Plutonium: MOX for FR, MOX for PWR (once-through);
- Neptunium: Pu-238 for space programs;
- Cesium: radioactive source (Cs-137);
- Strontium: heat generator (Sr-90);
- Curium: source for Cf-232.



U-Pu fuel brings useful materials **back to fuel cycle**



Fuel Assembly of 5th generation (based on TVS-2M). Source: TVEL

2016 May
- Launching pilot operation (LTR) of 3 experimental fuel assemblies with 18 U-Pu fuel rods for VVER-1000 (Balakovo-3 NPP)

2020 October
- Launching construction works at SCP for U-Pu fuel fabrication line

2021 April
- Commissioning of assembly lines for experimental U-Pu fuel assemblies
- Start of fuel rods manufacturing (loading of pellets)

2021 September
- Completion of pilot operation (LTR) of 3 experimental fuel assemblies with U-Pu fuel for VVER-1000

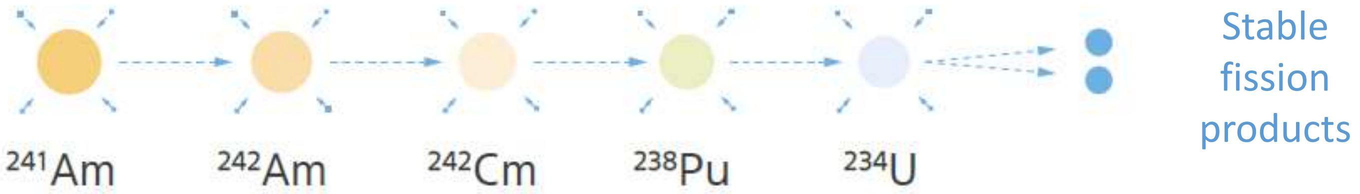
2021 October
- Experimental full-scale U-Pu fuel assemblies of TVS-2M design are manufactured (TVS-2M is one of the basic fuel assembly designs for VVER-1000)

2021 December
- U-Pu fuel assemblies of TVS-2M design are loaded into a reactor core for a pilot commercial operation (LTA)

2023 June
- U-Pu fuel assemblies of TVS-2M design successfully completed first 18-months operation campaign

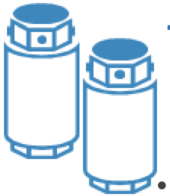
Minor Actinides Transmutation allows to **get rid off the most long-lived waste**

- Minor actinides (americium, neptunium, curium) are fission products of uranium and plutonium. Their total content in UNF is less than 1%. However, it is their impact that determines the activity and heat release of highly-radioactive waste after 300 years of holdup**.**
- Minor actinides could be transmuted by the accelerated elementary particles: by protons - in ADS, by neutrons - in fast reactors.
- ROSATOM’s fleet of operating fast reactors (BN-600, BN-800) as well as those which are under construction and development (BN-1200M, BREST-300, SVBR, MOSART) applicable for minor actinides burning on an industrial scale.
- Technology is proven in the certain tests in the research reactors (BOR-60).



- MA transmutation drastically decreases volume and danger of RW

The Casks
Two options



Transport & Transfer SNF Cask (TTC)

- Spent fuel removal from the NPP cooling pool;
- Temporary spent fuel storage until its reloading into IC SC.
- Multicycle transport operations, including fresh U-Pu fuel shipment and unloading.
- Possibility to change to long-term storage mode (welding or metallic seals).
- 18 SFAs VVER-1200.
- 117 t when loaded.

Increased Capacity Storage Cask for SNF and HLW (IC SC)

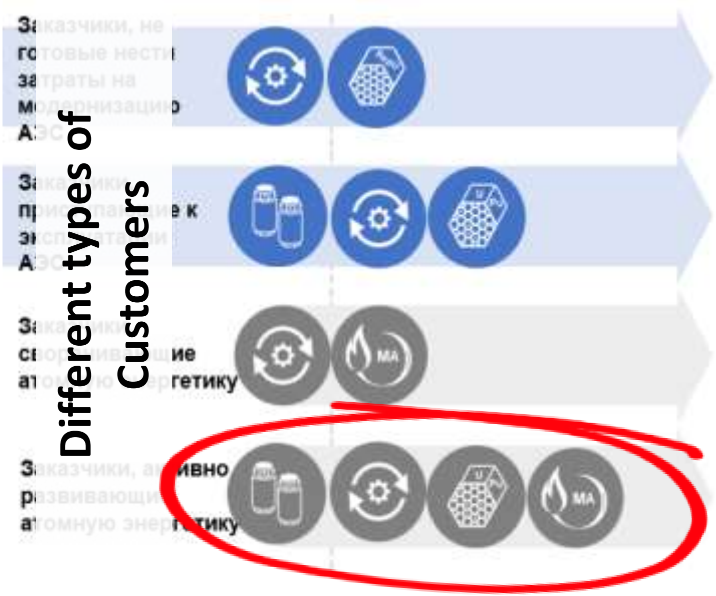
- Spent fuel long-term storage;
- One-time spent fuel shipment to Russia for reprocessing;
- Return vitrified HLW resulted from reprocessing for long-term storage.
- 3-32 SFAs VVER-1200.
- Less than 160 t.

Significant ~30% economy of expenses on cask acquisition per a spent fuel assembly in comparison to the option using just small capacity casks.

Sustainability for all

Customization and optimization

- Could be proposed on a complex or component-by-component basis on customer’s demand.
- Could be adjusted both for growing, stable and even fading scenario of Nuclear industry development.
- The components could be provided within a individual timeline basis.
- Sustainable NFC takes into account all the Customer's requests, while maintaining its main advantage - efficient fuel supply with reduction the amount of radioactive waste to be disposed.



SNF reprocessing and HLW partitioning

Dry storage systems

U-Pu Fuel

Minor Actinides Transmutation

Expected Economics*

Long-term storage of SNF at NPP site and then – direct geological disposal	Reprocessing** of SNF and then – disposal of only HLW	Reprocessing of SNF, partitioning of HLW and then – disposal of only ‘short-lived fraction’
~ $1,17 million/tU	**~ $1,14 million/tU**	**~ $0,91 million/tU**
Long-term storage of SFA at the customer’s site: providing the casks and site equipment	Creation of the accumulative platform and transportation of SFA in to Russian Federation	Construction of the Cask Storage Facility and transportation of SFA in the Russian Federation
	Temporary technological storage of SNF before processing	Temporary technological storage
Costs of disposal of SFA, including the choice of the site, underground research laboratory, construction, operation and closing of object	Reprocessing of SFA	Reprocessing of SFA, including partition of HLW
	Transportation of HLW to the country of the Customer	Loading of SLF HLW in casks and technological storage
	Temporary technological storage of HLW in the territory of the customer	Transportation of casks with SLF HLW to the country of the customer
	Disposal of HLW in the country of the customer	Disposal of SLF HLW in the country of the customer
Monitoring of a subject to disposal	Monitoring of infrastructure	Monitoring of infrastructure

Sustainable NFC allows to save more than 22% for lifecycle expenditures

in comparison with the ‘Open’ NFC solutions

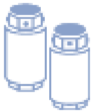
* Estimation are made for 5990 SFA [2820 tHM] (60 years of 2 NPP VVER-1200 operation)
** at RT-1 in Russian Federation
*** in the country of SNF origin

Minimal Waste
in numbers

2-unit VVER-1200
NPP

~ 6,000 SFAs
for 60 years of operation

Interim Storage



~ 340 casks
TTC-based solution (18 SFA)

NPP on-site Interim storage

~ 200 IC SC
IC SC-based solution based (31 SFA)

Cask Storage Facility

After Reprocessing and Partitioning

~ 30 IC SC ready-to-dispose
1,100 m^3 of SLF
when U-Pu fuel is providing as well

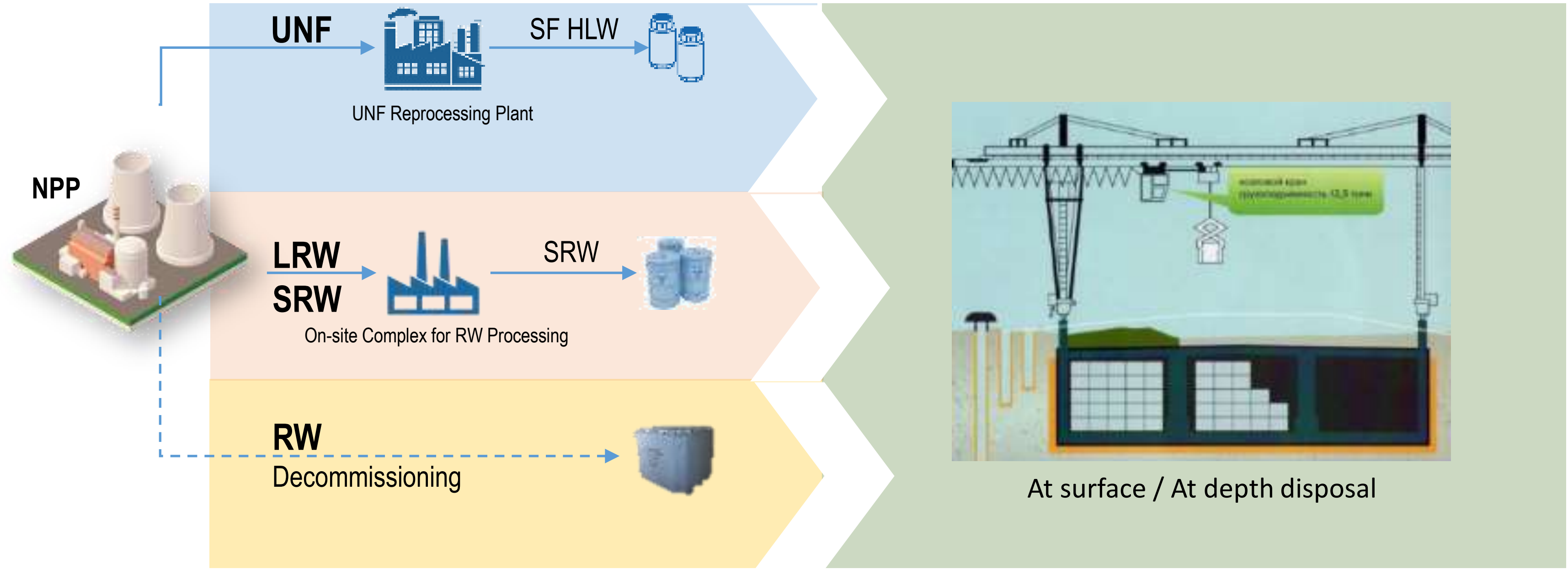
Disposal in near-surface waste repository

Direct disposal in deep geological repository

~ 7,000 m^3 with packaging

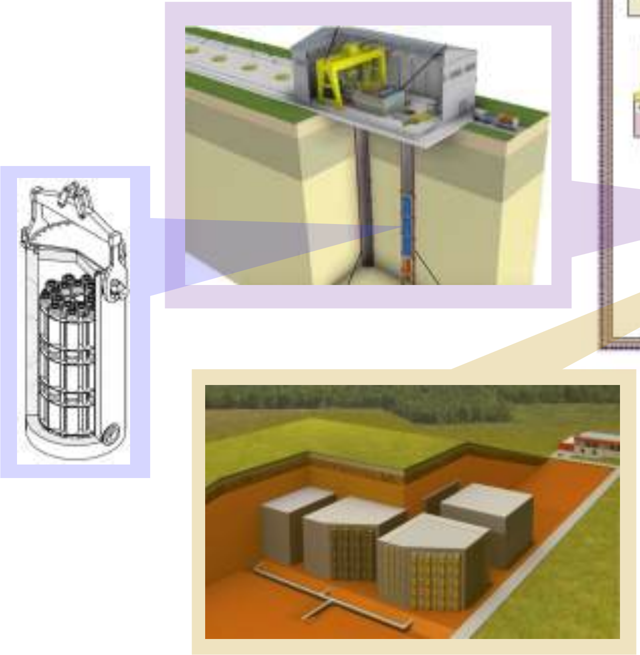
1,100 m^3 instead of ~**7,000 m^3 and**
350 years of danger instead of ~**1,000,000 years.**

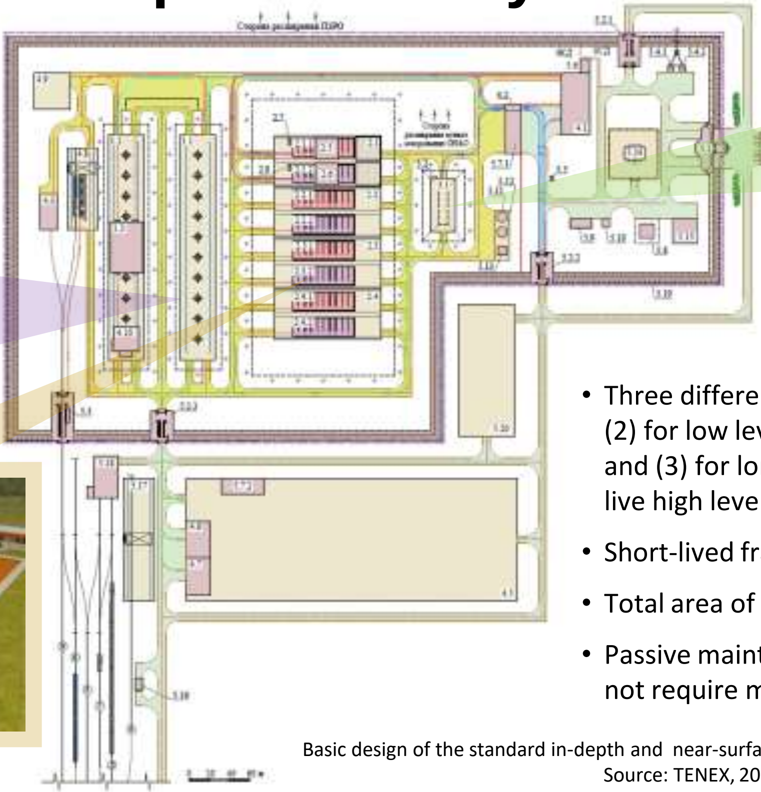
Ultimate Waste Disposal
Radioactive Waste Disposal Facility Concept



Radioactive Waste Disposal Facility materials flow chart.
Source: TENEX, ROSATOM

Radioactive Waste Disposal Facility
Standard Design





- Three different zones: (1) for very low level waste, (2) for low level and short-lived intermediate waste and (3) for long-lived intermediate waste and short-live high level waste.
- Short-lived fraction disposal at a depth of 72 meters;
- Total area of the site is 22 hectares;
- Passive maintenance-free safety system which does not require monitoring of safety parameters.

Basic design of the standard in-depth and near-surface radioactive waste disposal facility.
Source: TENEX, 2023

Standard RWDF in relation to the Sustainable NFC makes it possible to ensure the safe disposal of **all RW generated as a result of NPP operation for the whole its lifespan**

Sustainable Nuclear Fuel Cycle

is the most efficient and responsible way of nuclear fuel use

- ROSATOM proposes Nuclear Fuel Cycle solution that fully meets modern environmental requirements, particularly in terms of responsible consumption and waste minimization.
- The product is called Sustainable Nuclear Fuel Cycle, and allows (along with the construction and operation of NPP) to ensure clean energy production without leaving a nuclear legacy to the next generations.
- Components of the Sustainable NFC are based on advanced technologies: SNF reprocessing, HLW partitioning, MA transmutation etc.
- By recycling more than 97% of useful materials, Sustainable NFC helps to release the fullest potential of nuclear energy
- Sustainable NFC makes it possible to exclude deep geological disposal of radioactive waste and to dispose all the NPP waste at one small site.
- Sustainable NFC seems to be economically attractive and suitable for any customer.

Thank you for your attention!

Mikhail Baryshnikov
TENEX

Tel.: +7 495 545 0045, ext. 1012
Mob.: +7 909 162 8373
E-mail: mvlbaryshnikov@rosatom.ru
www.rosatom.com

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