WORKSHOP ON APPROACHES TO FINANCING A MULTINATIONAL REPOSITORY – CHALLENGES AND ALTERNATE APPROACHES

State atomic energy corporation “Rosatom”

Russian approach to high level waste and spent fuel management

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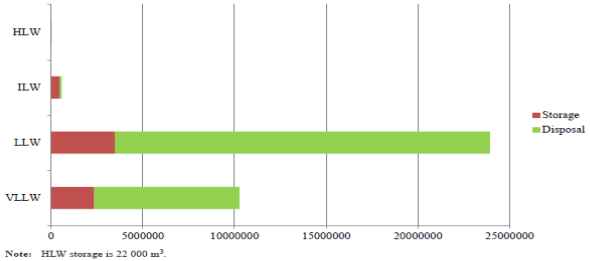
OECD Headquarters

The current situation in SNF & RW management

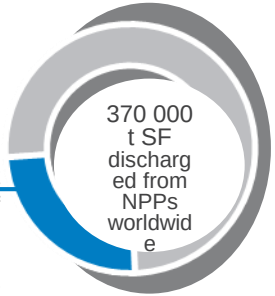
Volumes of solid radioactive waste, both in storage and in final disposal



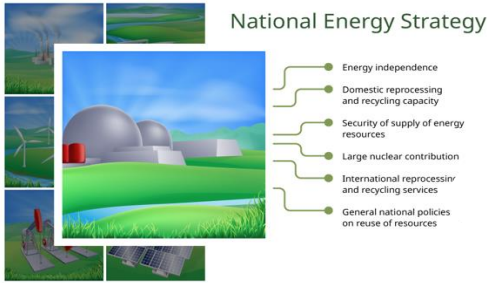
SNF accumulation worldwide

250 000 t of SNF in storage

120 000 t of reprocessed spent fuel



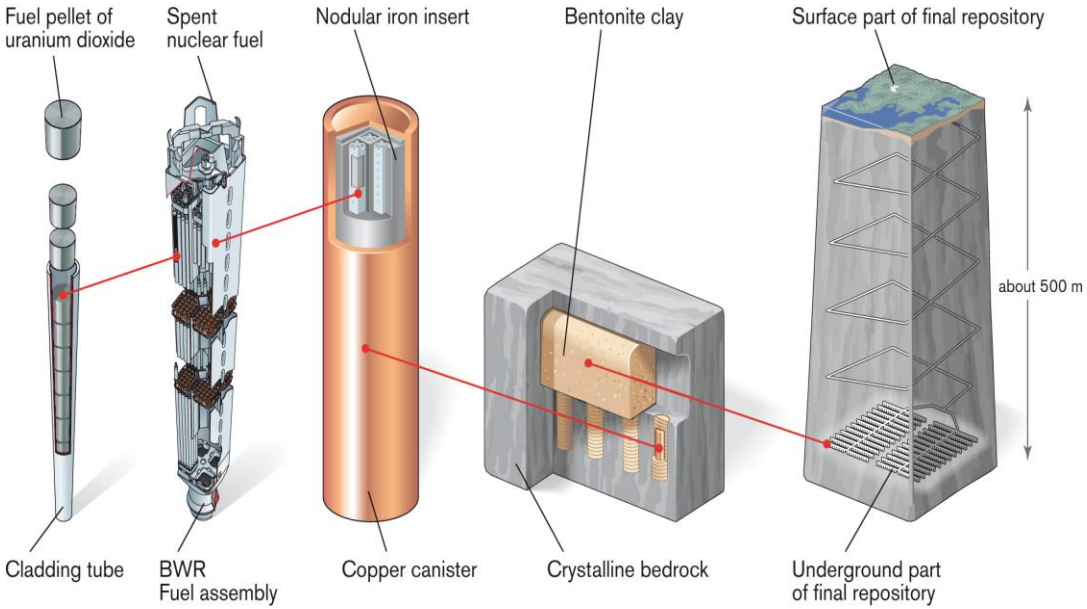
Is the spent nuclear fuel a resource or a waste? Strategic options



SNF Direct disposal

SNF is stored for several decades and disposed in a geologic repository

Finland, Sweden, USA, Canada, Germany

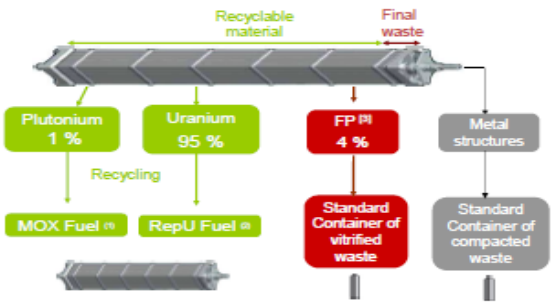


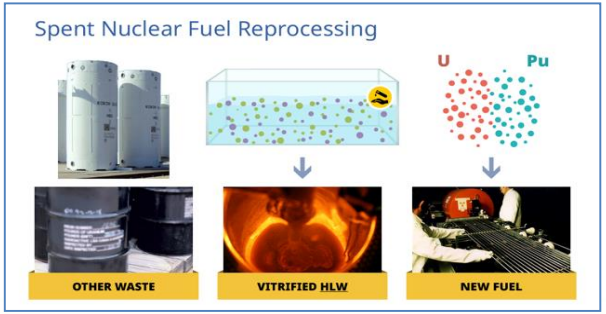
Reprocessing& Recycling today

Reprocessing/Recycling – SNF is reprocessed, U and Pu reused as fuel in light water reactors or fast reactors – high level waste disposed in a geologic repository

France, Russia, Japan, India and China (countries with large and ambitions nuclear power programmes)

Monorecycling today - MOX and repU fuel (up to 25% saving of nat U)

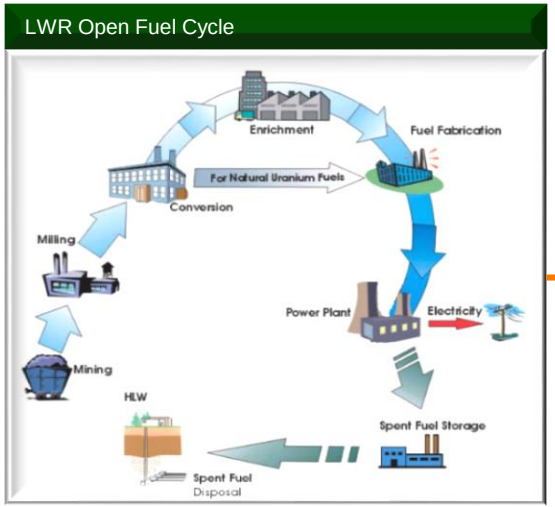


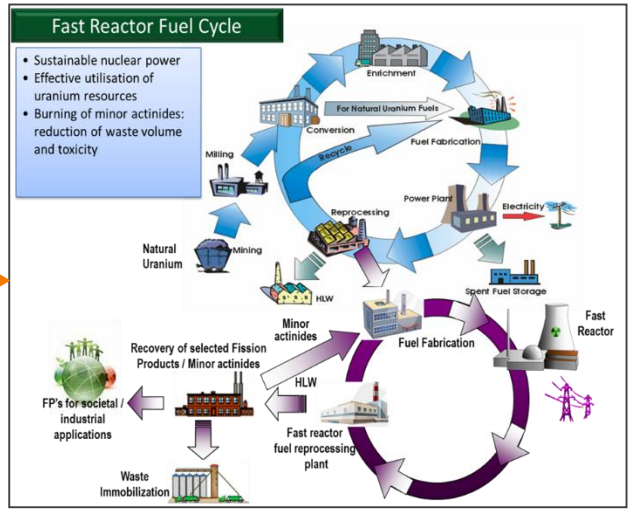


World Map of MOX Fuel users

World Map of repU Fuel users

Advanced Fuel Cycles





URANIUM DEMAND

Without recycling	100%
Recycling in light water reactors	75%
Recycling in fast reactors	5%

BN-800

Advanced nuclear system with LWR and FR , recycling U and Pu can provide long term (thousand of years) supply of low carbon electricity

Russian Nuclear Power Plants: 37 nuclear power units, 30 GW

They produce 18,9% of the electricity generated in the country.

- **VVER-1000/1200: 15 units (13 units VVER-1000 + 2 units VVER-1200) in operation**
  - **6 units under construction (Baltic NPP -2 units, Kursk NPP -2 units, Novovoronezh NPP-1, Leningrad NPP-1 unit)**

•RBMK-1000: 11 units in operation

•VVER-440: 5 units in operation till 2030, 3 units are in the course of decommissioning

•EGP-6: 4 units in operation, decommissioning

•BN-600 (FR) 1 units in operation

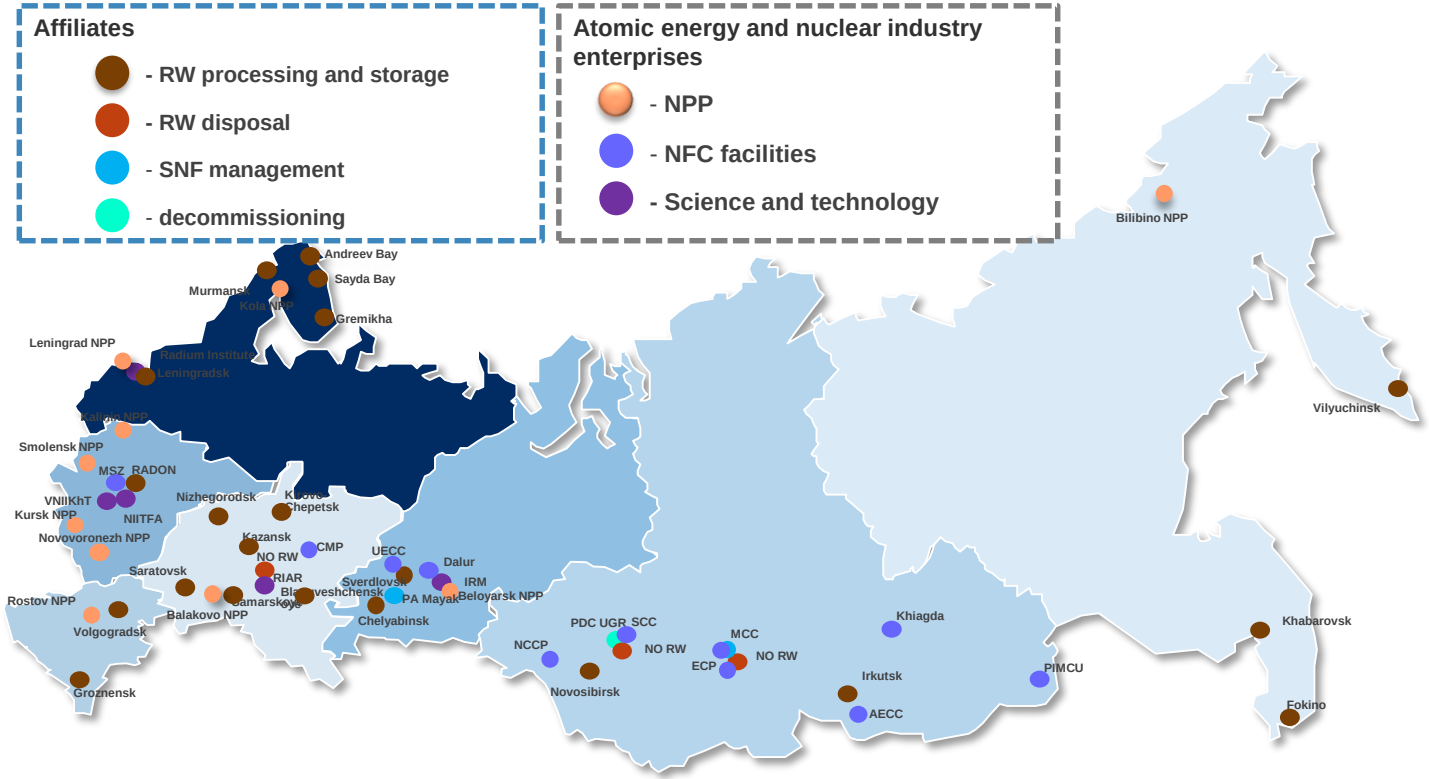
•BN-800(FR) 1 unit in operation

•FTNPP 1 unit - "Academician Lomonosov" will replace Bilibino NPP (shout down in 2019-2021 years)

•Research reactors, Ice-breakers

•Submarines

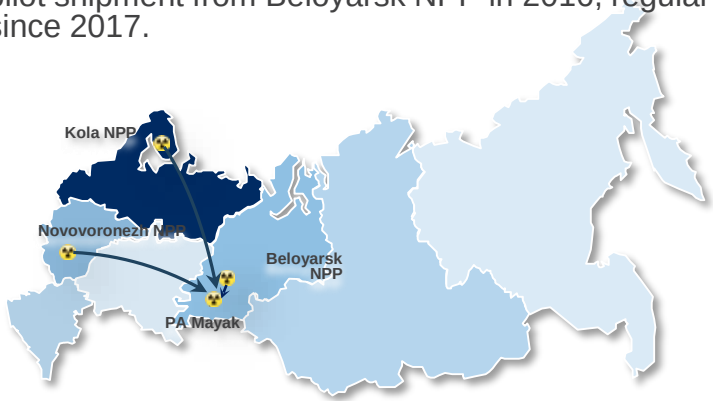
Key Enterprises in RW and SNF Management and Nuclear Decommissioning



SNFM infrastructure in Russia for closed NFC

SNF Reprocessing at PA Mayak

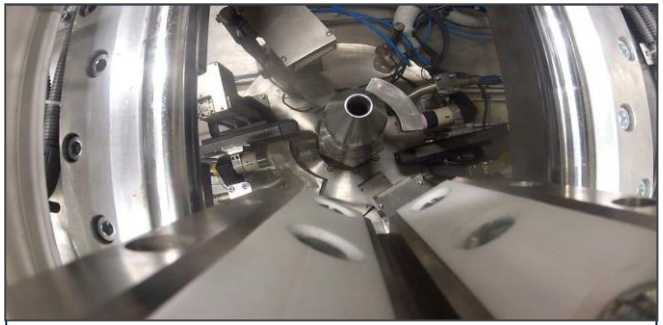
- **Routine reprocessing of** WWER-440, BN-600, nuclear submarine, research and production reactor SNF.
- 2016 – starting the industrial reprocessing of **RBMK-1000 SNF unsuitable for storage**.
- Starting the industrial reprocessing of **WWER-1000 SNF**.
- **AMB SNF:** pilot shipment from Beloyarsk NPP in 2016, regular shipment – since 2017.



- **Research reactor SNF shipment activities**
  - RIAR - Dimitrovgrad
  - IPPE, NIFHI - Obninsk
  - NITI, PNPI - Leningrad
  - MEPhI, NRC Kurchatov Institute - Moscow
  - NIIP - Moscow Region
  - IRM - Ekaterinburg
  - and other

SNFM infrastructure in Mining &Chemical Combine

Centralized wet and dry RBMK &VVER-1000 SNF storage facilities

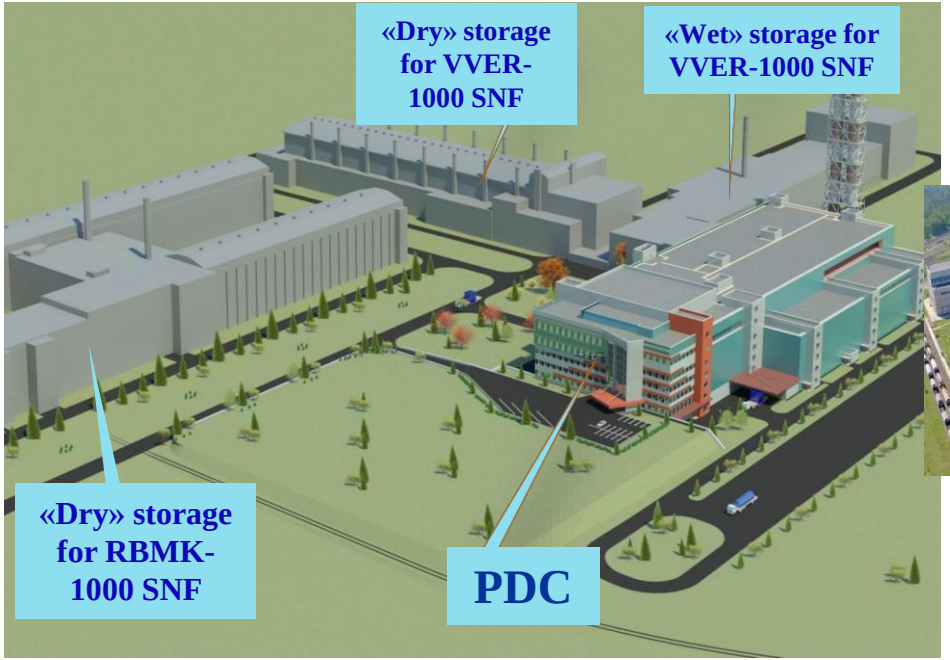


MOX-fuel for BN-800 fabrication

Centralized wet SNF storage facilities

Test Demonstration Centre for SNF reprocessing

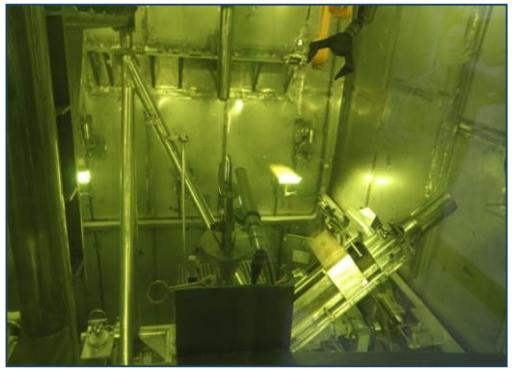
Test Demonstration Centre for SNF reprocessing within SNF management complex in MCC



2015 – Construction of PDC's first start-up complex is finished.
2021 – Full-scale PDC commissioning with a design capacity of 250 tons of SNF

Test Demonstration Centre - the first unit (research hot cells)

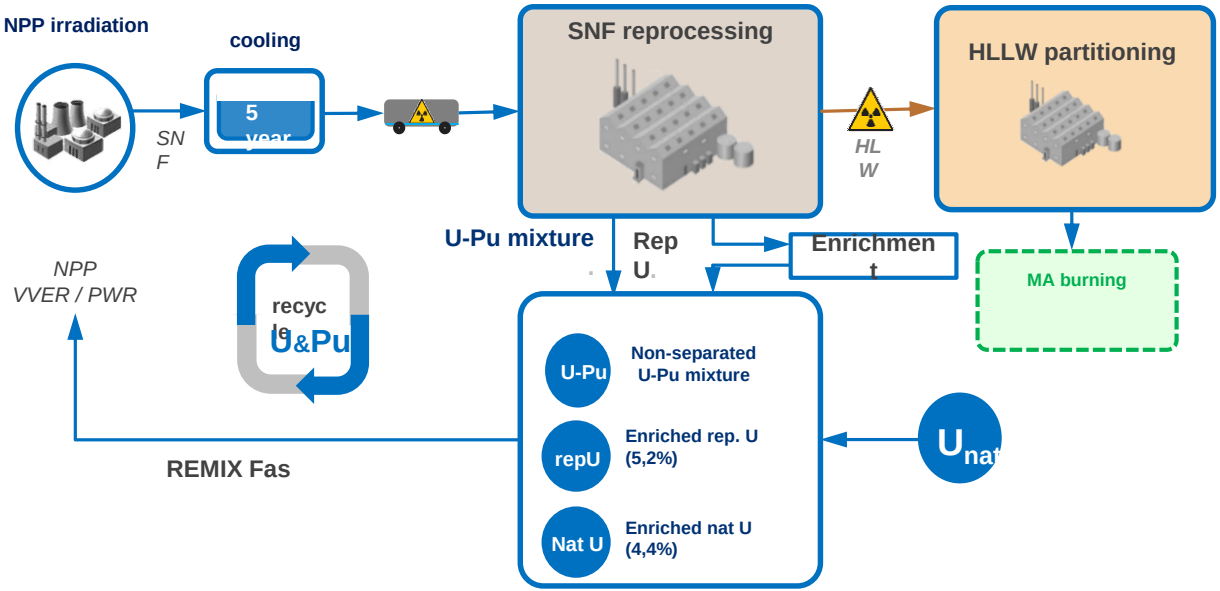
- Pilot-Demonstration Center 1st unit with a capacity of up to 5 t/y was completed. In 2016, technology testing has started.



"hot cell" equipment

REMIX fuel – U& Pu multi - recycling in LWR reactors

REMIX fuel is the mixture of U and Pu from LWR SNF reprocessing, with the addition of enriched uranium (natural or rep. U) .
REMIX fuel enables multiple recycling of the entire quantity of U and Pu from SNF, with the 100% core charge and 20%- saving of natural uranium in each cycle.



Different types of REMIX fuel

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REMIX-A
with enriched uranium

- U-Pu — Non-separated U-Pu mixture
- repU — Enriched rep. U - 0%
- $U_{nat.}$ — Enriched nat U (19,75%)

- The Pu content is equal to the initial content in SNF
- On each recycle, the fresh fuel is added nat uranium (enrichment of 19.75%). After the SNF reprocessing part of the rep U is not in demand
- Number of recycles - 7

REMIX AB
with repU enrichment and nat U feeding

- U-Pu — Non-separated U-Pu mixture
- $repU_{,}$ — Enriched rep. U (5,2%)
- natU — Enriched nat U (4,4%)

- The Pu content is equal to the initial content in SNF
- On each recycle, the fresh fuel is added the repU (enriched to 5,2 %) and nat U (enriched to 4.4%)
- Number of recycles - 7

REMIX-B
with nuclear materials volume reduction (without uranium feeding)

- U-Pu — Non-separated U-Pu mixture
- $U_{per.}$ — Enriched rep. U (up to 6,2%)
- Nat U — nat U - 0 %

- The Pu content is 4%
- On each recycle, the fresh fuel is added the repU
- There is no nat U feeding (nuclear materials volume reduction)
- Number of recycles – up to 4

REMIX FUEL STRATEGY ROAD MAP

2014 2016 2017 2018 2020 2030

Pilot project for 3 experimental REMIX FAs fabrication and irradiation

FAs fabrication for NPP and RR

- Start of irradiation in MIR RR and Balakovo NPP
- Post-irradiation examination

- REMIX fuel performance

- REMIX Fuel fabrication facility
- Safety case development for VVER-1000/1200 with REMIX fuel

- Fuel fabrication facility
- 6 FAs REMIX
- License for REMIX fuel loading

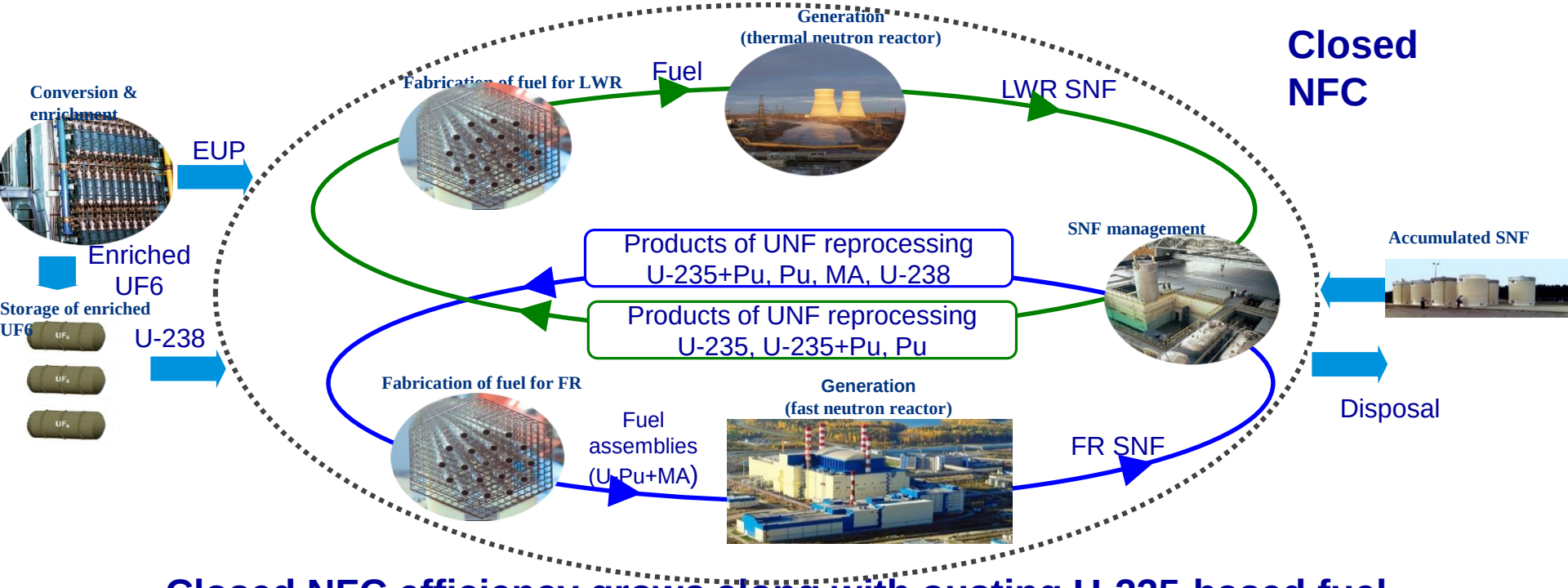
100% core charge REMIX-fuel VVER-1000/1200

100% core charge REMIX-fuel

Irradiation of experimental REMIX FAs is carried out in the MIR RR at NIIAR, Dimitrovgrad

FAs with REMIX fuel loading for irradiation to Balakovo NPP

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



Closed NFC efficiency grows along with ousting U-235-based fuel by U-Pu fuel

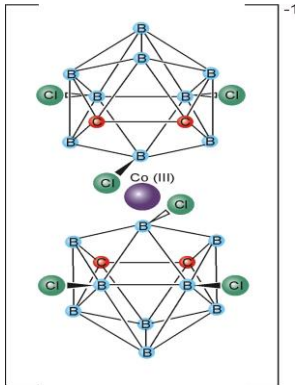
The R & D program for CNFC advanced technologies with BN-800

- Development and scaling of BN-800 MOX SNF management technologies (transportation , storage and reprocessing) (2019-2024);
- Development of technologies of partitioning HLW and transmutation of MA in FR (2019-2034);
- Development of the technologies of all NFC stages with mixed nitride uranium-plutonium fuel (irradiation of nitride fuel in BN-800, reprocessing, demonstration of fuel recycling)(2019-2027).

Extraction Cascade of the EF-35 Extraction (from 1996)

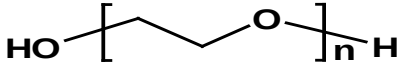
More than 1200 m^3 of HLW

was processed with Cs-Sr recovering



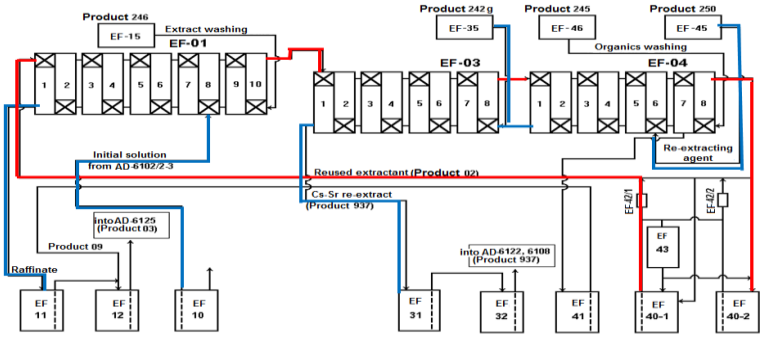
ChCoDiC

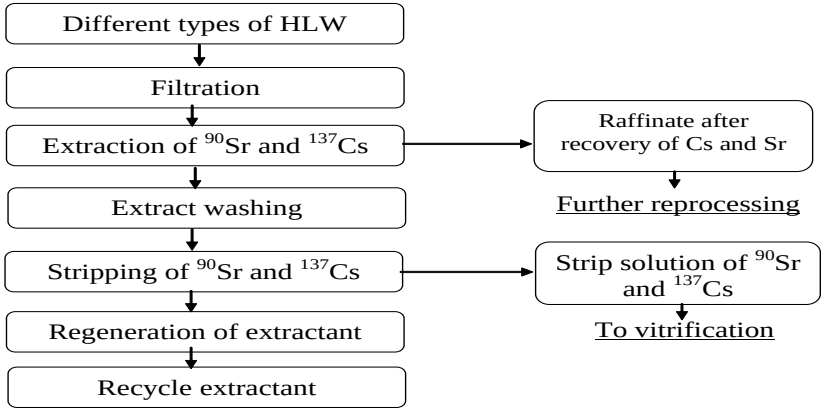
cobalt dicarbollyde



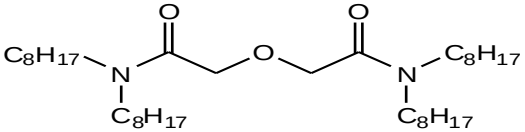
PEG

polyethylene glycol



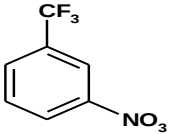


TODGA-Based Technology for Extracting Trans Plutonium and Rare-Earth Elements. Extraction of Rare-Earth Elements, Am-241 and Cm-244 Using Elution - Displacement Chromatography

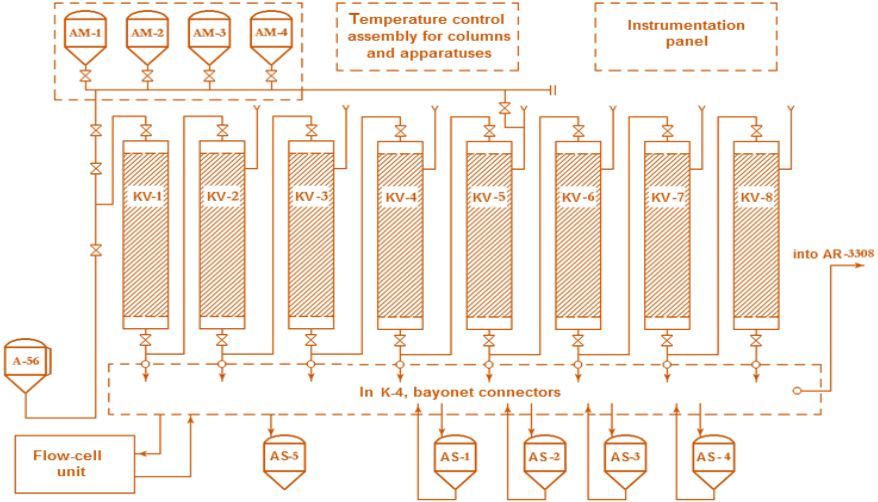


TODGA

N, N, N ', N'-dioctyl diamide diglycolic acid



meta-nitrobenzotrifluoride



Fractions:

- Am 65 g,
  Cm less than 0.8 %,
  Eu less than 0.1 %.
- Cm 9 g, Am less than 6 %

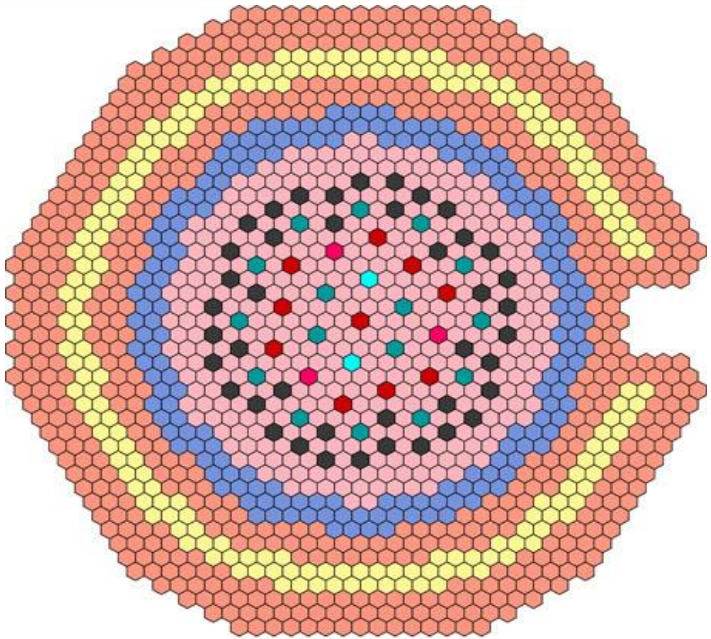
Development of advanced technologies for HLW partitioning

- Maturing of HLW partitioning technology (with Am, Cm, RE, Cs-Sr recovering from HLLW and its separation) including modernization partitioning facility at Mayak plant – (up to 2022)
- Developing and deployment facility of HLW partitioning facility at the MCC (up to 2025)
- Developing and maturing the technologies of Am, Cm oxides and mixed U-TPE oxides precipitation and production, the facility deployment (up to 2025)
- Developing and maturing the technologies for MA-bearing fuel fabrication (up to 2023)
- Fabrication, irradiation , PIE, recycling experimental Am and Np-bearing fuel (up to 2034)
- Complex database for fuel characteristics and codes for MA recycling (up to 2030)

Russian approaches in the minor actinides transmutation

- Transmutation of MA (Np, Am) in fast reactors in Russia
- Incineration of TRU's (including Np, Am, Cm) in molten salt fast reactors

Transmutation of MA in fast reactors



The following scenarios are considered when analyzing the concept of handling MA in energy fast:

- Homogeneous transmutation of MA in the fuel
- Heterogeneous transmutation of MA in special assemblies (example for BN-1200 in the figure)

Calculations of the MA transmutation efficiency have shown that FR can be an effective burner for MA.

More than 2 tons of MA can be burned in the reactor during the reactor operation, i.e. the decrease in the amount of MA due to burning out is approximately the order (see Table)

The best option (for FR) is the option of transmutation of Np and Am with isolation and storage of Cm

The necessary efficiency can be achieved both in the homogeneous approach and in the heterogeneous

Table 1. The total balance of MA for various methods of burning them

Method of burning out MA	Without burning	homogeneous			heterogeneous		
		all MA	without Cm	Without Cm+Am	all MA	without Cm	Without Cm+Am
MA Balance	2520	310	500	1150	315	500	1140

Development of technologies for transmutation of MA in FR

1. Justification of neutron-physical characteristics of core with MA and efficiency of transmutation of MA in FR, development of requirements for fuel with of minor actinides. (Incl. the experiments with MA- FAs in BFS, in BOR-60 and BN-800)(up to 2032)

2. Studies in support of homogeneous recycling of Np (desing, fabrication, irradiation and post-irradiation examination of mixed oxide and nitride uranium-plutonium fuel with Np in amounts of 0.1% to 1%) (up to 2031)

3. Studies in support of homogeneous and heterogeneous recycling of Am (desing, fabrication, irradiation and post-irradiation examination) The result – the option with optimal performance of Am recycling in FR FC

- homogeneous recycling of Am with content from 0.4% to 1.2% (mixed nitride and oxide fuel, uranium nitride and oxide fuel)(up to 2031);
- heterogeneous recycling of Am with a content of up to 10-12% (mixed nitride and oxide fuel, uranium nitride and oxide fuel)(up to 2026).

Incineration of TRU's (including Np, Am, Cm) in molten salt fast reactors with homogeneous core

Benefits for MA burning in Molten Salt Reactors

- overcoming the difficulties of solid fuel fabrication / re-fabrication with large amounts of transuranic elements (TRU);

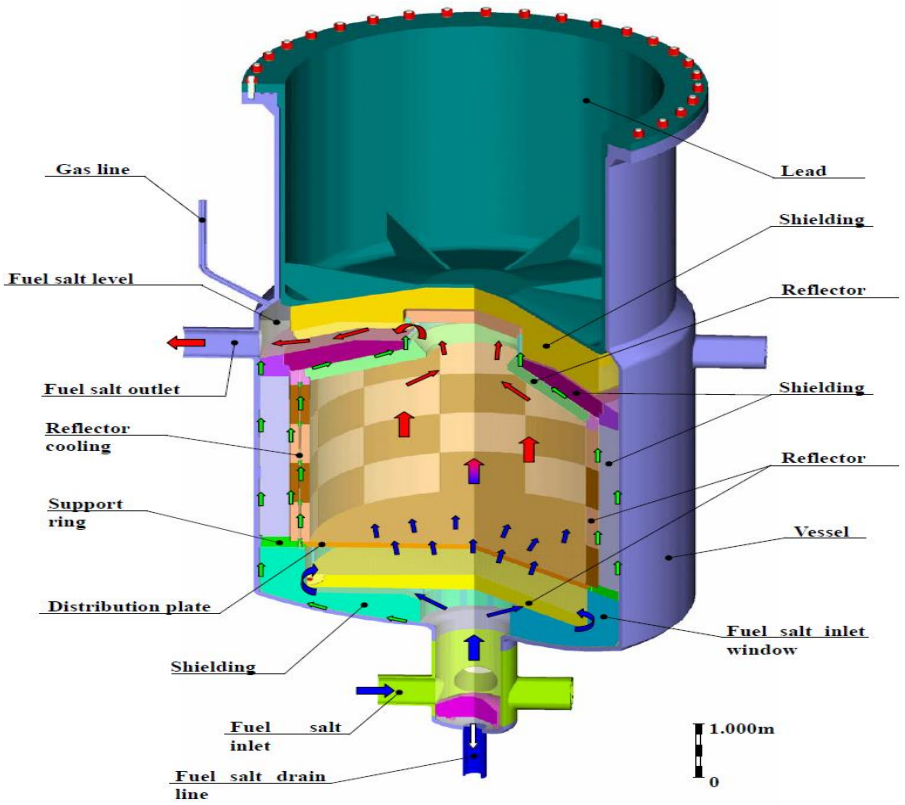
- fuel make up (fertile/fissile) without shutting down the reactor;

- on-line fission-product removal using physical (inert gas sparging) and pyrochemical processes;

- thermal expansion of fuel salt provides strong negative temperature reactivity coefficient in homogeneous core;

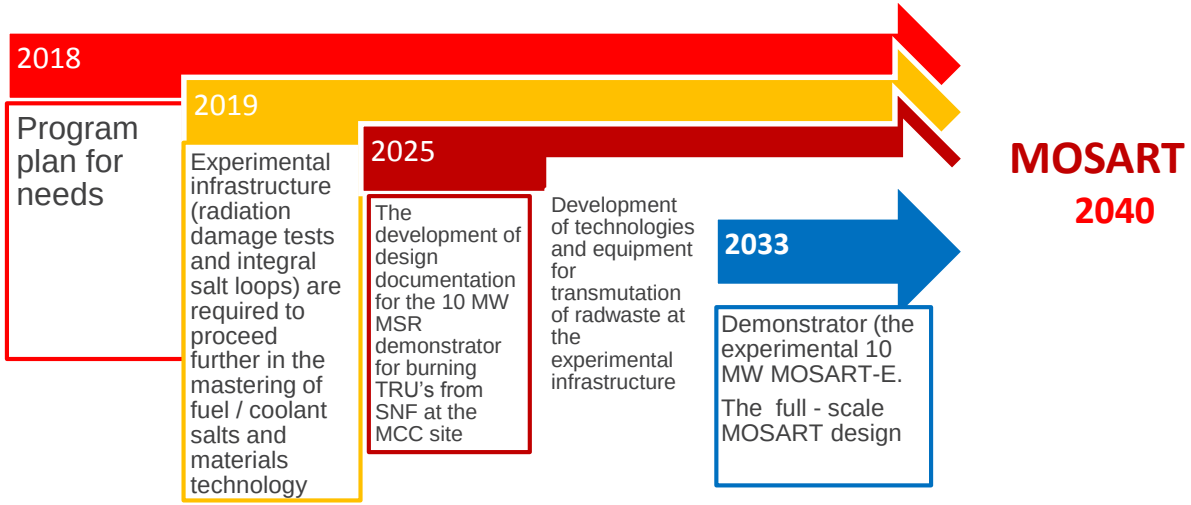
- better resource utilization by achieving high fuel burn-up

The MOSART concept with a fast spectrum homogeneous core

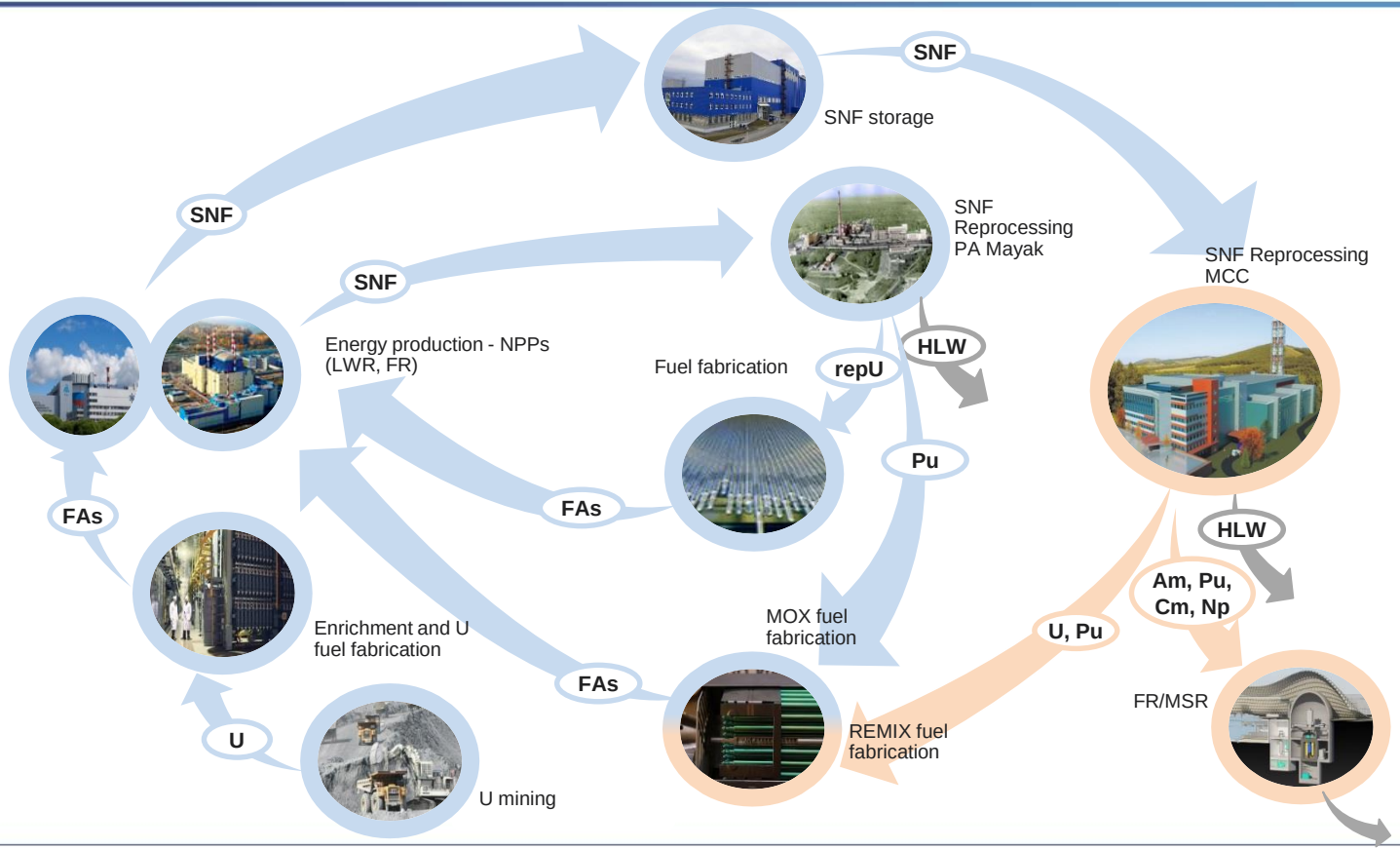


- MOSART fuelled with compositions of plutonium plus minor actinide trifluorides from LWR spent nuclear fuel
- MOSART salt contains no uranium or thorium and thus is a pure actinide burner. As a consequence, the reactor destroys the maximum quantities of actinides per unit of energy output.
- Basis for MOSART concept is the use of Li,Be/F or Li,Na,Be/F solvents with decreased of BeF_2 (27-25 mole %) content and its high enough solubility for AnF_3 (2 to 3 mole % at 600°C).
- Fuel salt clean up for Li,Be/F MOSART system could be based on the reductive extraction in liquid bismuth
- Optimized configuration of homogeneous core meets most important safety issues: (1) areas of reverse, stagnant or laminar flow are avoided, (2) max temperature of solid reflectors was minimized and (3) temperature coefficients of reactivity in core with 0.2 m graphite reflector in the range 900-1600K are strongly negative (– 4.125 pcm/K)

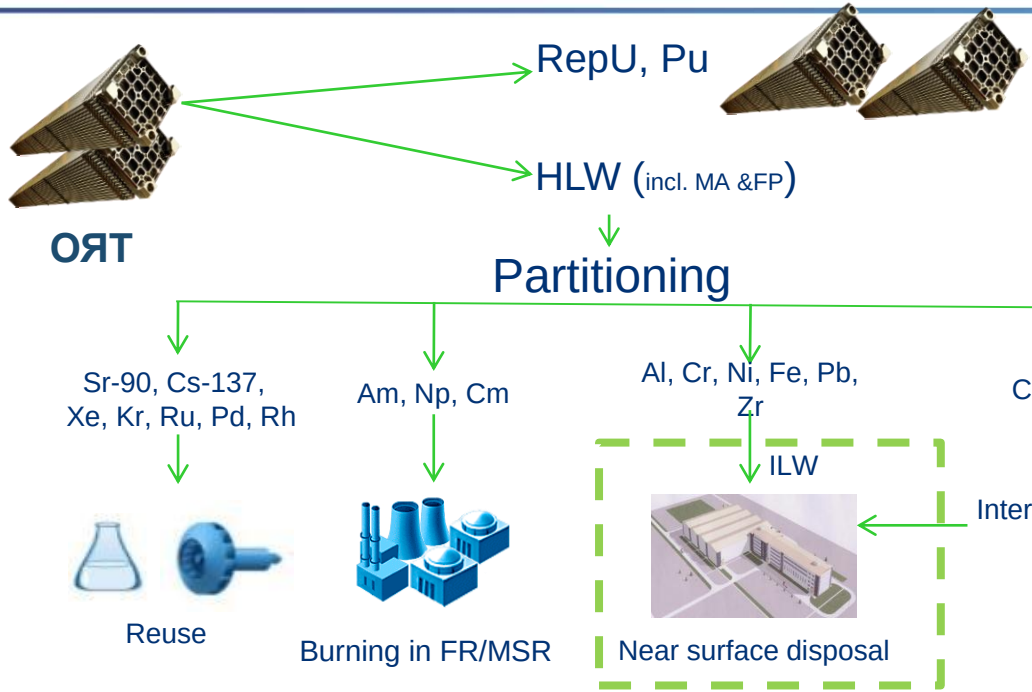
The construction of a large power MOSART is proposed to be preceded by the construction of 10 MWt Demo MOSART unit to demonstrate the control of the reactor and fuel salt management with its volatile and fission products with different TRU loadings for start up, transition to equilibrium, drain-out, shut down etc. There are opportunities to further improve the efficiency of burning minor actinides in MOSART, which will be justified by the results of the experimental setup.



Infrastructure of Advanced Fuel Cycles in Russia



The advance HLW management



Advanced Fuel Cycles can significantly reduce the amount & radiotoxicity of HLW to be disposed of. The waste for returning to the customer can be ILW for near surface disposal.

Contact information

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