Rosatom`s activities in the Spent Nuclear Fuel Management: status, trends, projects

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Russian Nuclear Power Plants fleet

VVER-1000/1200:
13 units in operation (12- VVER-1000, 1- VVER-1200) + 8 units under construction

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 is scheduled for 2019-2021

BN-600 (FR) 1 units in operation
BN-800 (FR) 1 unit in operation

Research reactors
Ice-breakers
Submarines

Annual accumulation UF amounts about 700 tons, up to 230 tons/year reprocessed

18,6% of the electricity generated in the country
10 NPP
35 nuclear power units most of them located in the European part of the country
Residual operational lifetime of NPPs by sectors (reactor\year)

- **Sector of growth:** VVER-1000, 1200
  - Accrued operational life: 94%
  - Residual lifetime: 6%
- **Sector of functioning:** RBMK-1000
  - Accrued operational life: 79%
  - Residual lifetime: 21%
- **Phase-out sector:** VVER-440, AMB, EGP
  - Accrued operational life: 56%
  - Residual lifetime: 44%
- **Development sector:** Fast reactors
  - Accrued operational life: 67%
  - Residual lifetime: 33%

- Fleet of various reactors should be equipped with different technologic facilities of SNF management
- Commissioning of numerous VVER-1000, 1200 NPP units
Accumulation of spent nuclear fuel at Rosatom enterprises' site
Reprocessing is a basic method of UNF management.
RT-1 Reprocessing Plant in Ozersk.
The first SNF Reprocessing Facility in Russia

- UNF reprocessing plant in Russia
- Operation since 1977
- Over 5000 ton of SNF reprocessed
- Annual reprocessing of appr. 200 tons of SNF (from VVER-440, BN-600, VVER-1000, damaged spent fuel from RBMKs, research reactors, icebreakers and submarines)
- The list of the reprocessed SNF is diversifying (plans for reprocessing of SNF from AMB, EGP and all the types of research reactors)
- The technology of reprocessing: Purex-process (extraction of regenerated Uranium, Plutonium and Neptunium as the reprocessing products)
- Enhancement of RW management system
- Production of isotopes Cs-137, Am-241, Pu-238, Sr-90
Centralized water-cooled ("wet") SNF storage facility;
Centralized air-cooled ("dry") SNF storage facility;
Pilot Demonstration Center for innovation-based SNF treatment;
MOX fuel fabrication for fast neutron BN-800 type reactors.
The full-scale storage complex for SNF from RBMK-1000 and VVER-1000 was built in December 2015. Constructions maintain integrity under earthquake load up to 9.6 points and withstand direct plane crash.
“Dry” centralized storage

The “dry” storing technology is based on the **passive principle of safety protection** in case of a power supply loss all conditions of safe SNF storing will be retained thanks to the **natural air-cooling convection**.

All engineering operations while transferring SNF to the storage as well as the storing process itself are fully automated to exclude the influence of “human factor” on SNF storage safety.
2015 – Construction of PDC’s first start-up complex is finished.
Initial data to be received for the large-scale commercial plant for SNF reprocessing.
2016 – Start-up facility of research hot cells starts operation. New treatment technologies of SNF from both thermal and fast neutron energy reactors along with closing the NFC.
Radioactive waste generation after thermal reactors UNF reprocessing at PDC

<table>
<thead>
<tr>
<th>Radioactive waste volumes:</th>
<th>Existing technologies</th>
<th>Pilot-demonstration Center Technology</th>
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<tbody>
<tr>
<td>Vitrified HLW $m^3/t$ SNF</td>
<td>$\sim 0.6$</td>
<td>$0.1$</td>
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<tr>
<td>Solidified intermediate level waste, $m^3/t$ SNF</td>
<td>$\sim 40$</td>
<td>$3.0$</td>
</tr>
<tr>
<td>Low level liquid radwaste volume (Controlled release of effluents), $m^3/t$ SNF</td>
<td>$\sim 100$</td>
<td>No</td>
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By-product management

- Utilization Rep U – fuel fabrication for LWR
- Utilization Pu - fuel fabrication for FR & LWR
- RW – conditioning for storage and disposal
MOX fuel fabrication industrial plant was constructed at MCC in 2014.

For Russia, this is the first step towards commercial involvement of the plutonium potential into the nuclear fuel cycle by closing the nuclear fuel cycle at BN-800 fast neutron reactors

Loading of the full active zone BN-800 by MOX fuel is scheduled for 2019.

System for fuel pellets sintering, MOX fuel fabrication

System for assembling fuel rods into the final fuel assembly structure
REMIX fuel – U& Pu multi-recycling in thermal reactors (VVER-1000)

REMIX fuel is the mixture of U and Pu from LWR SNF reprocessing, with the addition of enriched uranium (natural and rep. U)

2014 – start of the project for 3 experimental Fas REMIX fuel fabrication and irradiation in RR and NPP.

2017 – 2017 – start of the project for REMIX fuel fabrication pilot plant, and safety case for REMIX fuel developing.

REMIX fuel assemblies 1% $^{239}$Pu + 4% $^{235}$U

Fuel fabrication based on (U-Pu)O$_2$ Enriched uranium (natural or rep. U)

U and Pu recycling

Non-separated U-Pu mixture

Spent REMIX Fuel (1±2%) Pu + (~1%) $^{235}$U

Burn-up level ~ 50 GW·day/tU

100% core charge

SNF cooling ~5 years

SNF reprocessing

Final disposal of radwaste

Partitioning of HLLW, Radioisotopes for medicine and industry
Integral indicators of fuel balance in REMIX- NFC (60 years life cycle)

The total consumption of uranium and separation work

 Integrity accumulation of SNF / HLW

a) Open NFC with increased burn up (70 GW/t) UOX-fuel
b) Closed NFC with REMIX fuel (50 GW/t burn up)

Closed NFC with REMIX-fuel: the benefits

Save natural U and separation works (the integral consumption for 60 years is reduced by 25% compared to Open NFC)
All Pu and rep U returns back into the fuel cycle, all spent fuel is recycled (dramatically reduce the total number of stored spent fuel and HLW about 6 times in the end of the life cycle of NPS); 5 cycles REMIX fuels completely cover the 60-year term of life of the reactor - the reactor can work "on same" fuel (with feeds by the enriched uranium
The "quality" waste for final disposal (the content of long-lived actinides) are fundamentally improved: in Open NFC in this category all SNF, in REMIX CNFC all the uranium and plutonium from spent fuel back to regenerated.
REMIX fuel it is possible to load 100% of an active zone of the VVER reactor;
Don’t need considerable expenditure for modernization of the NPP equipment;
the full guarantee of non-proliferation – no pure plutonium.
2014 - 2016 – Rosatom`s project activity for 3 experimental Fas REMIX fuel fabrication and irradiation in RR and NPP

Safety justification

- Khlopin Radium Institute
  - Neutron physical modeling
- Kurchatov Institute
  - Safety analysis
- VNIIAES
  - Safety case
- Bochvar`s VNIINM
  - The fuel element design, fuel performance
- Gydropress
  - Safety case
- Atomenergo project
  - License of Russian regulator

Fabrication

- PA Mayak
  - Pu
- Khlopin RI
  - UO₂
  - Pellet fabrication
- MSZ
  - Master mix
- VNIINM
  - Components for fuel elements
- NZKHK
  - SKHK
  - NZKHK
  - Fas fabrication

- 10 Fuel elements
- 3 FAs

Irradiation in RR MIR RIIAR
Irradiation in Balakovo NPP
FAs with REMIX fuel loading for irradiation to Balakovo NPP

Experimental fuel assemblies with fuel rods containing fuel REMIX – installed in the reactor
FAs with REMIX fuel loading in reactor core (Balakovo NPP)
The start of the project for REMIX fuel fabrication pilot plant, and REMIX fuel safety case developing is approved by the decision of Rosatom in July, 2017.
The stages of the project for REMIX fuel fabrication pilot plant, and REMIX fuel safety case developing:

- **2016**: 3 experimental Fas with REMIX fuel fabrication
- **2017**: 10 research Fas with REMIX fuel fabrication
- **2018**: REMIX fuel safety case for VVER-1000 with REMIX-fuel loading developing
- **2019**: REMIX fuel fabrication pilot plant
- **2020**: Irradiation
- **2021**: Post-irradiation investigations
- **2025**: REMIX-fuel full core loading (one VVER-1000 unit)
The creation of the integrated complex for SNF management (including storage, reprocessing, MOX-fuel fabrication) is under finishing.

Sitting REMIX fuel fabrication pilot plant at MCC will allow to significantly reduce the investment and logistic expenses.

Existence of the natural containment.

The cost of reprocessing and recycling at the integrated plant is significantly less (520-710$/kg for reprocessing and a fabrication uranium - plutonium fuel) than for separate activities (1000$/kg for reprocessing and 1500$/kg for a fabrication uranium - plutonium fuel) (IAEA estimates).
The concept for SNF management integrated plant

- Wet storage
- Dry storage
- Test demonstration plant (reprocessing VVER-1000 SNF)
- RT-2 reprocessing plant
- U-Pu fuel fabrication
- U enrichment
- U mining
- RW storage before disposal
- NPP with VVER-1000, RBMK-1000, BN-800
- U mining
- U enrichment
- U, Pu
- TPO
- BAO
- MSR
- P&T
HLLW partitioning – no need of the geological disposal site for the new comer country customer

ILW

Reprocessing SNF

U+Pu

U+Pu fuel for LWR

HLW

Cs, Sr

RE

Solidified intermediate level waste

Long live nuclides (PGM, Tc, Se)

MA (Np, Am, Cm)

Molten salt reactor for MA burning

Storage ~ up to 300 years

For near surface disposal

For near surface disposal

Storage for future need (valuable raw materials)

RW for returning to the customer

It is used NFC in Russia
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