Back End strategy in the Russian Federation: interfaces related issues and potential solutions

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Content of the presentation

1. Rosatom Mission, Goals and Responsibilities
2. Overview of the strategy for spent fuel management in Russia
3. Interfaces issues in BEFC
4. Other issue (communication between reactor operators, associated vendors, regulators, waste management organization, mechanisms for information management, mechanisms for knowledge management)
1. Rosatom Mission, Goals and Responsibilities
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 is scheduled for 2019-2021
- BN-600 (FR) 1 unit in operation
- BN-800 (FR) 1 unit in operation
- FTNPP 1 unit - "Academician Lomonosov"
  - will replace Bilibino NPP (shut down in 2019-2021 years)
- Research reactors Ice-breakers
- Submarines

Annual accumulation amounts 650-700 tons, up to 230 tons/year reprocessed
The Mission of Rosatom is

To provide the planet with clean, safe, affordable energy and innovations based on nuclear technologies.

The State Corporation Rosatom is

- Over 300 enterprises
- Over 250 thousand of employees
- State management authority in the field of atomic energy use
- State management authority in the field of RW management
- Employer sponsored education for students ~ 2,000 people per year;
- Staff evaluation and development ~ 108,000 people;
- Establishment of a managerial candidate pool, including TOP-30 and TOP-1000.
Rosatom Responsibilities in Back End activity

- Nuclear and radiation safety at Rosatom enterprises
- SNF, RW and RM management
- Nuclear decommissioning
- State customer and coordinator of relevant federal target programs
Rosatom Structure in Relevant Activities

Director for the State Policy on RW, SNF and ND

Office for SNF Management
Office for RW Management
Nuclear legacy, remediation and decommissioning office
Nuclear submarine dismantling office
International Coordination Office

Affiliates
- Mining & Chemical Combine (Krasnoyarsk Region)
- RosRAO (19 offices)
- Pilot demonstration Center UGR (Tomsk Region)
- National Operator for RW Management
- Federal Center on nuclear and radiation safety
- Radon

Competitive tender
- Managing SNF, RW and decommissioning activities
  - 45 enterprises (including Rosenergoatom (10 NPPs), TVEL (8 organizations), Innovation Management Unit (8), Nuclear Weapons Complex (10), ARMZ (3), Atomenergomash (3), Healthcare (3))
- Engineering and service suppliers
  - over 250 enterprises
Key Enterprises in RW and SNF Management and Nuclear Decommissioning

**Affiliates**
- RW processing and storage
- RW disposal
- SNF management
- Decommissioning

**Atomic energy and nuclear industry enterprises**
- NPP
- NFC facilities
- Science and technology
Russian State Safety Regulatory Authorities

Rostecnadzor

Technical issues of Nuclear and Radiation Safety and Security

EMERCOM of Russia
  Fire Safety

FMBA of Russia
  Radiation Protection of Personnel

Rospotrebnadzor
  Radiation Protection of Population

Ministry of Environment
  Environmental Safety

Rosprirodnadzor
2. Overview of the strategy for spent fuel management in Russia
Principal Chart of Two Component Nuclear Power Generation
(System of Fast Neutron & Thermal Neutron Reactors)

Conversion & enrichment

Fabrication of fuel for LWR

Fuel

LWR SNF

Products of UNF reprocessing
U-235+Pu, Pu, MA, U-238

Fuel assemblies (U-Pu+MA)

Products of UNF reprocessing
U-235, U-235+Pu, Pu

Generation (fast neutron reactor)

Generation (thermal neutron reactor)

SNF management

Storage of enriched UF6

Accumulated SNF

Disposal

Enriched UF6

U-238

EUP

Closed NFC

Closed NFC efficiency grows along with ousting U-235-based fuel by U-Pu fuel
SNFM infrastructure in Russia for closed NFC

- SNF type for reprocessing increasing (SNF VVER-1000 – since 2016)
- PuO2
- Partitioning and isotopes production
- Modernization of the HLW management infrastructure
- MOX-fuel for BN-800 fabrication
- SNF Centralized wet and dry storage facilities
- Test Demonstration Centre for SNF reprocessing (commissioning in 2021)
- Underground research laboratory (commissioning in 2022)
Technologic Patterns of SNF Management: Temporal Storage and Reprocessing

VVER-1000

Centralized dry/wet storage at MCC (Zheleznogorsk)

PDC, RT-2 Reprocessing (starting in 2021)

VVER-440, BN-600, SNF of research reactors, submarines, AMB and EGP reactors

RT-1 at Mayak Reprocessing

Reprocessing after storage

RBMK-1000

Centralized dry storage at MCC (Zheleznogorsk)

5% Reprocessing

95% Reprocessing

Reprocessing is a basic method of SNF management
Siting and Construction License for a URF (URL)

- URL pre-construction activities were started
- 2018 – strategy for deep geological repository development was approved
Geological Disposal: the Strategy

**Pre-construction activities (< 5 years)**
- Knowledge management strategy
- RD&D Program
- Monitoring program
- Disposal concept update
- URF support structures
- RW producers
- WAC

**URF activities (≥ 5 years)**
- RD&D activities at URF
- Disposal concept update
- Design optimization
- WAC quality assurance program
- Scientific and public expertise of the safety case
- International collaboration

**Operation of the first unit (≥ 30 years)**
- Specific RD&D extension
- Monitoring
- Development of the closure solutions
- First unit packages emplacement

**URF construction (≥ 5 years)**
- URF personnel training
- RD&D activities at URF
- Safety case
- Disposal concept update
- Launch of the URF and demonstration facility
- RW producers predisposal management programs
- Informational center in Krasnoyarsk

**Decision on repository construction (≥ 5 years)**
- URF personnel certification
- Long-term safety case development
- Decision on the first unit of the repository construction
- First unit operation plan
- Waste packages transportation

**URF construction (≥ 5 years)**
- Additional RD&D
- Knowledge preservation
- Long-term monitoring

**Closure of the first unit (≥ 5 years)**

The key areas of focus at each phase:
- Management system and work force
- RD&D program
- Design development
- Practical efforts at the site
- Pre-disposal management of RW
- Stakeholder engagement
3. Interfaces issues in BEFC
The characteristics SNF that must be considered for its management

- fuel type(s) (geometry, weight and enrichment);
- burnup (minimum to maximum range);
- cooling time (decay heat);
- radionuclide inventory;
- the physical state of the clad (clad failure and external contamination).
# The influence of characteristics SNF for BE activities

<table>
<thead>
<tr>
<th>The characteristics SNF</th>
<th>Storage</th>
<th>Transportation</th>
<th>Reprocessing &amp; recycling</th>
<th>Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open FC</td>
<td>Closed FC</td>
<td>Open FC</td>
<td>Closed FC</td>
</tr>
<tr>
<td>fuel type(s) (geometry, weight and enrichment)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>burnup</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>cooling time</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Radio nuclide inventory</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>the physical state of the clad</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Fuel type(s) (geometry, weight and enrichment)- influence on transportation and receiving facility

<table>
<thead>
<tr>
<th>Cask</th>
<th>TUK-11BN</th>
<th>TUK-6</th>
<th>TUK-109</th>
<th>TUK-13B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor type</td>
<td>BN-600/800</td>
<td>VVER-440</td>
<td>RBMK-1000</td>
<td>VVER-1000</td>
</tr>
<tr>
<td>Max height of cask, mm</td>
<td>4540</td>
<td>4145</td>
<td>6200</td>
<td>6035</td>
</tr>
<tr>
<td>Max diameter, mm</td>
<td>2740</td>
<td>2670</td>
<td>3150</td>
<td>2060</td>
</tr>
<tr>
<td>SFA capacity, pcs.</td>
<td>35</td>
<td>30</td>
<td>144 PSFa</td>
<td>12</td>
</tr>
<tr>
<td>Decay heat, kW</td>
<td>10,7</td>
<td>20</td>
<td>5,6</td>
<td>20</td>
</tr>
<tr>
<td>Max enrichment for U-235, %</td>
<td>33</td>
<td>4,4</td>
<td>2,6</td>
<td>4,5</td>
</tr>
</tbody>
</table>
Higher burnup means reduction in SNF mass per unit of energy generated but
- Higher isotopic inventory per tone of SNF,
- Higher heat output,
- Higher neutron emissions,
- Long-term integrity of higher burnup UOX and MOX fuels
These all make the management of higher burnup SNF more challenging
### Burn up influence on transportation – modernization of casks

<table>
<thead>
<tr>
<th>Cask Type</th>
<th>TUK-109</th>
<th>TUK-6</th>
<th>TUK-13</th>
<th>TUK-109T</th>
<th>TUK-140</th>
<th>TUK-141</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBMK-1000</td>
<td></td>
<td></td>
<td></td>
<td>Modernization is carried out</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>144 ПТ SFA</td>
<td>30 SFA</td>
<td>12 SFA</td>
<td>Capacity</td>
<td>155 ПТ SFA</td>
<td>36 SFA</td>
</tr>
<tr>
<td></td>
<td>5,6 kW</td>
<td>20 kW</td>
<td>20 kW</td>
<td>Decay heat</td>
<td>8,4 kW</td>
<td>30 kW</td>
</tr>
<tr>
<td></td>
<td>2,6 %</td>
<td>3,6 + 4,4 %</td>
<td>4,4 %</td>
<td>Enrichment max</td>
<td>3,2 %</td>
<td>4,87%</td>
</tr>
<tr>
<td></td>
<td>30 GWd/t_{HM}</td>
<td>57 GWd/t_{HM}</td>
<td>58 GWd/t_{HM}</td>
<td>Burn-up max</td>
<td>37 GWd/t_{HM}</td>
<td>67,9 GWd/t_{HM}</td>
</tr>
<tr>
<td>VVER-440</td>
<td></td>
<td></td>
<td></td>
<td>Capacity</td>
<td>36 SFA</td>
<td>18 SFA</td>
</tr>
<tr>
<td>TUK-109</td>
<td></td>
<td></td>
<td></td>
<td>Decay heat</td>
<td>30 kW</td>
<td>36 kW</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Burn-up max</td>
<td>67,9 GWd/t_{HM}</td>
<td>67,9 GWd/t_{HM}</td>
</tr>
</tbody>
</table>
**Solutions for recycling SNF reprocessing products**

<table>
<thead>
<tr>
<th>Reprocessing Products</th>
<th>Technological Solution</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RepU</strong> obtained during SNF reprocessing with burnup $&lt;$ 35 GW·day/tU</td>
<td>Purification and Enrichment at Siberian Chemical Plant (Seversk)</td>
<td>Fuel supply for VVER-440/1000</td>
</tr>
<tr>
<td><strong>RepU</strong> obtained during SNF reprocessing with burnup in the range of 35-55 GW·day/tU</td>
<td>Enrichment in Seversk with improved parameters as a result of mixing with natural or “slightly irradiated” component</td>
<td>Fuel supply for RBMK and VVER-440/1000</td>
</tr>
<tr>
<td><strong>RepU</strong> obtained during SNF reprocessing with burnup $&gt;$ 55 GW·day/tU</td>
<td>Production at Machine Building Plant (Electrostal) of pellets through direct mixing of powder with variable enrichment</td>
<td>Fuel supply for RBMK and CANDU*</td>
</tr>
<tr>
<td>Reactor-grade Pu</td>
<td>Fabrication of MOX fuel assemblies for BN-800</td>
<td>Pu utilization in BN-800</td>
</tr>
<tr>
<td></td>
<td>Fabrication of REMIX fuel assemblies for VVER-1000/1200*</td>
<td>Fuel supply for VVER-1000/1200*</td>
</tr>
</tbody>
</table>

* Solutions are being currently developed
Recycling of RepU and Pu
Currently existing technique

**RepU Treatment Chart**

- Reprocessed $\text{U}_3\text{O}_8$
- RepU Treatment Line at Seversk
  - Dilution / Purification
  - UN
  - Conversion
  - $\text{UF}_6$
  - Enrichment
  - ERU/$\text{UF}_6$
  - Reconversion
  - ERU/$\text{UO}_2$ powder
  - Fabrication
  - RMBK-1000

**PuO$_2$ based MOX Fuel Fabrication Chart**

- MOX Fuel Fabrication Facility at Zheleznogorsk
  - Plutonium blending and affinage unit
  - Power reactor grade $\text{PuO}_2$
  - Depleted $\text{UO}_2$
  - MOX-fuel pellet fabrication line
  - Components (claddings, plugs, strings)
  - Fuel rods fabrication line
  - Components (spacers, tubes, heads)
  - Fuel assemblies fabrication line
  - BN-800

Components
- (claddings, plugs, spacers, heads)
REMIX fuel is the non-separated 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.
Integral indicators of fuel balance in REMIX- NFC (60 years life cycle)

The total consumption of uranium and separation work

<table>
<thead>
<tr>
<th></th>
<th>The total consumption of uranium</th>
<th>The total consumption of separation work</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>85.7 KT MEPP</td>
<td>24 KT MEPP</td>
</tr>
<tr>
<td>b</td>
<td>60.9 KT MEPP</td>
<td>18.6 KT MEPP</td>
</tr>
</tbody>
</table>

Integral accumulation of SNF / HLW

<table>
<thead>
<tr>
<th></th>
<th>The integral accumulation of SNF</th>
<th>The integral accumulation of HLW for disposal</th>
<th>Including actinides</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>9014 T</td>
<td>9014 T</td>
<td>8949 T</td>
</tr>
<tr>
<td>b</td>
<td>547 T</td>
<td>32.9 T</td>
<td></td>
</tr>
</tbody>
</table>

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 30% compared to Open NFC)
All Pu 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)
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.
NFC scheme using regenerated nuclear materials in LWR

- RW disposal
  - NO RAO

- Reprocessing
  - MCC
  - PA Mayak

- Conversion and enrichment
  - Radiochemical purification
  - Conversion
  - SCC

- Production of nuclear fuel and FA fabrication
  - MSZ
  - Fabrication Fas from repU
  - Conversion UF6 -> UO2
  - Fabrication Fas from repU

- RW disposal
  - NO RAO

- U, Pu, MA+FP

- (U, Pu, MA+FP)

- Conversion
  - Urep (~1%) 2 ppb
  - Urep (~1%) 2 ppb
  - Urep (~14%) 2 ppb

- Enrichment
  - Urep + nat (2 ppb → 5 ppb)
  - Urep up to 15 ppb
  - UF6 ~3,1% 2 ppb → 5 ppb
  - UF6 до 26%
  - UF6 до 5,7% 15 ppb

- Fabrication
  - UO2 up to 5,7%
  - UO2 up to 17%

- Fas REMIX fabrication
  - MCC
Example of the influences of the physical state of the clad. Damaged Fuel RBMK

- RBMK-1000 power reactors have been operated at Leningrad, Kursk and Smolensk NPPs in the European part of Russia.
- Before 2012 all SFAs were stored in at-reactor and away-from-reactor wet storages facilities at NPPs.
- Since 2012 the RBMK-1000 SNF has been shipped to the centralized storage facility.

**Complex for SNF preparing for dry storage at NPP**
- Cut SFAs into the bundles
- Place the bundles into the ampoules
- Load the filled ampoules into a basket
- Load the filled basket into TUK-109 cask
- Dry SNF in TUK-109 cask
- Prepare TUK-109 cask for shipment

**Centralized dry storage facility at MCC**
- Receives the TUK-109 cask with SNF
- Open the TUK-109 cask
- Transfer the basket with SNF to the hot cell
- Reload the ampoules with SNF into the canisters
- Seal the canisters with welding
- Place the canisters into the storage cells

Receiving defective and leaky spent fuel (non-conforming SFAs) for dry storage is prohibited.
Non-Conforming SFAs

1. Leaky SFAs

2. Tight SFAs with structural damages:
   – more than two destroyed SG in succession
   – damaged or destroyed SG 10 or SG 11 located near the between the bundles
   – local increase of the SFA diameter more than 87 mm induced by the damaged SG
   – a gap between the bundles is less than 9 mm

3. Severely damaged SFAs (bent, deformed, partially destroyed) and pilot SFAs with a peculiar structure

Damages of RBMK-1000 SFAs

Shares of leak-tight non-conforming SFAs with different damages (statistics on 2012-2014)
The aim was to start delivery of leak-tight damaged RBMK-1000 SNF for reprocessing on a regular basis.

Concept of leak-tight damaged SNF handling:

- Cut the SFAs in the hot cell (cutting bay) of Leningrad NPP complex
- Use the non-tight expendable ampoules
- Use TUK-109 cask
Removal and Reprocessing of Leak-Tight Damaged SNF (2)

Perform Work
- Design and fabricate the non-tight expendable ampoules and basket for TUK-109 transport packaging
- Design, fabricate and mount the equipment for handling the new ampoules in the hot cell (cutting bay) of Leningrad NPP complex
- Acquire a hydraulic crane, special yokes and a railcar for the cask handling facility at RT-1 plant
- Increase the load capacity of cranes in the storage facility at RT-1 plant
- Modify the hoist trolleys in the pool the storage facility at RT-1 plant
- Arrange an area for reloading of some ampoules from one basket to another in the storage pool at RT-1 plant
- Design and fabricate the auxiliary equipment for handling casks, baskets and ampoules at RT-1 plant
- Prepare the Safety Analysis Reports
- Obtain licenses on activities to be performed and a certificate of approval for package design and shipment
- Carry out the combined trials of the equipment
Removal and Reprocessing of Leak-Tight Damaged SNF (3)

Transport packaging for leak-tight damaged RBMK-1000 SNF and its components

- Transport Package
- Basket
- Non-tight Expendable Ampoule
Removal and Reprocessing of Leak-Tight Damaged SNF (4)

Receipt and preparation of leak-tight damaged RBMK-1000 SNF for reprocessing at RT-1 plant

- Receive TUK-109 cask
- Unload TUK-109 cask
- Put TUK-109 cask upright
- Remove the energy absorbing container from TUK-109 cask
- Put TUK-109 cask on a railcar
- Transport TUK-109 cask
- Remove the lid
- Withdraw a basket
- Install the basket on a hoist trolley
- Transport the basket in the storage pool
- Reload some ampoules to another basket to reduce weight
- Install the basket on the hoist trolley
- Transfer the basket in the hot cell
- Withdraw the ampoules from the basket
- Put the ampoules in horizontal position
- Transfer the ampoules for chopping
Removal and Reprocessing of Leak-Tight Damaged SNF (5)

Main Results

- Transport packaging for leak-tight damaged RBMK-1000 SNF was created
- Equipment for TUK-109 cask handling at RT-1 plant was prepared
- Equipment for handling non-tight expendable ampoules in the hot cell (cutting bay) of Leningrad NPP complex was prepared
- Preparation for regular delivery of leak-tight damaged RBMK-1000 SNF for reprocessing was performed

From 2016 removal and reprocessing of Leak-Tight Damaged RBMK SNF is proceed on a regular basis
Impact of waste acceptance criteria for DGR – needs for P&T. Infrastructure for Advance Fuel cycle
4. Other issue (communication between reactor operators, associated vendors, regulators, waste management organization, mechanisms for information management, mechanisms for knowledge management)
Other issues

Mechanisms to facilitate communication between reactor operators, regulators, waste management organization

Rosatom (as a State management authority in the field of atomic energy use) organizes

- Meeting on the regular base between reactor operators, fuel vendor, the storage/reprocessing operators, and waste management organization
- Conference to exchange current information
- Scientific technical body on discussing the current state, programs and prospects of the new technologies

Mechanisms for information management (records retention) – databases in reactor operators, fuel vendor, the storage/reprocessing operators.

Now – Rosatom launched the project for new database developing (with all the history, technical description, the main isotopic composition for each Fas).
Mechanisms for knowledge management

The goal - to support of existing structures, competencies, knowledge retention mechanisms, culture, external network, and knowledge management systems is to foster interdisciplinary worldwide dialogue on the state of the art KM solutions and future agenda of integrating KM tools into R&D, engineering and operations domains due to rapid advances in technology.

The need to maintain and manage nuclear knowledge was triggered by several factors, among them economic and safety requirements, as well as the need to preserve design and construction knowledge, foster global scientific cooperation and develop human resources in the industry. Operators, regulators, public organizations and private companies use approaches and tools of nuclear knowledge management to improve business processes and performance.

ROSATOM’s knowledge management tools include

- corporate effective communication strategy (a social network of professional communities)

- corporate data base solution (corporate e-library)

- corporate management strategy(an information system for the IP rights managing)

-education, training and personnel development - a multilevel educational and advanced training system is made available to all the employees.
Education and training

**ROSATOM Training and development system**

**Universities**
- National Research Nuclear University (MEPhI) and the consortium of key universities
  - Traditional higher education degree programmes in nuclear sector
  - Non-degree programmes for Rosatom employees
  - Degree programmes in nuclear sector for international students (Vietnam, Turkey, Jordan, Bangladesh etc)
- Other universities
  - Traditional higher education degree programmes for students in non-nuclear sector (e.g. construction, machinery)
  - Specific non-degree programmes for Rosatom employees

**In-company training**
- ROSATOM Corporate Academy
  - Leadership, Hi-Po and management development programmes
  - Functional non-technical training in nuclear sector, e.g. finance, supply chain, HR, IT etc
  - Customized programmes for different businesses and corporate functions
- Central Institute for continuing education and training (SICET)
  - Professional training programmes in specific technical nuclear areas (e.g. nuclear safety)
  - Special programmes for NPPs staff
  - Customized programmes for different businesses
- Local training centres
  - Professional qualification courses for blue collars and line managers (technical skills)
  - Regulatory training courses and exams
  - Full-scale simulator training courses (for NPPs)
The system of personnel development in ROSATOM

Key principles of Development Programmes

- Clearly defined target groups and selection criteria
- Active involvement of Rosatom executives
- Individual preparation
- Ongoing learning transfer through project-work during the programme
- Learning outcomes evaluation and rating of graduates at the end of development programmes
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