Strategies and National Programs of Closed Fuel Cycles: Russian Expert Vision

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Actual Agenda:  
New Technological Platform (NTP) of Nuclear Power

NTP – Innovation Nuclear System (INS – definition by INPRO Project), which will includes:

- Full-scale reprocessing of Thermal Reactors SNF with production of Pu bearing fuel for Fast Reactors
- Fast Reactor Fleet with its Closed Fuel Cycle (FR CFC)
- This FR CFC includes full Recycle of Long-Lived MA and FP

So called Module of NTP = TR SNF Reprocessing Plant + FR Fleet + FR CFC
<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>FACILITY</th>
<th>AMOUNT</th>
<th>OPERATION (Year)</th>
<th>CAPACITY (Fuel Type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Marcoule (UP1)</td>
<td>18,000</td>
<td>1958 -1985</td>
<td>400 (GCR); decom</td>
</tr>
<tr>
<td></td>
<td>La Hague (UP2/3)</td>
<td>25,000</td>
<td>1967/1990~</td>
<td>1600 (LWR)</td>
</tr>
<tr>
<td>Germany</td>
<td>WAK</td>
<td>180</td>
<td>1971 -1990</td>
<td>30 (LWR); decom</td>
</tr>
<tr>
<td>Japan</td>
<td>Tokai-Mura</td>
<td>1,000</td>
<td>1977 ~</td>
<td>90 (LWR)</td>
</tr>
<tr>
<td></td>
<td>Rokkasho-Mura</td>
<td>-</td>
<td>2006 ~</td>
<td>800 (LWR)</td>
</tr>
<tr>
<td>Russia</td>
<td>Chelyabinsk</td>
<td>3,500</td>
<td>1971 ~</td>
<td>400 (VVER-440) real 100</td>
</tr>
<tr>
<td></td>
<td>Krasnoyarsk</td>
<td>-</td>
<td>2020 ~</td>
<td>1500 (VVER-1000)</td>
</tr>
<tr>
<td>UK</td>
<td>B205</td>
<td>42,000</td>
<td>1967~</td>
<td>1500 (GCR)</td>
</tr>
<tr>
<td></td>
<td>THORP</td>
<td>4,390</td>
<td>1994 ~</td>
<td>900 (LWR)</td>
</tr>
<tr>
<td>USA</td>
<td>NFS West Valley</td>
<td>194</td>
<td>1966 -1972</td>
<td>194 (LWR); decom</td>
</tr>
<tr>
<td>EURATOM</td>
<td>Mol</td>
<td>105</td>
<td>1966 -1975</td>
<td>105 (GCR+LWR); decom</td>
</tr>
<tr>
<td>India</td>
<td>Trombay/Tarapur/Kalpakam</td>
<td>?</td>
<td>1977~</td>
<td>~200 (LWR/PHWR)</td>
</tr>
</tbody>
</table>
### Possible Reprocessing Plants

<table>
<thead>
<tr>
<th>Country</th>
<th>Reprocessing Plant (capacity, t/Year)</th>
<th>Start</th>
<th>Types of SNF</th>
<th>Possible Market/ NB</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUSSIA</td>
<td>RT-2/3 (up to 2000 t)</td>
<td>2025-2030</td>
<td>UO2 : VVER-1000, RBMK-1000 PWR</td>
<td>1000 t/Year – Russia 1000 t/Year - World</td>
</tr>
<tr>
<td>France</td>
<td>Gen-IV Plant (up to 2000 t)</td>
<td>2040-2050</td>
<td>UO2 , MOX: Any types of LWR and FR</td>
<td>1000 t/Year – France 1000 t/Year – World</td>
</tr>
<tr>
<td>China</td>
<td>Gen-III Plant (up to 2000 t)</td>
<td>2020-2025</td>
<td>UO2 , MOX: Only LWR</td>
<td>Only China</td>
</tr>
<tr>
<td>India</td>
<td>Gen-III Plant (up to 2000 t)</td>
<td>2020</td>
<td>UO2 : LWR и HWR MOX FR</td>
<td>Only India</td>
</tr>
<tr>
<td>Japan</td>
<td>Gen-IV Plant (up to 1000 t)</td>
<td>2050+</td>
<td>UO2 , MOX: Any types of LWR and FR</td>
<td>Only Japan</td>
</tr>
<tr>
<td>US</td>
<td>Gen-III Plant (up to 2000 t)</td>
<td>2040+</td>
<td>UO2 : LWR</td>
<td>Only US</td>
</tr>
</tbody>
</table>
# Advanced Fuel Cycle

<table>
<thead>
<tr>
<th>Policy</th>
<th>Korea</th>
<th>USA</th>
<th>Japan</th>
<th>France</th>
<th>Russia</th>
<th>China</th>
<th>India</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wait and See</td>
<td>Direct → Reprocesssing</td>
<td>Reprocessing</td>
<td>Reprocessing</td>
<td>Reprocessing</td>
<td>Reprocessing</td>
<td>Reprocessing</td>
<td>Reprocessing</td>
</tr>
<tr>
<td>Introduction Of AFC</td>
<td>~ 2050</td>
<td>~ 2025</td>
<td>2020 ~ 2040</td>
<td>~2025</td>
<td>~2025</td>
<td>~2025</td>
<td>~2020</td>
</tr>
<tr>
<td>Reprocessing or Recycling Technology</td>
<td>Pyro</td>
<td>UREX+, Pyro</td>
<td>NEXT, Pyro</td>
<td>COEX /GANEX</td>
<td>Advanced Aqueous, Pyro, Vibro</td>
<td>Purex, Pyro</td>
<td>Purex, Pyro</td>
</tr>
<tr>
<td>Fast Reactor</td>
<td>SFR (Metal)</td>
<td>SFR (Metal, Oxide)</td>
<td>SFR (Oxide, Metal)</td>
<td>SFR (Oxide) GFR (Carbide, Nitride)</td>
<td>SFR /LFR (Oxide, Nitride)</td>
<td>SFR (Mixed oxide)</td>
<td>SFR (Mixed carbide, Oxide, Metal)</td>
</tr>
</tbody>
</table>
Examples of Transition Scenarios (1)

Evolutionary Transition Scenario
Long-term horizon (2050)
1. Existing Large Reprocessing Plant for LWR SNF based on water technology
2. Adaptation the water reprocessing technology to FR SNF
3. Large centralized Reprocessing Plant for FR SNF based on water technology
4. Long-term horizon (after 2040-2050) development of AINFCT (Pyro) for CNFC Countries – Japan (China?) – “French Influence Scenario”
Examples of Transition Scenarios (2-1)

Combined Transition Scenario -1
Middle-term horizon (2025-2030)

1. New Large Reprocessing Plant for LWR SNF based on water technology (2020-2025)

2. Accelerated development the Pyro AINFCT for FR SNF reprocessing

3. Reprocessing Plant for FR SNF (2025)

Countries – (India?, Russia, US?)
Examples of Transition Scenarios (2-2)

Combined Transition Scenario - 2
Long-term horizon (2040)
1. Existing Large Reprocessing Plant for LWR SNF based on water technology - till 2040
2. Development the AINFCT for FR SNF reprocessing
3. Large Reprocessing Plant for Gen-IV Reactors SNF - 2040

Countries – France (Itself French Scenario)
Examples of Transition Scenarios (3)

Accelerated Innovative Transition Scenario
Middle-term horizon (2025)

1. New Large Reprocessing Plant for LWR SNF based AINFCT (Fluoride volatility + Pyro) – 2025
2. Accelerated development the Pyro AINFCT for FR SNF reprocessing
3. On-Site Reprocessing Plants for FR SNF - 2025

Countries – Russia?, India?
Russian National Program
The Initial stage till 2020:

Creation of experienced-industrial infrastructure of CNFC and technologies development, providing its evolution.

Transitional stage 2020-2030:

Development of CNFC technology on industrial scale.

Main stage after 2030:

NE development based on a new technological platform.
Large-scale NE as a basis of the energy provision for national and world development is possible when based on the following key technological and system decisions:

- NE system based on CFC with FR and TR;
- NE system with high temperature reactors;
- Optimum recycle for MA and LLFP;
- International Fuel Cycle Services Centres
Concept of the program is:
consolidation of efforts and resources to create the basis of new technological platform in 2020-2030 and till 2050, including:

1. key technologies of new generation:
   - high safety reactor technologies (SFR, PFR, PBFR);
   - the new types of fuel;
   - dry reprocessing of spent fuel;
   - final disposition of radioactive waste.

2. the experimental research base, providing achievement of these tasks, as well as groundworks for new technologies.
Russian Federal Tasks-oriented Program
“New Generation Nuclear Power Technologies”
(2010-2020)

◆ New Reactor Systems:
  ■ Commercial SFR
  ■ Unique Test SFR – MFTR (MBIR)
  ■ Pb FR – BREST-300
  ■ Pb-Bi FR – SVBR-100

◆ Advanced NFCT
  ■ Pyro-reprocessing (Molten Salt + Fluoride Vol.)
  ■ High-density Fuels for FR
  ■ HLW management

◆ Advanced experimental base

◆ Others
### Characteristics of new Russian fast test reactor – Multi-functional Fast Test Reactor (MFTR/MBIR)

**FTP “New Generation Nuclear Power Technologies**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum flux $\Phi_{\text{max}}, \text{n/cm}^2\cdot\text{s}$</td>
<td>$\sim 6.0 \cdot 10^{15}$</td>
</tr>
<tr>
<td>Thermal power, MWth</td>
<td>$\sim 150$</td>
</tr>
<tr>
<td>Electric power, MWe</td>
<td>$\sim 40$</td>
</tr>
<tr>
<td>Number of independent experimental loops (~1 MWth each, sodium, heavy metal and gas coolant + water coolants)</td>
<td>3 (+1 behind reactor vessel)</td>
</tr>
<tr>
<td><strong>Fuel</strong></td>
<td>Reprocessed Vi-pack MOX, (PuN+UN)</td>
</tr>
<tr>
<td>Core height, mm</td>
<td>400-500</td>
</tr>
<tr>
<td>Maximum heat rate, kW/l</td>
<td>1100</td>
</tr>
<tr>
<td>Number of vertical experimental channels 100-200 mm in diameter</td>
<td>up to 7</td>
</tr>
<tr>
<td>Maximum fluence in one year, n/cm²</td>
<td>$\sim 1,2 \cdot 10^{23}$ (~55 dpa)</td>
</tr>
<tr>
<td>Design lifetime</td>
<td>50 year</td>
</tr>
<tr>
<td>RR creation time</td>
<td>2009 – 2018</td>
</tr>
</tbody>
</table>
RIAR planned participation in the field of AFC

- **Large Multi-purpose Pyro Complex (MPC) - 2017**
  - Molten salt Reprocessing Facility
    - capacity – up to 2 500 kg of FR SNF per Year (fuel type: oxide, nitride, metallic, IMF)
  - Fluoride volatility Reprocessing Facility,
    - capacity – up to 1000 kg of SNF per Year (mainly – LWR SNF)

- **New Lab for Experimental and Innovative Fuel Production – 2010-1014**
  (incl. Fuel and Targets with MA)

- **New facility for HLW treatment**

- **Demonstration of Closing Fuel Cycle based on Pyrochemical technologies -2017-2020-... on a levels:**
  - Up to 120-130 spent FAs of BN-600/800
  - Full scale CFC for MBIR from initial fuel loading
  - Other experimental implementations
Main goals of RIAR MPC for 2020

- Development of Pyro reprocessing technologies on a semi-industrial level:
  - **FR SNF** – molten salt technologies
    - MOX
    - Mixed Nitrides
    - Metallic
  - **LWR SNF** – combination of fluoride volatility and molten salt technologies
    - UOX
    - MOX
  - **Others**
    - So called hard-to-reprocessing SNF (test and transportation reactors)
    - Innovation types of fuel (IMF, MSR +++)

- Demonstration of Closing of BN-800 Fuel Cycle - on a semi-industrial level
  - up to 30% annual loading, i.e. up to 3.5 – 4 t of MOX SNF per Year

- Testing and Demonstration of Closing FR Fuel Cycle for MA
- Develop the Initial Data for full scale Design of Industrial Pyro Module for FR SNF Reprocessing
3D View on MPC
Layout of MPC

- HLW treatment
- Repair Zone
- Repair Zone
- Isotopic Production
- Water reprocessing
- Deccladding
- Fluoride volatility repr.
- Molten salt reprocessing
3. India – 6 Units of PFBR/CFBR + Water reprocessing
5. Rep. of Korea – KALIMER (2025+)

6. US - Probably INL site (2050+): AFCI
7. Japan - Pilot JSFR (2025+)
<table>
<thead>
<tr>
<th>Country</th>
<th>Reactor</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Capacity (MWe) /+NB</th>
<th>Reprocessing</th>
<th>Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>BN-800</td>
<td>MOX (nitrid)</td>
<td>Na</td>
<td>880 MWe / Pu weapon grade</td>
<td>Pyro</td>
<td>2014</td>
</tr>
<tr>
<td></td>
<td>BREST</td>
<td>Nitride</td>
<td>Pb</td>
<td>1200 MWe</td>
<td>Pyro</td>
<td>2020+</td>
</tr>
<tr>
<td>China</td>
<td>2 units CDFR</td>
<td>MOX</td>
<td>Na</td>
<td>800/900 MWe</td>
<td>?</td>
<td>2018+</td>
</tr>
<tr>
<td></td>
<td>6 units PFBR/CFBR</td>
<td>MOX</td>
<td>Na</td>
<td>500 MWe</td>
<td>Water</td>
<td>2011-2023</td>
</tr>
<tr>
<td></td>
<td>Series FBR</td>
<td>Met. U+Pu</td>
<td>Na</td>
<td>500 MWe / BR=1.6</td>
<td>Pyro</td>
<td>20223+</td>
</tr>
<tr>
<td>France</td>
<td>ASTRID</td>
<td>MOX</td>
<td>Na</td>
<td>350-500 MBt / MA fuel</td>
<td>Water</td>
<td>2020+</td>
</tr>
<tr>
<td>Korea</td>
<td>KALIMER</td>
<td>Met. U+Pu+Zr</td>
<td>Na</td>
<td>300-500</td>
<td>Pyro</td>
<td>2025-2030</td>
</tr>
<tr>
<td>Japan</td>
<td>JSFR</td>
<td>MOX</td>
<td>Na</td>
<td>?</td>
<td>Water</td>
<td>2025+</td>
</tr>
<tr>
<td>US</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Schedule of NTP development

- **France**
  - 2006-2008 – start of NTP
    - Conceptual Design of ASTRID Reactor
    - Design of new fuel facility for ASTRID (MOX and fuel with MA)
  - 2012-2014
    - Start of ASTRID construction
  - 2020
    - ASTRID putting into operation

- **India**
  - 2011
    - Putting into operation of PFBR -500 with pellets MOX fuel
  - 2013 - 2023
    - Putting into operation of 5 units of CFBR (totally – 3,0 GWe of SER!)
  - 2015 - 2025
    - Industrial FR CFC (water reprocessing of FR MOX fuel)
  - 2023+
    - New generation of SFR with metallic fuel and pyro reprocessing

- **Rep. of Korea**
  - 2025 - 2030
    - Pilot SFR with metallic fuel and pyro reprocessing

- **China**
  - 2020
    - CDFR-800/900

- **Japan**
  - 2025
    - Pilot JSFR
Final key notes

New International Policy of Russian State Corporation “Rosatom”

- Russian Federal Tasks-oriented Program (FTP) “New Generation Nuclear Power Technologies” (2010-2020) now is open for international cooperation
- Not only for R&D collaboration
- But also for large-scale commercial type cooperation based on main Projects of Russian FTP
- For example:
  - International fast reactor MBIR
  - International R&D Center based on RIAR Pyro Reprocessing Complex
  - International commercial fast reactor Project
  - Possible International Consortium for mutual development and future selling of Commercial FR and CFC service on a World Market
- Nowadays we are ready to initiate the widely international discussions
- We are open for any ideas!