VVER NPP experience and development. MIR.1200 project

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Present Russian Nuclear Reactors Technologies:

1. Light-water reactors (VVER, VBER, etc.)
2. Gas-cooled reactors (GT-MGR, VTGR)
3. Metal-cooled reactors (BN, etc.)

These reactors were designed for installation for wide range conditions.
Evolution of VVER focusing on field-proven technology, compliance with modern international safety requirements and using reference and tested design solutions.

- Life time is 60 years
- Enhanced power and efficiency
- Improved Operation & Maintenance
- Exclusive use of digital I&C equipment
- Advanced passive residual heat removal systems for severe accidents
- Improved reliability of safety systems
- More efficient use of fuel
- Modified fuel elements
- Core damage frequency: $10^{-6}$

- Transition to the design in compliance with the Western standards and regulations
- Taking into account severe accident consequences (incl. Fukushima NPP scenario) for preventing radioactive releases
- Higher efficiency of implementation (higher automation of designing process and project management) and life cycle management
- Increasing the number of components manufactured in EU
- Core damage frequency: $10^{-6}$

Gen1 VVER-440
- Reactor Model: V 230,
- (Reactor Model: V 213 installed at the sites located in Russia, Czech Republic, Slovak Republic, Ukraine, Hungary, Bulgaria),
- VVER 1000
- Reactor Model: V 320 installed at the sites located in Russia, Czech Republic, Ukraine, Bulgaria)

Gen2 VVER-440, 70-80 ies
- (Reactor Model: V 213 installed at the sites located in Russia, Czech Republic, Slovak Republic, Ukraine, Hungary, Bulgaria),
- VVER 1000
- Reactor Model: V 320 installed at the sites located in Russia, Czech Republic, Ukraine, Bulgaria)

Gen2 VVER-1000, 80-90 ies
- (Reactor Model: V 428 for Tianwan NPP and V-466 for BID OL3 (NPP design named VVER 91/99)
- AES-92 Reactor Model: V 392 for Kudankulam NPP, V-466 for Belene NPP
- VVER-640
- Reactor model V-407 project created for developing regions export. It was licensed for construction for Leningrad site. Project was stopped because of Russian financial crisis in 1998)

Gen3 VVER-1000 and VVER-640: Compliance with international safety standards

Gen3+ VVER-1200: Improved safety & economics

Gen3+ VVER-1200+: Compliance with the Western regulations & supply models
VVER 440/1000 designs were developed for implementation in the Russia, Europe and Asia regions

Russian nuclear reactors worldwide

<table>
<thead>
<tr>
<th></th>
<th>Russia</th>
<th>Globally</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructed</td>
<td>36</td>
<td>56</td>
<td>92</td>
</tr>
<tr>
<td>Under current Rosatom operation</td>
<td>32</td>
<td>-</td>
<td>32</td>
</tr>
<tr>
<td>In Progress</td>
<td>10</td>
<td>15</td>
<td>25</td>
</tr>
</tbody>
</table>

More than 30 units of installed fleet
6 more units being in progress
≥ 6 units pending by the customer

Strong Reference and Challenging Perspectives
Two operating VVER-1000 power units at Tianwan NPP in China
VVER NPP defense-in-depth barriers

FUEL ELEMENT CLADDING
Preventing of fission product release to coolant of primary circuit

PRIMARY CIRCUIT
Preventing of fission product release to containment

SYSTEM OF PROTECTIVE TIGHT ENCLOSURES
Preventing of fission product release to environment
VVER Nuclear Steam Supply System standard design equipment

Primary coolant circuit system with horizontal steam generators

1. Thermal power – 3200 MW
2. Primary coolant circuit configuration – 4 loops
3. Operation lifetime – 60 years
4. SSE (SL-2) Seismic loads – 0.25 g
5. The intentional crash of a commercial airplane is considered
6. Availability factor - 92%

All equipment designed for railway transportation.
Main technology parameters evolution within reference technology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VVER-1000</th>
<th>VVER-1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal thermal power of the reactor, MW</td>
<td>3000</td>
<td>3200</td>
</tr>
<tr>
<td>Load factor</td>
<td>0,78</td>
<td>0,92*</td>
</tr>
<tr>
<td>Coolant pressure at the reactor outlet, MPa</td>
<td>15,7</td>
<td>16,2</td>
</tr>
<tr>
<td>Coolant temperature at the reactor inlet, °C</td>
<td>290</td>
<td>298,6</td>
</tr>
<tr>
<td>Coolant temperature at the reactor outlet, °C</td>
<td>319,6</td>
<td>329,7</td>
</tr>
<tr>
<td>Maximum linear heat rate, W/cm</td>
<td>448</td>
<td>420</td>
</tr>
<tr>
<td>Pressure at the outlet of SG steam header (absolute), MPa</td>
<td>6,27</td>
<td>7,0</td>
</tr>
<tr>
<td>Primary design pressure, MPa</td>
<td>17,64</td>
<td>17,64</td>
</tr>
<tr>
<td>Secondary design pressure, MPa</td>
<td>7,84</td>
<td>8,1</td>
</tr>
<tr>
<td>FA-maximum burnup fraction of fuel in FAs withdrawn (in the base</td>
<td>55</td>
<td>up to 70*</td>
</tr>
<tr>
<td>equilibrium fuel cycle), MW day/kgU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA-averaged burnup fraction of fuel in FAs withdrawn (in the base</td>
<td>49</td>
<td>55</td>
</tr>
<tr>
<td>equilibrium fuel cycle), MW day/kgU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period between refuellings, months</td>
<td>12</td>
<td>12/(18-24)*</td>
</tr>
<tr>
<td>Time of fuel residence in the core, year</td>
<td>4</td>
<td>4/5*</td>
</tr>
</tbody>
</table>

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## Fuel parameters evolution

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FA type</strong></td>
<td>TVS (TVS-M)</td>
<td>UTVS</td>
<td>TVSA</td>
<td>TVS-2</td>
<td>TVSA-ALFA TVS-2M</td>
</tr>
<tr>
<td><strong>Bundle type</strong></td>
<td>DBA</td>
<td>U-Gd</td>
<td>U-Gd</td>
<td></td>
<td>U-Gd</td>
</tr>
<tr>
<td><strong>Reload batch average enrichment, % U²³⁵</strong></td>
<td>4,31</td>
<td>3,77</td>
<td>~4,26</td>
<td>4,83</td>
<td>4,88</td>
</tr>
<tr>
<td><strong>FA quantity in reload batch, pcs.</strong></td>
<td>54</td>
<td>48</td>
<td>42</td>
<td>54</td>
<td>36</td>
</tr>
<tr>
<td><strong>FA burnup, MW×days/kgU</strong></td>
<td>49</td>
<td>49</td>
<td>55</td>
<td></td>
<td>68</td>
</tr>
<tr>
<td><strong>Fuel cycle</strong></td>
<td>3-year</td>
<td>3-year</td>
<td>4⋅(310-320) EFPD</td>
<td>3⋅(350-370) EFPD</td>
<td>5⋅(310-320) EFPD</td>
</tr>
<tr>
<td><strong>Natural Uranium consumption kg/MW×days</strong></td>
<td>0,240</td>
<td>0,205</td>
<td>0,199</td>
<td>0,210</td>
<td>0,193…0,187</td>
</tr>
</tbody>
</table>
VVER NPP safety objectives

Safety Objectives

Reactivity Control
Core Cooling
Primary Circuit Heat Removal
Prevention of Primary Circuit Damage
Prevention of Activity Releases

Reactor Coolant Inventory
- Reactor Shutdown
- Reactor Power Limitation
- Subcritical in Shutdown Condition
- Secondary Heat Sink
- Steam Generator Feed

Pressure Limitation
- in Reactor Coolant System
- in Containment
- Cutoff the Containment
- Heat Removal from the Containment

Main
- Reactor control and protection system
- Emergency boron injection system
- Low and high pressure injection to the primary circuit from accumulators
- Possibility to use two high pressure injection pumps in instead one low pressure pump
- Emergency feedwater
- Steam discharge to the atmosphere
- System of passive heat removal from steam generators
- Primary circuit safety valves of low pressure
- System of passive heat removal from steam generators
- Cutoff valves system, Emergency spry system, Hydrogen recombiners, Chemical reagents supply
- System of passive heat removal from the containment

Res.

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4x100% separated active safety systems

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The structures, systems and components fulfilling safety functions used in postulated core melt accidents (level 4 of Defense in Depth) are practically independent from the structures, systems and components used to prevent core melt accidents.

Active parts of the systems and components necessary for ensuring the containment function in a core melt accident are fulfill the single failure criterion.
**Probabilistic Design Criteria**

- **Total core meltdown frequency less than** $10^{-5}$ 1/plant-yr;
- **Exclusion of accident scenarios, which can lead to large release at an early stage of an accident;**
- **Total limiting accident release frequency less than** $10^{-7}$ 1/plant-yr.

**PSA Results for VVER-1000 Tianwan NPP operating in China:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Average total core damage frequency during power operation of power unit</td>
<td>$2.67 \times 10^{-6}$</td>
</tr>
<tr>
<td>2. Average total core damage frequency during shutdown regimes</td>
<td>$7.2 \times 10^{-7}$</td>
</tr>
<tr>
<td>3. Average total core damage frequency for internal initiating events</td>
<td>$3.39 \times 10^{-6}$</td>
</tr>
<tr>
<td>4. Total limiting accident release frequency</td>
<td>$6.3 \times 10^{-8}$</td>
</tr>
</tbody>
</table>