Margins and robustness

Design solutions providing the V-491 reactor plant reliability

Presented by Mikhail Bykov
- **CR 1.1.1 Robustness;**
  The criterion CR1.1.1 deals with robustness of design to prevent failures and/or disturbances in accordance with level 1 of DID.

- **CR 1.2.1 I&C and inherent characteristics;**
  Capability of instrumentation and control system (I&C) and/or inherent characteristics to detect and intercept and/or compensate deviations from normal operational states.

- **CR 1.2.3 Inertia**
  The term “inertia” means the capability of a nuclear reactor system to cope with anticipated operational occurrences; the main objective is to avoid consequences that could delay a restart and a return to normal operation.
Evaluation parameters

- **EP1.1.1.1: margins of design;**
  
  The term margin is defined here as the difference between a design limit and the actual design value of the corresponding safety related parameter, such as stress, temperature, etc.

- **EP1.1.1.2: simplicity of design;**

  The options to simplify the reactor design is to reduce the number of components of the cooling system and to reduce the number of active components.

- **EP1.1.1.3: Quality of manufacture and construction**

  Quality of manufacture and construction (for example reduction of welds in piping and vessels and application of automatic welding during manufacturing).
Target function - the evolution of technical characteristics

Seismic resistance

OBE=6 points  
SSE=7 points

→

OBE=6 points  
SSE=7 → 8 points

For a further assessment of the Belarusian NPP held on 8 points on the MSK-64 scale (0.24 g at the free surface of the plate). Main equipment has the necessary safety margins. Seismic resistance of some pipelines with an additional fixing

Life time

30 y → 60 y

Availability

0.8 → 0.92

Thermal power

3000 MW → 3200 MW

\( P_{2\text{des}} \)

7.84 MPa → 8.1

At least, safety margins are not reduced
Reactor

- RPV inner diameter increased by 100 mm for decrease in neutron flux to the reactor vessel;
- The length of the vessel is increased by 300 mm;
- Increased barrel length of 200 mm;
- Welds number are reduced and location of welds across the core is optimized;
- Limitation of nickel content in welds;
- Decrease in $T_{ko}$ of the nozzle area shells to minus 35 °C;
- Limitation of harmful impurities in base metal and welds;
- New surveillance program (arranging of surveillance specimens to be irradiated immediately on RPV wall);
- Improvement of reliability of monitoring the fluence to the reactor vessel;

60 years + 3200 MW
Reactor

V-491 and V-320 projects differences in design of reactor vessel and upper head:

1) Number of CR -121;
2) Number of I&C connections – 18, located at the periphery;
3) The use of advanced steel;
4) Arranging of surveillance specimens to be irradiated immediately on RPV wall;
5) Vessel lengthened by 300 mm;
6) The number of welds is reduced and their location in the core region is optimized.
Reactor

V-491 and V-320 project differences in design of core barrel:
1. Application of removable compensation plates to adjust the gap in the spacer collar.
2. The height-adjustable supports of fuel assemblies.
3. Emergency support in the central part of the bottom to allow the passage of coolant in the core barrel breakage accident.
4. Application of pressing devices of core barrel based on expanded graphite.

V-491 and V-320 project differences in design of Protection Tube Unit (PTU):
1. PTU and core baffle are fixed for the core barrel break accident.
2. Application for core monitoring only in-core instrumentation detectors channels the same length.
**V-491 and V-320 projects differences in design of core baffle**

1. Six stops are set to hold the PTU against lateral movement relatively core barrel and allow the SCRAM in case of core barrel break accident;

2. Changed location and diameters of the lengthwise holes for better cooling;

3. Increased height of the baffle
## Reactor core

<table>
<thead>
<tr>
<th>Parameters</th>
<th>VVER-1000</th>
<th>VVER-1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nominal thermal power of the reactor, MW</td>
<td>3000</td>
<td>3200</td>
</tr>
<tr>
<td>2. Fuel height in the core in the cold state, mm</td>
<td>3530</td>
<td>3730</td>
</tr>
<tr>
<td>3. Number of FAs with CPS CR</td>
<td>61</td>
<td>up to 121</td>
</tr>
<tr>
<td>4. The re-criticality temperature, °C</td>
<td>220</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>5. Maximum linear power, W / cm</td>
<td>448</td>
<td>420</td>
</tr>
<tr>
<td>6. Fuel Cycles</td>
<td>3x350; 3x1.5; 4x1; 5x1</td>
<td>3x1.5; 4x1; 5x1</td>
</tr>
<tr>
<td>7. Maximum fuel burn, MW * day / kg U</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>8. Load following modes</td>
<td>-</td>
<td>100-75-100 Nnom</td>
</tr>
<tr>
<td>9. CPS CR</td>
<td>-</td>
<td>The increased length of the section with Dy₂O₂TiO₂</td>
</tr>
</tbody>
</table>
Reactor core

- Increased amount of fuel;
- Reduced power per unit length;
- Reduced temperature of re-criticality;
- Increased representation of core measurements by in-core instrumentation detectors;
- Increased number of CPS control rods;
- Increased number of places of possible installation of control rods, it provides the ability to optimize the location of control rods in a control group.
## Core coolability

<table>
<thead>
<tr>
<th>Parameters</th>
<th>VVER-1200</th>
<th>VVER-1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power, MW</td>
<td>3200</td>
<td>3000</td>
</tr>
<tr>
<td>Reactor outlet pressure (absolute), MPa</td>
<td>16.2</td>
<td>15.7</td>
</tr>
<tr>
<td>Fuel height in the core in the hot state, m</td>
<td>3.75</td>
<td>3.55</td>
</tr>
<tr>
<td>Inlet reactor coolant temperature, °C</td>
<td>298</td>
<td>291</td>
</tr>
<tr>
<td>Outlet reactor coolant temperature, °C</td>
<td>329</td>
<td>321</td>
</tr>
<tr>
<td>Core heat flux distribution coefficient</td>
<td>2.40</td>
<td>2.60</td>
</tr>
<tr>
<td>Maximum fuel cladding temperature, °C</td>
<td>355</td>
<td>352</td>
</tr>
<tr>
<td>Minimum DNBR</td>
<td>1.39</td>
<td>1.3</td>
</tr>
<tr>
<td>Maximum fuel pellet temperature, °C</td>
<td>1852</td>
<td>1805</td>
</tr>
</tbody>
</table>
### CPS drive ShEM-3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ShEM-2</th>
<th>ShEM-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Operation period, years:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Mechanical units;</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>- Electromagnets;</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>- Position indicator.</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>2. Maximal operated motion of control rod bar, mm</td>
<td>3600</td>
<td>3800</td>
</tr>
<tr>
<td>3. Interval of the control rod position discrete check by position indicator, mm</td>
<td>350</td>
<td>20</td>
</tr>
<tr>
<td>4. The error of control rod position check by position indicator, mm</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>5. Total amount of sensor check control rod positions</td>
<td>11</td>
<td>191</td>
</tr>
<tr>
<td>6. Maximal pulling force, kgs</td>
<td>34</td>
<td>70</td>
</tr>
<tr>
<td>7. Allowable electromagnet temperature, °C</td>
<td>170</td>
<td>260</td>
</tr>
<tr>
<td>8. Cooling air rate, m³/h</td>
<td>400+50</td>
<td>250</td>
</tr>
<tr>
<td>9. Allowable cooling air feed break, h</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>10. Sealing units</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Steam generator

- The increased **inner diameter to 4.2 m**, vaporization area, heat exchange area;
- The increased $P_{2\text{calc}}$ 7.84 to 8.1 MPa, nominal, from 6.27 to 7 MPa;
- The increased steaming power from 1470 to 1602 t/h;
- The increased **SG water supply** in secondary circuit from 52 to 63 t;
- **Rare corridor** heat exchange pipes bundle;
- Additional procedures for sludge accumulation decreasing;
- Easy access for pipe space inspections;
- Enlarged space under heat exchange pipes for easy sludge removal;
- The improved stressed state of the coolant collector;

60 years + 1602 t/h + 7 MPa + 0.2 %
Pressurizer

- Individual injection line from Boron Emergency Injection System into Pressurizer;
- Extended graphite seals are applied in detachable joints;
- Pressurizer capacity remains the same – 79 m³;
- Control of the level in the pressurizer is modernized to minimize regulators operation and to use natural changes of the primary circuit volume;
- Thermal insulation – BSTI

60 years + safety
Pressurizing system

- 4-stage injection system with controllable injection;
- Absence of necessity to discharge the primary circuit medium during normal operation of systems;
- Material of all pipelines including connecting is stainless steel;
- Improved values of set points for injection operation, absence of necessity in injection operation under conditions of primary and secondary regulation.

60 years + transient process stability (Robustness)
Main coolant pump set

- Application of plate clutch torsion bar instead of gear clutch torsion bar;
- Use of water lubrication in main radial-axis bearing;
- Natural circulation heat removal from lower radial bearing during shutdown condition;
- Spherical shape of welded-stamped pump casing;
- Engine lubrication system with uninflammable liquid;
- Leak tightness of shaft seals during 72 hours without cooling;
- 5% increased water supply.

60 years + fire safety + leak tightness of seals
Consequently, almost all equipment was modernized, both in operation parameters and in design in order to provide the main characteristics of AES-2006 project:

- Increased power;
- Seismic resistance assurance;
- Increased NPP life;
- Improved availability factor.
Reactor unit elements simplification in design and operation

- Safety systems algorithms simplification owing to re-criticality temperature decrease;
- Reduction of number of control rods detachable joints (mounting and maintenance simplification);
- Loosed requirements to operation due to justification of brittle fracture resistance for ECCS water temperature of 20 °C (there is no necessity in ECCS water heating);
- Loosed requirements to equipment and tubing fastening due to LBB conception application (mounting and maintenance simplification);
• Simplification of operation due to elements service life increasing (CPS control rod drive);
• Reduction of composite welded joints amount in ECCS, Pressurizer System (mounting technology simplification);
• Reduction of the reactor vessel welds number (manufacture time shortening, operational control scope reduction);
• Renunciation of double-chamber equalizing vessels in favour of single-chamber vessels;
• Corridor heat exchanging pipes bundle in steam generator decreases sludge accumulation, simplifies sludge removal and check-up of heat exchange area;
• Increased maintenance period from 4 to 8 years;
• Gate-type equipment application allows steam generator maintenance concurrently with fuel reload.
Use of referent technical solutions;

Use of the Quality assurance program for designing and manufacture of RP equipment and pipes;

Collaboration with companies that have certificates of the regulatory body for NPP equipment production;

Use of materials admitted by the regulatory body for equipment manufacture.
International certification of projects and quality programs

Certificates of the regulatory body for designing and production of equipment for NPP and experimental facilities

V-320
1) Ductile-to-brittle transition temperature decrease, decrease of impurities in the reactor vessel metal;
2) Application of detachable joints with expanded graphite;
3) Automated welding of reactor circulation pipes;
4) Application of stainless steel pipes for connecting line and ECCS pipes – reduction of number of composite welded joints
5) Fewer number of welded joints for reactor vessel;
6) Providing the conditions for “clean mounting” of the equipment at manufacturing factories and during NPP mounting.
Monitoring, control and diagnostic system (MCDS)

Goals:
- monitoring of core and reactor plant parameters;
- SCRAM and preventive protection signals by local parameters (DNBR, linear power);
- giving advices to operator for power field control;
- monitoring of vibration load for RP elements, loose parts, primary circuit tightness and remaining life
- presentation of the current core and reactor plant parameters, data exchange of different systems, data archiving;
- monitoring of margins to operational limits and safety limits for parameters measured and calculated by MCDS;
- monitoring of water chemistry and giving recommendations for the operator;
- self-diagnostics of hardware and software.
MCDS

V-320 ICIS
In-core instrumentation system

Includes:
- in-core instrumentation system (ICIS);
- system of integrated diagnostics (SID);
- vibration-noise diagnostics system (VDS);
- coolant leak detection system (CLDS);
- loose parts detection system (LPDS);
- remaining life automated control system (RLACS);
- system of integrated analysis (SIA).
MCDS is a decentralized system. It consists of different systems with the same goal of reactor plant control and diagnostics during its operation. MCDS is designed by the principle of combining the functionally completed systems that fully perform their functions and are joined by data exchange.
More comprehensive application of inertia, inherent safety and passive features

- 20 % increase of secondary circuit water volume (from 52 to 63 m³);
- Use of stainless steel for pressurizing system and ECCS piping;
- Water chemistry justification for ECCS water 20 °C;
- Exclusion of combustible liquids inside the containment along with maintaining the required RCP coastdown period;
- Passive heat removal systems for steam generators and containment;
- Re-criticality temperature decrease;
- Increase in time of keeping the RCP shaft sealing leak tightness from 24 to 72 hours without cooling;
- Justification and application of leak before break concept for \( D_{\text{nom}} \) larger than 200 mm;
- Enlargement of SG internal diameter – extension of evaporating surface and height for gravity steam separation;
- Enlargement of water layer between the core and reactor vessel.
V-491 design is based on the V-320 design and represents evolution of this design:

- Preservation or increase of safety margins and reliability;

- Development of control and monitoring of process variables and parameters characterizing a state of the reactor core, RP equipment and piping;

- Extended use of inherent safety features, natural phenomena, passive principles for simplification of technical solutions and/or enhancement of performance characteristics.
Thank you for your attention!