Program of VVER technology enhancement and improvement of its consumer attractiveness under conditions of dual-component nuclear power system

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- Decision of the joint meeting of the Scientific and Technical Council No. 1 and Scientific and Technical Council of State Corporation Rosatom No.8 of 23.03.2017;

- Preferential voting results at the Praesidium of the Scientific and Technical Council of State Corporation Rosatom in 2015 (1-St place - CNFC with VVER and BN);

The basis for the Program development were the materials of the Strategy for nuclear industry development in Russia to 2050 and for the perspective to 2100.
Maintaining of effectiveness and competitiveness as compared to other types of generation and foreign competitors;

Ensuring of the commercial order for the industry;

Ensuring of the highest safety as a tool of provision of acceptability to the society;

Embedding into the dual-component nuclear industry with a view to remove the challenge of fuel supplies and management of spent nuclear fuel and radioactive waste.

In recent years the research and development activities were focused in the field of substantiation of AES-2006 and VVER TOI designs.
### Directions of VVER Technology Development

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<th>Horizon</th>
<th>Focus areas</th>
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<tr>
<td>2 years</td>
<td>✓ Update of VVER TOI basic design;</td>
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<tr>
<td>5 years</td>
<td>✓ Development of element base of traditional VVER technology to maintain the competitiveness in the world market.</td>
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<tr>
<td>Up to 10 years</td>
<td>✓ Development of technology for spectral VVER regulation;</td>
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<tr>
<td>Up to 20 years</td>
<td>✓ Development of VVER-SKD</td>
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**Key performers:** SC EC Atomstroyexport, SC OKB Gidropress, OKBM Afrikantov, NRC Kurchatov Institute
- Finalization of the basic VVER-TOI design at specific sites by the results of construction, commissioning and operation of AES-2006 (NVNPP unit 6 and LNPP-2 unit 1);
- Reduction of capital and operating costs thanks to development of the element basis of the VVER technology and serial reproduction of the design solutions;
- Accounting of new requirements of the Customers including foreign ones set to
- Exclusion of the over-regulatory requirements to beyond-design basis accidents management including personnel actions with the purpose of optimization of the safety systems

- Development of more effective technical solutions for heat removal from the core and containment to the ultimate heat sink during beyond design basis accidents (leak of primary coolant under conditions of loss of all AC sources)

- Performance of the full set of activities to substantiate the operation of AES-2006 and VVER TOI NPP units in the manoeuvring modes

- Reduction of metal consumption or development of more highly-technological structures, for example: Application of sheet-templates instead of rolling in production of the pipelines from the borated steel for racks of the spent duel pool
Development of active protection systems for perception of seismic and shock loads (use of damping and energy absorbing devices)

Development of the design and layout solutions for nuclear island buildings effective from the point of view of the NPP safety of in case of an aircraft crash (shielding of the reactor building with other buildings, extra embedment of the containment to 8-10 m, shock absorption)
Consideration of the possibility and feasibility of location of the spent fuel pool outside the containment (in a separate building)

Development of a universal multi-purpose packaging for transportation of uranium-plutonium fuel, spent fuel storage at the NPP site and transport of the spent nuclear fuel to the reprocessing facility.
## Expected results

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<th>R&amp;D expenditures (bln. rub.)</th>
<th>Savings of capital expenditures</th>
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<tr>
<td>VVER-TOI</td>
<td>12</td>
<td>18% (to AES 2006)</td>
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<tr>
<td>VVER-TOI+</td>
<td>5</td>
<td>15% (to VVER TOI)</td>
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Set of activities to substantiate the possibility for application of uranium-plutonium fuel in the core of VVER TOI reactors;

- Development of the fuel cycles with uranium-plutonium fuel;
- Upgrading of the reactor CPS and other subsystems of APCS;
- Upgrading of the systems for management of fresh and spent nuclear fuel, cooling system of the spent fuel pool;
- Computational reactor safety substantiation
Increase of capture on resonance absorption of $^{238}$U at the beginning of the campaign (≥ 10% more in comparison with the capture in the regular core) by reduction of water-uranium ratios at the beginning of the campaign and transition to a tighter range of neutrons:

$$^{238}\text{U}(n,\gamma) \rightarrow ^{239}\text{Np}(\beta^-) \rightarrow ^{239}\text{Pu}$$

- Rejection from the boron control of the reactivity margin
- Improvement of fuel use (reduction of initial load of $^{235}$U) by decrease of the value of the necessary initial reactivity margin
Benefits:
- Growth of the reproduction factor to 0.7 ÷ 0.8, reduction of the consumption of natural uranium in the open fuel cycle to 130-135 t/GW (el)-year (i.e. 30% as compared to a regular VVER);
- Ensuring of the opportunity of 100% loading with MOX fuel;
- Successful operation in open and closed nuclear fuel cycle
- Refusal from zirconium

Disadvantages:
- Reduction of the volumetric core capacity;
- Necessity of new reactor and core design;
- Additional neutron spectrum control system.
Gates of VVER-S design with use of spectral control technology:

1. Spectral control
   - Movable followers
   - Change of the coolant density

2. Capacity
   - Fuel element diameter 6.8 mm
     - ~700 MW (el.) → “Reduced” vessel
     - ~1250 MW (el.) → Vessel “V-1000”
     - ~1800 MW (el.) → Vessel “V-1500”
   - Fuel element diameter 9.1 mm
     - ~700 MW (el.) → Vessel “V-1000”
     - ~1250 MW (el.) → Vessel “V-1500”
Performance of design development studies of the fuel assemblies, followers, actuators of control rods, reactor protective tubes unit
Demonstration of the following savings of the natural uranium in the VVER-S reactor through the life cycle as compared to VVER TOI in operation at different fuel types:

NRC Kurchatov Institute jointly with OKB Gidropress completed the development of technical requirements to VVER-S reactor and submitted it for review to Rosenergoatom
### Time line of the project implementation

<table>
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<th>Time Frame</th>
<th>Description</th>
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<tr>
<td>2018-2025</td>
<td>Development of technical specifications, pre-project and basic R&amp;D for the NPP with evolutionary option of VVER-S (materials, codes, databases, benchmarks, test stands, design options for fuel assemblies and reactor)</td>
</tr>
<tr>
<td>2023-2028</td>
<td>Design development of the NPP with evolutionary option of VVER-S (conceptual design, technical offer, basis design, feasibility study, working documentation)</td>
</tr>
<tr>
<td>2028-2035</td>
<td>Construction of the pilot NPP with evolutionary option of VVER-S</td>
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The performance of R&D program for the period to 2025 will require about 14 bln. roubles.
The economic inefficiency of the solutions proposed requires fundamentally new project proposals for the unit.

Suggestion: development of technical solutions to support the projects of integral reactor plant:

Concept of the integral reactor plant:
- Thermal capacity of the reactor plant is 100-600 MW;
- Reactor plant with integral layout of the main reactor equipment;
- Control rod actuators inside the reactor vessel;
- Exclusion of large leaks from the primary circuit;
- Retention of the melt in the reactor vessel.

Key advantages of the unit with integral reactor plant:
- Reduction of capital costs;
- Opportunities for investors’ involvement;
- Potentially high competitiveness at the expected foreign market.
Target indicators of the project with vessel-type reactor and coolant of super-critical parameters:

- Efficiency up to 45%;
- Minimum reproduction factor is 0.8 (maximum - 1.0); improved use of fuel with orientation to closed nuclear fuel cycle.

Key challenges - unavailability:

- structural materials of the core and core internals;
- nuclear constants;
- database on thermal-physical properties of the coolant and materials under supercritical parameters.

The form of the project implementation in the near future is the performance of focused R&D and D&D in the framework of the area SCWR of the Forum "Generation IV".

Arrangement of the focused R&D the framework of the Forum "Generation IV". Annual funding of the R&D and D&D performed in Russia in the amount of about 150 mln. roubles.
Conceptual options

Double-circuit reactor plant

Secondary circuit: 24 MPa, 500°C, Efficiency factor up to 40%

Single-circuit reactor plant

Reactor: fast resonance spectrum (25 MPa, 540°C)*

*for single-circuit reactor plant

Efficiency up to 45%
The minutes of the meeting No.2 of the Scientific and Technical Council of State Corporation Rosatom of 28.09.2017 highlighted the practical unavailability of promising studies in the Customer's R&D of the VVER nuclear fuel.

Requirements to the modern UOX-fuel: Improvement of the uranium consumption, thermal-technical reliability, increase enrichment for more than 5% by U\textsuperscript{235}, further unification of the fuel assemblies (transition to the unified type of fuel assemblies) etc.

The further improvement of the safety of nuclear power industry requires a complete rejection of use of zirconium alloys in the reactor core.

It is necessary to change the design of the fuel assemblies in view of regulation of the water-uranium ratio for the reactor plant VVER-S.

It is necessary to perform the works in the area of use of new structural materials for fuel elements and assemblies for VVER-SKD.
Influence of replacement of the cladding material for consumption of $^{235}$U, along preservation of the fuel assembly energy (uranium enrichment - 5%)
Conclusion:

The VVER technology possesses a great upgrading potential and capable to ensure high effectiveness of the dual-component nuclear power system of the future.

We suggest:

1. Approve the Program of VVER technology enhancement and improvement of its consumer attractiveness under conditions of dual-component nuclear power system

2. Make the necessary organizational decisions that open the opportunities and ensure the necessary research, development and design works on development of a new Rosatom product - reactor plant and power unit with innovative VVER-S within dual-component nuclear power system based on closed nuclear fuel cycle as a prerequisite for long-term development strategy of State Corporation Rosatom.
Thank you for your kind attention!