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Basic Engineering Solutions in the VBER-500 Power Unit for Regional Power Systems

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VBER Reactor Plant Design Concept

- Operation experience in VVERs
- Experience in developing designs of district heating nuclear plants for large cities

- Use of mastered marine nuclear reactor technologies
  - Operation experience with more than 460 reactors with the total service life of 6500 reactor years
  - Longstanding experience in designing and fabrication
  - Results of earlier done R&D work

Bases for VBER Power Unit Efficiency

Criterion type	Characteristics
Safety	• Elimination of most hazardous large and medium leaks in LOCAs • High safety in the postulated severe accident • Effective localization of SG leaks • Reduced annual collective dose in equipment repair and maintenance
Economics	• Simplification of RP systems due to application of a once-through SG • Application of canned MCPs that do not require supporting systems • Enhanced efficiency of the thermodynamic cycle due to the use of weakly superheated steam • Reduced construction term due to the application of the modular technology in the construction-and-assembling work combined with open-air installation operations • Relatively low one-time investments • High level of design continuity and elimination of the need in high-cost R&D work
Convenience in operation	• High maneuverability due to the use of once-through SGs • Stable water and gas chemistry due to the pressurized primary circuit (no gas blow-off, makeup, reduced sampling) • High automation of the control process (use of the "self-control" capabilities, once-through steam generator, minimized number of systems used in normal operation – PCDS and pressurizer) • Minimum amount of liquid radwaste because of no leaks and minimum water exchange throughout the cycle

Nuclear Marine Technology Solutions in VBER-500 RP

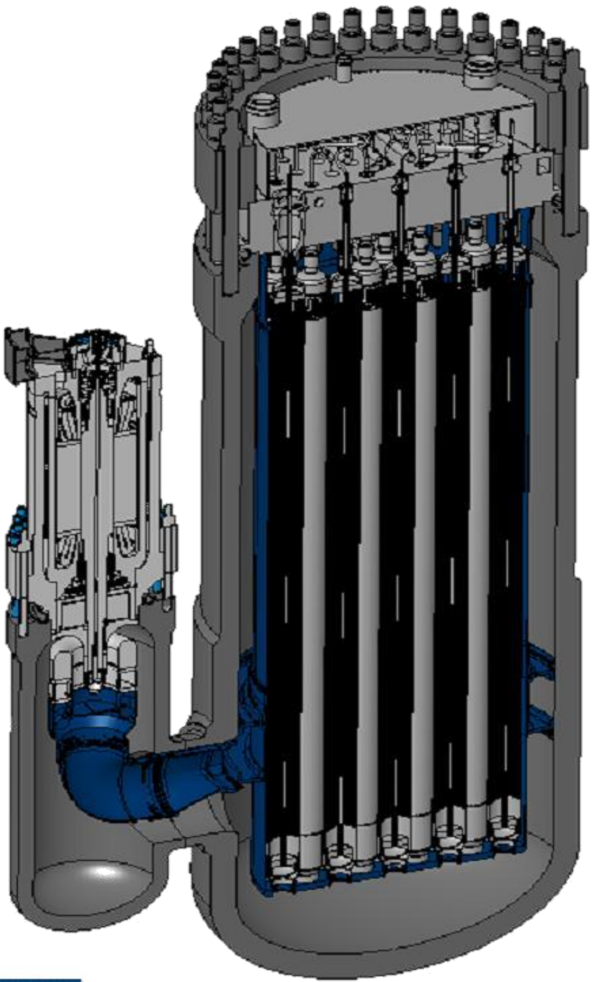
- Distributed layout of the reactor unit; primary circuit circulation arranged in the main circulation path; coaxial design of the internal nozzle; reactor unit attachment scheme; assemblage and installation technology; in-service inspections and diagnostics
- Once-through modular SG; fabrication process; in-service inspections and diagnostics
- Canned monoblock MCP with dry winding separated from the water cavity by a thin-walled jacket; in-built cooling and gas-venting systems; MCP check valve design; utilized materials (in vessel, bearings, insulation); manufacturing process; in-service inspections and diagnostics
- CRDM with a canned stepping motor and overrunning clutch
- Leak-tight fast-acting valves; steam generator overpressure protection device; secondary circuit feed valve
- Passive heat removal system through steam generators
- Schematic and design solutions for the primary purification and cooldown system (PCDS)
- Pressure-actuated electric circuit breaker
- "Dry" refueling method

R&D Results for VBER-600 NPP

Specification	Value
Thermal power, MW	1692
Electric power, MW	600 (612)
Service life	60 years
Serial unit construction term	42 months
Power factor	0.9
Efficiency	36.3 %
Construction cost, billion rubles	157.82 (based on data from the SPbAEP consolidated estimate, in prices of second quarter 2010 for the power of 612 MW (e))
Specific investments in construction of a two-unit VBER-600 NPP	3642.5 $/kW (in prices of second quarter 2010 for the power of 612 MW (e))

- R&D work completed for the VBER-600 NPP verified that it is technically feasible to develop a medium-sized power unit that ensures economic characteristics in terms of the construction cost at the level recommended by Rosatom STC dated Oct. 22, 2009. The target has been achieved – the excess of specific investments in construction of 600 MW power units is below 20% compared to specific investments for large power units.
- The analysis of VBER-300 and VBER-600 technical and economic performance shows that an effective area where VBER economics could be enhanced is uprating the power of the HX loop (~120 MW) followed by developing a power range based on the unified HX loop from the reference four-loop VBER-500 plant.

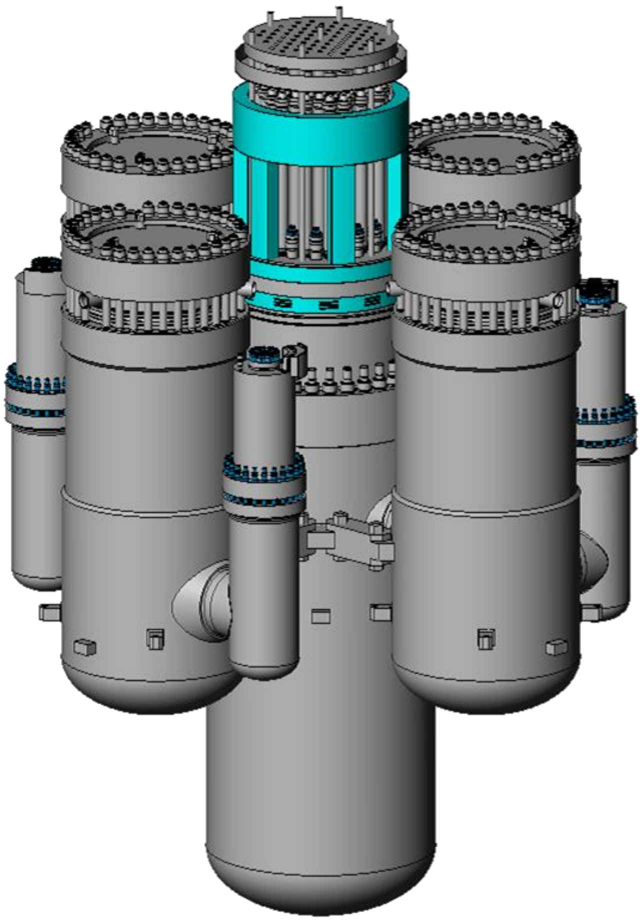
Unified Heat-Exchange Loop in VBER-500



Thermal power, MW	355*
Primary circuit parameters:	
Operating pressure, MPa	16.3
Primary coolant temperature - core outlet, C - core inlet, C	 330 284
Primary coolant flow rate, t/h	4970
Steam output, t/h	642.5
Steam pressure, MPa	6.18
Steam temperature, °C	310.4
Feedwater temperature, °C	216
Pump capacity, kW	1400
Tube system material	42CrNiMo
HX tube, mm	10×1.1
HX surface, m^2	3775

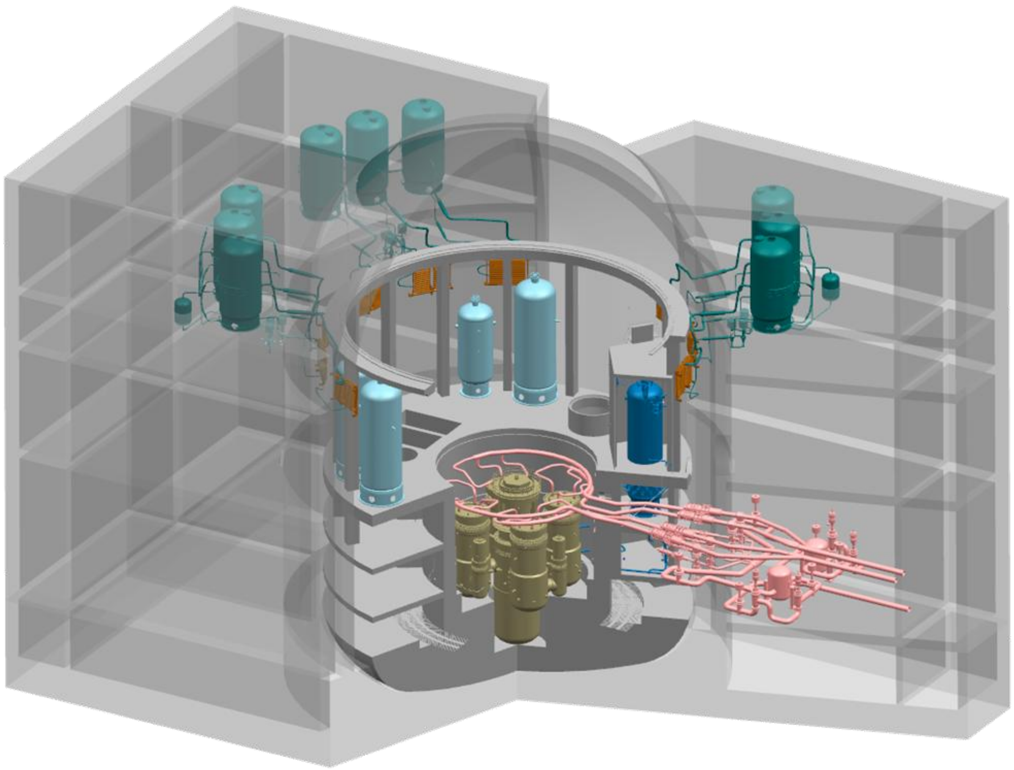
* VBER-300 loop power = 229.2 MW (78.7 MW(e))
VBER-600 loop power = 282 MW (100 MW(e))

VBER-500 Reactor Unit



Number of loops, pcs.	4
Thermal power, MW	1420
Electric power, MW	500
Primary coolant temperature - core outlet, °C - core inlet, °C	 330 284.1
Primary coolant flow rate, t/h	19560
Steam output, t/h	2570
Steam pressure, MPa	6.18
Steam temperature, °C	310.4
Feedwater temperature, °C	216
Pump capacity, kW	1400
Circumscribed diameter, m	12.3
Height, m	17.16
Nozzle inner diameter (ID), mm	1000
Reactor unit mass, t	1690
Reactor unit mass in operating condition, t	1960

VBER-500 RP Layout in Containment

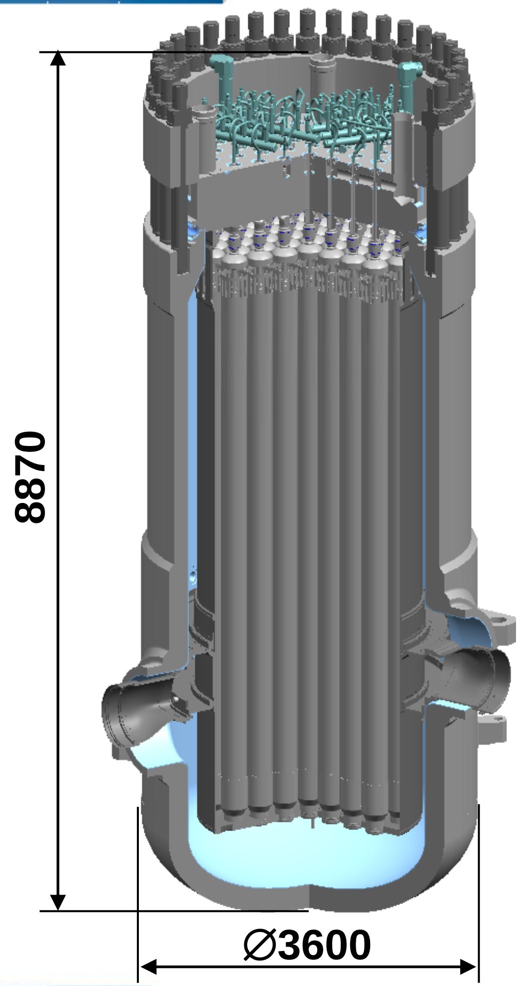


Double containment:	
- internal	**metal**
- external	**concrete**
Internal containment:	
- diameter, m	**35**
- height, m	**45.9**
External containment:	
- outer diameter, m	**41**
- height, m	**48.9**

Peculiarities of LOCA Behavior (on the Example of VBER-600 RP)

- The maximum possible primary circuit leak is limited to the value of DN 130 mm (that is implemented in the postulated accident with a rupture of the main nozzle of the reactor considering operation of the safety retainers).
- When the primary pressure falls, safety retainers (ties) reduce the leak size – the rupture cross section is reduced to 7% of the maximum value.
- No core draining and no overheating of fuel cladding.
- No depressurization of fuel cladding.
- Radiological consequences of the accident are due to the primary coolant reactivity release.
- The maximum containment pressure in the accident is below 0.3 MPa, and it is reached in 3–5 minutes after the beginning of the accident.
- There is no problem with disassembling the core after a primary circuit depressurization accident.
- The steam generator leak size is small (less than D_{eq}=60 mm).
- Secondary circuit safety devices are not actuated in accidents. The leak is localized promptly by closing the localizing valves (the isolated segments of the secondary circuit are designed to withstand the primary pressure).

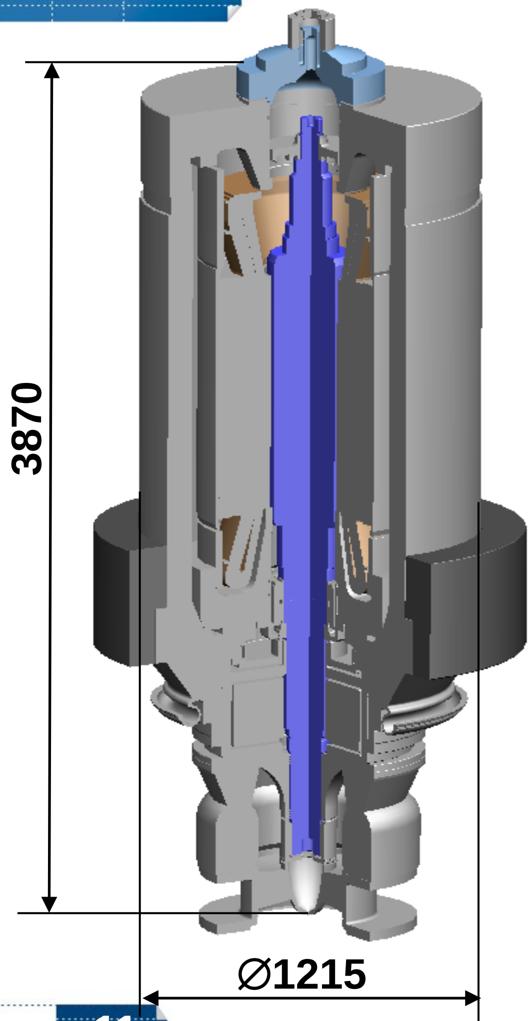
Results of Once-Through SG Application



- No steam-generator blow-through system:
  - reduced amount of liquid radwaste;
  - reduced capacity of the liquid radwaste purification and handling systems;
- No blow-through water purification system:
  - no tanks, coolers, filters and pumps;
- The steam generator vessel operates under the primary pressure:
  - no safety valves to protect the steam generator vessel from overpressure;
  - no primary coolant release when localizing a leak in the tubing system;
- Steam generator repair without opening the primary circuit:
  - reduced dose rates in repair and maintenance of the steam generator.

Steam output, t/h	2570
Feedwater temperature, C	216
Steam pressure downstream of SG, MPa	6.18
Steam temperature downstream of SG, C	310.4
HX tube material	42CrNiMo
HX tube	10×1.1

Results of Canned Pump Application



- **No primary coolant leakage:**
  - **reduced amount of liquid radwaste;**
  - **reduced capacity of the liquid radwaste purification and handling systems;**
- **No sealing water system:**
  - **no coolant beyond the containment;**
  - **no coolant pressure relief, cooling, purification and degassing (gas-removal systems are not required);**
  - **no high-pressure sealing water pumps;**
- **No lubrication system:**
  - **no oil tanks, coolers, filters and oil pumps; at the same time, the fire safety problem is efficiently solved, and reactor compartment fire-fighting system is simplified**

Capacity, m^3/h	6550
Head, m	41.2
Consumed power, kW	1400

Modular Construction Technology

The modular RP design is suited for constructing the main building by the "open top" method in combination with installation of large blocks.

Modular main circulation path:
Reactor vessel + two-vessel blocks*, no pipelines in the main circulation path, no systems in SGs and MCPs

Large factory-made modules:
storage pool, reactor cavity structures,
support collar and element blocks of the containment

Reducing the construction term

*There is an option of installing an integral vessel

Modular design of PCDS, EHRS and CPRS

Optimizing RP Parameters to the Turbine Plant Thermodynamic Cycle

- Weak superheating of live steam in VBER-600 RP (and respectively in VBER-500) makes it possible to pass over from the HPP+S+MPPT+ISSS+LPC thermodynamic cycle adopted in the K-600-6,9/50 (VVER-600) turbine plant to the HPC+ISSS+LPC cycle.
- Computational and design studies by OJSC Power Machines (LMZ) on selecting the turbine design and turbine plant cycle arrangement showed that the efficiency of at least 36.3% can be ensured for the turbine plant.
- The turbine plant designer identified specific actions to ensure the efficiency of the turbine plant:
    - Optimize gas dynamic characteristics for flow paths in the high-pressure part (HPP), medium pressure part (MPPT), low-pressure cylinder (LPC);
    - Optimize the design of steam inlet and steam outlet in the high-pressure cylinder (HPC);
    - Optimize the low-potential part of the turbine island;
    - Optimize the cycle arrangement and thermohydraulic characteristics of the HX equipment in the regeneration system;
    - Optimize thermohydraulic characteristics of interim separator steam-superheater

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Maneuvering Characteristics of the RP in the Power Adjustment Modes

- **Design features of the VBER RP (once-through SG with steam superheating) meet the requirements of power grids for maneuvering modes.**

- **Daily power variation in the range of 50–100% N_{nom} is ensured without the boron control system for the entire fuel cycle (through changing the coolant temperature at the core inlet by the feed water flow rate and by moving the control rods).**

- **For the EOL, the daily maneuvering range can be expanded to 30–100% N_{nom}.**

- **The range of primary automated frequency adjustment (+2 -8)% is ensured by self-control.**

- **Technical requirements for the turbine concerning the power control are coordinated with LMZ.**

Conclusion

VBER power units can be used for regions where large power units are inapplicable because of the state of the power grid systems in such regions.

Compared to large power units, VBER NPP is characterized by lower requisite investments and a shorter construction term, which provides the conditions for using investment capabilities of the regions, including the implementation of private-government partnership, and reduces commercial risks for potential investors.

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