Status report 66 - VBER-300 (VBER-300)

Overview

Full name	VBER-300
Acronym	VBER-300
Reactor type	Pressurized Water Reactor (PWR)
Coolant	Light Water
Moderator	Light water
Neutron spectrum	Thermal Neutrons
Thermal capacity	917.00 MWth
Electrical capacity	325.00 MWe
Design status	Conceptual Design
Designers	JSC "Afrikantov OKB Mechanical Engineering" (OKBM), Nizhny Novgorod
Last update	01-04-2011

Description

Introduction

The VBER-300 reactor plant (RP) is a medium-size power source for ground-based nuclear power plants and nuclear cogeneration plants, as well as for floating nuclear power plants (FNPPs) and desalination complexes. Possible applications are:

- electricity generation;
- cogeneration of electricity and heat for district heating;
- seawater desalination.

The VBER-300 RP design is a result of the evolution of modular marine propulsion reactors. The thermal power increase is due to an increase in mass and overall dimensions while the RP appearance and main design solutions are kept as close as possible to those of marine propulsion reactors. The design is being developed using the experience of VVER-type reactors operation and achievements in the field of NPP safety.

The technology of modular marine propulsion PWRs, as well as that of VVER-type power reactors, has been verified and proven by the successful operating experience of marine propulsion RPs. The total operating experience of marine propulsion reactors exceeds 6500 reactor-years.
Long-term experience in the design, construction and operation of marine propulsion RPs and the results of R&D for their design validation, the technological basis and the personnel potential of Russian enterprises are the background for producing highly-reliable nuclear power sources for nuclear power plants (NPPs).

Specific features of the VBER-300 RP are [1-3]:

- possible application for both ground-based and floating NPPs;
- use of proven nuclear ship building technologies, engineering solutions and operation experience of VVER reactors;
- high safety level; compliance with the safety requirements for new-generation NPPs;

- economic competitiveness of VBER-300 based NPPs;
- possibility to enlarge or reduce the source power using only unified VBER-300 RP equipment (RPs consisting of two, three, or five loops).

The VBER-300 is a thermal neutron reactor that can be used for a variety of purposes (electricity and heat generation, seawater desalination) in a medium power range, in the autonomous mode or inside small power systems (in direct proximity to the consumer).
The diagram of a ground-based nuclear cogeneration plant with VBER-300 is given in Fig. 1.
A standard two-circuit system is used for heat removal from the core.

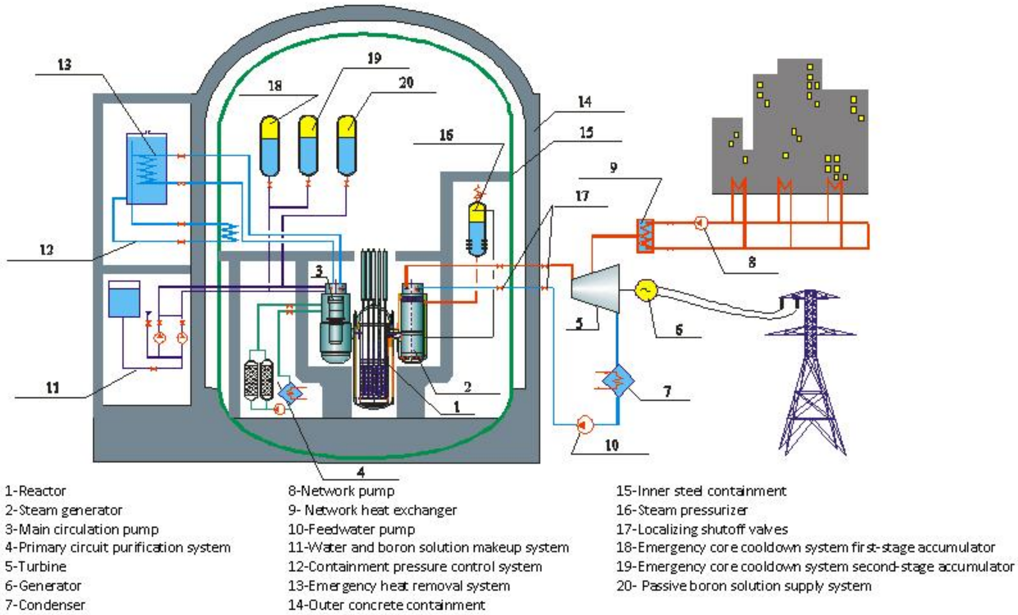

Fig 1. Diagram of a ground-based nuclear cogeneration plant with VBER-300.

Light water acts as a primary coolant and moderator. The hot primary coolant is cooled in the once-through steam generator (SG) that generates slightly superheated steam and directs it to the turbine.
Part of the steam is taken off from the turbine to heat up the district heating circuit fluid.

Main RP design decisions are as follows [13, 7]:

- modular RP design: reactor, SGs and main coolant pumps (MCPs) are interconnected with short nozzles without long pipelines;
- four-loop system with forced and natural circulation of primary coolant;
- pressurized primary circuit with canned pumps and leak-tight bellow-type valves;
- once-through coil SG;
- external steam pressurizer system;
- passive safety systems;
- proven equipment installation, repair and replacement technologies, as well as proven equipment diagnostic and monitoring systems and tools.
- The general view of VBER-300 reactor unit is shown in Fig. 2.

Main parameters of the RP and entire small-size nuclear cogeneration plant are given in Table "Summary table technical data for the small-size nuclear cogeneration plant with the VBER-300 RP" in Appendix 1.

Description of the nuclear systems

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The reactor unit is intended to generate steam with the required parameters. The reactor unit (Fig. 2) consists of:

- integral vessel system;
- reactor core;
- once-through SGs;
- MCPs;
- control rod drive mechanisms.

The main technical characteristics of the reactor unit are given in the Table in Appendix 1.
The vessel system consists of a reactor vessel and four 'SG and MCP' unit vessels connected to the reactor vessel by strong coaxial nozzles.
The reactor vessel is a welded cylindrical shell with an elliptical bottom, four main nozzles and a flanged portion. The reactor vessel accommodates the reactor core, reactor cavity and in-vessel unit. Each 'SG and MCP' unit consists of a SG with its vessel connected with the MCP hydraulic chamber by a nozzle.

The modular design helps to minimize reactor unit mass and overall dimensions and reactor structural volume, therefore decreasing the specific capital investments, excluding main circulation pipelines and associated large and medium break LOCAs.
The size of primary pipeline depressurization with account of flow restrictors does not exceed DN 48 mm.
Vessel system design service life is 60 years.

Basic mass and size characteristics of the reactor unit:

Overall height (mm)	15750
SG WOrking Mass (t - without external pressurizer)	1300
Reactor Vessel Diameter in the Core Area (inner/outer, mm)	3300/3700
Reactor Unit Circumscribed Diameter (mm)	11200

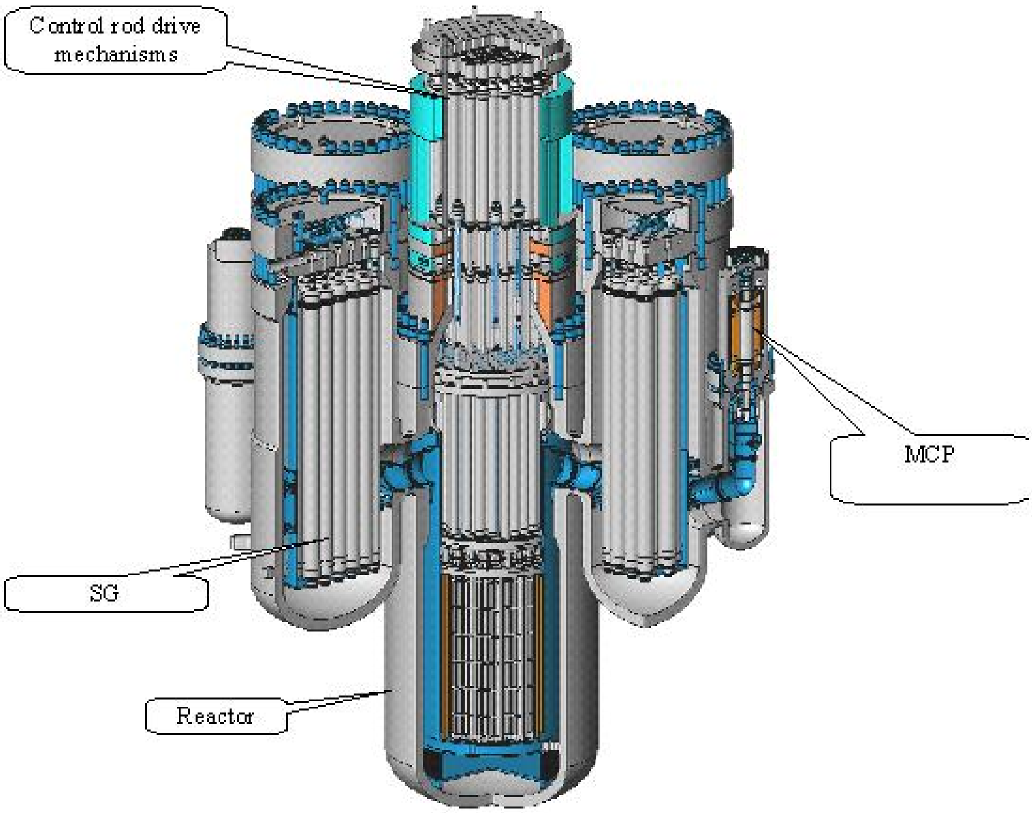


Fig. 2. General view of the VBER-300 RP.

The SG tubing together with the casing is a modular coil-type vertical cylindrical surface heat exchanger (HX) where the primary coolant circulates on the tube side, and the secondary coolant on the shell side.

The tubing heat exchange surface consists of 55 identical coiled steam generating modules; three of these modules are witness samples that can be removed from the SG without touching the rest of the tubing system. The modules are enclosed into the common tubing shell. The steam generating modules and witness sample modules are grouped on the feedwater and steam sides into three independent sections.

The heat exchanging surface of a steam generating module is made of 10×1.4 mm and is made of seven rows of cylindrical multiple-wound coils wound on the central tube of the module (Fig. 3).

The MCP consists of an axial flow pump and a canned electric motor constituting a single module.

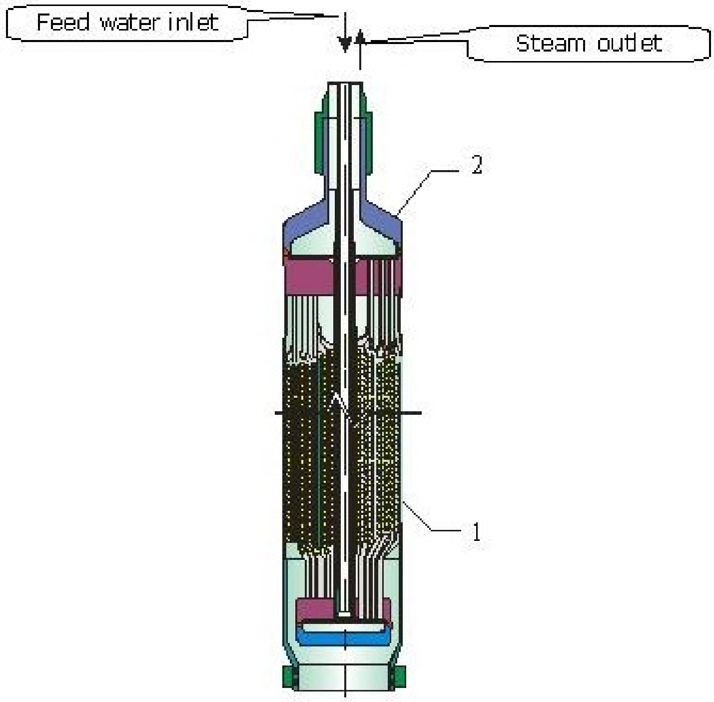


Fig. 3. Steam generating module
(1 - tubing, 2 - steam generating module)

The pump flow channel includes a guide flange, an axial-type console impeller and a guide vane. The guide flange and the guide vane shape the flow at the impeller inlet and move the coolant from the impeller to the pressure chamber.
The asynchronous electric motor consists of a stator, a rotor, a cover, and bearings. The magnetic conductor and stator windings are separated from the rotor cavity by a thin-wall partition welded to the stator casing.

The electric motor rotor is supported by two slide bearings. The axial force acting on the rotor is taken up by an upper thrust bearing and a journal installed at the rotor top end. A flywheel is also installed on the rotor top end.

The VBER-300 concept is based on the maximal possible use of engineering solutions verified and validated in the process of design and operation of VVER reactor cores. The priority was given to ensuring reliability and safety of the reactor core and entire RP and achieving high economic indicators of the fuel cycle.

The above described concept is manifested in the cassette design of the reactor core, reliability of which was confirmed by the long successful operation of VVER reactors.

The fuel is uranium dioxide in form of pellets 7.6 mm in diameter. Uranium enrichment is up to 5% (maximum licensed enrichment).

The fuel assemblies (FAs) of the VBER-300 core are shroudless, with skeleton structure, of TVSA type (Fig. 4). The TVSA FA design was originally developed by OKBM for the VVER-1000 reactor [4].

The TVSA design was used in VVER-1000 reactors at the Kalinin NPP, in the Ukraine and in Bulgaria, and the results confirmed TVSA serviceability, high load-carrying capacity and high resistance to deformation [5].

The TVSA of the VBER-300 RP ensures:

- flexible fuel cycle;
- uranium enrichment as high as 5% (maximum licensed enrichment);
- operation in manoeuvring modes;
- FA vibration strength and geometrical stability during the entire service life owing to the load-carrying skeleton;
- possibility of FA on-site dismantling and repair.

Main characteristics of the TVSA FAs and entire VBER-300 core are given in Table 1.

The reactor core also uses gadolinium fuel elements. A gadolinium fuel element contains gadolinium in the uranium dioxide fuel pellet, and its geometry is the same as the regular fuel element geometry. Gadolinium content is the same as in VVER reactors.

The reactivity margin for burn-up is compensated not only by gadolinium fuel elements, but also by injection of boric acid solution into the primary coolant.

The cluster system of reactivity compensation is used to compensate for temperature and power reactivity effects, reactivity margins for core poisoning by xenon-135 and samarium149, operating margins to change reactivity during reactor power variation, and to provide core subcriticality at reactor shutdown. Fig. 5 shows a diagram of FA elements arrangement.

Clusters are bundles of 18 absorber rods on a common cross bar moving inside guide tubes of E-635 zirconium-alloy with the outer diameter of 12.6 mm and wall thickness of 0.6 mm. Each cluster is moved by its own drive.

All control rods fulfil both reactivity compensation and emergency protection functions. Emergency protection functions (reliable core shutdown) are performed when the control rods are passively inserted into the core by gravity from any position on emergency alarm signals from the control system when the drives are de-energized.

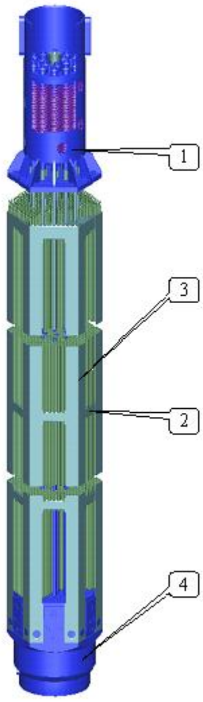


Fig. 4. VBER-300 TVSA FA

Characteristics	Value
Rated thermal capacity [MW]	917
Number of FAs	85
Circumscribed diameter [mm]	2420
Equivalent diameter [mm]	2285
Height [mm]	3530
Power density [MW/m3]	63.4
Number of control rod drives	48
FA arrangement pitch [mm]	236
FA across flats size [mm]	234
Pitch of fuel elements in the FA [mm]	12.75
Outer/inner diameter of regular/gadolinium fuel elements [mm]	9.1/7.73
Fuel element cladding material	Alloy E110
Number of regular/gadolinium fuel elements in the core	26520
Core heat transfer surface area [m2]	2198.7
Average linear heat rate of regular/gadolinium fuel elements [W/cm]	95

Table 1. Main characteristics of VBER-300 core

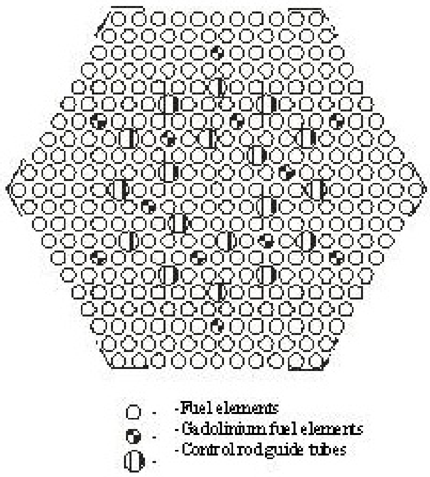


Fig. 5. Map of FAs

2.2 Fuel handling system

VBER-300 nuclear fuel is handled and transported as follows;

- transportation of spent FAs from the reactor into the decay storage pool and then from the storage pool into the transportation container installed in the pit is performed by the fuel handling machine, which serves both the reactor and the decay storage pool;
- the dry method is used for reloading the fuel and in-vessel equipment; the reloaded FA is in water inside the fuel handling machine protective tube; dry transportation of in-vessel equipment is performed in a shielded transportation container that provides biological protection for the servicing personnel;
- the reactor compartment crane is equipped with a double lift system for moving the transportation container, in-vessel equipment and other heavy objects;
- handling and transportation operations in the reactor compartment are performed by an electric travelling polar crane;
- fresh and spent fuel is, respectively, supplied to and out of the reactor compartment along the transportation ramp and through the transportation gate located at the operating level of the reactor compartment.

Acceptance and storage of fresh fuel, as well as its preparation for loading into the core, are provided by the fresh fuel storage. Fresh fuel is delivered to the site in containers, four cassettes in each container, in a special railway carriage. The fresh fuel storage accommodates the number of FAs needed to reload the core plus a 20% margin. Besides, there is a place to store the full core inventory plus a 10% margin. The fresh fuel storage and the reactor compartment are connected with an internal railway with a flat car.

Before refuelling, the control rod drive mechanism cooling system is dismounted, control rod drives are detached from the control rods, the reactor cover is opened, and the top structure is removed. Then the protective tubes unit is dismantled and the crossing pole is installed.Transportation of in-vessel equipment is dry, in a shielded transportation container that provides biological protection for the servicing personnel.

Refuelling is performed by the fuel handling machine (Fig. 6), which handles one FA at a time. The fuel handling machine design includes a refuelling tube which accommodates one FA with the coolant, thus providing the biological shielding and heat removal from the FA during refuelling.

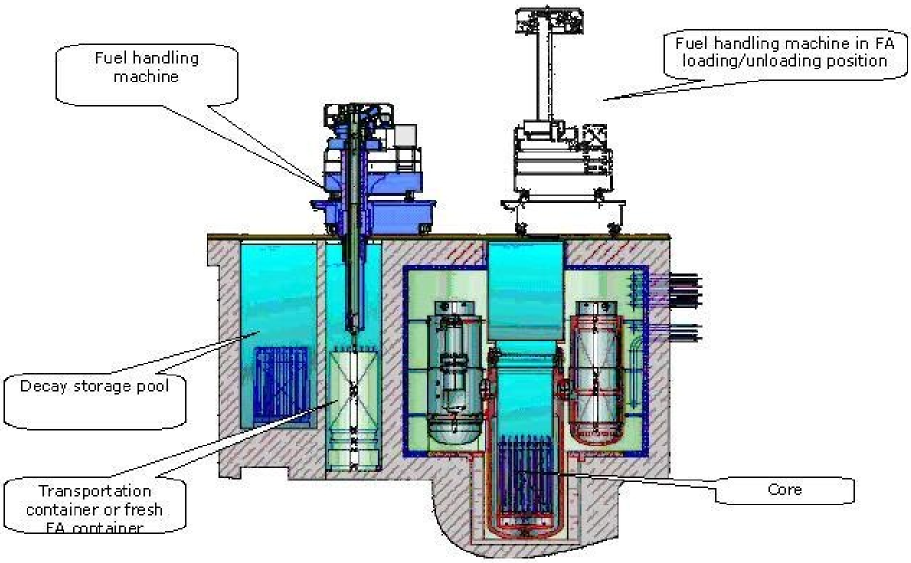


Fig. 6. Refuelling process diagram

Each spent FA is unloaded from the reactor by the fuel handling machine, transported into the decay storage pool and installed onto an assigned storage rack shelf. After that, the fuel handling machine takes one fresh FA from the fresh fuel storage rack, transports it into the reactor and installs into the assigned core cell. In the process of refuelling, it is possible to inspect the integrity of fuel elements cladding.

The decay storage pool can store the spent nuclear fuel as long as six years and can accommodate the entire core inventory.

2.3 Auxiliary systems

2.3.1 Pressurizer system

The VBER-300 uses an external steam pressurizer system. The system includes:

- one steam pressurizer;
- electric heaters;
- piping, control and safety valves, primary measurement transducers.

Main operating modes and parameters of the pressurizer system are given in Table 2.

Characteristic	Value
Working fluid	Steam, primary coolant
Rated pressure, MPa	16.2
Temperature in the pressurizer, °C	348.2
Steam space, m^3	22
Total pressurizer volume, m^3	37

Characteristic	Value
Number of working electric heater units	14
Power of one working electric heater unit, kW	90
Safety valves actuation pressure, MPa	19.1

Table 2. Main technical characteristics of the pressurizer system.

The steam pressurizer is a vessel filled with saturated water and steam with a phase interface. The water space of the pressurizer where electric heaters are located is connected to the hot leg of the primary circuit. The steam space is connected to the cold leg of the primary circuit in the area of MCP pressure chamber; from this chamber, underheated water is supplied to the pressurizer when the valves in the injection line are open.

In order to prevent accumulation and formation of explosive concentrations of hydrogen compounds in the pressurizer steam space, the steam-gas mixture is continuously removed from under the pressurizer cover along the steam removal line into the bubbler. Primary coolant chemistry in the VBER-300 RP with the steam pressurizer is achieved and maintained in the same way as in the VVER-1000 RP.

2.3.2 Purification and cooldown system

The purification and cooldown system is intended to maintain the required primary coolant quality, to decrease boric acid concentration in the primary coolant, to provide normal and emergency reactor cooldown, and to adjust primary coolant chemistry by injecting chemical reagents.

The system consists of the following components:

- recuperative HX;
- two cooling HXs;
- two circulation pumps (main and standby);
- one ion-exchange filter with a combined operation principle, three anion-exchange filters, one cation-exchange filter;
- filter-trap;
- piping, valves, primary measurement transducers.

In order to limit coolant outflow in case of pipeline or equipment depressurization, the nozzles connecting the system to the reactor unit are equipped with flow restrictors.

2.4 Fuel cycle

The VBER-300 RP design concept allows adopting a flexible fuel cycle for the reactor core with standard VVER FAs. The interval between partial refuelling is one or two years. The number of FAs in the refuelling batch is 15 or 30, maximal fuel burnup does not exceed 60.0 MW×day/kgU for the cycle with 30 fresh FAs in the reloading batch and maximum initial uranium enrichment.

Maximum power peaking factors in the discussed VBER-300 RP operation modes do not exceed the maximum values established for VVER-1000 reactors. Natural uranium consumption is within 198-240 gU^{nat}/MW×day. Main characteristics of the discussed VBER-300 fuel cycles are given in Table 3.

Characteristic	Value	
Cycle length	6×1 years	3×2 years
Maximum uranium enrichment [%]	4.25	4.95

Characteristic	Value	
Number of FA in the reloading batch	15	30
Partial refuelling repetition factor	5.67	2.83
U mass in FA [kg]	446.6	446.6
Cycle length [effective days]	350	690
Average (FA average) burnup [MW·day /kg U]	47.9 (52.0)	47.4 (59.2)
Consumption of natural uranium [g/(MW·d)]	198	235
Specific consumption of FA [1/MW·day]	$0.47 \cdot 10^{-4}$	$0.47 \cdot 10^{-4}$

Table 3. Main characteristics of the discussed VBER-300 fuel cycles

Description of safety concept

3.1 Safety Concepts

The principal decisions on safety of the power unit with the VBER-300 reactor are based on the systematic approach integrating the experience and achievements in the area of safety of NPPs and marine propulsion nuclear plants and the requirements defined by locating a nuclear power source near large populated areas and the need to provide resistance against terroristic actions [6].

The safety assurance engineering solutions incorporated in the design correspond to worldwide trends followed by many of the state-of-the-art advanced NPPs:

- priority to accident prevention measures, design simplification;
- inherent safety;
- defence-in-depth principle;
- passive safety systems;
- enhancement of safety against external impacts (including terroristic actions);
- limitation of severe accident consequences.

The main attention in the VBER-300 design is paid to inherent safety features aimed at energy release limitation and reactor self-shutdown; limitation of pressure, temperature, and coolant heating rate; limitation of the size of primary circuit depressurization and outflow rate; and preservation of reactor vessel integrity in severe accidents.
The inherent safety features are provided by engineering solutions of the passively safe reactor stable against all possible disturbances, including personnel errors and terroristic actions:

- negative fuel and coolant temperature reactivity coefficients, negative reactivity coefficient on coolant specific volume, as well as negative steam and integral power reactivity coefficients;
- lower core power density as compared with marine propulsion reactors and VVER-1000 reactors (lower than 72 kW/l);
- stable natural circulation in all heat transfer circuits providing heat removal from the shutdown reactor;
- connecting the majority of primary circuit pipelines to "hot" sections of the circuit and arranging the nozzles on the reactor vessel above the core level, which ensures that steam outflow take place and decreases requirements for the emergency core cooling system (ECCS) flow rate;
- the reactor unit has short load-bearing nozzles between the main equipment units, without lengthy large-diameter primary pipelines;

- small-diameter flow restrictors in the nozzles of primary circuit auxiliary systems; these restrictors, in combination with the modular layout of the main equipment, rule out accidents with large and medium leaks of the primary circuit;
- provision of such material properties and stress-strained state of the vessel structures, which, in combination with the high requirements for production quality and diagnostic systems, practically exclude the loss of operability;
- canned MCPs;
- once-through SGs that limit the increase of secondary circuit heat removal power (overcooling of the primary circuit coolant) in case of a steam line rupture.
- The following main safety systems are incorporated in the VBER-300 design (Fig. 7):
- reactor emergency shutdown systems;
- emergency heat removal systems;
- ECCS;
- accident localization systems, including a double containment and localizing valves in the primary circuit auxiliary systems and systems adjoining them;
- reactor vessel cooling system.

The following design features and engineering solutions ensure high reliability of the safety systems:

- passive functioning of the systems without exceeding the established design limits over the entire range of design basis accidents, including LOCAs and loss of all alternating current sources during not less than 72 hours;
- redundancy and diversity of the reactor shutdown, core cooling and residual heat removal systems;
- containment of emergency radioactive releases by means of the double containment, passive systems and redundant fast-acting valves;
- separation of safety systems channels to exclude common cause failures; use of elements meeting the safe failure principle;
- redundancy and diversity of control systems achieved through the use of self-actuated devices;
- use of diagnostic means and periodic inspections to exclude failures in the safety system elements not revealed during operation.

With two-channel safety systems, the regulatory requirements for safety are met by both deterministic and probabilistic characteristics due to redundancy of the channels elements and redundancy of the safety systems themselves.
The safety actuation systems provide automated and remote control of the safety systems equipment from independent control panels (located in the main and standby control rooms).

3.2 Containment

In order to provide personnel and population protection against the consequences of the design basis and severe accidents, the following engineering solutions for the containment are used in both ground-based and floating VBER-300 unit designs:

- passive containment heat removal system limiting containment pressure in LOCAs;
- system of fuel retention in the reactor vessel in accidents with severe core damage;
- separation of functions ensuring protection against external natural or human-caused impacts and internal emergency impacts;
- iodine and aerosol air purification system for the space between the containment and the protective enclosure purifying air from radioactive leaks from the containment in accidents with containment overpressure.

The reactor containment of a ground-based nuclear cogeneration plant is double, consisting of an internal steel shell and an outer non-preloaded concrete shell (Fig. 8).
The steel shell is cylindrical, 28.0 m in diameter, 34 m high. The concrete shell is made of monolithic non-preloaded reinforced concrete with the external diameter of 34 mm and height of 42.2 m.

3.3 Safety analysis

The design uses the systematic approach to analyse and validate safety based on both deterministic and probabilistic methods.

The deterministic safety analysis is performed using a set of computer codes developed in OKBM and tested during calculations of steady-state and transient modes of NPP operation. The codes take into account the specific features of plant design, circulation circuits, SGs, cooldown systems, control systems etc., and are based on the experimentally proven calculation methods and correlations with long-term experience of application.

The codes were verified by the results of single-effect and integrated experiments performed at thermo-physical test facilities (modular reactor mock-ups), as well as by the experimental data available from full-scale nuclear objects testing and operation.

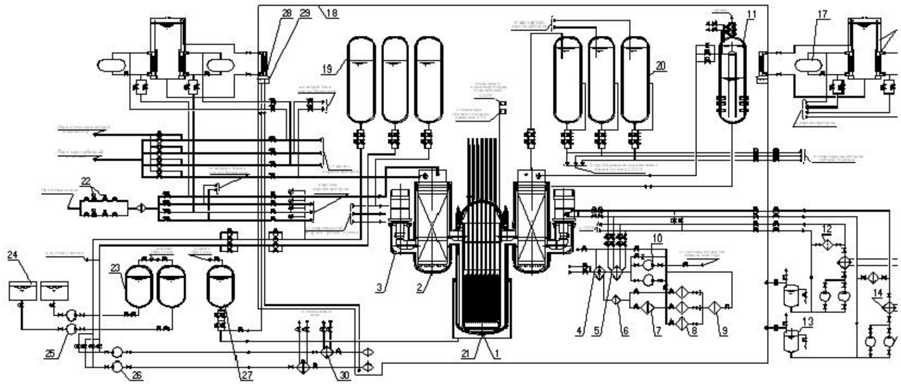
The main codes used for safety analysis were reviewed and certified by the Council on Software Certification of the Gosatomnadzor of Russia.

Besides design basis accidents, the design analyses a wide range of severe accidents where initiating events are coupled with additional safety system failures and/or personnel errors.

Severe accidents include:

- complete power plant de-energization with safety actuation system failures;
- primary pipeline rupture coupled with complete de-energization (Fig. 6) or core cooldown failures;
- transient processes with safety actuation system failures (Fig. 7).

Probabilistic safety analysis is used to support the deterministic analysis with regard to elimination of design weak points and estimation of the effectiveness of safety features improvement decisions; in other words, i.e., the probabilistic safety criteria established in the regulatory documentation.



1-Reactor
2-SG
3-MCP
4-Recuperator
5-Cooldown HX
6-Filter trap
7-Filter based on a combined operation principle
8-Anion exchange filter
9-Cation exchange filter
10-Purification and cooldown system pump
11-Pressurizer
12-Intermediate circuit filter
13-Intermediate circuit tank
14-Intermediate HX
15-Intermediate circuit pump
16-HX unit
17-Water storage tank
18-Containment
19-Hydraulic accumulator
20-Secondary stage ECCS tank
21-Reactor vessel cooling tank
22-Feedwater complex
23-Soluble poison tank
24-Water supply tank
25-Primary circuit make-up pump
26-Recirculating pump
27-Reactor caisson filling tank
28- HX of containment pressure supp system
29-Condensate tank
30-HX of recirculation system

Fig 7. Safety systems of VBER-300 RP

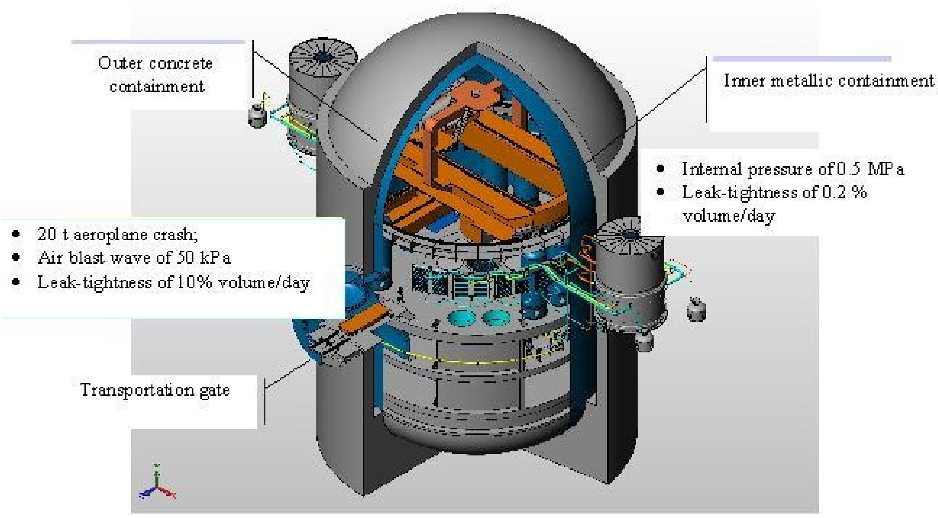


Fig. 8. Nuclear cogeneration plant containment.

3.4 Mitigation of severe accident consequences

Owing to improved VBER-300 RP safety characteristics, the evaluated core meltdown probability is low. Nevertheless, in accordance with the regulations and with account of the experience in similar domestic and foreign new-generation RP design, the VBER-300 design incorporates the analysis of safety assurance in postulated severe accidents.

In accordance with regulations, the permissible emergency exposure doses for the population in accidents with severe core damage should not be exceeded [7, 8], and population evacuation should not be necessary. These requirements conform to the current internationally established norms and recommendations of the Agency [9, 10].

The standard approach to controlling severe accidents is based on a combination of two types of engineering solutions and measures:

- aimed at prevention of core damages (decrease of core damage probability);
- aimed at mitigation of severe accident consequences.

The highest priority of solutions and measures stipulated in the VBER-300 design to mitigate severe accident consequences is retention of the melted corium inside the reactor vessel, since the severe accident consequences are mostly determined by reactor vessel damage and corresponding additional loads on the containment when the corium exits the vessel.

The VBER-300 RP features:

- decreased core power density as compared with large-sized reactors (VVER, PWR);
- relatively low level of residual heat at the stage of core degradation and corium movement to the bottom;
- absence of penetrations in the reactor vessel bottom, which are potential ‘weak spots’ in situations when the corium impacts the bottom;
- smooth external surfaces of the reactor vessel bottom, which creates more favourable conditions for steam evacuation when the core is cooled by boiling water.

The VBER-300 design provides a special emergency vessel cooling system to solve the problem of retaining the corium inside the reactor vessel in severe accidents. This system is passive: the reactor vessel is cooled by boiling water, the generated steam is condensed in the containment (emergency containment cooling system), and the condensate passes through the system of condensate gathering tanks and pipes and once again goes for reactor vessel cooling.

Estimation calculations performed by the VBER-300 developers show that the task of corium retention inside the VBER-300 reactor vessel can be successfully solved.

The developers’ calculations also show that in a severe accident the permissible population exposure doses are not exceeded and, therefore, obligatory population evacuation is not needed. The emergency response area ends at a distance of maximum 1 km away from the NPP. The developers claim that the VBER-300 design fully meets the safety requirements for new-generation reactors that are set by the NRC, US industry, and NPI consortium (EPR reactor), and also meet the Agency recommendations on the safety of advanced reactors [9].

3.5 NPP protection against natural and man-caused impacts

The structures, systems and equipment of the nuclear cogeneration plant with the VBER-300 RP are developed with account of natural and man-caused impacts and can be arranged on a variety of sites meeting the established regulatory requirements.
In accordance with the regulatory requirements, the VBER-300 RP design takes into account the following natural and man-caused impacts: earthquakes, extreme wind loads, low and high temperatures, aircraft crash on any part of the power plant, a blast wave, etc.

The design of the FNPP with the VBER-300 RP includes additional protection measures:

- water area protection against unauthorized access by floating vessels and objects;
- designs of vessel structures and seawater systems in accordance with the floodability requirements stated in the Sea Shipping Register of Russia.

Proliferation resistance

Proliferation resistance of the VBER-300 RP is ensured by the following features:

- enrichment of uranium dioxide fuel with 235U is lower than 5%, in accordance with the Agency recommendations;
- use of the standard fuel cycle of VVER reactors with available infrastructure and mechanisms of protection against proliferation;
- for FNPPs, use of the nuclear vessel servicing and maintenance infrastructure available in Russia.

Safety and security (physical protection)

Technical features and technological approaches used to ensure physical protection of the NPP with the VBER-300 RP are similar to conventional approaches used for NPPs with VVER and PWR reactors.
NPP physical protection system includes the following technical measures:

- security alarms, TV observation system, and operational communications;access control system;
- engineered security features
- organizational measures.

The physical protection system is zoned. For FNPPs, there are two zones: the zone of water area (bound by breakwaters and dams and coastal service area) and the zone of floating power unit (FPU) which is highly controlled.
The following technical features contribute to VBER-300 protection against external impacts:

- double containment with separate functions of protection against external natural or man-caused impacts and internal emergency impacts;
- protection of the water area against unauthorized access by floating vessels or objects (for an FNPP).

Description of turbine-generator systems

The FNPP design will use a turbine-generator set based on the T-275/200-60/50 design developed by JSC "LMZ"; this design will be upgraded to meet the barge mounting requirements.

Tentatively, the turbine will have the following characteristics:

- double-cylinder turbine set: high-pressure and low-pressure double-flow cylinders;
- turbine length without the generator is about 20 m;
- maximal width is about 11 m;
- height above the turbine compartment floor is about 6 m;
- below-turbine cross-stream condenser; overall height of the condenser group is about 15 m;
- the total area occupied by the turbine plant equipment is about 1450 m^2.

Main characteristics of the turbine-generator set are given in Table 4.

Characteristic	Value
Live steam pressure upstream high-pressure cylinder valves [MPa]	6.03
Live steam temperature upstream high-pressure cylinder valves [ºC]	300
Feedwater temperature [ºC]	220
Rated electric power [MW]	325

Characteristic	Value
Rotation speed [rpm]	3000
Rated capacity usage time per year, minimum [hr]	8000
Lifetime [yr]	60

Table 4. Main characteristics of the turbine-generator set

The condensation unit consists of a surface condenser, condensate pumps of the modular desalinating plant, air ejectors, special valves, fittings and piping.

The feedwater system includes three electric feedwater pumps (one main and two standby ones). Each pump has a recirculation line to the deaerator providing pump testing and operability in transients.

Electrical and I&C systems

Each power unit includes an RP, a steam turbine, a generator and a modular step-up transformer. It is proposed to use a 325 MW power generator of TZV-320-2UZ type with complete water cooling developed by JSC "Elektrosila" (Saint-Petersburg).

According to the accepted power output scheme, the electric power generated by the power unit is supplied along high-voltage power lines to the buses of power grid distributing stations. The voltage is 220 kV.

The units are connected to the existing power grid using the "generator/transformer unit-power line" scheme. Besides two power units, standby transformers are also connected to the existing supply lines.
FNPP house loads are powered from main and standby transformers.

Those consumers, which secure the safety of main expensive equipment in case of NPP blackout, are powered from two standby diesel generators (main and backup). Each of the two standby diesel generators can cover the operating loads in case the other generator fails to actuate.

Besides, for each power unit two groups of storage batteries are provided with the respective direct current boards.

Spent fuel and waste management

The improved fuel utilization efficiency are secured by the following conceptual and engineering solutions of the VBER-300 [1]:

- All improvements of the nuclear fuel and fuel cycles of the VVER-1000 reactors are directly applicable to the VBER-300, including the transition to a closed fuel cycle;
- There is also a possibility to use MOX fuel; and
- Increases in the fuel burn-up are provided by geometrical stability and operational reliability of the skeleton-design ductless fuel assemblies.

VBER-300 spent fuel handling technology is the same as for VVER-1000 reactors.
Plans for the future include spent nuclear fuel reprocessing at the refurbished reactor fuel fabrication plant RT-1 and the new RT-2 to be built at the Mining Chemical Combine, with subsequent manufacture of nuclear fuel from the recovery products.
The following design features of the VBER-300 contribute to minimization of the radioactive wastes:

- The leak-tight primary circuit, which is standard for shipboard reactors;
- A closed-loop system of primary coolant purification and boron removal;
- The use of waste less technologies in coolant management; and
- The reprocessing of radioactive wastes using the state-of-the-art low waste technologies.

The use of the design features and technologies proven by multi-year operation experience of icebreaker reactors secures that the quantity of radioactive waste from the VBER-300 plant will not exceed: for solidified liquids ~ 40 m^3, and for solid wastes ~ 20 m^3.

Plant layout

9.1 Ground-based two-unit nuclear cogeneration plant

The basic engineering feature of the nuclear cogeneration plant is independence of the two power unit buildings. Each power unit includes the reactor compartment, main control room building, and turbine island consisting of turbine compartment, auxiliary systems compartment, deaerator compartment, and electric equipment compartment (Fig. 9).

On the side of turbine islands, there are free-access areas: turbine islands of units 1 and 2; electrical equipment compartments; deaerator compartments; outdoor switchgear buildings and structures; and integrated auxiliary building with makeup water demineralizer unit, sewage treatment facilities, and heating system makeup unit.

On the side of reactor compartments, there are restricted areas: reactor compartments No.1 and No.2; special building for the two units arranged symmetrically between the two reactor compartments; special integrated auxiliary building which includes fresh fuel storage and solid radwaste reprocessing and storage unit.

The reactor compartment consists of a cylindrical protective containment with a spherical dome, and two independent annexes attached to the containment from the opposite sides (Fig. 9).

The containment houses the reactor unit with auxiliary systems, spent fuel storage pool, and transportation and handling equipment.

The annexes to the reactor compartment contain the equipment of normal operation and safety systems, electric and control systems, and ventilation systems of the containment and attached units.

The annexes that accommodate process safety system channels, safety actuation system channels, and normal operation systems are boxes of monolithic reinforced concrete with the outer walls 0.9 m thick, rigidly connected to the containment from two opposite sides.

Such separation and arrangement of safety system channels on the opposite sides of the containment is provided to avoid simultaneous damage of all safety systems by a crashing aeroplane.

The turbine island is butt-joined to the reactor compartment.

The metal skeleton of the turbine island and deaerator compartment is a double frame with the spans of 36 and 12 metres. Transverse frames are arranged at a step of 12 m. Lateral stability of the building is ensured by rigid frame joints of deaerator compartment skeleton and rigid connection between the columns and the basement.

The turbine island is of a standard type.

The diameter of the turbine island is 36.0 m and the height to the bottom side of girders is 33.6 m.

The turbine island is a double-span building with an annex on the “A” line side:

- main span: turbine compartment, size 36×54 m;
- auxiliary span: deaerator compartment, size 12×54 m;
- annex on the “A” line side: auxiliary systems compartment, size 12×24 m.

The turbine is installed lengthwise in the turbine compartment.

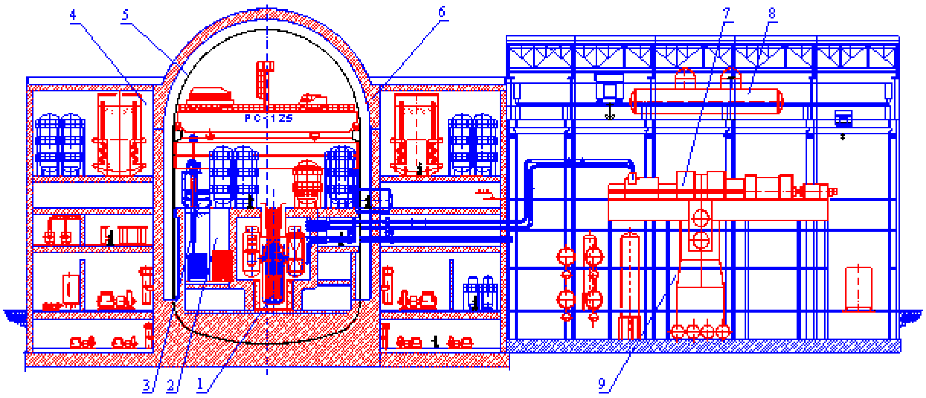


Fig. 9. Main building of the VBER-300 power unit

1: Reactor	4: Safety systems rooms	7: Turbine generator
2: Storage pool	5: Leak-tight enclosure	8: Deaerator
3: Fuel handling machine	6: Containment	9: Condenser

According to the **general layout** (Fig. 10), buildings and structures are arranged in compliance with the process requirements and sanitary and fire-prevention guidelines.
In the centre of the industrial site, there are main buildings of the first and second power units. Each main building includes the reactor compartment, main control room building, turbine compartment, auxiliary systems compartment, deaerator compartment, and normal operation electric equipment compartment. On the side of turbine compartments there are pump stations with turbine compartment cooling system towers.

Between the two power units there is a special building for both units with a vent stack. This special building is connected with the main buildings by pedestrian and transport overpasses.

On the opposite sides of each reactor compartment there are two cooling water buildings with standby diesel power stations.

The power lines exit the power unit and go toward the cooling towers. For the purpose of supplying power to the standby transformer of unit 1 and to the construction substation, there is a 110 kV outdoor switchgear and a main control panel with a unit of auxiliary structures, which are also arranged on the side of the cooling towers.

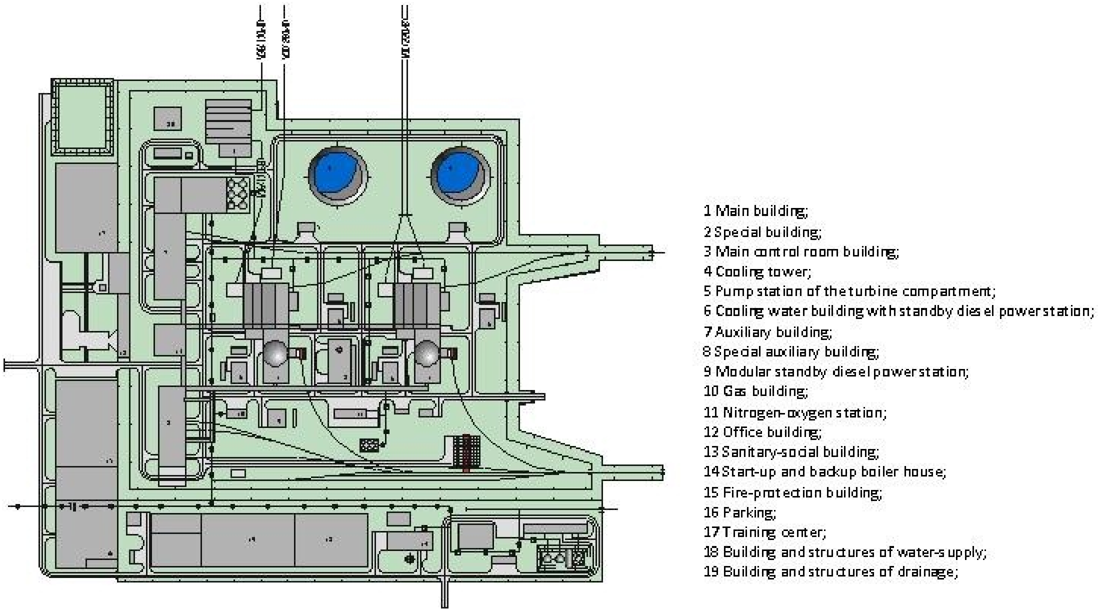


Fig. 10. General layout of nuclear cogeneration plant with twoVBER-300 reactors.

9.2 FNPPs

An FPU of a two-reactor FNPP (Fig. 11) is a towed autonomous floating structure classified as a berth-connected vessel as per the Sea Shipping Register of Russia. The FPU is arranged on a platform supported by three pontoons (one central and two side ones).
The FPU with two RPs is functionally divided into three parts: centre, bow and stern. RPs are mounted in the central part and the turbine generators are mounted in the bow and stern parts.
The main power generating equipment (RP and turbine generators) is installed in the centre plane of the central vessel (Fig. 6). Compartments of auxiliary systems and mechanisms, power distribution systems, ventilation and air conditioning systems, ship systems, automatics and control systems, etc. are located in the side vessels and their superstructures.
The central pontoon carries two independent RPs. Each RP includes a reactor compartment, an electric equipment compartment, and power unit control room compartments. There is also a refuelling and repair compartment.
The main reactor unit equipment with auxiliary systems is located inside the steel containment. The FA storage is located on the central pontoon between the RPs.

The turbine generators together with their auxiliary equipment and systems are mounted in the bow and stern parts of the central pontoon. The port side pontoon carries the equipment intended for conversion, distribution and supply of electricity with a voltage up to 220 kV to coastal objects and for FNPP house loads.
The starboard side pontoon carries the auxiliary equipment such as standby and emergency electric power sources and pumps.

The philosophy governing FPU layout is as follows. The starboard side ('clean side') facing the coast is equipped with facilities for docking with the floating pier, which provides permanent communication of the FPU with the coast and with high-voltage terminals for electric power transmission to the coast. The port side ('dirty side') is intended for docking of logistic ships providing transfer of containers with fresh/spent fuel and radioactive waste.

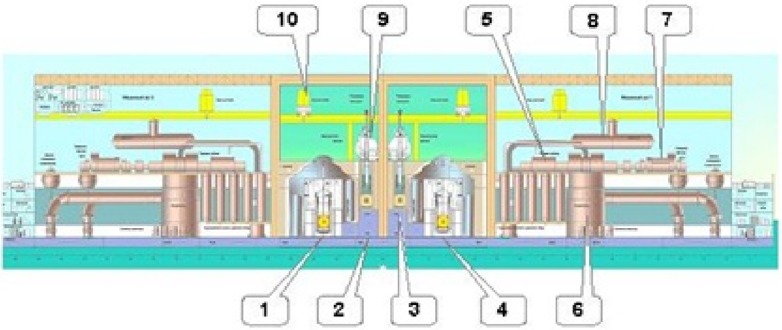


Fig. 11. FPU with two VBER-300 RPs

The total displacement of a two-reactor FPU is 49 000 tons.

The highest priority during FPU design development is to facilitate FPU construction at Russian shipbuilding plants, first of all, at shipbuilding plants of the Far East, which are located not far from probable FNPP operating sites and have the required experience and infrastructure to build nuclear vessels. To that end, it was decided that the FPU will be a trimaran consisting of three right-angled steel vessels joined afloat at an outfitting yard using special joining structures.

Main dimensions of the FNPP with two RPs are given in Table 5.

Length [m]	170
Width [m]	62
Board depth [m]	10
Draught [m]	5.5

Overall height [m]	35
Displacement [t]	49 000

Table 5. Main dimensions of the FNPP with two VBER-300 RPs

In the central part of the FNPP there is a reactor compartment with two stand-alone VBER-300 RPs.

Each RP is arranged inside its own pressurized steel containment. On the outside, the reactor compartment is guarded with a protective enclosure consisting of multi-layer ceilings of the superstructure roof, machine room bulkheads, and superstructure side rooms.

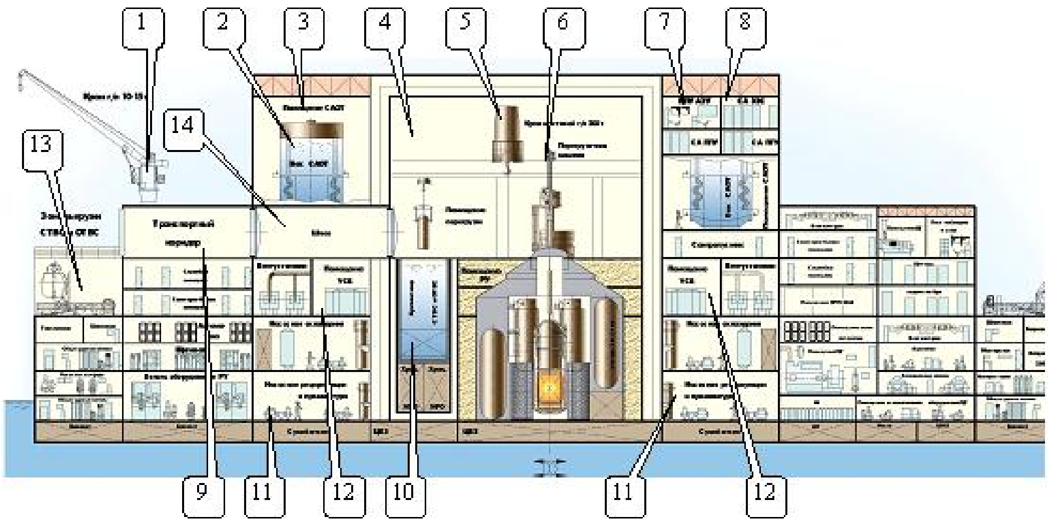
All these structures constitute the external protective barrier of the reactor compartment, which is capable of withstanding external physical impacts, including aircraft crash on the FPU.

The FNPP has two stand-alone machine rooms accommodating turbine-generator sets and auxiliary systems. The machine rooms are located to the bow and stern of the reactor compartment and separated from them by transverse bulkheads of the reactor compartment protective enclosure.

Each machine room has overall dimensions of 54×36 m and a height of 33 m (above the double bottom). This height is required because a bridge crane should be installed in the machine room for turbine-generator set maintenance. Each machine room accommodates one turbine-generator set mounted lengthwise.

In order to make possible construction of an FNPP with the accepted layout, the main equipment of the turbine-generator set is installed in the central vessel of the FNPP.

A one-reactor FPU design was also analysed, and the results are shown in Fig. 12.



1 - Crane 10-15 t; 2 - EHRS tank; 3 - EHRS compartment; 4 - Refueling compartment; 5 - Bridge crane 200 t; 6 - Fuel handling machine; 7 - Power unit main control room; 8 - Electric power system automatics; 9 - Transportation corridor; 10 - Fresh and spent fuel storage; 11 - Recirculation and intermediate circuit pump station; 12 - Safety actuation systems compartment; 13 - Fresh and spent fuel unloading area; 14 – Gate.

Fig. 12. FPU with one VBER-300 RP

Normal operation of the FNPP requires a certain arrangement of water space and coastal infrastructure consisting of:

- hydraulic engineering facilities (jetties, beacons, boom barriers);
- docking structure (sea-walls, piers, etc.);
- anchor links;
- power transmission pylons intended for transport of generated electricity to the consumers;
- facilities providing security of the external plant perimeter both on the coast and on the sea sides (fences, watch-houses,

observation and control system, etc.);
- communications and links (roads, telephone and secure communication lines).

Plant performance

To enhance the technical and economic characteristics of the RP and entire FNPP, the following solutions and approaches were accepted in the design:

- compact modular layout of main RP equipment reducing RP equipment metal intensity and reactor compartment structural volume;
- extension of RP service life to 60 years;
- increase in RP efficiency due to cogeneration;
- NPP location in immediate proximity to large cities, which minimizes heat transportation costs and losses;
- simplification of requirements to safety systems (their number, capacity, operation speed, power supply, control and monitoring) due to advanced inherent safety features and passive principles of systems actuation and operation;
- improvement in fuel cycle characteristics and reduction of annual expenses for fresh fuel and spent fuel handling;
- adoption of proven component designs validated by analyses and experiments and commercially mastered technologies of nuclear icebreaker propulsion RPs and such reactors as VVER-1000, AST-500, and KLT-40S;
- lower amounts of liquid and solid radwaste conditioned by using leak-tight equipment and systems and increasing the service life of main replaceable equipment (steam generator tubing, MCP removable internals, etc.);
- reduction of the duration of refuelling and scheduled maintenance and repair activities, with scheduled maintenance activities performed during refuelling.

The main factor contributing to improvement of VBER-300 technical and economic characteristics is the use of well known and proven reactor unit design with the compact modular layout of the primary system equipment and short nozzles interconnecting main RP equipment (reactor, SG, MCP).

This reactor unit design helps to minimize the mass and overall dimensions of the primary circuit, exclude the primary piping, minimize the reactor compartment structural volume and, consequently, reduce capital construction investments.

The design of PAES-300 FNPP possesses practically all the characteristics of a ground-based NPP and has the following additional advantages:

- FNPPs can be serially manufactured in shipyards and then delivered to the customer fully assembled, tested and ready for operation;
- minimum scope and cost of capital construction work needed to prepare the FNPP docking site at the operating water area of (4.5 ha), which is small as compared to the large sites of ground-based NPPs (as large as 30 ha);
- no need to create transportation links, power transmission lines, or preparatory infrastructure required for ground-based NPPs;
- high degree of freedom in selecting the location for a FNPP as it can be moored in any coastal region independent of its seismicity;
- considerable reduction of construction period (4 years) and, consequently, shorter period before construction credit repayment;
- availability of the entire nuclear vessels servicing and maintenance infrastructure in Russia will permit to minimize costs for FNPP maintenance and refuelling and requirements to qualification of local labour, which could be especially important when exporting such plants to the developing countries;
- adoption of the available nuclear-powered vessels disposition technologies, which allow realizing the "green lawn" concept at the FNPP operating site or, if necessary, replacing FNPPs with expired service life with new ones.

Main technical and economic parameters of NPPs with VBER-300 RPs are given in Table 6.

Index	Value	
	Floating	Ground-based

Index	Value	
Power plant output, net	650	650
Service life, years	50	60
Plant availability target	90	90
Specific capital investments for construction (NOAK), $/kW	2800	3500
Net cost of electric power, ¢/kW·hr	3,3	3,5
Net cost of heat power, $/Gcal	-	~18

Table 6. Main technical and economic parameters claimed by the developers of NPPs with VBER-300 RPs.

Development status of technologies relevant to the NPP

Technologies used for VBER-300 RP development and their current status are given in the Table below.

Reactor technology	**Status**
Modular PWRs for Russian nuclear vessels	Widely used reactor technology, operation experience of marine multi-purpose reactors exceeds 6500 reactor-years
VVER-1000 power reactors (reactor cores)	Widely used reactor technology (20 operating reactors)
Reactor of the nuclear cogeneration plant (AST-500) in part of safety ensuring approaches and solutions	Under construction; AGENCY review was performed
Icebreaker type KLT-40S reactor for the FOAK FNPP (for the floating variant)	The RP and FPU designed were developed; FPU construction license was obtained from the regulatory authority (RF GAN); fabrication of equipment and construction of FPU are under way at "Baltiysky Zavod"

Main engineering solutions of the VBER-300 RP are as follows [1-3]:

- modular RP design: reactor, SG and MCP casings are welded to each other and are interconnected with short coaxial nozzles without long pipelines;
- the reactor is of PWR type, the one that is best proven in the world practice;
- pressurized primary circuit with canned pumps and leak-tight bellow-type valves;
- four-loop system with forced and natural circulation of primary coolant;
- once-through coil SG with titanium tubing;
- cassette core with standard VVER fuel (TVSA FAs) with lowered heat rating meeting the requirements of the existing VVER nuclear fuel cycle;
- passive safety systems for reactor emergency shutdown, core cooldown, and reactor shutdown cooling;
- vessel system service life of 60 years; use of existing metallurgical, press forging and machine-assembly technologies

available at the manufacturers of marine nuclear propulsion plants;
- use of existing equipment mounting, repair and replacement technologies and systems and means of equipment diagnostics and monitoring;
- minimum impact on the personnel, population and environment; consequences of any accidents are minor and are concentrated within the NPP site.

The **basic** VBER-300 RP production **technologies** mastered on the commercial scale are as follows:

- technology of vessel system welding;
- technology of SG tubing manufacture of titanium alloys;
- technology of manufacturing and assembling the in-vessel coaxial elements that provide coolant circulation;
- canned MCPs development and fabrication technology;
- technology of VVER skeleton-type TVSA FAs;
- technology of fabrication of normal operation system and safety system elements (self-actuated devices, pressurizer, tanks, HXs, pumps, filters).

Deployment status and planned schedule

The designs are being developed by Russian organizations and enterprises having a unique experience in designing, building and operating nuclear reactors for the Navy and civil fleet.

Main participants of the VBER-300 project

Company	Responsibility area
JSC “Afrikantov OKB Mechanical Engineering” (OKBM), Nizhny Novgorod	Leading designer of the NPP, chief designer of the VBER-300 RP
RRC “Kurchatov Institute”, Moscow	Scientific supervisor of the RP design
Scientific Research and Design Institute “Atomenergoproyekt” (NIAEP), Nizhny Novgorod	General designer of the ground-based NPP
JSC “TsKB Lazurit”, Nizhny Novgorod	General designer of the floating NPP
JSC “Power Machines”	Chief designer of the turbine generator set
FSUE “NIIIS”	Chief designer of the automated process control system

The VBER-300 design incorporates the results of R&D on reliability, safety and fabrication technologies previously achieved during development of similar VVER reactors and power units, including the results of general industrial programmes on new-generation NPPs development.

Specifically, the VBER-300 design:

- makes full use of the proven calculation methods, verified, validated and certified codes and databases;
- does not require development or certification of new materials;
- incorporates proven elements and structures and commercial fabrication technologies.

With account of the fact that the VBER-300 design in question has larger power than currently operating modular marine propulsion RPs, it will be necessary to perform some development work (fabricate and test pilot samples) for individual RP equipment only.

The design status is as follows.

The VBER-300 preliminary design was completed in 2002, and “Technical and commercial proposal” (a shorter version of technical and economic investigation) for construction of a ground-based or floating NPP with the VBER-300 RP was prepared.

The preliminary design passed the branch review by Rosatom of Russia and was approved by the scientific and technical council.

Presently, there are two directions of further project development:

1. Within the framework of scientific and technical cooperation between Russia and Kazakhstan.

2. Replacement of outdated NPP capabilities or construction of new medium-size NPPs in Russia.

The scientific and technical cooperation between Russia and Kazakhstan is regulated by the "Complex program of cooperation between Russia and Kazakhstan in the area of peaceful nuclear energy". This program produced the following results beneficial for the VBER-300 project:

- the "Nuclear stations" joint venture was organized (registered in Almaty, Kazakhstan) to develop and promote NPPs with small and medium size reactors (including VBER-300) in the markets of Russia, Kazakhstan and other countries;
- construction is under discussion;
- Russian organizations developed technical assignment documents for the NPP with VBER-300, and final designs of RP, turbine plant, and automated process control systems. The technical assignment documents and the final designs were approved by Kazakhstan;
- special technical requirements were developed for the site selection stage (list of regulatory and technical documentation for the NPP with VBER-300);
- declaration of intent was developed and publicly heard at the future NPP site (Aktau, Mangistaus Region);
- main provisions were developed for the feasibility study and justification of investments (justification of investments into construction of an NPP with VBER-300 RPs in the Mangistaus Region of Kazakhstan on the site of BN-350 reactor);
- performed calculations confirmed the economic efficiency of investments into construction of a two-unit NPP with VBER-300 RPs;
- an intergovernmental agreement is being prepared for development and construction of the NPP with VBER-300 in Aktau; to that end, a special work group was formed in Rosatom.

Plans for the future include development of final designs of RP, turbine plant, and automated process control system, as well as development work for the RP and feasibility study for the NPP design.

As for the second direction, the Russian Government has approved the General plan of deploying new nuclear power plants until 2020, and in accordance with this plan, power units with VBER-300 reactors are to be constructed at the site of Primorskaya NPP.

Key R&D work for the VBER-300 RP was completed (optimization of circuitry and layout, reactor and SG material studies, purging of models for reactor and MCPs, etc.)
Apart from that, OKBM developed a series of RPs of different power based on standard VBER-300 equipment; the series includes RPs with the number of loops from 2 to 5 and with the electric power from 100 to 460 MW.

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Technical data

General plant data

Reactor thermal output	917 MWth
Power plant output, gross	325 MWe
Power plant output, net	22.7 MWe
Power plant efficiency, net	33 %
Mode of operation	Load follow
Plant design life	60 Years
Plant availability target >	90 %
Seismic design, SSE	3 g
Primary coolant material	Light Water
Moderator material	Light water
Thermodynamic cycle	Rankine
Type of cycle	Indirect
Non-electric applications	District heat

Safety goals

Core damage frequency <	10E-6 /Reactor-Year
Large early release frequency <	10E-7 /Reactor-Year
Occupational radiation exposure <	5 Person-Sv/RY
Operator Action Time	24 Hours

Economic goals

Mode of deployment	Distributed
Levelized unit electricity cost for NOAK plant	3.5
Heat	18 $/ Gcal

Reactor core

Active core height	3.53 m
Equivalent core diameter	2.285 m
Average linear heat rate	95 KW/m

Average fuel power density	21.3 KW/KgU
Average core power density	63.4 MW/m^3
Fuel material	UO_2
Fuel element type	Smooth-rod, Cylindrical
Cladding material	Zircaloy-4
Outer diameter of elements	9.1 mm
Lattice geometry	Triangular
Number of fuel assemblies	312
Number of fuel Elements in fuel assemblies	85
Enrichment of reload fuel at equilibrium core	4.95 Weight %
Fuel cycle length	72 Months
Average discharge burnup of fuel	47 MWd/Kg
Burnable absorber (strategy/material)	Gd_2O_3
Control rod absorber material	Dysprosium titanate, Boron carbide
Soluble neutron absorber	H_3BO_3
Mode of reactivity control	Control rods
Mode of reactor shut down	Control rods

Primary coolant system

Primary coolant flow rate	4483 Kg/s
Reactor operating pressure	16.3 MPa
Core coolant inlet temperature	292 °C
Core coolant outlet temperature	327.5 °C

Power conversion system

Working medium	Water , Steam Water
Working medium flow rate at nominal conditions	472 Kg/s
Working medium pressure (SG outlet)	6.37 MPa
Working medium temperature (SG outlet)	305 °C
Working medium supply flow rate at nominal conditions	472 Kg/s
Working medium supply temperature	220 °C

Reactor pressure vessel

Inner diameter of cylindrical shell	3400 mm
Wall thickness of cylindrical shell	205 mm

Design pressure	18.2 MPa(a)
Design temperature	350 °C
Base material	Steel, 15Cr2NiMo, VA-A
Total height, inside	8265 mm
Transport weight	306.6 t

Steam generator or Heat Exchanger

Type	Vertical, coiled, once-through
Number	4
Mode of operation	Secondary coolant on the tube side, primary coolant on the shell side
Total tube outside surface area	2624 m^2
Number of heat exchanger tubes	3850
Tube outside diameter	10 mm
Tube material	Titanium alloy
Transport weight	49.8 t

Reactor coolant pump (Primary circulation System)

Circulation Type	Forced
Pump Type	Canned, centrifugal, single-stage, vertical
Number of pumps	4
Pump speed	3000 rpm
Head at rated conditions	55 m
Flow at rated conditions	5380 m^3/s

Pressurizer

Type	External, steam
Total volume	42 m^3
Steam volume (Working medium volume): full power	15 m^3
Steam volume (Working medium volume): Zero power	15 m^3

Primary containment

Type	Steel
Overall form (spherical/cylindrical)	Cylindrical
Dimensions - diameter	34 m

Dimensions - height	48.9 m
Design pressure	0.5 MPa
Design temperature	150 °C
Design leakage rate	0.2 Volume % /day

Secondary containment

Type	Concrete
Overall form (spherical/cylindrical)	Cylindrical
Dimensions - diameter	37 m
Dimensions - height	55 m
Design leakage rate	10 Volume % /day

Residual heat removal systems

Active/passive systems	Active and passive systems

Turbine

Type of turbines	Steam, condensing-extraction
Number of turbine sections per unit (e.g. HP/MP/LP)	2 (1 high-pressure cylinder + 1 double-flow low-pressure cylinder)
Turbine speed	3000 rpm
HP turbine inlet pressure	6.08 MPa(a)
HP turbine inlet temperature	300 °C

Generator

Type	Three-phase, Synchronous, air-cooled
Number	1
Active power	325 MW
Voltage	20 kV
Frequency	50 Hz
Total generator mass including exciter	340 t

Condenser

Type	Surface type , double-circuit
Condenser pressure	5.0 kPa

Plant configuration and layout

Plant configuration options	Ground-based
Surface area of the plant site	30 ha
Elevation or underground embedding of the nuclear island	48 m
Core catcher	None. The molten corium is to be contained inside the reactor vessel owing to external cooling of the vessel bottom.
Protection against aircraft crash	External concrete containment. Crashing aeroplane parameters: mass 20 t, crash speed 200 m/s.
Protection against flooding	Protection against internal flooding: layout of NPP compartments, floor drains, draining systems.