Nuclear power plant with VVER-1500 reactor

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Presently nuclear power industry can become competitive on the Russian electricity market with its inexpensive organic fuel.

One of the ways to solve this problem is to construct nuclear power plants of a new generation with high economic efficiency and safety performance parameters. .

The worldwide experience of development of the nuclear power industry demonstrates that after 2010 the units with the power of 1300-1600 MW will be in demand. Increase of the power per unit in the developed countries (France, Germany, US, Japan) to the level of ~1500-1600 MW (e) is determined by the increasing trend of electricity consumption, competition requirements and high degree of concentration of power consumption.

Comprehensive analysis including economic conditions, investment and industrial situation in Russia demonstrated that for the near future the VVER-1500 reactors upgradeable to the electric power of 1600 MW (VVER-1500/1600) can be a viable solution.

Accordingly, it was decided to finalize the design of VVER-1500 by 2007 and construct a pilot unit by 2013. The pilot unit will be a reference plant for the series of NPP with VVER-1500/1600 reactors and will initiate their implementation in Russia. The site for the pilot unit is chosen in the vicinity of the operational Leningrad NPP..

It is expected that the economic parameters, safety performance and operational reliability of the unit will exceed those VVER-1000 units that are traditional for Russian nuclear power industry and will be at least not worse than those of similar foreign designs.

Rosenergoatom concern, as an operating utility of all Russian nuclear power plants, acts as the contractor and investor of development of the design and construction of the pilot VVER-1500/1600 unit.

Presently, a large scope of research and developmental work is in progress per contract with Rosenergoatom in order to verify the design solutions of the VVER-1500/1600. In parallel with that, the design package for the pilot unit is being produced.

Specifics of the VVER-1500/1600 design – development of the basic design.

For the first time in the practice of designing in Russia, the design documentation of the pilot VVER-1500/1600 unit includes a distinct "basic part" (basic design).

The basic design is the major part of design and safety justification documentation independent of the siting conditions.

The basic design is intended to be used at all sites for such units without any modifications.

Production of the basic design provides:

– unification of the design solutions for serial nuclear power units;

– decrease of the time period required to produce site specific design documentation and to complete the approval, authorization and licensing procedures for the pilot and for all the subsequent units.

– ready-to-use commercial product for participation in tenders for designing and construction of power units in Russia and abroad.

Design description

The design is based on the technical solutions used in the VVER-1000 units of the third generation with enhanced safety features and improved operational and economical performance (NPP-92). Presently, a license has been issued by the regulator to construct the Unit 6 of Novovoronezh NPP of such design. The parameters of the VVER-1500 reactor unit are summarized in the table below.

The VVER-1500/1600 design is characterized by the following main properties:

– compliance with the modern safety regulations, codes and standards, taking into account the recommendation of IAEA and European organizations operating nuclear power plants (EUR);

– high competitive ability on the Russian and foreign markets;

– safety and operational reliability parameters exceeding those of VVER-1000 and not inferior to the European designs N4 and EPR.

Besides that, the design makes full advantage of the accumulated operating experience of the VVER-1000 units (V-320 design), including the recommendations made by various IAEA missions.

The major design features of the unit include:

– extensive use of passive safety systems;

– tolerance to human failures;

– design lifetime of at least 50 years;

– maneuverability;

– high degree of physical protection.

The design of the pilot NPP includes the VVER-1500/1600 (V-448) reactor unit.

The reactor is rated for thermal power of 4350 MW with maximal fuel burnup rate of 70 MW day/(kg of uranium) and for the fuel cycles with the duration of campaign ranging from 12 to 24 months.

The reactor unit has four primary coolant circulation loops with the temperature at the reactor outlet increased to 330^0C.

Each loop includes a main circulation pump, horizontal steam generator producing steam at the pressure of 7.8 MPa (compared to 6.27 MPa for VVER-1000) and a system of main circulation pumps.

The design lifetime of the major equipment of the reactor unit is 60 years, interval between technical certifications of the reactor unit – 8 years.

The design concept of the VVER-1500/1600 reactor is based on the development and implementation of the tested systems and components with proven reliability, used in the operational NPP with VVER reactors.

The main parameters of this unit are presented in the table. The parameters are subject to modifications in the course of design finalization.

main technical parameters of the VVER-1500/1600 reactor unit
(subject to modifications in the course of design finalization)

Table

Parameter	Value
Rated thermal power, MW	4350
Steam generation at nominal power, tons/hour	8840
Coolant flow rate at nominal power, m^3/hour	110760
Nominal steady state pressure at the core outlet, MPa	16,2
Coolant temperature in the core at nominal power, ^{O}C - inlet - outlet	 298,5 330,7
Pressure of the generated saturated steam at the SG outlet at nominal power (absolute), MPa	7,8
Humidity of the generated steam at the SG outlet under normal operating conditions, %, no more than	0,2
Heat generation intensity per unit of core volume, kW/l	89
Maximal linear heat generation of the fuel element W/cm	353
Feedwater temperature under normal operating conditions, °C	230
Feedwater temperature with isolated high pressure reheaters, °C	187
Duration of the fuel exposure in the core (campaign) for the basic operation mode, years	5-6
Maximal fuel burnup (for the basic operation mode), MW day/kg U	70
Effective time of use of the rated power within five-year fuel cycle, hours	8100
Number of fuel assemblies in the core	241
Periodicity of refueling, months.	12-24

The reactor unit is housed in the double full pressure containment with the monitored gap between the shells (Fig. 1)

Figure 1. Reactor outline.

The turbine, electric generator and their auxiliary systems are located in the turbine hall adjacent to the containment.

The design of the turbine hall is based on the use of one-shaft condensation turbine with the rotation rate of 3000 rpm. The turbine is mounted on a vibration insulating foundation.

Component selection

One of the main principles of development of the pilot VVER-1500/1600 unit is to preferably ensure possibility of production of the equipment of the plant and reactor unit within Russia. Selection of the optimal and limiting parameters of the equipment was oriented at the abilities of the existing manufacturers, not to require long term and expensive modernizations of the factories.

The VVER-1500/1600 design conserves the design solutions of the earlier VVER units that proved effective and reliable during operation and modernizations of the NPP with VVER.

The reactor includes traditional set of components: reactor vessel, internals, upper module, control and protection system, control rod drives, in-core detectors and neutron flux detectors.

Similar approach to conservation of the proven design solutions is used in relation to other equipment of the reactor unit – steam generator, primary coolant pumps, piping, condensers and other components.

The reactor vessel of VVER-1500/1600 has larger inner diameter compared to VVER-1000 (4960 mm). This allows housing the core providing electric power of 1500-1600 MW and decreasing the neutron influence on the reactor vessel to such a level that the vessel lifetime can be increased to 60 years. The vessel is transportable by tracks and ships.

The unit is equipped with fast (3000 rpm) turbine produced by LMZ plant (St Petersburg). Structurally, the turbine consists of five cylinders: one dual flow HP cylinder and four dual flow LP cylinders.

The steam generator PGV-1500/1600 is traditionally horizontal. Typical design of such steam generators for the VVER units is well known and has extensive accumulated operating experience. The design of the steam generator for VVER-1500/1600 was improved compared to the PGV-1000, including the following new features: “corridor” layout of tube bundle, incorporation of economizer zone, decreased tube diameter and thickness etc.

Safety provisions

The design of NPP with VVER-1500/1600 reactor is based on a combination of passive and active safety system performing critical safety functions.

For the active channels having 4x100 % structure, normal operation functions and safety functions are combined in the same components. This, in addition to the use, for example, combination of jet and centrifugal pumps, substantially increased the reliability of performing the safety function and decreased the amount of components, valves, pipes, penetrations, alarm systems, instrumentation, cables etc.

Passive systems can independently perform all the safety functions without any contribution of active systems or operator interventions for at least 24 hours. They are operable in case of station blackout, including the loss of emergency AC power sources.

Likewise, the active systems are capable of ensuring safety in case of the most probable accidents for unlimited period of time.

Some of the active safety systems also perform normal operation functions. In this case, no transition or change of operation mode is required if an accident occurs. This substantially increases the reliability of performing the safety functions, ruling out “long term latent failures” and “failures to actuate per demand”.

The VVER-1500/1600 design includes two protection shells (containments) with ventilated gap between them. The inner containment ensures leak tightness of the volume wherein the reactor unit and its major auxiliary components are housed. The outer containment is capable of withstanding all natural or man made impacts on the NPP that are possible at the plant site (aircraft crash, explosions, tornado etc.).

The volume between two containments provides additional degree of leak tightness by means of removal of all substances leaking from within the containment. For this purpose, there are two independent ventilation systems – active and passive ones. The active system directs all the gas to the vent stack through filter system, the passive system – through another set of filters and venting exhaust located on the top of the containment.

The emergency reactor shutdown is performed by gravity insertion of control rods into the core or fast injection of boric acid into the coolant. The number of control rods in the new VVER design is increased from 61 to 118, providing extra efficiency adequate to trim the reactor and cool down to 100 °C without boron injection, taking into account possible failure of one control rod. This increases the plant safety in case of the accidents causing deep cooling of the primary circuit and inadvertent injection of pure water into the reactor.

For cool down and residual heat removal in case of accidents without large loss of primary coolant there are passive heat removal systems through steam generators that can remove heat to surrounding air through special heat exchangers located outside of the protective casing.

Emergency makeup of the primary circuit with boron solution in case of loss of coolant accidents is performed by means of passive system of accumulator tanks, including four accumulator tanks of the first stage with the initial pressure of 5.9 MPa and twelve accumulator tanks of the second stage with the initial pressure of 1,5 MPa. The inventory of the accumulator tanks is sufficient for at least 24 hours without actuation of active makeup systems.

The design of the new generation NPP also includes beyond design accident management systems. Despite extremely low probability of core meltdown, there are systems designed for controlling this process. It is technically possible to contain the molten core materials within the reactor vessel, however should it for some reason fail, they can be collected in a special container under the reactor vessel.

Diversification of the principles of performing safety functions by the safety systems (fig. 2) ensures high safety performance of the plants.

Credibility of the new technologies is supported by the use of similar technical solutions in the Russian designs of VVER-1000 for NPP-92 , Kudankulam NPP in India, Tiangwan NPP in China.

Conclusion

The anticipated economic performance of the NPP with VVER-1500/1600 reactor (construction cost per 1 kW of rated power, electricity generation cost, investment return period, pure discounted profit margin etc.) justify the conclusion that the parameters of such NPP will be among the best nuclear power plants and will give economic advantage as compared to the alternative power sources.

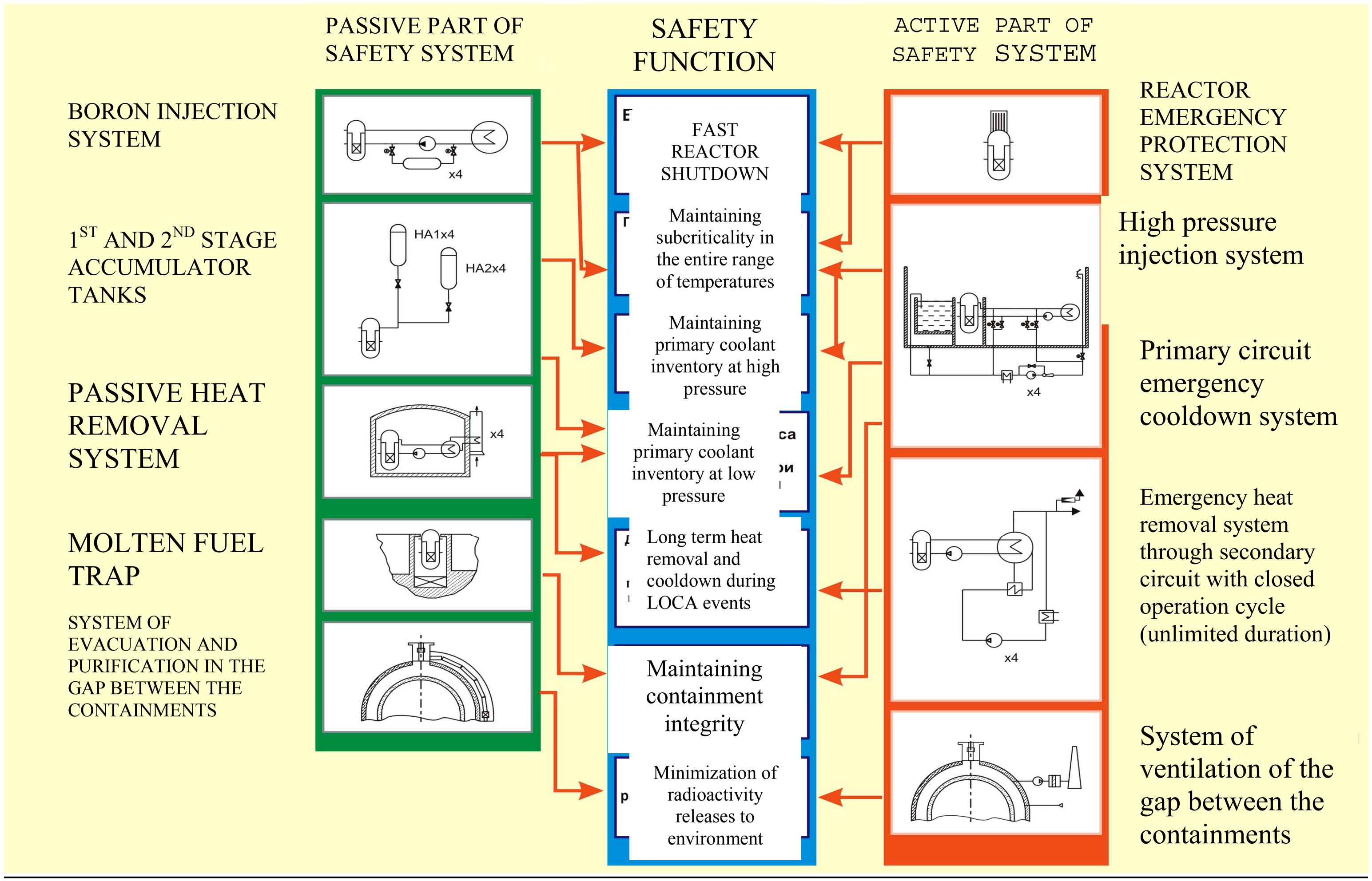

Рис. 2 Diversification of safety functions.