Design and Construction of Advanced Water Cooled Reactors Evolution of VVER Technology Towards NPP-2006 Project

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Abstract. In the frames of evolutional development of VVER technology in Russia a new design, NPP-2006 was developed in 2006-2008. The main goals of the project were elimination of excessive conservatism and improvement of economic characteristics. These problems are solved in projects of construction "Novovoronezh-II" and "Leningrad-II" nuclear power plants. The first units of these NPPs are under construction now. The NPP-2006 design will be the basic one for commercial nuclear power in Russia in the nearest future.

1. NTRODUCTION.

Role of NPPs with VVER reactors in nuclear power of Russian Federation

Current status of nuclear power in Russian Federation can be described as follows:

There are 10 NPPs with 31 Units in operation, total installed capacity 23.242 MW.
As of 01.01.2008 the operating experience of NPPs of Russian design was totaled to 1030 reactor-years with the following contributions by reactor types:
VVER – 350 reactor-years,
RBMK – 490 reactor-years,
EGP – 130 reactor-years,
BN – 60 reactor-years.
The chronology of commissioning the front units of each VVER-type design starting from the very first model is shown in the Table 1.

Table 1.

VVER reactor type	NPP	Front Unit	Connected to the grid	Units (total number)	Note
VVER-210	Novovoronezh	1	1964	1	
VVER-70	Reinsberg	1	1966	1	
VVER-365	Novovoronezh	2	1969	1	
VVER-440	Novovoronezh	3	1971	16 + 19 = 35	
VVER-1000	Novovoronezh	5	1980	1 + 4 = 5	
VVER-1000	Zaporogje	1	1984	21	unified design
VVER-1000	Tianwan	1	2006	2	modified design for China
VVER-1000 (1150 MW)	Novovoronezh-II Leningrad-II	under construction under construction		2(+2) 4	"NPP-2006" design

The majority of units with VVER reactors (59 of 66 reactors built) are in operation nowadays.

- Current stage of VVER evolution

Each VVER reactor design version has several stages of development:

- technology mastering,

- active development of the technology,
- attaining the technology limits.

The availability factor increasingly changes during these 3 stages, starting from about 61% to 86% (the example for VVER-1000 in the period 1993 - 2008) and then up to 92%.
The technology mastering stage provides a reserve due to insufficient knowledge and imperfection. These factors are the most significant at this stage while their influence decreases further on the second and third stages.

Basic documents governing the development process.

The target-oriented indicators presented in the basic documents for long-term development of nuclear power industry to 2015 - 2020 [1- 5] are shown in the Table 2.

Table 2.

№	Basic documents	Inst. Capacity, GW	Electricity generation TW-h	Load factor	NPP share
1	Strategy of nuclear power development in Russia in the first half of XXI century (NS-2000)	52	340	80%	25%
2	Energetic strategy of Russia for the period up to 2020 (ES-2003)	32/42	230/300	82%	20%
3	Federal target-oriented program “Development of nuclear power industry complex of Russia in 2007–2010 and outlook up to 2015” (FTP-2006)	41	300	85%	20%
4	General scheme of power plants placement up to 2020 (Genscheme -2007)	53/59	372/412	80%	23%
5	Program of Rosatom State Nuclear Energy Corporation activity for long-term period (2009 – 2015) (PLA-2008)	33	234.4	82%	20%

All the NPPs are included into Regional target-oriented programs and schemes for spatial planning. Placement and construction of NPPs are carried out in tight contacts of the Customer with Region Authorities.
It should be noted that the Genscheme-2007 was adopted by Russian Government before the world economic crisis onset.

The current targets are shown in Table 3.

Table 3.

Characteristics	2006	2010	2015	2020
NPP installed capacity, GW	23.2	24.2	33.0	41.0
Electricity generation, TW-hour/year	154.7	170.3	224.0	300.0
Nuclear share in electricity generation in Russia, %	16.0	16.0	18.6	20-23
Reduction of operating costs (as compared to 2006),%	100	90	80	70
Reduction of operating costs per unit (as compared to 2006),%	100	90	85	70

The main requirements to the development of modern Russian nuclear energetic are as follows:
- Economic efficiency
- Guaranteed safety
- Absence of real limitations induced by the fuel base in a historically significant time span

- Spent fuel and radioactive waste management. The fuel cycle must secure the safety of final radioactive wastes disposal
- The share of nuclear power at the country energy market shall be not less than 25 – 30%
- Structure of energy production shall provide an opportunity for nuclear energy market expansion
- The export potential: the export share in nuclear electricity generation shall be comparable to the share of its internal consumption.
- Priorities of NPPs territorial placement in Russia
- Priorities of NPPs territorial placement in Russia depend strongly on the regions involved: the European part – maximum number of sites, Siberia and Far East – isolated facilities.

There are 3 main preconditions for NPP placement feasibility taking Russian circumstances into account:

- capacity of a unit shall be not less than 1000 MW;
- a unit shall be operated in the base load regime;
- a region with construction site shall be to the west from the Urals.

The criteria for choice of alternative construction sites in a region are as follows:

- necessity of power balance improvement;
- minimization of expenses associated with transmission lines construction;
- efficiency of a NPP in comparing with alternative sources;
- minimization of expenses associated with meeting regulatory requirements in various safety areas;
- personnel availability for construction and operating stages.

The outcomes from selection of new construction sites for “NPP-2006” implementation [5] are shown in the Table 4.

Table 4.

№	Construction site	Number of units	Connection of front unit to the grid	Condition
1	Novovoronezh-II	2	2012	under construction
2	Leningrad-II	4	2013	under construction
3	Baltic	2	2016	siting license obtaining
4	Seversk (Tomsk)	2	2015	siting license obtaining
5	Tver (Kalinin-II)	4	2015	siting license obtaining
6	Nizhny Novgorod	3	2016	siting license obtaining
7	South-Ural	2	2016	siting license obtaining
8	Central	2	2017	siting license obtaining

2. NPP-2006

2.1. The main goal of the project

The basic “NPP-2006” design for near-term development was elaborated with the following measures taken:

- elimination of excessive conservatism
- improvement of the steam turbine thermal circuit
- improvement of steam pressure parameters at the SG outlet and reduction of pressure losses in steam lines

Economic efficiency was improved due to:

- optimization of passive and active safety systems used in NPP-91 and NPP–92 designs
- unification of the equipment used
- reduction of material consumption
- shortening of the construction period duration

As a result the thermal power was increased up to 3200 MW, and the power unit (gross) efficiency – up to 36.2%

The main targets to be achieved with the new reactor designs:

- Reactor power rising
- Increasing of main reactor equipment life time
- Load factor increase
- Safety systems improvement as a means to limit occupational exposure and radioactive material release to the environment during normal operation as well as in DBA and BDBA (SA) conditions
- Decrease of radioactive waste volume
- Exclusion of a possibility of sudden large break of primary circuit by means of application of the LBB conception
- Meeting the customer requirements (for example – manoeuvrability, special fuel, seismic conditions and so on) to maximum extent possible
- The ways to achieve the above goals are:
- Evolutional method for technical problems solution
- Adapting, to maximum extent possible, all results of previous Scientific and Research Works done for VVER of different modifications
- Account of VVER operation experience
- Meeting the requirements of modern Russian and international standards (IAEA, EUR, INSAG).

2.2. Specificity of "NPP-2006" design procedure in Russia

There are three base engineering companies in Russia with high-skilled personnel and necessary experience for NPP project development. These are well-known R&D institutes "Atomenergoproject" in Moscow, Saint-Petersburg and Nizhny Novgorod.

Two of them, Moscow and Saint-Petersburg institutes fulfilled in 2006-2008 two comparable versions of "NPP-2006" design on the base of "NPP-92" and "NPP-91" designs, respectively.

Such a parallel work had, of course, evident advantages and disadvantages.

Meanwhile, all the works were supervised from the common centre – Concern "Rosenergoatom" and Rosatom State Nuclear Energy Corporation.

The design is developed based on common grounds, in particular:

- Federal law applicable to the peaceful use of nuclear energy
- "Technical assignment for development of the baseline design NPP-2006", "Technical assignment for Reactor Plant of NPP-2006"
- Applicable norms, rules and standards currently in force in Russia
- As a result, for example, the share of unification for the equipment in two versions of "NPP-2006" design was raised from 25% in August 2006 to 47% in August 2007.

The main technical characteristics of the "NPP-2006" design

The main characteristics of the “NPP-2006” design in comparison with previous VVER-1000 NPP designs [7] are shown in the Table 5.

Table 5

	Characteristics	V-320	V-392B	NPP-2006
1	General parameters			
1.1	Thermal power of reactor, MW	3000	3000	3200
1.2	Nominal electric power, MW	1000	1000	up to 1200
1.3	Effective hours of nominal power use, h/year	7000	7360	8400
1.4	Design NPP lifetime, year	30	40	60
1.5	Fuel cycle, year	3	3-4	4-5
1.6	Maximum fuel burn-up, MW-day/kg U	40.2	55	up to 60-70
2	Main parameters of the primary circuit			
2.1	Rate of coolant flow through the reactor, m^3/h	84800	86000	85600
2.2	Coolant temperature at reactor inlet, °C	289.7	291	298.6
2.3	Coolant temperature at reactor outlet, °C	320	321	329.7±5
2.4	Nominal pressure at core outlet, MPa	15.7	15.7	16.2±0.3
3	Main parameters of the secondary circuit			
	Turbine			
3.1	Steam pressure, MPa	6.27	6.27	6.8
3.2	Steam temperature, °C	278.5	278.5	287
	Generator			
3.3	Rotor winding cooling and stator core cooling	gas and water		water
3.4	Stator winding cooling			water

Comparative characteristics of NPPs with VVER-1000 and NPP-2006 reactors and their relevant alterations (expected) [7] are shown in the Table 6.

Table 6

Characteristic	NPPs with VVER-1000	NPP-2006	Alteration, %
Rated power, MWe	1000	1150	+ 14.7
Yearly output, bln. kWh	7.5	9.0	+ 20.0
NPP life time (designed), year	30	50	+ 66.7
Average annual duration of scheduled outages	40	25	-37.5
Availability factor, rel. un.	0,80	0,92	+15.0
Constructional volumes per 1 MW, m3/ MW	620	512	-17.4
Spent fuel volume (in the form of fuel assemblies), t/bln. kWh	5.5	3.5	-36.4

Comparison of “Novovoronezh-II” and “Leningrad-II” projects.
Comparison of the modifications implemented in “Novovoronezh-II NPP” and “Leningrad-II NPP” projects focused on safety systems [6] is shown in the Table 7.

Table 7

Systems	Novovoronezh-II (V-392M)	Leningrad-II (V-491)
Blowdown, make-up system of the primary circuit	Make-up: 3 pumps x 60 t/hour with fulfilling their functions in all regulation range – one in operation, two in reserve	Make-up: 2 pumps x 60 t/hour for “rough” boric regulation and coolant leaks compensation, 3 pumps x 6.3 t/hour for “fine” regulation and leaks

		compensation
Active part of emergency core cooling system	Two-channel integrated system of high and low pressure with – ejector-pumps with redundancy of 2x200% and internal redundancy of 2x100%	Separated 4-channel systems of high and low pressure with channel redundancy of 4x100% each
Emergency boric acid injection system	2-channel system with channel redundancy of 2x100% and internal redundancy of 2x50%	4-channel system with channel redundancy of 4x50%
Emergency feed-water system ___________ Emergency SG cooling system	N/A _____________________ Closed-circuit 2-channel system with redundancy of 2x100%	4-channel system with channel redundancy of 4x100% with emergency feed-water tanks_________________ N/A
Passive core water injection system	Passive 4-channel system with channel redundancy of 4x33% with 2 tanks in every channel	N/A
Passive system of the heat removal	Passive 4-channel system with channel redundancy of 4x33% with 2 air-cooling heat exchangers in every channel	Passive 4-channel system with channel redundancy of 4x33% with 18 water-cooling heat exchangers in every channel

Characteristics of the main equipment, in particular in comparison with the previous design versions are present more detail in numerous dedicated publications of R&D institutes “Atomenergoproject” of Moscow and Saint-Petersburg, as well as Experimental & Design Organisation “GIDROPRESS.”

State of “Novovoronezh-II” NPP construction as of September 2009, unit 1

State of “Leningrad-II” NPP construction as of September 2009, unit 1

REFERENCES

[1] Strategy of nuclear power development in Russia in the first half of XXI century (NS-2000). Approved on the Meeting of the Government of Russian Federation of May 25, 2000

[2] Energetic strategy in Russia for the period up to 2020 (ES-2003). Decree of the Government of Russian Federation of August 28, 2003 № 1234-р

[3] Federal Target Program "Development of Nuclear Power Industry of Russia in 2007–2010 and – 2015" (FTP-2006). Decree of the Government of Russian Federation of October 06, 2006 № 605

[4] General scheme of power plants placement up to 2020 (Genscheme -2007). Approved by the decree of the Government of Russian Federation of February 22, 2008 № 215-р.

[5] Program of Rosatom State Nuclear Energy Corporation activity for long-term period (2009 – 2015) (PLA-2008). Decree of the Government of Russian Federation of September 20, 2009 № 705.

[6] "РОСЭНЕРГОАТОМ", monthly journal of Russian Nuclear Energetic, 2007-2009, press@atompress.ru

[7] "Development of VVER Technology in the Frames of Federal Target Program on "Development of Nuclear Power Industry of Russia in 2007-2010 and - 2015" S. Ryzhov, V. Mokhov, I. Shchekin, A. Churkin, 6th MNTK, May 21-23, 2008