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International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13)

BN-1200 Reactor Power Unit Design Development

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Paris, France

4-7 March 2013

Introduction

- Since the middle of the last century, an extensive infrastructure of sodium fast reactors (BN) has been developed in the Soviet Union and subsequently in the Russian Federation
- Design development and implementation of BN-350, BN-600 and BN-800 reactors enabled to create an effective design, production and operation infrastructure, which is the basis for BN technology further development
- Based on well-developed BN technology, a commercial 1200 MW power unit with sodium fast reactor is now under development in Russia

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Main Goals of BN-1200 design

- Develop a reliable new generation reactor plant for the commercial power unit with fast reactor to implement the first-priority objectives in changing over to closed nuclear fuel cycle
- Improve technical and economic indices of BN reactor power unit to the level of those of Russian VVER of equal power
- Enhance the safety up to the level of the requirements for the 4th generation RP

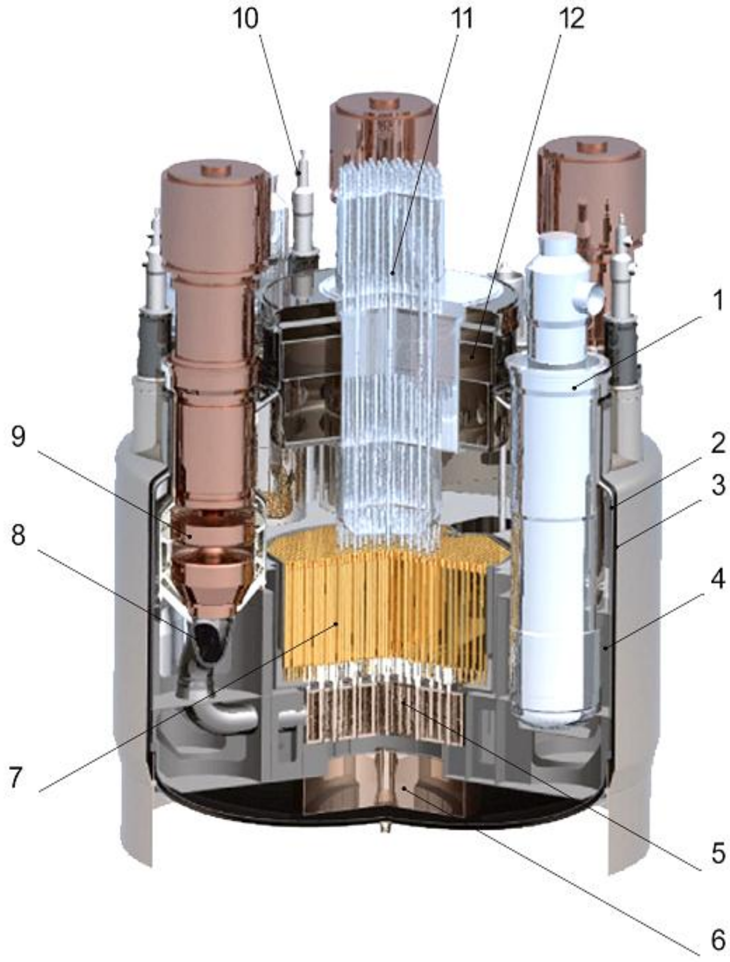
Main Provisions of BN-1200 design

- Use to the maximum extent possible the well-tried scientifically proven engineering solutions implemented in Russian BN reactors
- Apply new engineering solutions to improve power unit safety and cost effectiveness as well as fuel efficiency
- Select electric power equal to that of AES-2006 to use general approach for NPP site selection and unification of turbogenerator and other electric equipment of electric energy generation system
- Provide transportation of large-size equipment by railway

Main characteristics of BN-1200 power unit

Reactor	BN-600	BN-800	BN-1200
Nominal thermal capacity, MW	1470	2100	2800
Gross electric power, MW	600	880	1220
Number of heat generating loops	3	3	4
Primary circuit temperature at IHX inlet/outlet, °C	535/368	547/354	550/ 410
Secondary circuit temperature at SG inlet/outlet, °C	510/318	505/309	527/355
Third circuit parameters: Live steam temperature, °C Live steam pressure, MPa Feed water temperature, °C	 505 14 240	 490 14 210	 510 14 (170) 240 (275)
Efficiency, gross/net, %	42.5 / 40	41.9 / 38.8	43.5 / 40.7

Design decisions on BN-1200 reactor



1 – intermediate heat exchanger (IHX)

2, 3 – main and guard vessels respectively

4 – support skirt

5 – pressure chamber

6 – core catcher

7 – core

8 – pressure pipeline

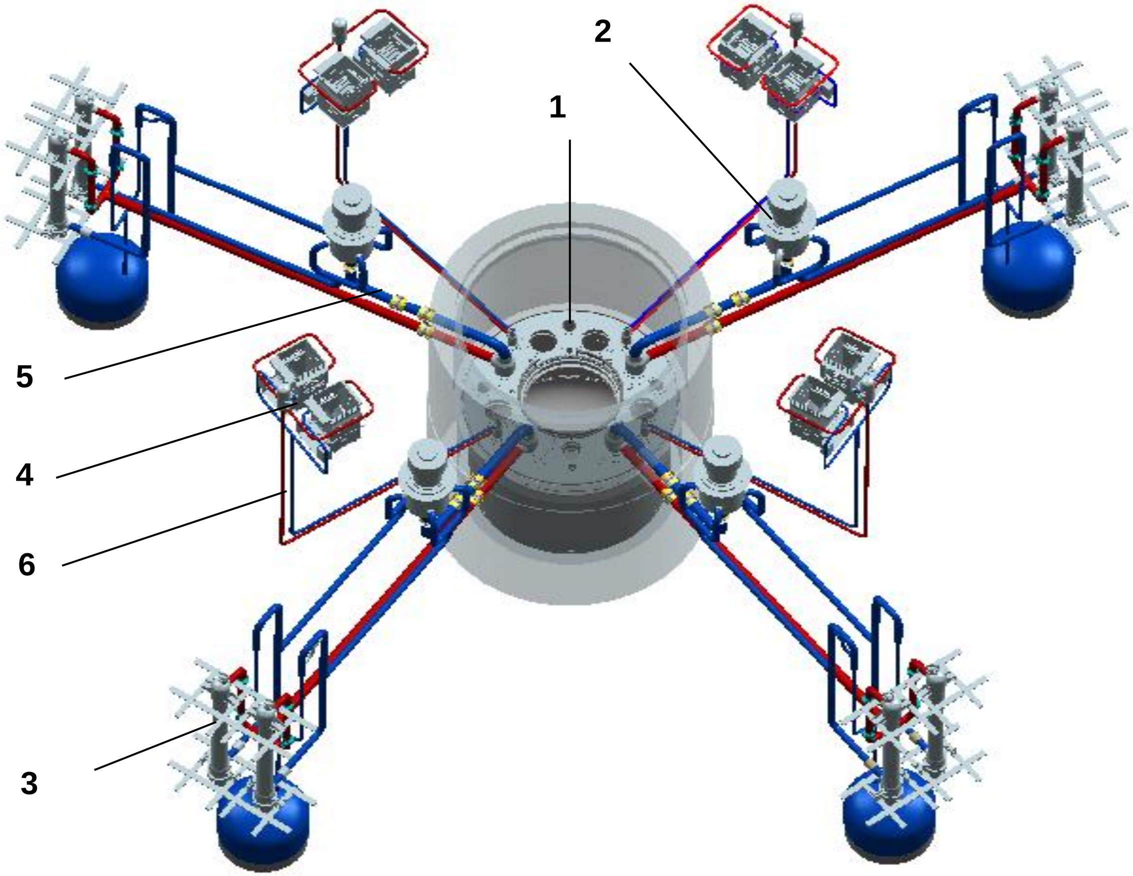
9 – primary circuit main circulating pump (MCP-1)

10 – EHRS heat exchanger

11 – control rod drive mechanisms (CRDM)

12 – rotating plugs

Design decisions on RP layout



1 – reactor

2 – secondary circuit main circulating pump (MCP-2)

3 – steam generator (SG)

4 – air heat exchanger (AHX)

5 – secondary circuit main pipelines

6 – emergency heat removal system (EHRS) pipelines

Main design solutions (1)

BN-1200 development is based on maximum possible use of engineering solutions, which showed good results in BN-600, and used in BN-800

- primary circuit integral layout with guard vessel and main vessel supported in its lower part
- rotating plugs of in-reactor refuelling system with sealing hydraulic locks based on tin-bismuth alloy
- separate suction cavities of primary circuit pumps with check valves at pump discharge, which allow one of four RP heat removal loops to be disconnected in case of equipment failure without reactor shutdown
- in-reactor storage for spent fuel assemblies (FA)

The equipment fabrication process does not basically change relative to that one proven during BN-800 equipment fabrication, including reactor vessel assembling at the site.
The only novelty is assembling of the large rotating plug at the site, as far as its dimensions exceed the railway shipping clearances.

Main design solutions (2)

New engineering solutions introduced in BN-1200 design are aimed at safety increase, provision of power unit high cost effectiveness as well as fuel efficiency

- Placement of the EHRS equipment and primary sodium purification system equipment inside the reactor vessel ⇒ to avoid the radioactive sodium leaking outside ⇒ to reduce the number of auxiliary systems
- Extending of the SG design ⇒ to reduce RP specific material consumption
- Using of a new structural material – steel 12Cr-Ni-Mo-V-Nb ⇒ to increase the SG lifetime
- Reduction of the neutron irradiation of in-reactor structures ⇒ to ensure the extended reactor service life up to 60 years
- Simplification of the refuelling system and reduction of the spent FAs residual energy release through 2 year storage time in the in-reactor storage ⇒ the sodium storage drum for spent FAs intermediate storage before washing and transportation to the water pool is excluded
- Application of bellows thermal expansion compensators ⇒ to reduce the sodium pipeline length of the secondary circuit ⇒ to decrease the total construction volume and power unit material consumption
- RP parameters have been optimized: feed water temperature and steam pressure increase ⇒ efficiency increase (gross) by 1.5 % ⇒ the corresponding turbine generator equipment is under development.

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Core Design Characteristics (1)

- The reactor cores with two types of fuel (MOX and nitride) are under development for BN-1200 reactor.
- The objective of nitride fuel implementation is to completely meet the requirements for inherent safety of the Russian project “Proryv”.
- MOX fuel is developed as a backup option in case of any difficulty or delay in nitride fuel validation.
- Core arrangement is characterized by:
  - top sodium cavity aimed at decreasing sodium void reactivity effect
  - application of fuel of uniform enrichment

Core Design Characteristics (2)

Characteristic	Nitride fuel	MOX fuel
Number of FAs in the core	432	432
FA width across flats, mm	181	181
Fuel element diameter, mm	9,3	9,3
Core height, mm	850	850
Fuel loadings, t	59	47
Main fuel FA residence time * , year	4	4
Average burnup* , MW·day/kg	90	112
Breeding ratio	up to 1.35	up to 1.2

* FA residence time and fuel burnup meet the basic design option with achievement of maximum damage dose of ~ 140 dpa using new structural materials for fuel element claddings. During the initial operation stage, less fuel burnup is possible

Power unit design solutions (1)

By now, the following has been performed:

- Integrated engineering investigations and ecological studies aimed at selecting an option of prototype power unit location at Beloyarsk NPP site
- Development of various schematic layout design options with variation of RP power and overall dimensions, RP equipment design, parameters of the third circuit and the turbine generator facility
- Studies in space and planning designs to select the optimum option of main vessel components layout
- Studies in optimization of handling, installation and maintenance equipment of NPP nuclear fuel handling system
- Development of options for general layout and BN-1200 power unit site

Power unit design solutions (2)

The round shape option has been accepted with reactor cavity in the centre and diametrical arrangement of RP equipment

- The adopted layout meets the modularity requirements for both the equipment and process systems. All four process loops are arranged in the structural units absolutely identical in plan and along the height.
- The cylindrical building with the dome above the RP can take load up to 20 t in case of air crash, shock-wave pressure of 30 kPa and maximum design earthquake of magnitude up to 8.
- The selected option will allow taking of 400 t load in case of air crash without changes in main systems layout. Additionally, only the outer building structures shall be strengthened.

Economic indices improvement (1)

Reactor	BN-600	BN-800	BN-1200
RP specific material consumption, t/MWe	13.0	9.7	5.6
Specific volume of the main vessel, m^3/MWe	1150	750	560
Continues reactor operation between refuelling intervals, eff. day	120…170	155	330
Average fuel burnup, MW×day/kg	70	70 - 100	up to 138
Plant capacity factor	0.77 – 0.8	0.85	0.9
Service life, year	45	45	60

Economic indices improvement (2)

Equipment	Main equipment service life before replacement not less than a year:		
	BN-600	BN-800	BN-1200
MCP-1/MCP-2 removable part (impeller)	6.5 / 15	5 / 5 *	15
Primary circuit cold trap	Replacement is not required		10 … 30 **
CRDM (bottom part)	15	15	30
SG	15 / 30 ***	23	30

•Specified service life is less than in BN-600 because of more intensive operation conditions
**** The service life of new cold trap built-in the primary circuit depends on the decisions, which will be made as per the results of R&D**
***** Evaporator / steam superheater**

Engineering solutions for BN-1200 safety enhancement

Engineering solutions on safety	BN-600	BN-800	BN-1200
Solutions on sodium circuits: ▪ sodium/sodium intermediate circuit ▪ enclosing of vessels with radioactive sodium ▪ enclosing of pipelines with radioactive sodium (r/s) ▪ enclosing of secondary circuit pipelines	+ + + - + (partially)	+ + + - + (partially)	+ + pipelines with r/s are excluded +
Emergency protection: ▪ active ▪ passive, based on hydraulically suspended rods ▪ passive, based on temperature principle of operation	+ - -	+ + -	+ + +
Emergency heat removal system: ▪ as a part of the third circuit ▪ air heat exchanges are connected to the secondary circuit ▪ air heat exchanges are connected to the primary circuit	+ - -	 + -	 +
Core catcher	-	+	+
Emergency release confinement system	-	-	+

Main R&D Work Areas and Technological Tasks to Implement the Design

- Validation of RP equipment (MCP-1, 2, entrainment filter, refuelling complex, SG, bellows compensators)
- Validation of physical and thermohydraulic characteristics of the core; fuel element lifetime tests using BN-600 reactor;
- Mastering of passive safety systems (EHRS, hydraulically- and temperature-actuated emergency protection rods);
- Development of new structural materials to ensure RP service life up to 60 years, to increase lifetime of the replaceable equipment and fuel burnup;
- Feasibility studies in fuel cycle closing (including minor actinides transmutation);
- Computer code verification and certification

Progress and plans for BN-1200 design

- By 2014, it is planned to determine and validate the main design decisions for the power unit, and to develop the RP final design with validating R&D work
- By 2016, it is planned to complete the verifying R&D work
- The Beloyarsk NPP, where BN-600 reactor is operated and BN-800 reactor is being constructed, is the optimum site to construct the prototype BN-1200 power unit. Partially, the infrastructure required for new power unit is already available at this site
- BN-1200 RP equipment can be completely fabricated at the national production facilities developed for BN-800 RP
- It is panned to decide on BN-1200 power unit construction at the stage of RP and power unit final design development based on power unit safety and cost analyses

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Conclusion

- The experience gained in sodium fast reactor development and operation in Russia shows this technology maturity and possibility to develop BN-1200 design for commercial construction.
- Due to optimum combination of reference and new decisions, high technical and economic characteristics and safety indices of BN-1200 design, as well as, possibility of fuel breeding enable to attribute this design to the fourth generation of NPP power units.
- There are necessary manufacturing plants in Russia to ensure prototype BN-1200 reactor construction at the beginning of 20s and further transition to the commercial construction.