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

Development of Fast Sodium Reactor Technology in Russia

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BN technology assimilation

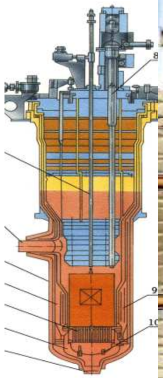
- 50-year proven experience in development and operation
- BN-800 reactor construction aimed at closed nuclear fuel cycle mastering
- Possibility to switch over to commercial construction – BN-1200 project

Power reactors

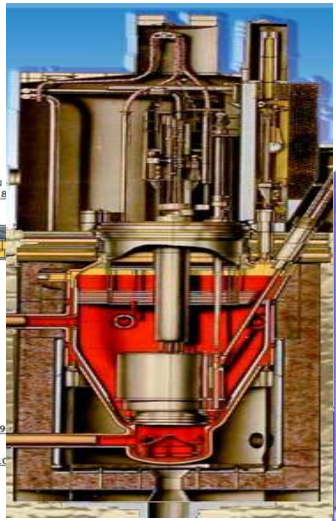
Experimental reactors

BR-5/10 in 1959

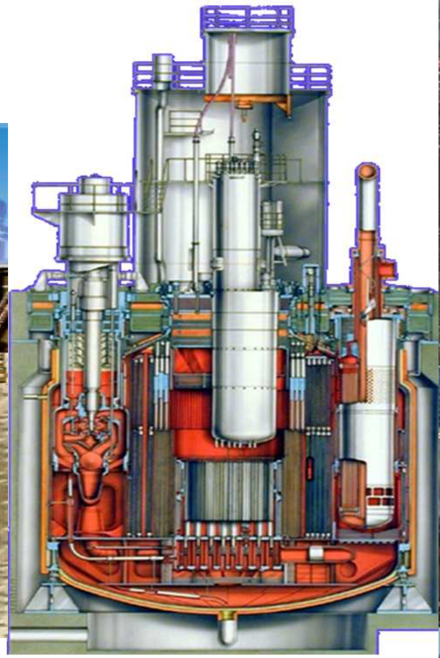
BOR-60 in 1969



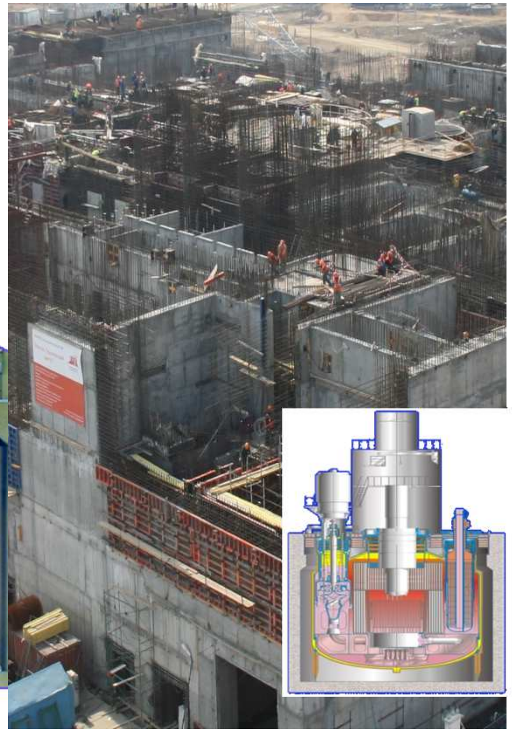
BN-350 in 1973



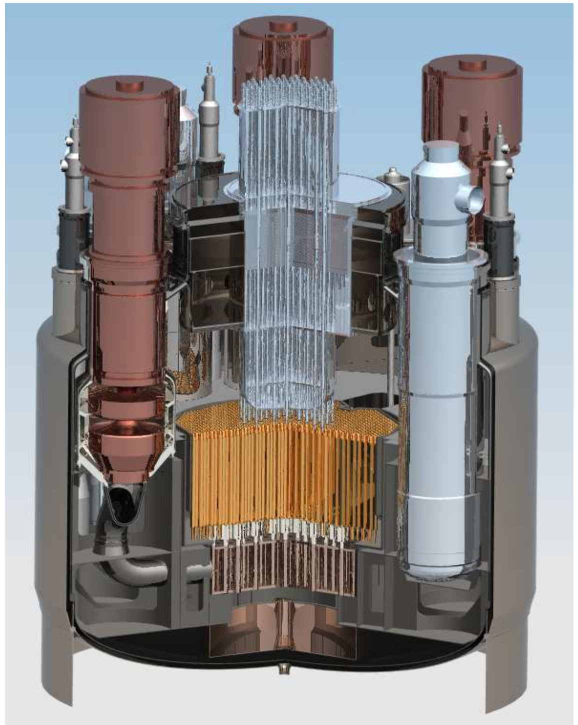
BN-600 in 1980



BN-800 Construction - by 2014



BN-1200 development



Reactor plant parameters

Parameter	BN-350	BN-600	BN-800	BN-1200
Thermal power, MW	750	1470	2100	2800
Sodium temperature, ºC - at reactor inlet/outlet - at SG inlet/outlet	 288/437 420/260	 368/535 505/318	 354/547 505/309	 410/550 527/355
Steam temperature, ºC	405	505	490	510
Steam pressure, MPa	4.5	14	14	17.5
Efficiency, gross/net	*	42.5/40.0	41.9/38.8	43.5/40.7

*125-150 MW electric power generation and up to 100000 t/day fresh water production

Evolution of engineering solutions (1)

Improvement of BN RP layout solutions

Characteristics	BN-350	BN-600	BN-800	BN-1200
Primary circuit layout	Looped	Integrated	Integrated	Integrated
Auxiliary sodium systems in the primary circuit	Yes	Yes	Yes	No
Number of heat removal loops	6	3	3	4
Number of turbines	4	3	1	1
Presence and design of the emergency heat removal system	No	One channel with Na/air HXs connected to the secondary circuit	Three channels with Na/air HXs connected to the secondary circuit loops	Four channels with Na/air HXs connected to autonomous primary Na|Na HXs
Number of SG modules	6 × 2	3 × 24	3 × 20	4 × 2

Evolution of engineering solutions (2)

Reactor core design and fuel cycle (1)

Some of the BN reactor core parameters

Parameter	BN-350	BN-600	BN-800	BN-1200
Fuel volume fraction	0.450	0.443	0.429	0.471
Reactor core height, m	1.06 (1.03)*	0,75 (1,03)*	0.90	0.85
Fuel rod diameter, mm	6.1 (6.9)*	6.9	6.9	9.3
Average power density, kW/l	(390)*	(400)*	450	230
Fuel type	UO_2	UO_2	MOX	Nitride/MOX

*After modernization

Evolution of engineering solutions (3)

Reactor core design and fuel cycle (2)

- **First loading of BN-800 core includes:**
  - **enriched UO_2 subassemblies;**
  - **subassemblies of MOX fuel pellets;**
  - **subassemblies of vibropacked MOX fuel;**
- **MOX fuel pellets will be used after the core hybrid fuel burnup;**
- **Distinctive feature of BN-800 operation is the use of MOX-fuel based on weapon-grade plutonium to dispose of it. At the same time, MOX-fuel will be used that is based on plutonium from VVER reactors; and then, based on BN-generated plutonium.**

Evolution of engineering solutions (4)

Objective related to mustering of fuel burnup in BN reactors (MW·day/kg)

Parameter (fuel cladding)	BN-600 UO_2	BN-800 MOX	BN-1200	
			MOX	Nitride (UPuN)
Achieved burnup (cold worked ChS-68)	70	-	-	-
Planned burnup (cold worked ChS-68)	74	68	-	-
Planned burnup (cold worked EK-164)	93	90	75	-
Planned burnup (EK-181, ChS -139)	-	-	92	74
Planned burnup (ODS types of steel)	-	-	from 112 to 132	90

Evolution of engineering solutions (5)

Reactor design

- The integral BN reactor concept was developed in BN-600 RP design and applied without major changes in BN-800 and BN-1200 RP designs:
  - Reactor vessel bottom support;
  - Conical roof;
  - Rotating plugs;
  - Box-like structure under IHX and main circulation pump (MCP) that ensure sodium circulation through individual IHX - MCP loops;
- MCP check valves that enable to isolate any heat removal loop.

Evolution of engineering solutions (6)

Reactor design

- **Major changes in BN-800 RP design as compared to BN-600:**
  - **Reactor seismic safety enhancement;**
  - **Inclusion of a core catcher into the reactor vessel;**
- **Major changes in BN-1200 RP design:**
  - **Primary circuit equipment is completely integrated in the reactor tank;**
  - **In-reactor shielding is basically made of boron carbide and concentrated immediately around the core.**

Evolution of engineering solutions (7)

Steam Generator Design

- Sectional-modular SG design concept was selected for BN-600 and BN-800 RP enabling to isolate SG modules in case of inter-circuit leakage without reducing the RP power.
- Experience gained in BN-600 SG operation:
  - verified that the sectional-modular SG design concept is efficient with relation to RP reliable operation;
  - showed a trend in developing a sufficiently reliable design of a large-module straight tube steam generator.
- In the BN-1200 reactor, a straight tube SG design is used similar to BN-600 and BN-800, but in BN-1200 only two modules per loop are used. Each of these modules joins the evaporator and superheater portions of the tubing system.

Evolution of engineering solutions (8)

Refueling system

- **BN-600 reactor refueling system is sufficiently effective and reliable: the refueling operations take not more than 10 days and start 2-3 days after the shutdown.**
- **BN-600 reactor refueling system was used in BN-800 design without major changes.**
- **BN-1200 reactor refueling system design has been changed to reduce its material consumption: the main innovation consists in excluding ex-vessel sodium drum for interim storage of spent subassemblies before their washing by extending the in-vessel storage period of spent subassemblies up to two years.**

Requirements for new BN reactor designs (1)

BN-800

The development of BN-800 reactor meets a whole range of goals aimed at mastering the BN technology:

- Use in practice the knowledge and skills obtained during BN-600 development and operation at a new level;
- Master MOX-fuel and other elements of the fuel cycle;
- Maintain and update the entire infrastructure required for developing a commercial BN reactor.
- Demonstrate the enhanced safety level of the power unit having a design which was improved after the Chernobyl accident to the level enabling to obtain the first license for an NPP construction issued in Russia after such an accident.

Requirements for new BN reactor designs (2)

BN-1200 (1)

BN-1200 reactor is being developed for commercial construction – the main focus is on the safety and economic issues:

- **Eliminate the need to evacuate the population living in the vicinity of an NPP in case of all technically possible accidents including extremely unlikely ones with failure of all active safety systems and single failures of passive safety systems provided in the design to limit the consequences of such accidents;**
- **Provide power unit competitiveness through RP design significant simplification and confidence in feasibility of designing power units with 60-year service life.**

Requirements for new BN reactor designs (3)

BN-1200 (2)

BN-1200 technical and economic performance compared with those of BN-600 and BN-800

Characteristics	Reactor		
	BN-600	BN-800	BN-1200
RP specific material consumption, t/Mwe	13.0	9.7	5.6
Reactor continuous operation period between refueling intervals, eff. days	20…170	155	330
Average fuel burnup, MW·day/kg	70	70-100	up to 138
Load factor	0.77 – 0.8	0.85	0.9
Service life, year	45	45	60

Status of projects (1)

BN-350

- Reactor BN-350 was successfully operating during 26 years between 1973-1999. Its load factor was ~ 80% with respect to the allowable power, assigned based on the analysis results of reactor safety conditions – maximum 750 MWt.
- After the Republic of Kazakhstan was established, the reactor was shut down mainly due to organizational problems related to field supervision aimed at providing reactor reliability and safety upon the expiration of its service life of 20 years.
- By now a large scope of work on the reactor decommissioning, including sodium disposal, have been done.

Status of projects (2)

BN-600 (1)

Main work results

Load factor	77.2 % during the 2001–2011 period with the unplanned losses of load factor not exceeding 0.7%. Planned time for scheduled preventive repair and refueling includes two shutdowns per year and a repair of the three turbomachines
Sodium leaks	27 outward sodium leaks (including five radioactive sodium leaks) and 12 SG leaks. Outward leaks were mainly conditioned by deviations in fabrication quality of auxiliary pipelines. The last sodium outward leak occurred in 1993 and the last sodium leak in SG was in 1991
Fuel burnup and subassembly residence time	Average fuel burnup has been increased from 42 to 70 MW day/kg; subassembly residence time is approximately twice as long
Reactor emergency shutdowns	The average number of reactor emergency shutdowns during 7000 hours of operation between 1990–2011 is ~0.2 (for the NPPs around the world it is ~0.6). There were no reactor emergency shutdowns during the 2001–2012
Average radioactive gas emissions during the 2001-2012	<1% of the allowable level
Collective dose rate for the personnel during the 2001-2011	0.475 person Sv·per year

Status of projects (3)

BN-600 (2)

Service Life Extension

- **Validation of possibility to extend the reactor service life for 15 year till 2025 instead of 2010 as designed.**
- **License issued by Rostekhnadzor of Russia for extending the reactor service life for 10 years on condition that a number of power unit equipment would be replaced and certain measures would be taken to enhance reactor safety (mainly, it is the development of the additional emergency heat removal system) in 2010 .**
- **Additional safety enhancement measures are being taken based on the results of an additional analysis (stress-test) performed after the accident at Fukushima NPP.**

Status of projects (4)

BN-800

- BN-800 reactor construction is entering its final stage.
- Almost all the equipment is fabricated by Russian factories.
- A special workshop was erected at the NPP site to assemble reactor vessel large preassembled modules which were installed in the reactor well without completing the construction work on the reactor building structures. The gained successful experience is important in terms of ensuring accelerated construction of commercial BN reactors.
- Reactor is scheduled for startup in 2014.

Status of projects (5)

BN-1200

- Currently, the RP final design and turbomachine final design are under development.
- It is scheduled to issue RP final design in 2014, to fully complete R&D in 2016 except for the activities performed in validation of high fuel burnup.
- Selection and validation of the main design solutions related to the power unit are scheduled for 2014
- There is a preliminary decision to construct the first BN-1200 reactor at the Beloyarskaya NPP site, where BN-600 and BN-800 reactors are located.

Thank You for your attention!