BN-600 and BN-800 Operating Experience

Summary / Objectives:

This presentation will first place the context of the choice of Sodium Fast Reactor in the French Nuclear Policy and its rationale for a closed fuel cycle. It will then present the position of the French Sodium Fast Reactor program in the context of Generation IV. The presentation will then focus on the ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) project. The technical achievements, major innovation progress and management challenges will be presented. The ASTRID project description will highlight the major use of digital tools (numerical simulation, use of virtual reality, multiscale and multi-physics modeling, PLM: Product Lifecycle Management) used to perform efficiently such a complex project.

Meet the Presenter:

Mr. Ilya Pakhomov is the Head of Laboratory in the State Scientific Center of the Russian Federation - Institute for Physics and Power Engineering named after A.I. Leypunsky (IPPE). Since 2006, he has been charged with developing advanced sodium fast reactors as an engineer, junior researcher and head of laboratory. In 2014, he become a member of the working group on scientific and technical support of the BN-1200 project in IPPE. Currently, he is head of laboratory - management of experiments and engineering safety of fast sodium reactors. He is responsible for research of operability elements of the core, safety issues of sodium fires and safety during interloop leaks in the sodium-water steam generators. He is also involved in the formation of an R&D plan for the Fast Sodium Reactors.

Long-term experiment of SFR in Russia and basic concept of BN-600:

The SFR development has been ongoing for more than 60 years in USSR and Russia, and multiple prototype and experimental reactors and industrial power units have been operated. The fundamental difference of BN-600 from previous SFR in Russia is pool type arrangement of primary coolant. The successful operation of BN-600 has been continued from 1980.

Main Characteristics of the BN-600 Power Unit (1/2)

General parameters:	
Thermal power, MWth	1470
Electric power, MWe	600
Number of circuits	3 (primary and secondary circuits - sodium, 3 circuit – steam-water)
Design lifetime, year	30 (extended to 40)
Primary circuit:	
Arrangement	Pool-type
Reactor vessel support	At the bottom
Vessel cooling agent	Cold sodium
Number of heat removal loops	3
Sodium temperature at core Inlet/outlet°C	377/550
Sodium flow rate, t/h	25000
Core and fuel:	
Fuel	Uranium dioxide pellets
Max. fuel burnup, % h.a.	11.1
Diameter, mm	2058
Height, mm	1030
Intermediate heat exchanger:	Shell-and-tube design, secondary sodium flowing on the tube side

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Main Characteristics of The BN-600 Power Unit (2/2)

Primary pump:	Centrifugal, one stage
Rotating speed, rpm	250-970
Steam generator:	Once-through, section & modular, 8 sections (3×8=24 modules)
Inlet/outlet sodium temperature, °C	518/328
Inlet/outlet water/steam temperature, °C	241/507
Life steam pressure, MPa	14
Secondary pump:	Centrifugal, one stage
Rotating speed, rpm	250-750
Turbo generator:	Standard
Power, MW	210
Decay heat removal system:	
Primary and secondary circuits	Normal operation system. Bypass with AHX on loop №5 of secondary circuit
Third circuit	Steam generator-deaerator, emergency feedwater pumps
Refueling system:	2 rotating plugs, vertical refueling mechanism
Fuel transfer system:	Elevators with guide ramp
Spent fuel storage:	In-vessel storage, sodium and water pools
Washing of subassemblies from sodium:	Steam-gas-water

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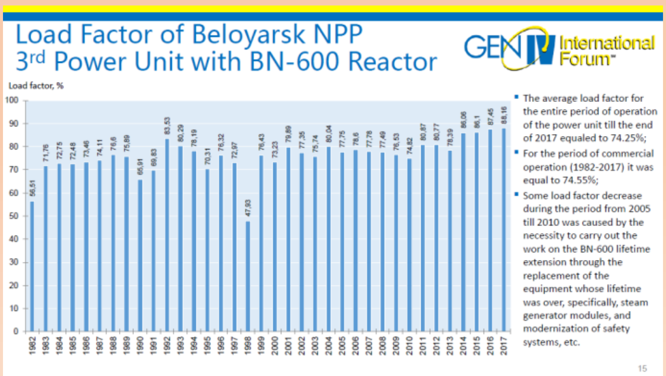
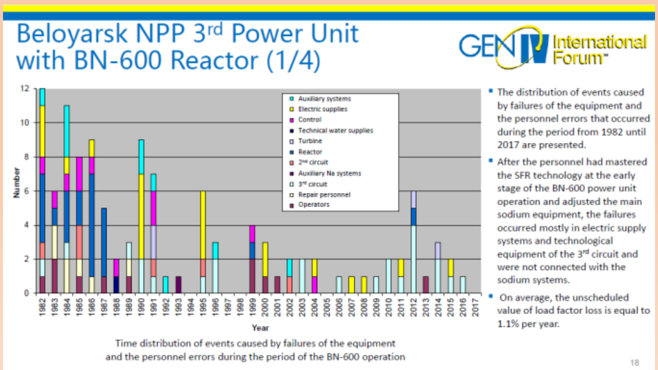
Core and load factor of BN-600:

The burnup design of BN-600 was gradually enhanced with core modification. The successful operation and research made it possible to increase the design value of fuel burnup up to 11.1 % h.a. and change over the longer fuel element life time with 4-hold reactor refueling.

The average load factor is 74.25% by 2017, and during 1982-2004, the load factor slightly decreased due to scheduled maintenance. Only 3 % of whole was due to failure of the equipment or personal errors. The failures mostly occurred in electric supply system and technical equipment of 3rd circuit.

The operating-time of SFR equipment testify to good compatibility of coolant with structural materials used and its low corrosion activity.





Sodium leaks:

The sodium leaks outside and inter-circuit leaks in SG was gained at the early stage of operation. 27 sodium leaks were detected and there were 14 cases sodium fires. The accumulated leaks experience proved the effectiveness of the protection systems, and no sodium leaks occurred in this 24 years.

Steam generator have demonstrated high performance characteristics and have operated without inter-circuit leaks for 27 years except 12 leaks in early stage of operation.

Beloyarsk NPP 3rd Power Unit with BN-600 Reactor (3/4)

The main characteristics of large sodium leaks at BN-600

Date of leak	Place of leak	Detection method	Causes	Amount of sodium leaked
13.01.80	Sodium reception system	Ionization smoke detector	Defects of flange joints	50 kg
11.08.81	SG valve seal	Electric heating control, ionization detectors	Defects of flange joints	300 kg
02.07.82	SG valve seal	Personnel visual inspection	Defects of flange joints	30 kg
31.12.90	SG drainage line	Electric heating	Manufacture defects	600 kg
07.10.93	Primary sodium purification system	Electric heating, radioactive aerosol detection	Insufficient homing action of pipelines	1000 kg
06.05.94	Drainage line of intermediate heat exchanger	Personnel visual inspection	Cutting the pipe before sodium freezing	650 kg

The experience in sodium leaks outside and inter-circuit leaks in SG was gained at the early stage of the BN-600 operation (when the personnel mastered the SFR technology, tested and optimized the design solutions, adjusted operation modes, detected defects in manufacture of equipment.)

- All 27 sodium leaks that occurred at the early stage of the BN-600 reactor operation were mostly small leaks:
  - In 21 leaks the amount of sodium leaked didn't exceed 10 L (from 0.1 to 10 L).
- In 6 other leaks the amount of sodium leaked was 30, 50, 300, 600, 650 and 1000 L.

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Characteristics of Intercircuit Leaks in BN-600 Power Unit SG Modules

Parameters at the time of leak	No. of leak 1	2	3	4	5	6	7	8	9	10	11	12
Module	RH	SH	RH	SH	SH	SH	SH	SH	EV	RH	SH	RH
Date of leak	24.06.80	04.07.80	24.08.80	08.09.80	20.10.80	09.06.81	19.01.82	22.07.83	06.11.84	10.11.84	24.02.85	24.01.91
Leak rate, g/s	0.02-6	0.1-0.615	0.09-15	0.2-0.3	0.0064-0.23	140	250	-	0-3	0.02	0.14	4.6
Amount of water escaped into 2 circuit, kg	40	17.87	7	0.18	0.78	40	20.3	2.77	1.8	0.75	0.73	8.3

EV – Evaporator, SH – Superheater, RH – Reheater

- Evaluating all the deviations from normal operating mode that took place during the BN-600 operation, including those connected with sodium leaks, it should be emphasized that none of them resulted in any radiation impact on the population and environment. By the off-site impact criteria, all of them are below the International Nuclear Event Scale, and, therefore, are insignificant.

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Key result of BN-600:

During the operation of BN-600, many kind of goals were achieved in addition to more than 147.4 billion kWh of electricity production. On of most important results is the fact that the design parameters for sodium large-scale equipment operation period and life time have been achieved and even exceeded.

The life time of BN-600 was extended 10 years in 2010 and activities are currently underway to re-extend by 2020.

Key Results of BN-600 Power Unit Operation (1/2)

- During the operation of the BN-600 power unit, the following goals were achieved:
  - Long-term endurance tests of large-size equipment operating in sodium.
  - Mastering the sodium technology on an industrial scale.
  - Development and optimization of operating modes.
  - Mastering the technology of replacement and repair of sodium equipment including the primary components (pumps, steam generators, intermediate heat exchangers, rotating plugs).
  - Reaching the acceptable level of fuel burnup.

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Key Results of BN-600 Power Unit Operation (2/2)

- During the entire period of its operation (as of the end of 2017, 265 707 hours in critical state), BN-600 produced more than 147.4 billion kWh of electrical energy, making a notable contribution into the Urals power supply as one of the most cost-effective and eco-friendly power units:
  - Amount of gaseous radioactive products emission to the atmosphere, as a rule, does not exceed 1% of the acceptable level.
  - Amount of solid and liquid radioactive waste is also minimal, not exceeding 50 m^3 per year.
  - Personnel radiation exposure is lower than the average level existing in the nuclear industry.
- One of the most important results obtained during the BN-600 operation is the fact that the design parameters for sodium large-scale equipment operation period and life time have been achieved and even exceeded.
- During the period of industrial operation the BN-600 reactor demonstrated high safety and reliability characteristics and thus solved its task which was to industrially justify the reliability and safety of the SFR technology and, specifically, the technology of sodium coolant.

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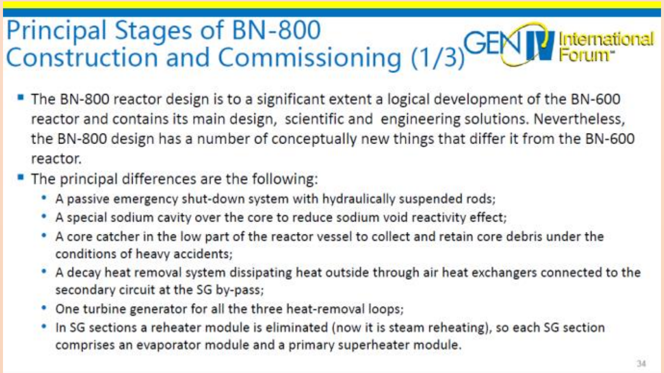
Basic concept of BN-800:

One of main issue of BN-800 is the demonstration of closed fuel cycle. The hybrid core system with both of MOX and enriched uranium fuels are used. BN-800 was designed based on BN600 design but it has number of new things including safety systems. BN-800 has operated 14543 hours and generated 9.4 billion kWh of electricity by the end of 2017.



Prospect for further SFR development in Russia and conclusion:

In compliance with further objectives in development and improvement of SFR technologies, demonstration of closed fuel cycle, commercialization of SFR technology, and development of large-scale SFR technology are highlighted.