STATUS OF THE ACTIVITIES ON SFR IN RUSSIA. PROSPECTS OF INTERNATIONAL COLLABORATION ON MONJU

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SODIUM-COOLED FAST REACTORS IN RUSSIA

Accumulated operational experience on SFR – more than 147 reactor-years

In Russia there are 2 facilities with fast reactors in operation:

- *Test reactor BOR-60 at the SSC RF RIAR (Dimitrovgrad)*
- *Commercial power unit No. 3 of the Beloyarsk NPP (BelNPP) with sodium cooled fast reactor BN-600 (Zarechny)*

BR-5/10
(1959-2002, Obninsk)

BOR-60
(1969, Dimitrovgrad)

BN-350
(1972-1999, Aktau)

BN-600
(1980, Zarechny)

BN-800
(2014, Zarechny)

- *Research reactor BR-10 at the SSC RF – IPPE (Obninsk) is on the stage of preparation for its decommissioning*
- *No. 4 power unit of the Beloyarsk NPP with the BN-800 reactor is under construction*

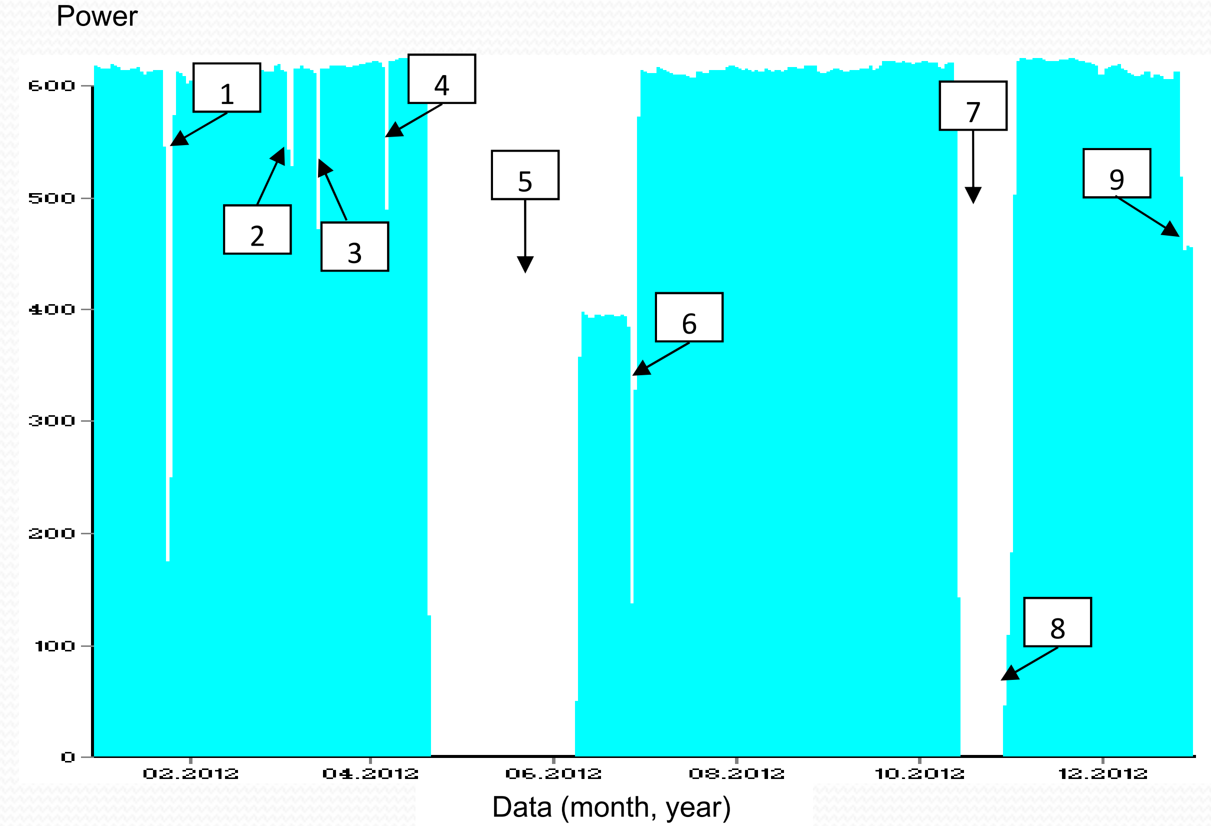
Basic parameters of the BN-600 power unit

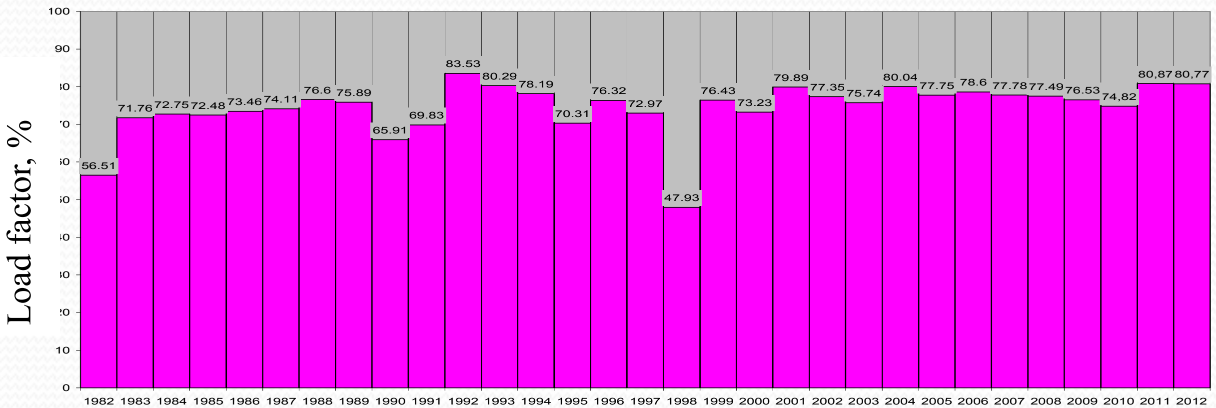
Parameter	Value
Thermal power, MW	1470
Electric power, MW	600
Number of heat removal loops	3
Configuration of the primary circuit	Pool
Steam generator design	Once-through, sectional-modular
Maximum neutron flux density, $n \cdot cm^{-2} \cdot s^{-1}$	$6.5 \cdot 10^{15}$
Fuel	UO_2
Max. fuel burn-up, % h. a.	11.1
Inlet/outlet core coolant temperature, ºC	377/550
Inlet/outlet SG coolant temperature, ºC	518/328
Inlet/outlet SG water/steam temperature, ºC	241/507
Live steam pressure, MPa	13.2
Design lifetime, year	30+10

BASIC OPERATIONAL INDICES

- *The industrial power unit No.3 of the Beloyarsk NPP with the BN-600 reactor is under operation more than 33 years.*
- *BN-600 power unit has produced during its operation about 125 billion kW·h of electricity.*
- *In 2012, BN-600 power unit:*
  - had been in operation on the power levels during 7250 hours;
  - had produced 4256.93 million kW·h of electricity,
  - had delivered 263.12 Tcal of heat for heat consumers from power unit's collectors,
  - had load factor equal to 80.77%.
- *Average BN-600 load factor for the period of its commercial operation since 1982 is equal to 74.4%.*
- *During 2012, there were no unscheduled shutdowns of the power unit.*
- *Six power decreases occurred during 2012.*
  - All these events are classified in accordance with INES scale as "out of scale" cases.
- *There were 2 scheduled power unit shutdowns for refueling and preventive maintenance works (PMW) in 2012:*
  - Spring PMW – from 21.04 till 09.06.2012;
  - Autumn PMW – from 14.10 till 31.10.2012.

LOAD MAP OF THE BN-600 POWER UNIT IN 2012





1 – switching-off turbogenerator (TG) No.4 for elimination of leakage in tube bundle of TG-4 condenser (24-27.01.2012)

2 – power decrease up to 60% of nominal power for elimination of leakage in tube bundle of TG-5 condenser (05-06.03.2012)

3 – power decrease up to 60% of nominal power for elimination of leakage in tube bundle of TG-6 condenser (15-16.03.2012)

4 – power decrease up to 60% of nominal power for elimination of leakage in tube bundle of TG-5 condenser (07.04.2012)

5 – scheduled shutdown of the power unit for medium repair (21.04-09.06.2012)

6 – operation with 2 loops (67%N_{nom}) with switched-off TG-4, power decrease up to 30%N_{nom}, switching-on TG-4 and power increase up to N_{nom} (09-27.06.2012)

7 – scheduled shutdown of the power unit for routine repair (14-31.10.2012)

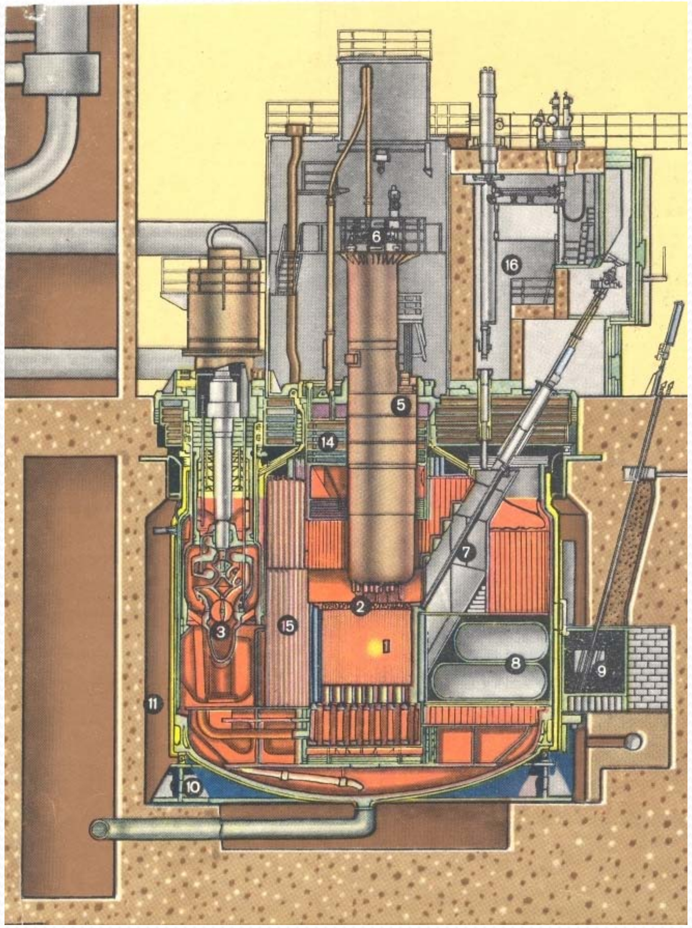
8 – switching-off TG-6 due to increase of vibration in the bearing of TG-6 during power increase after PMW (29-31.10.2012)

9 – power decrease up to 450 MW due to increase of radiation dose under reactor dome causing by leakage in standpipe of rotating plug (27.12.2012)

BASIC REPAIR AND MAINTENANCE WORKS IN 2012

- *Reactor refueling*
- *Putting into operation DHRS with AHX (IHX-5A)*
- *Routine repair of electric motors of the primary and secondary main circulation pumps*
- *Replacement of 3 modules in SG-5*
- *Repair of equipment and piping of the secondary and tertiary circuits of SG-4,5,6*
- *Repair of equipment and piping of the tertiary circuit of TG-4,5,6*
- *Operating control of structural material of:*
    - *the secondary and tertiary circuits of SG-4,5,6*
    - *the tertiary circuit of TG-4,5,6*
    - *Hydrogen cooling of G-6*
- *Routine repair of TG-4,6*
- *Overhaul of TG-5*
- *Overhaul of G-4 with replacement of the rotor's band*
- *Routine repair of G-5,6*
- *Maintenance works in G-4,5,6*
- *Complex of works for elimination of increased vibration in the bearing of TG-6*

ACTIVITIES ON DESIGN LIFETIME EXTENSION



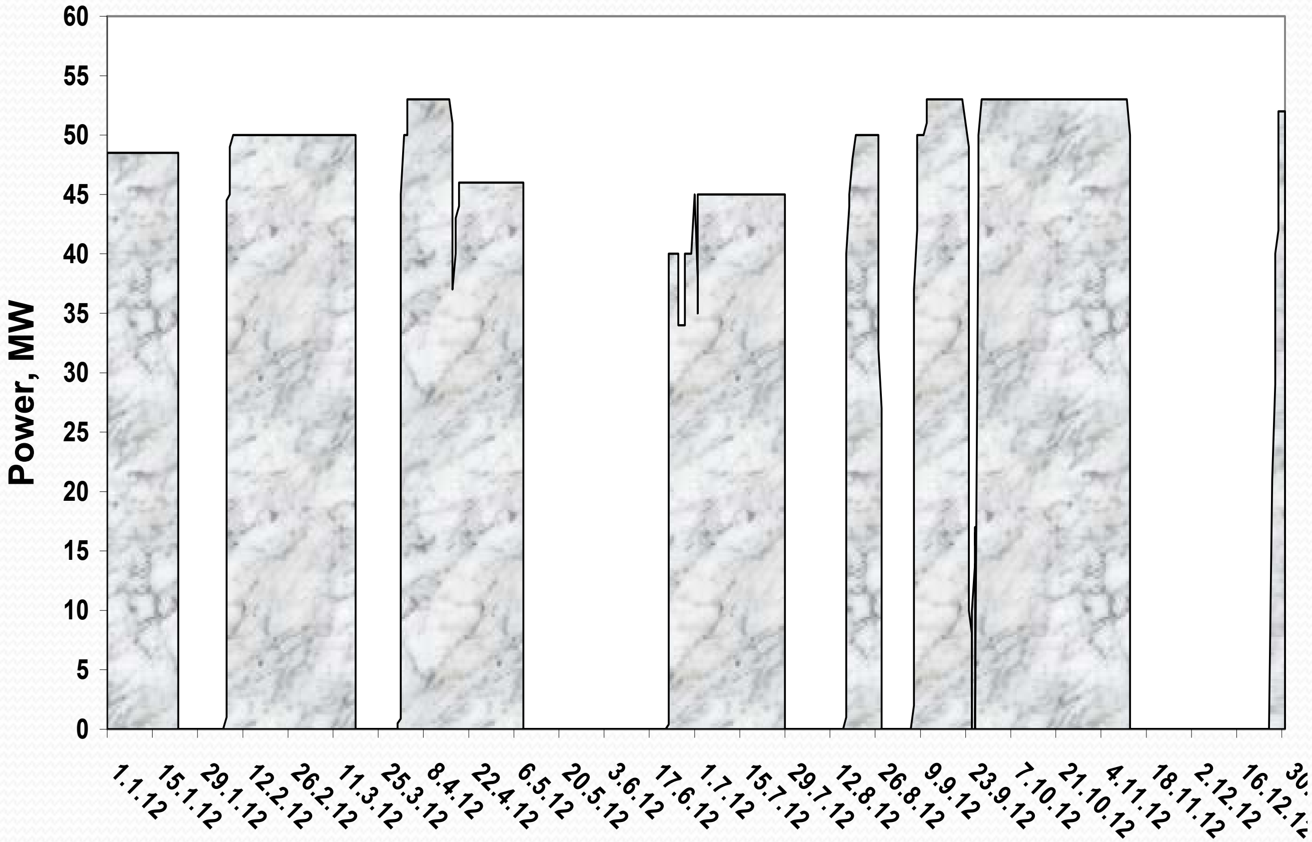
- *On April 7, 2010, the Beloyarsk NPP had got the Rostechnadzor's license for lifetime extension of the BN-600 power unit up to March 31, 2020.*
- *In 2012, activities on the BN-600 lifetime extension is carried out in accordance with "Roadmap of completion of works on preparation of the power unit No.3 of Beloyarsk NPP for additional lifetime":*
    - Implementation of measures on enhancement of the power unit's safety
    - Upgrading of systems and replacement of the power unit's equipment
    - Works on substantiation of lifetime extension of non-replaceable reactor facility elements
    - Complex of works on additional investigation and substantiation of residual operation life of the power unit's systems and elements
    - Correction of the Report on Profound Safety Estimation of the power unit and other operational documentation

BASIC OPERATIONAL PARAMETERS

- *The BOR-60 reactor is used for:*
  - Material tests
  - Isotopes production
  - Tests of the various equipments of fast reactors
  - Heat and electricity production.
- *BOR-60 reactor facility is in operation more than 43 years.*
- *In December 2009, Rostechnadzor has given the license to the RIAR for further operation of the BOR-60 reactor facility up to 31.12.2014.*

Parameter	Value
Thermal reactor power, MW	60
Maximum neutron flux density, $n \cdot cm^{-2} \cdot s^{-1}$	$3.7 \cdot 10^{15}$
Maximum core power density, kW/l	1100
Average core neutron energy, MeV	0.45
Fuel	UO_2, UO_2-PuO_2
Fuel burn-up rate, %/year	up to 6
Neutron fluence per year, $n \cdot cm^{-2}$	$5 \cdot 10^{22}$
Damage dose rate, dpa/year	up to 25
Inlet coolant temperature, ºC	310-330
Outlet coolant temperature, ºC	up to 530
Core run duration, days	up to 120
Reactor availability	up to ~0.73
Number of cells:	265
for FSAs	156
for absorber rods	7
instrumented cells	3

BOR-60 REACTOR OPERATION IN 2012



Index	Value
Time of reactor operation on power exceeding minimum controlled level, h	5359
Reactor load factor	0.61
Max reactor power, MW	53
Energy output: heat, MW·h electricity, MW·h	 254160 34459
Time of SG operation: SG-1, h SG-2, h	 5272 5272
Heat delivery to consumers, Gcal	48668

- *In 2012, there were 7 reactor shutdowns:*
  - 1 unscheduled shutdown and
  - 6 scheduled ones for implementation of preventive maintenance work, partial refueling, loading and unloading of experimental devices and assemblies with radioisotopes.
- *One unscheduled shutdown was carried out by remote initiation of reactor scram due to decrease of water volume in the tertiary circuit causing by leakage in the condenser*

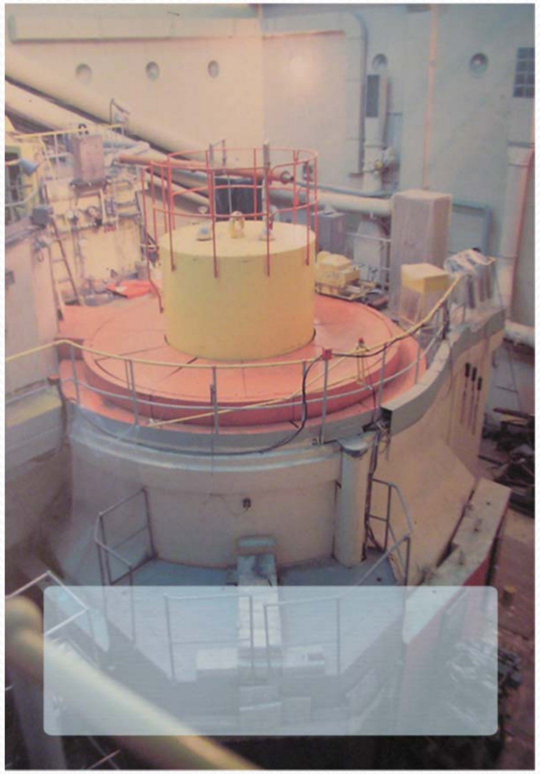
EXPERIMENTAL WORKS IN 2012

- *Irradiation of assemblies with structural materials (zirconium alloys, structural materials of various reactor types) within temperature interval from 320℃ to 450℃*
- *Production of radioisotopes of strontium-89 and gadolinium-153*
- *In-pile studies of capsules with hafnium hydride samples under temperature from 500℃ to 600℃*
- *In-pile tests of the SVBR-100 fuel pin models and fuel pin claddings from EP-823 steel, mock-up model of the stibium-beryllium neutron source for SVBR-100 reactor*
- *Irradiation of the models of absorbing elements of the BREST-OD-300 reactor based on boron carbide and hafnium dysprosium materials*
- *In-pile studies of fuel pin models with nitride fuel and with cladding made of EP-823 steel*

ACTIVITIES ON BOR-60 LIFETIME EXTENSION IN 2012

- *Technical inspection and lifetime extension of:*
  - PSS and control instrumentation
  - Technological equipment (primary circulation pumps, cold traps of the secondary circuit, piping of auxiliary sodium loops)
  - Electrical equipment
- *Development of the project for technical upgrading of the BOR-60*
- *Analysis of possibility of recriticality under hypothetical accidents with core disrupture*
- *Investigation of material properties of different elements*
- *Implementation of analytical substantiation of serviceability of in-vessel elements and equipment of the primary and secondary circuits*

CURRENT STATUS AND FUTURE ACTIVITIES



- *After operation during about 44 years the BR-10 experimental reactor was finally shutdown on December 6, 2002 and now it is on the preparatory stage of its decommissioning.*
- *Current status of the BR-10 reactor is as follows:*
  - All FSAs have been unloaded from the core and replaced by the dummy subassemblies
  - All FSAs are placed into the interim storage
  - Sodium has been drained from the primary and secondary circuits to the storage tanks and frozen
  - The inner surfaces of the primary circuit have been cleaned from sodium and decontaminated
  - Both loops of the secondary circuit have been cleaned from sodium.
- *Preparation works on installation of the following facilities are implemented:*
  - GETTER facility for demercurization of sodium-potassium coolant
  - MAGMA facility for conditioning radwaste of sodium and sodium-potassium coolant by solid phase oxidation method
  - LUIZA facility for treatment of coolant by method of gas-phase purification.
- *Fulfillment of regulation works on maintenance of serviceability and safety of reactor systems being in operation.*
- *Continuation of preparation of the documents required for getting the license for the BR-10 decommissioning and their submission to Rostechnadzor.*

Main BN-800 parameters

Parameter	Value
Thermal power, MW	2100
Electric power, MW	880
Number of heat removal loops	3
Configuration of the primary circuit	Pool
Steam generator design	Once-through, sectional-modular
Maximum neutron flux density, $n\cdot cm^{-2}\cdot s^{-1}$	$8.8\cdot 10^{15}$
Fuel	UO_2-PuO_2
Max. fuel burn-up, % h. a.	9.9
Inlet/outlet core coolant temperature, ºC	354/547
Inlet/outlet SG coolant temperature, ºC	505/309
Inlet/outlet SG water/steam temperature, ºC	210/490
Live steam pressure, MPa	13.7
Design lifetime, year	40

CURRENT STATUS OF BN-800 CONSTRUCTION

- *BN-800 reactor should be put into operation in 2014.*
- *Construction and assembling activities in 2012:*
  - Organization of the “clean area” for installation of steam generator modules
  - Testing reactor vessel
  - Erection of walls of reactor compartment up to level +62.25 m
  - Start of works on receiving of sodium
  - Concreting of the turbogenerator basement
- *Manufacturing and delivery of the equipment:*
  - Delivery of the equipment for electric supply systems
  - Manufacturing and delivery of diesel-generator facilities
  - Delivery of in-vessel components
  - Delivery of electric motors of the primary main circulating pumps
  - Delivery of piping and valves for reactor compartment and special building
  - Start of delivery of equipment for plant control system related to receiving sodium
  - Delivery of equipment for turbine hall, main and special building
  - Completion of delivery of equipment for safeguard systems.

VIEWS OF BN-800 NPP SITE (1/3)

Bird's-eye view of the reactor compartment of the main building (30.10.2012)

VIEWS OF BN-800 NPP SITE (2/3)

Bird's-eye view of the turbine hall. Concreting the turbogenerator basement (30.10.2012)

VIEWS OF BN-800 NPP SITE (3/3)

Bird's-eye view of the place for assembling metallic vault of the reactor compartment (30.10.2012)

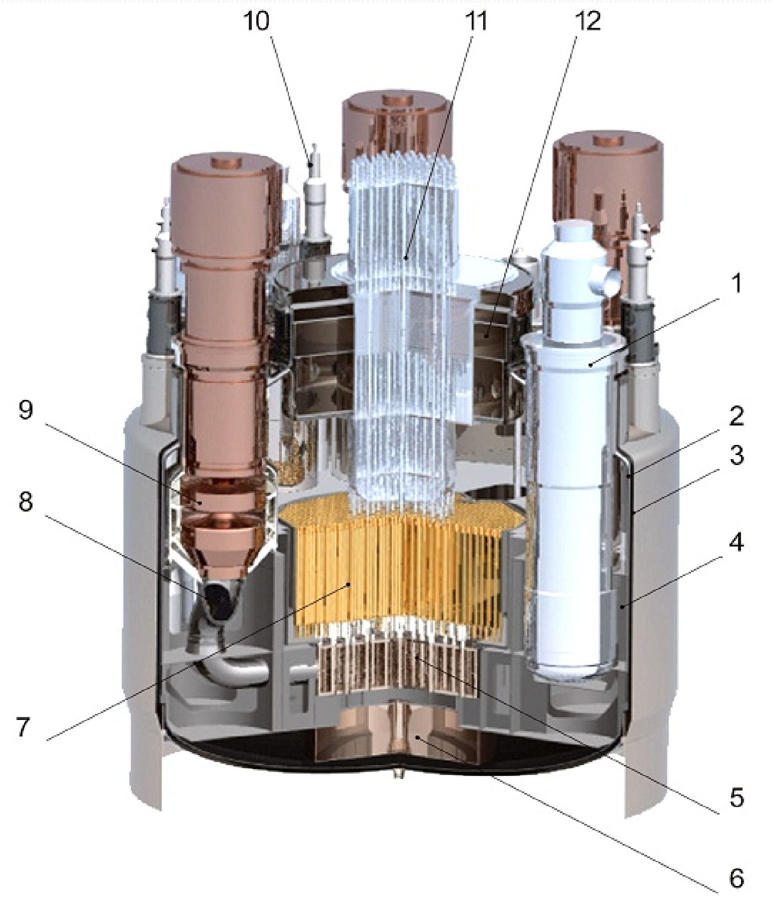
PROSPECTIVE ACTIVITIES ON SFR IN RUSSIA (1/2)

- *Near- and mid-term plans on SFR in Russia are determined by the FTP "Nuclear power technologies of a new generation for period of 2010-2015 and with outlook to 2020".*
- *In order to implement the transition to the new technological platform the FTP envisages the activities in the following directions:*
  - Development of advanced reactor technologies of the 4th generation
  - Construction of new test facilities and installations, upgrading and development of an experimental and bench-scale base in support and justification of the reactor technologies under development
  - Development of the technologies for production of advanced types of fuel for reactors of the next generation
  - Creation of materials and technologies of the CNFC for nuclear power systems with fast and thermal reactors of the new generation
  - Development of the integrated code systems of a new generation for analyses and substantiation of safety of advanced NPPs and CNFC.

PROSPECTIVE ACTIVITIES ON SFR IN RUSSIA (2/2)

- *The FTP implementation should be realized in two stages.*
- *The 1st stage (2010-14) envisages performance of the following main works on SFR:*
  - Development of a design of the large size sodium fast reactor BN-1200 including implementation of relevant R&D;
  - Completion of designing and commissioning of uranium-plutonium oxide fuel production plant for fast reactors of the new generation;
  - Development of a detailed design for construction of a multipurpose research fast reactor (MBIR) with sodium coolant;
  - Development of new radiation-resistant structural materials for the reactors of the new generation.
- *The most important works should be implemented at the 2nd stage (2015-20):*
  - Set-up of a pilot plant for production of compact fuel for nuclear reactors of the new generation;
  - Construction of a demonstration semi-commercial pyrochemical complex for fuelling nuclear reactors of the fourth generation;
  - Construction, refurbishment, technical upgrading and commissioning the required research base purposed for the justification of the new technological platform of nuclear power, including the MBIR reactor construction and commissioning the technically reequipped complex of big test facilities (BFS).
- *The following works on SFR are performed outside of the FTP framework:*
  - Conceptual study of a high-temperature sodium fast reactor BN VT for its application in high-temperature industrial technologies;
  - Development on the base of the BR-10 of technological processes proposed to be used for SFR decommissioning.

BN-1200 REACTOR



1 – IHX; 2, 3 – main and guard vessels respectively; 4 – supporting structure; 5 – inlet plenum; 6 – core debris tray; 7 – core; 8 – pressure pipeline; 9 – MCP-1; 10 – refueling mechanism; 11 – CRDM; 12 – rotating plugs.

Parameter	Value
Rated thermal power, MW	2800
Electric power, MW	1220
Load factor, %	90
NPP efficiency, %: gross net	 43.5 40.7
Number of heat removal loops	4
Design lifetime, year	60
Flowrate of the primary sodium, kg/s	15784
Flowrate of the secondary sodium, kg/s	12776
Primary circuit coolant temperature (IHX outlet/inlet), °C	410/550
Secondary circuit coolant temperature (SG outlet/inlet), °C	355/527
Tertiary circuit parameters: live steam pressure, MPa live steam temperature, °C feedwater temperature, °C type of intermediate steam reheating	 17.0 510 275 steam
Fuel	Nitride, MOX

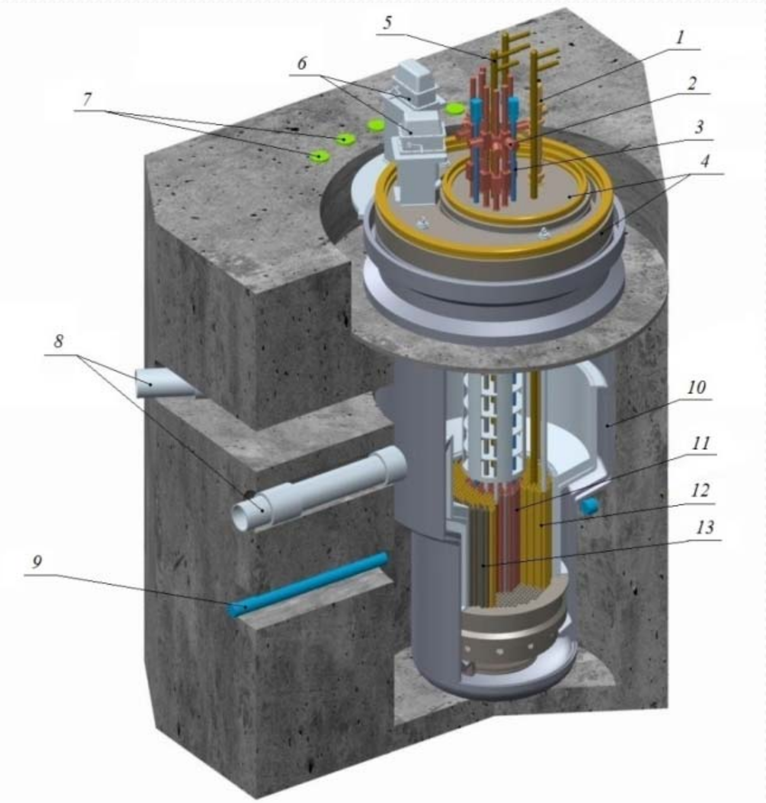
BN-1200 (1/2)

- *The most important new conceptual technical and design decisions accepted for the BN-1200 design are as follows:*
  - Pool type arrangement of the primary circuit with location of all sodium systems including cold traps and chemical-engineering control systems within the reactor vessel that makes it possible to eliminate in fact a danger of radioactive sodium release outside of the reactor vessel and its fire
  - Simplification of a refueling system by exception of intermediate storage drums of fresh and spent FSAs and organization of a capacious in-reactor vessel storage (IVS) of spent FSAs (SFSAs), providing a direct unloading of SFSAs (after their exposure in the IVS) from the IVS into washing cells and further into an exposure pool
  - Transition from sectional-modular SG scheme to integral one based on application of straight-tube large-capacity modules
  - Maximum enhancement of inherent safety features of the reactor facility and application of safety systems based on passive principles of functioning: passive systems of emergency protection, passive decay heat removal system through independent loops connected to a reactor vessel.

BN-1200 (2/2)

- *Besides, the BN-1200 design envisages:*
  - Traditional three-circuit design of the power unit;
  - Number of loops in the primary circuit - 4 (each loop contains one IHX and one MCP-1);
  - Number of loops in the secondary circuit - 4 (each loop contains one IHX, one MCP-2 and one SG);
  - Number of turbine units per power unit - 1;
  - Steam reheating;
  - Operation of the NPP at the stable (mainly, rated) power level with load factor equal to at least 0.9;
  - Flexible nuclear fuel cycle allowing transition from fuel made on the basis of plutonium extracted from SNF of thermal reactors to fuel made on the basis of own plutonium and providing opportunity of using different types of fuel (oxide, nitride).
- *A FOAK power unit with the BN-1200 reactor is discussed to be constructed at the BelNPP site.*

Multifunctional Research Fast Reactor MBIR



1 – refueling mechanism, 2 – CPS actuator drives; 3 - EC, 4 – rotary plugs; 5 – LC; 6 – rotary plug rotators; 7 - VEC; 8 – Primary circuit pipelines; 9 – HEC; 10 – vessel and safeguard shroud; 11 – FSA; 12 – side reflector; 13 - IRS

Start-up of the MBIR is scheduled in 2019.

Parameter	Value
Thermal power, MW	~150
Electric power, MW	~40
Maximum neutron flux density, $n \cdot cm^{-2} \cdot s^{-1}$	$\sim 5.5 \cdot 10^{15}$
Driven fuel	Vi-pack-MOX, (PuN+UN)
Test fuel	Innovative fuels, MA fuels and targets
Core height, mm	550
Maximum linear rating of fuel element, W/cm	470
Maximum neutron fluence per year, $n \cdot cm^{-2}$	$\sim 1 \cdot 10^{23}$ (up to 45 dpa)
Design lifetime, year	50
Number of autonomous test loops with different coolants	up to 5 (3 loop channels)
Total number of experimental subassemblies and target devices for radioisotope production	up to 14 (core) not limited (radial screen)
Number of experimental channels	up to 3 (core)
Number of experimental horizontal channels (Ø 200 mm)	up to 3 (outside reactor vessel)
Number of experimental vertical channels (Ø 350 & 50 mm)	up to 11 (outside reactor vessel)

PROSPECTS OF INTERNATIONAL COLLABORATION ON MONJU

- *Since number of operating SFRs is limited in the world, therefore, all specialists in the SFR area are very interested in use of the MONJU for international R&D and tests, especially who are involved in works on substantiation of the SFR safety.*
- *MONJU is a power reactor that provides full scale modeling of the industrial SFR power unit.*
- *Its application for R&D permits to carry out a wide spectrum of studies on substantiation of such reactor type:*
  - First of all, full-scale integral experiments with modeling of joint operation of all SFR power unit's systems.
- *Coolant natural circulation is considered as SFR inherent safety feature*
  - In this relation, it is very valuable to implement a series of tests on substantiation of coolant natural circulation in heat removal circuits under various conditions:
    - *With operation of DHRS with AHX*
    - *Without operation of DHRS with AHX (to evaluate safety margins for accidents with DHRS failure and with decay heat dissipation through piping and equipment walls).*

Thank you

for your attention !