The BN-1200 Project as a Basis for the Transition to the Two-Component Nuclear Power Industry

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MNTK-2016, Moscow
May 25-27, 2016

Introduction

- The development of a two-component nuclear power system based upon the VVERs and SFRs in the near-term future is ensured by:
  - capabilities of the SFRs to breed fuel and effectively utilize plutonium and uranium from VVER SNF and SFR SNF
  - Russian experience in the development and operation of the SFRs (BR-5, BOR-60, BN-350) and competences obtained in the course of BN-600 operation and BN-800 development
  - continuity in the basic engineering concept in the integral-type SFR and the use of many well-tried solutions, as well as the scope of the R&D work accomplished to validate new solutions adopted in the design of the commercial BN-1200 reactor
- The commercialization of the fast reactors based upon the BN-1200 project provides for the development of a complex of closed nuclear fuel cycle companies to integrate the operating and newly created technologically connected clusters of nuclear fuel cycle facilities.
- It is planned to develop a project of a power complex with the BN-1200 power units to demonstrate the economic efficiency of such system with account of long-term functioning

Tryout of Fuel Technologies and Closed Fuel Cycle Technologies in the BN-600 and BN-800 Reactors (1)

BN-600

- Use of uranium dioxide fuel — development of the reactor technologies started
  - high fuel burnup achieved (the average value is 74 MW·day/kg, which is ~ 1.5 times greater that that for the VVER reactors)
  - there are actual grounds to increase the fuel burnup to 90 MW·day/kg, and there are prospects for the burnup growth
  - similarities in the properties of the uranium oxide fuel and MOX-fuel determines the continuity of the results for these types of fuel
  - 42 experimental MOX-fuel subassemblies have been fabricated and successfully tested
  - part of these assemblies were reprocessed in the RT-1 plant

Tryout of Fuel Technologies and Closed Fuel Cycle Technologies in the BN-600 and BN-800 Reactors (2)

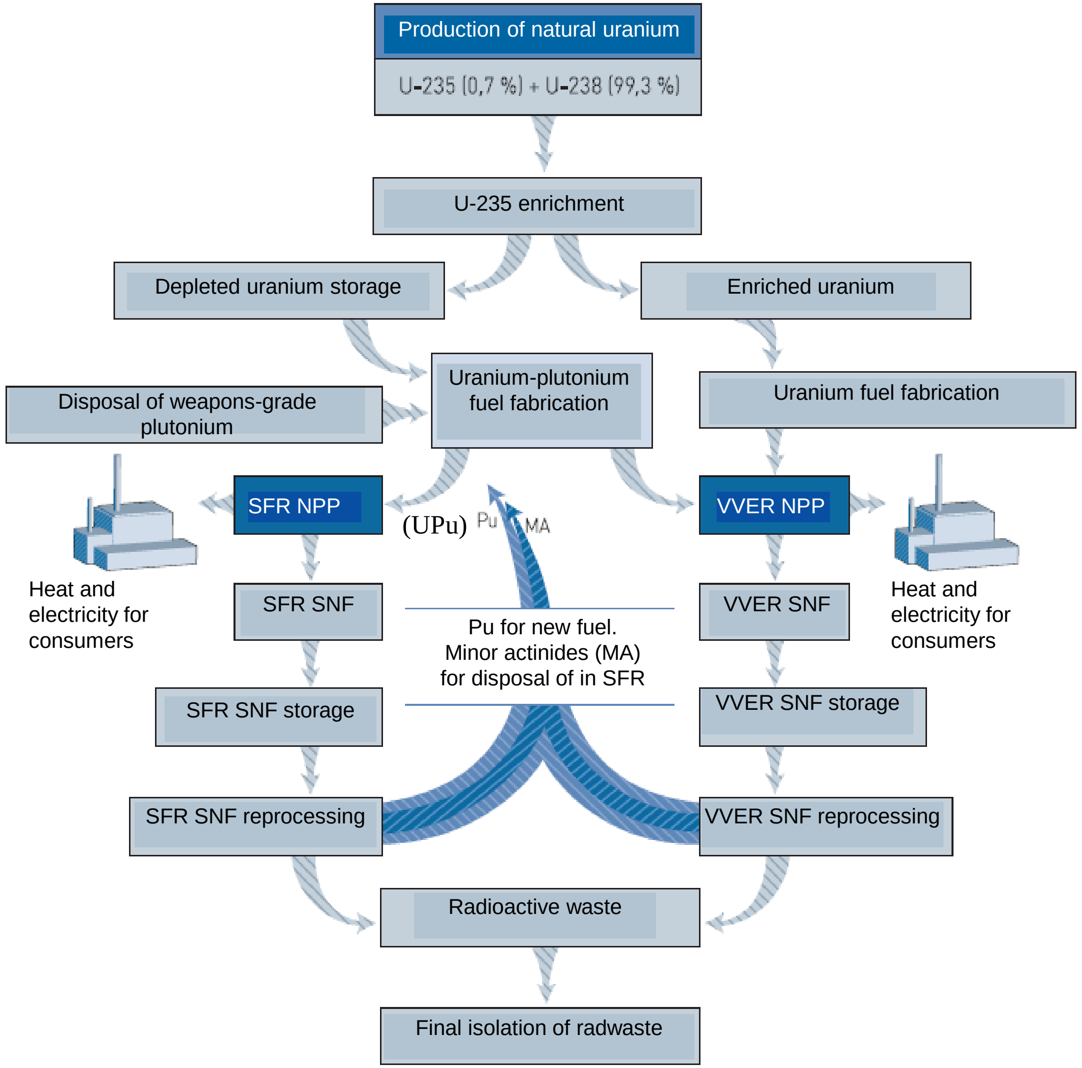
BN-800

- The use of the MOX-fuel sets conditions for the leading positions in the development of the closed nuclear fuel cycle technologies and for the possibility of improving the fuel
- Switching over to the full load of MOX-fuel fabricated by MCC
- The initial raw material for fuel fabrication is VVER-440 SNF
- Possible to use uranium-plutonium fuel based upon the plutonium with a wide isotope vector, while simultaneously placing fuel of various compositions in the core
- Massive reprocessing of spent MOX-fuel assemblies is planned and R&D work to develop the most promising reprocessing methods
- Achieving the record value of the neutron flux, 8×10^{15} n/cm^2·s
- Ensuring in BN-800 the express tests for both fuel pins and structural materials, including the advanced nitride fuel

Objectives for Implementation of the Closed Nuclear Fuel Cycle Based upon the BN-1200 Reactors (1)

- The transition to the two-component system of the nuclear power industry with closing the fuel cycle was adopted at the initial phase of the nuclear power industry evolution
- Phased development of the industrial power complex with account of the possible expansion or replication of the fuel cycle facilities
- Use of already developed and currently being developed nuclear fuel cycle production facilities and technologies: MCC, PA Mayak, SCC, logistics technologies for fresh and spent VVER, BN-600 and BN-800 fuel handling
- 2016, development of the conceptual design for the power complex with two BN-1200 power units and companies for the centralized fuel cycle, including the technical and economic studies

Schematic of the Closed Fuel Cycle for the VVER and SFR Reactors



BN-1200 Design Development Status

- **2007** – work commenced on the power unit design with the BN-1200 reactor plant according to the program of “Rosenergoatom” Concern OJSC
- The adopted basic engineering solutions are approved by the ROSATOM Scientific and Technical Council and by the “Rosenergoatom” Concern OJSC Scientific and Technical Council
- **2010** – work commenced as part of the implementation of the Federal Target Program
- **2014** – reactor plant final design, turbine plant final design and power unit design documents are developed
- **2015** – review of the design documentation is accomplished in compliance with the ROSATOM Directive No. 1-1/87-R dated February 27, 2015
- **2015** – design and review results are approved by the Decisions of the Scientific and Technical Council No. 1 and No. 8 dated August 12, 2015 and TK 118 dated August 12, 2015

Engineering Solutions Intended to Enhance the Safety Level and Improve the Technical and Economic Performance (1)

Reactor	BN-600	BN-800	BN-1200
Nominal thermal power, MW	1470	2100	2800
Electric power, gross, MW	600	880	1220
Number of heat generating loops	3	3	4
Primary coolant temperature, °C (intermediate heat exchanger inlet/outlet)	535/368	547/354	550/ 410
Secondary coolant temperature, °C (steam generator inlet/outlet)	505/318	505/309	527/355
Third circuit parameters: live steam temperature, °C live steam pressure, MPa feedwater temperature, °C	 505 14 240	 490 14 210	 510 17 275
Efficiency, gross / net, %	42.5 / 40	41.9 / 38.8	43.5 / 40.7

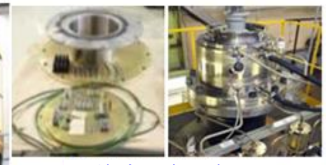
- Enhanced parameters of the feedwater and of the live steam at the steam generator outlet ⇒ enhanced (gross) efficiency of the plant
- The circular reactor building (in plane view) with the reactor well in the center is used
- Four identical heat removal loops are used ⇒ modular layout
- The main equipment is placed in the reactor vessel; pipelines are jacketed ⇒ external radioactive sodium leaks are prevented
- Expansion joints are used to compensate for temperature expansions in the secondary pipelines ⇒ reduced lengths of pipelines
- The Cr16Ni11Mo3 heat-resistant and radiation-resistant steel is used ⇒ longer service life of the power unit, at least 60 years

Engineering Solutions Intended to Enhance the Safety Level and Improve the Technical and Economic Performance (2)

- Uranium-plutonium nitride fuel is used as advanced fuel, and the MOX-fuel is used as sufficiently proven fuel
- The reduced core power density; larger fuel pins => the FSA cycle of operation is longer by 1.5 – 2 times
- In addition to the emergency trip system (along with the passive hydraulic protection), temperature-actuated protection is used
- Increased volume of the in-vessel storage basket => spent FSAs are held for two years and the spent FSA sodium-cooled canister is eliminated
- The primary shielding is in the core, and the in-vessel shielding is reduced
- Larger SG sections; vertical once-through vessel-type SGs (8 modules) are used instead of sectional-modular SGs (72 modules) in BN-600 and (60 modules) in BN-800
- A vertical elevator is used; the fuel handling and cleaning cells are combined
- Natural circulation is ensured in all emergency heat removal system circuits
- A light spherical dome is used above the central hall in combination with modern high-strength concretes and reinforcement rods
- The amount of equipment is considerably reduced in the emergency power supply system because the passive safety systems are used

Computational and Experimental Studies to Validate the Engineering Solutions


RCP shaft seal mockup test facility


Shaft seal mockup


Specimens of fuses


PIK 73 and PIK 74/1 assembly for UDShKK

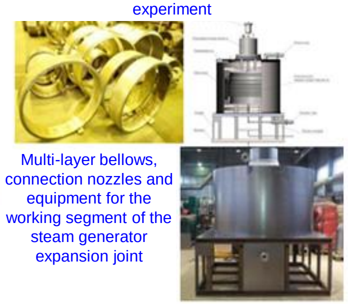

Cell for CRDM test facility


Preliminary testing of US-T


Elements of the AR-1 experimental installation in the course of experiment


AHX check valve model


7-tube SG model


Multi-layer bellows, connection nozzles and equipment for the working segment of the steam generator expansion joint


RCP pressure pipeline


Reactor core model


Top of IHX and AHX

TISEY test facility


Appearance of the caisson mockup specimen
(installed in the TsU-20N test facility)


V-200 test facility

Basic Results for Safety

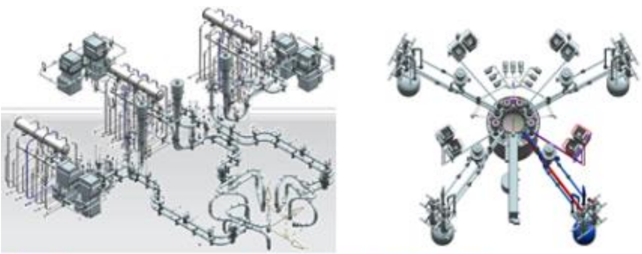
As a results of the actions taken in the project, the safety level has been considerably enhanced:

- The probability for severe core damage for internal events during the power operation of the reactor for BN-1200 is ~ 5×10^{-7} , which is by far lower than the respective values for BN-600, ~ 10^{-5} and BN-800, ~2×10^{-6}
- The requirement for preventing the need to evacuate the population in accidents has been fulfilled
- For the computational validation of the design, a design software package is used; new-generation computer codes are developed. By this day, around 60% of the computer codes have been qualified, the rest of them are at the verification and qualification stage.
- The test simulator is being verified, which was developed based upon the mathematical model of the power unit with the BN-1200 reactor plant with the use of the RASNAR-BN computer code

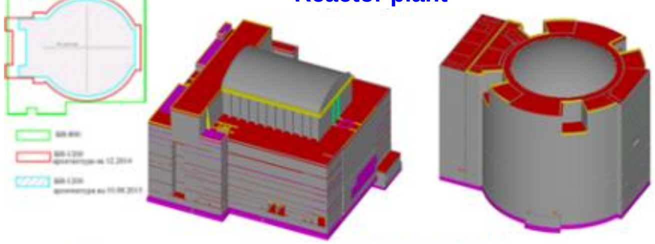
Basic Results for the Technical and Economic Performance (1)

Reactor	BN-800	BN-1200
Specific volume of the main vessel, m^3/MWe	750	550
Specific construction volumes of SG cells, m^3/MWe	32	16
Specific material consumption of the reactor plant, t/MWe	9.7	5.8
Specific metal consumption of the steam generator, t/MW	1.48	0.33
Cycle of operation, EFPD	155	330
Power factor	0.85	0.9
Service life, year	45	60

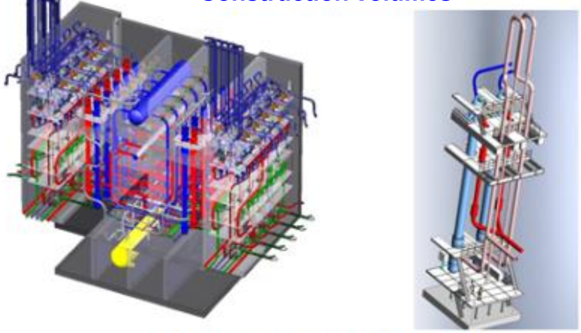
- The specific capital expenditures for the BN-1200 power unit (2015) are comparable with the respective characteristics for the VVER power units (the excess is below 4-16 % vs. the VVER-TOI)



Reactor plant



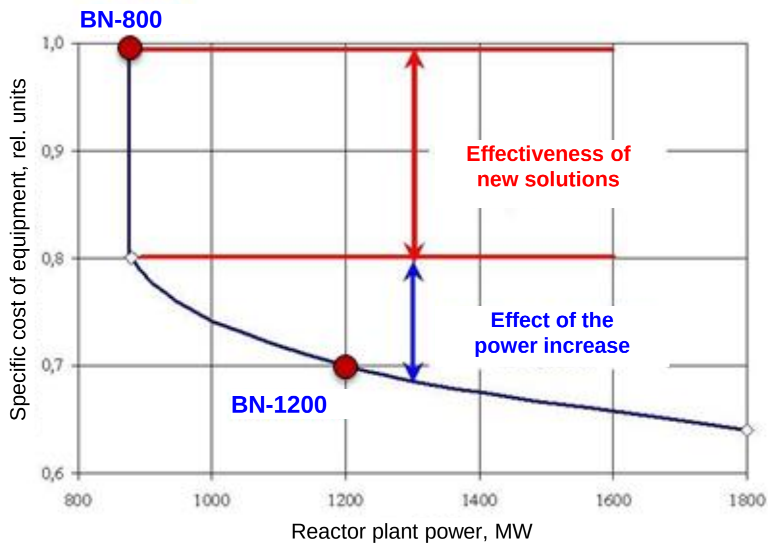
Construction volumes



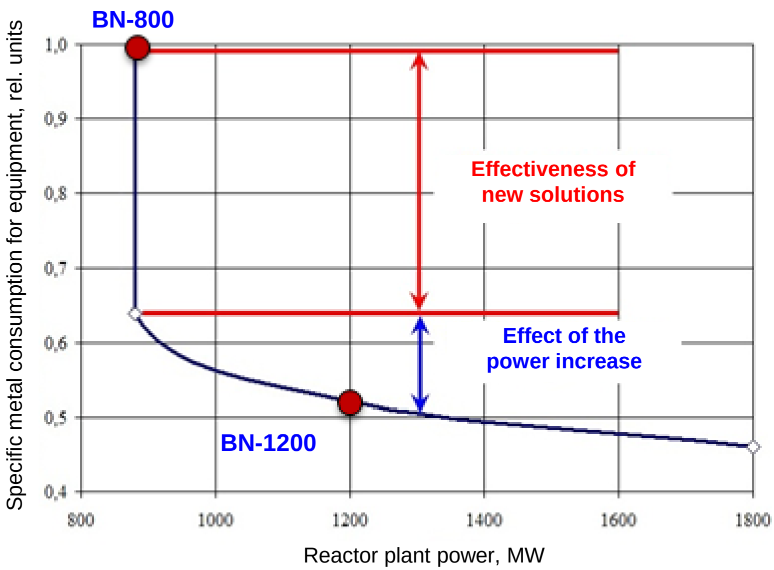
Steam generator (one loop)

BN-800 **BN-1200**

Basic Results for the Technical and Economic Performance (2)



Specific cost of reactor plant equipment as a function of power



Specific metal consumption for reactor plant equipment as a function of power

Improving the Technical and Economic Performance

- Reactor plant:
  - reactor coolant pump with the oil-bath lubrication system
  - canned reactor coolant pump-2 with a synchronized magnetic clutch
  - reduced number of AHXs
  - reduced number of cold traps-2
  - optimized sodium vessels in the secondary circuit
  - reduced diameter of exhaust pipelines
  - optimized fuel handling cell, fuel handling machine and plug lifting mechanism
- Power unit:
  - reduced diameter of the reactor building through SG arrangement with preserving the design of the existing equipment in the reactor island
  - reduced height of the exhaust stacks in the emergency heat removal system
  - optimized layout of the spent fuel pool and storage time for spent FSAs
  - reduced volume of the fresh fuel storage
  - reduced volume of rigging because of the AHX placed into the reactor island
  - optimized intermediate circuit systems and process water supply systems
- Implementation of the scheduled actions intended to further reduce the cost will enable the technical and economic performance to be improved for the power unit with the BN-1200 reactor plant by additional 10-15%

Conclusion

The development of the two-component power system with the VVER and BN-1200 power units will solve the deferred problems associated with the spent nuclear fuel and radwaste in the nuclear power industry, ensure that uranium is utilized effectively and reduce the uranium production and enrichment, enhance the competitiveness of the nuclear power industry in the energy resource market both in terms of safety, environment friendliness and the economic attractiveness