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Advanced Sodium Fast Reactor Power Unit Concept

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Russian Experience in Development and Implementation of BN Sodium Fast Reactors for NPPs

Reactor	Development	Construction	Operation
BN-350	1960 - 1965	1965 - 1973	1973 -1998
BN-600	1963 - 1972	1972 - 1980	1980 - in operation
BN-800	1975 - 1983 2002 - 2004	Under construction	Planned for 2014
BN-1600	1980's	-	-
BN-1800	2002 - 2005	-	-
BN-1200	From 2006	-	Planned for 2020

Main Tasks and Goals of BN-1200 Development

- Provide competitiveness against advanced power units with other reactor plants and fossil power plants.
- Enhance safety to eliminate the need for population protection measures beyond the NPP site in case of any feasible accidents.
- Ensure the breeding ratio of 1.2 (Stage 1), 1.3-1.35 (Stage 2) for the mixed uranium-plutonium oxide fuel and 1.45, for the nitride fuel.
- Prepare putting into operation of the reactor series within 2-3 years after the pilot power unit start-up.

Approaches to BN-1200 Development

❖ Use largely approved BN-600 technical solutions and solutions implemented in the BN-800 as a basis for reactor plant reliable operation.

❖ In order to enhance technical-and-economic performance and safety, introduce new technical solutions, which can be approved by R&D planned for BN-1200 pilot plant and following commercial plants.

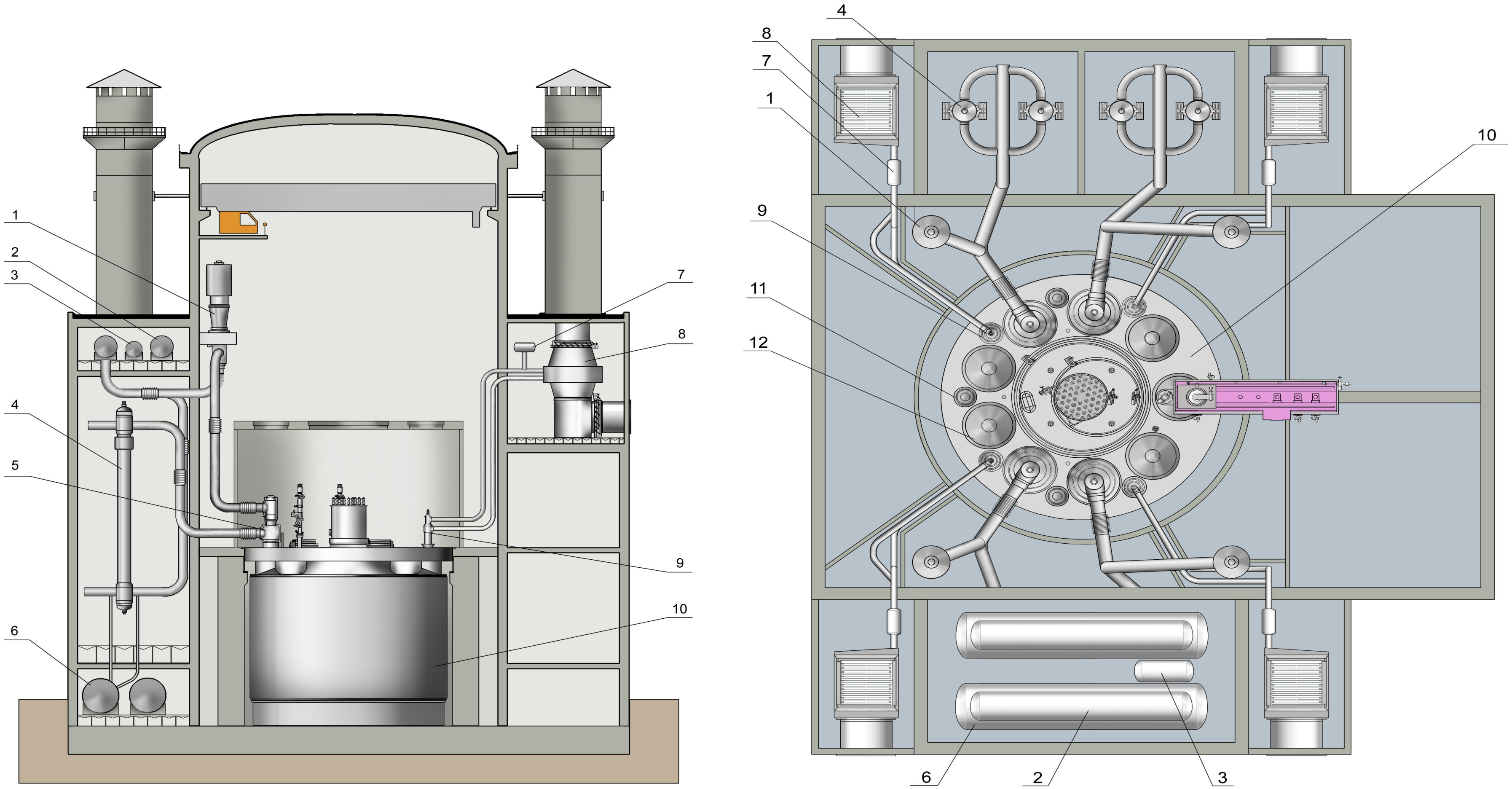
Approved Technical Solutions

- Pool type concept of the reliable barriers prevent coolant leaks from circuits through the use of leak enclosures and other means.
- Reliable barriers prevent coolant leaks from circuits through the use of leak enclosures and other means.
- Technical solutions are implemented for the most part of reactor plant equipment.
- Separate suction cavities with pressure check valves are used in the main circulation pump (primary circuit loop).
- In-reactor storage is used for spent fuel assemblies.

New Solutions to Improve Power Unit Performance

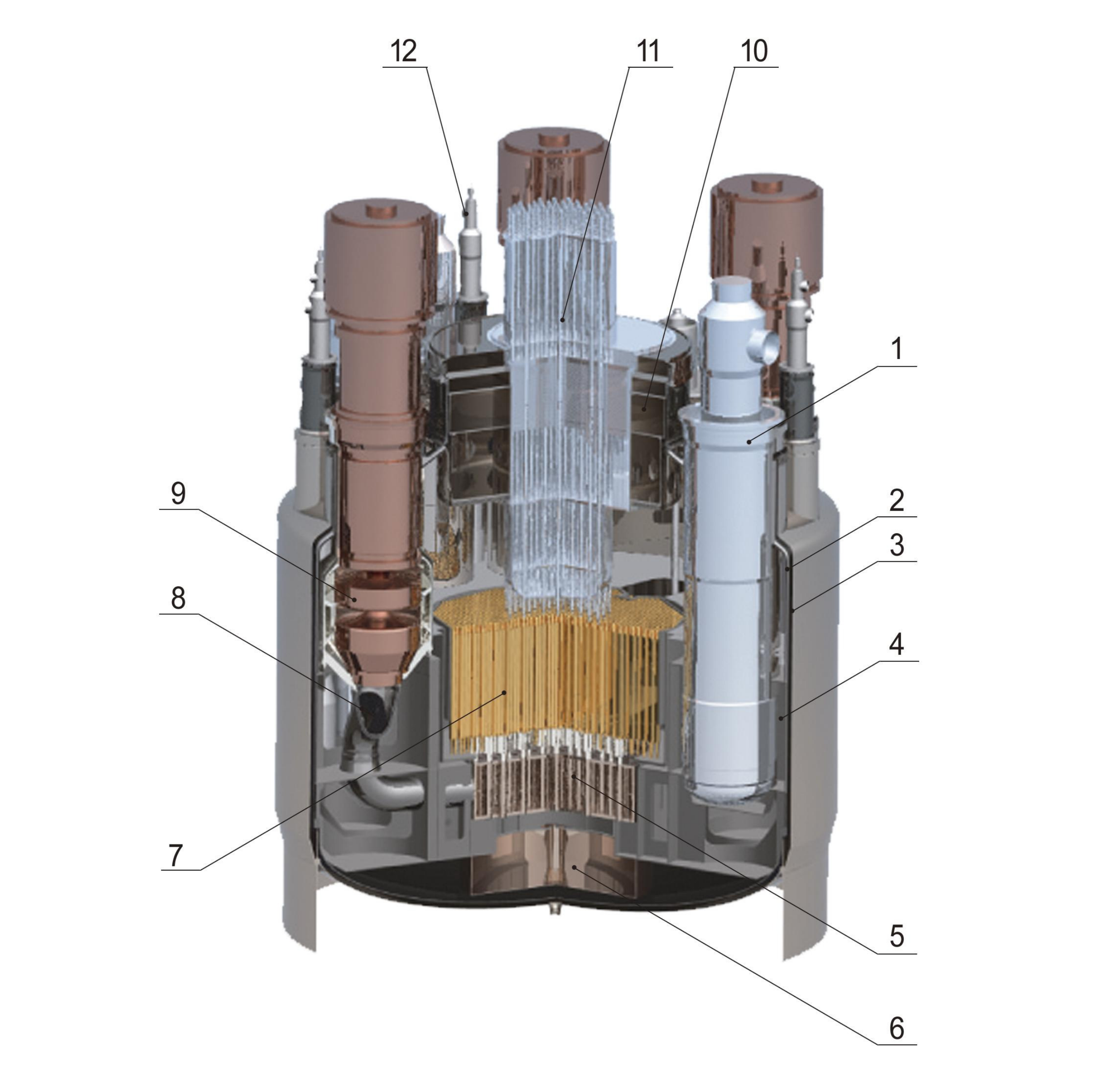
- The core uses greater size fuel element and wrapper tube (9.3 mm and 181mm respectively).
- Bellows compensators are installed on the secondary circuit pipelines.
- A simplified refueling procedure is used as compared to BN-600 and BN-800.
- Boron carbide is used for in-reactor shielding.
- The steam generator unit size was increased.

Reactor Plant Layout



1 – MCP-2; 2 – Buffer tank; 3 – Emergency discharge tank-2; 4 – SG; 5 – IHX; 6 – Emergency discharge tank-1; 7 – Expansion tank; 8 – AHX; 9 – Autonomous HX; 10 – Reactor; 11 – Cold trap; 12 – MCP-1

BN-1200 Reactor Unit



1 IHX
2 Main vessel
3 Safety vessel
4 Strongback
5 Core diagrid
6 Core debris tray
7 Core
8 Pressure pipeline
9 MCP
10 Rotating plugs
11 CRDM
12 FA reloading mechanism

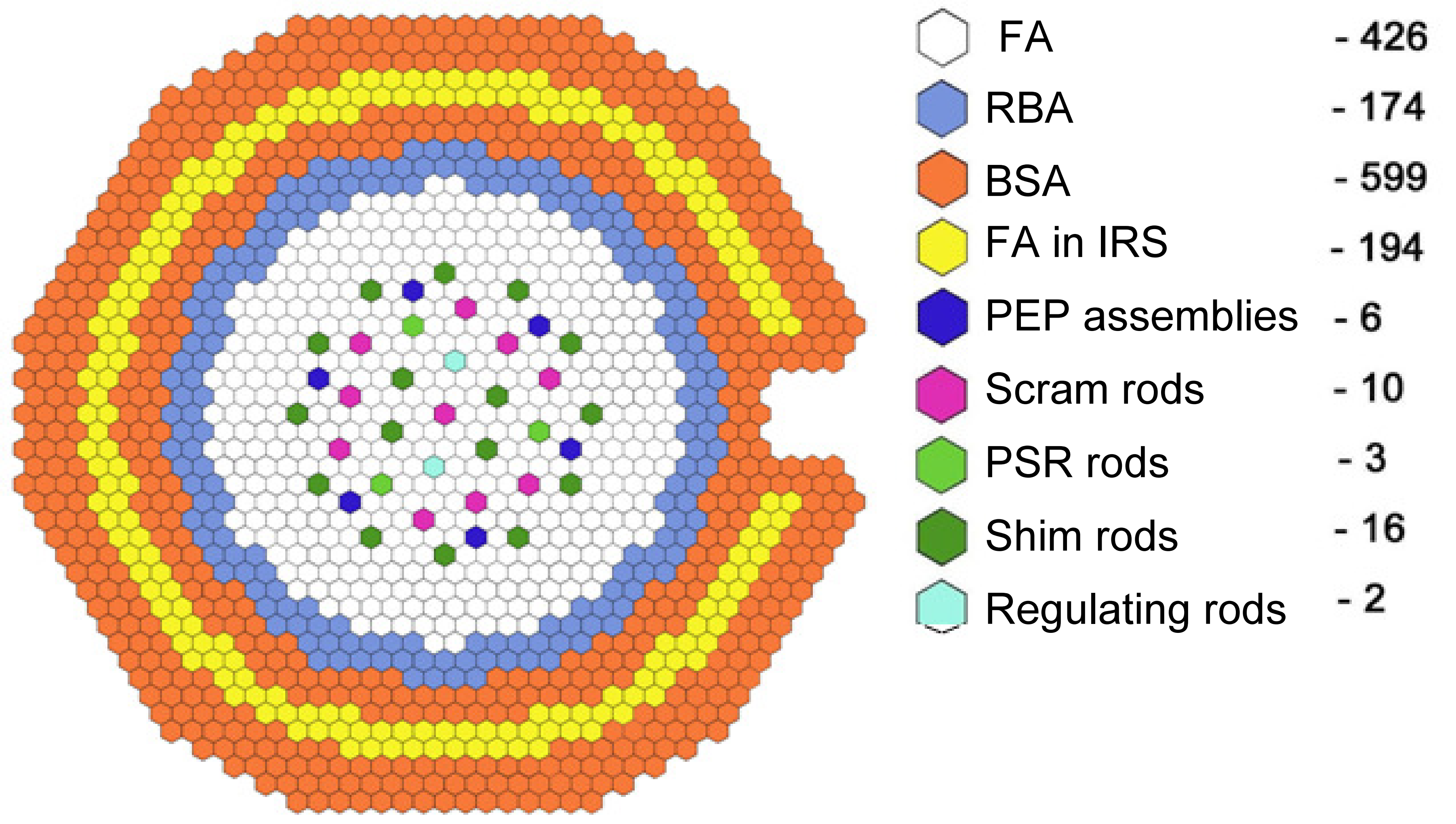
BN-1200 Main Technical Characteristics

Characteristic	Value
Nominal thermal power, MW	2900
Electric power, MW	1220
Primary coolant temperature at intermediate heat exchanger inlet/outlet, °C	550/ 410
Secondary coolant temperature at steam generator inlet/outlet, °C	527/355
Third circuit parameters: - live steam temperature, °C - live steam pressure, MPa - feed water temperature, °C	 510 14 240
Steam reheating type	Steam
NPP efficiency (gross), %	42
NPP efficiency (net), %	39

Core Main Operating Characteristics

Characteristic	Value
Thermal power, MW	2900
FA residence time (adaptation steps), year	4→ 5→ 6
Core fuel mass, t	46.9
Maximum fuel burn-up, % h.a.	14.3→ 17.8→ 21
Maximum damage dose per FA, dpa	140→ 170→ 200
Maximum linear rate of fuel pin, kW/m	46.5
Breeding ratio	1.2
Fuel element cladding hot spot temperature, °C	670
Pressure drop, MPa	0.5

Core Plan



FA – fuel assembly; RBA – radial blanket assembly; BSA – boron shielding assembly; IRS – in-reactor storage; PSR – passive shutdown rods.

Task of Fuel Cycle Closing

- Fabricate MOX-fuel for fast reactors:
  - Develop centralized production of MOX-fuel for fast reactors with ~100 t/year capacity including Phase 1 with ~50 t/year capacity to start up the pilot power unit and first commercial units.
- Reprocess VVER spent nuclear fuel (SNF):
  - Develop a new larger SNF reprocessing plant.
- Longer term goals include closing of the BN fuel cycle, further development and implementation of spent fuel water reprocessing for VVER, as well as dry reprocessing methods for the on-site fuel cycle.

Technical Solutions to Enhance BN-1200 Safety

- The outer primary circuit sodium pipelines were eliminated.
- In emergency, heat is removed from the reactor by a passive system directly connected to the primary circuit via reactor in-built heat exchanges.
- In addition to the passive system having hydraulically suspended rods, there is passive emergency protection, which is actuated on the increase in coolant temperature at the core outlet.
- The plant has equipment to retain the reactor emergency releases during beyond-design basis accidents.
- Achieved goals:
  - Probability of severe core damage was reduced by an order of magnitude (down to 10^{-6} 1/year) as compared to requirements of applicable regulatory documents.
  - Radioactive releases are restricted, which excludes the need for measures to protect population beyond the NPP site.

Enhancement of Technical-and-Economic Performance

Characteristic	BN-800	BN-1200
Capacity factor: design/target	0.8/0.85	0.9
Power unit service life, year	45	60
Specific reactor plant mass, relative units	1.0	0.58
Specific structure volume, relative units	1.0	0.57
Number of auxiliary systems, relative units	1.0	0.4

The BN-1200 specific capital cost in relative units is comparable with that of VVER-1200.

Main R&D

- **Validate the SG having major differences from BN-600 and BN-800 SGs in design and performance.**
- Validate other reactor plant equipment designs (MCP-1, 2, cold trap, refueling complex, bellows compensators).
- Validate physical and thermal-hydraulic core characteristics.
- **Perform lifetime tests of fuel elements burn-up to 20% h. a.**
- Test and improve passive safety systems (emergency heat removal system, scram rods using hydraulic and temperature operation modes).
- **Develop new structural materials to ensure reactor plant lifetime of up to 60 years, enhance replaceable equipment lifetime, increase fuel burn-up.**
- Perform technical-and-economic investigations for fuel cycle closing (including MA transmutation).

Conclusions

❖ Development of the commercial BN–1200 power unit was initiated in Russia based on positive long-term experience in sodium fast reactors.

❖ BN–1200 conceptual design has been completed, which shows the possibility to create a power unit competitive against VVER with similar power and having the safety level that meets requirements for Generation IV NPPs.

❖ In order to create the pilot BN–1200 power unit prior to 2020, main R&D of equipment is planned for completion within next 5 years. The core R&D will continue until the BN–1200 is commissioned.

THANK YOU

FOR YOUR ATTENTION