State Atomic Energy Corporation «ROSATOM»

Innovations and advances in nuclear technologies in Russia

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VVER technology development: Novovoronezh NPP II, unit 1 first Gen III+ unit in the world

Main parameters:

- Reactor type: VVER-1200
- Capacity: 1199 MW
- Commissioned: May 2016
- Commercial operation: February 2017
- Power output (design): 9,1 Bln kW*h

Generation 3+ features:

- Additional passive safety systems in conjunction with traditional active ones.
- Protection from earthquakes, tsunami, hurricanes, and aircraft crash impact by design.
- Designed according to the new safety standards:
  - the reactor hall is covered with a double layer protective containment;
  - corium “trap” under the reactor vessel;
  - a passive residual heat removal system

VVER technology development: new generation naval reactors and floating nuclear heat and power plant

New generation icebreakers

Equipped with two reactor units RITM-200. Commissioning: “Arktika” – 2019, “Siberia” - 2021, “Ural” - 2022

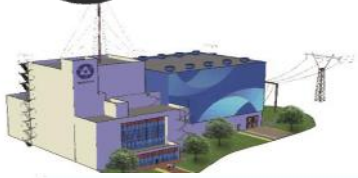
Reactor RITM – 200

Thermal power of 175 MW

Refueling period - at least 7 years

Fuel enrichment < 20%

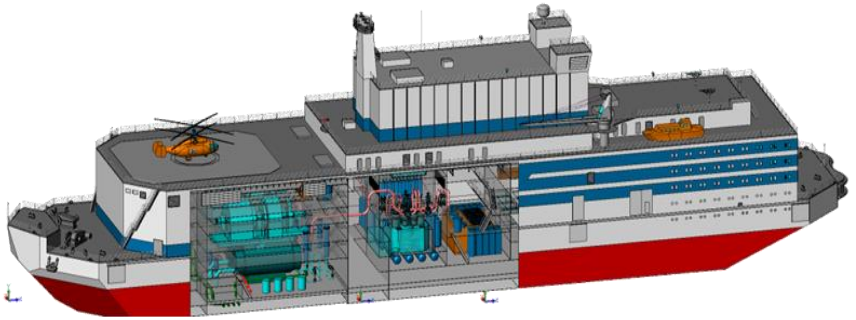
Service life 40 years



Pre-design R&D on small capacity NPPs based on RITM-200

Floating nuclear heat and power plant

Equipped with two reactor units KLT - 40C (RU) and two steam turbine units (STU) Coastal and hydraulic structures allow to transfer heat and electricity to the shore.



RU

STU

Nominal electric power - at least 70 MW

Period between refueling - 3 years

Nominal heat power - 50 Gcal/h

Service life – 40 years

Fuel enrichment < 20%

Fast reactors development: BN-800 Gen IV reactor – Major step towards closed nuclear fuel cycle

Main parameters:

- **Reactor type:** BN-800
- Power output (2016): 3,456 Bln kWt*h
- Thermal Power - 2100 MW
- Electric Power - 885 MW
- Fuel – uranium oxide, MOX fuel
- Annual Electricity Supply - 5 718 G
- Capacity Factor – 82%
- Efficiency unit NET - 38,9%
- Design Lifetime - 40 years

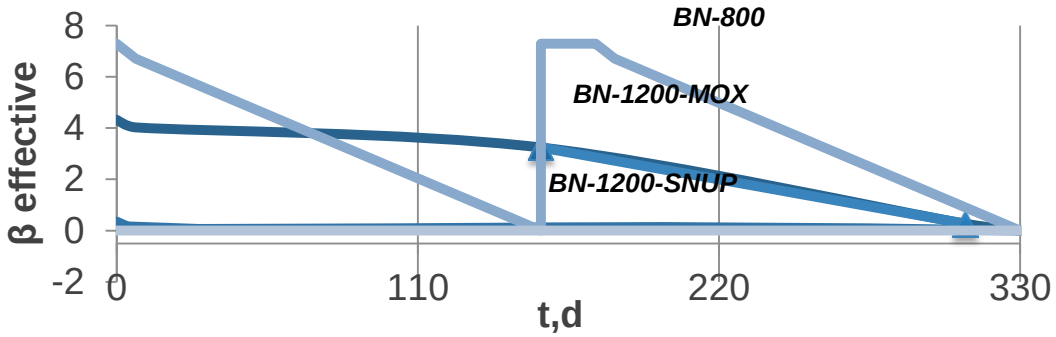
Fast reactors development: PRORYV Project

The integrated design of the BRESt-300 power unit – allows to localize the leak of coolant in the case of RU and eliminate the draining of the core. It excludes accident requiring evacuation.

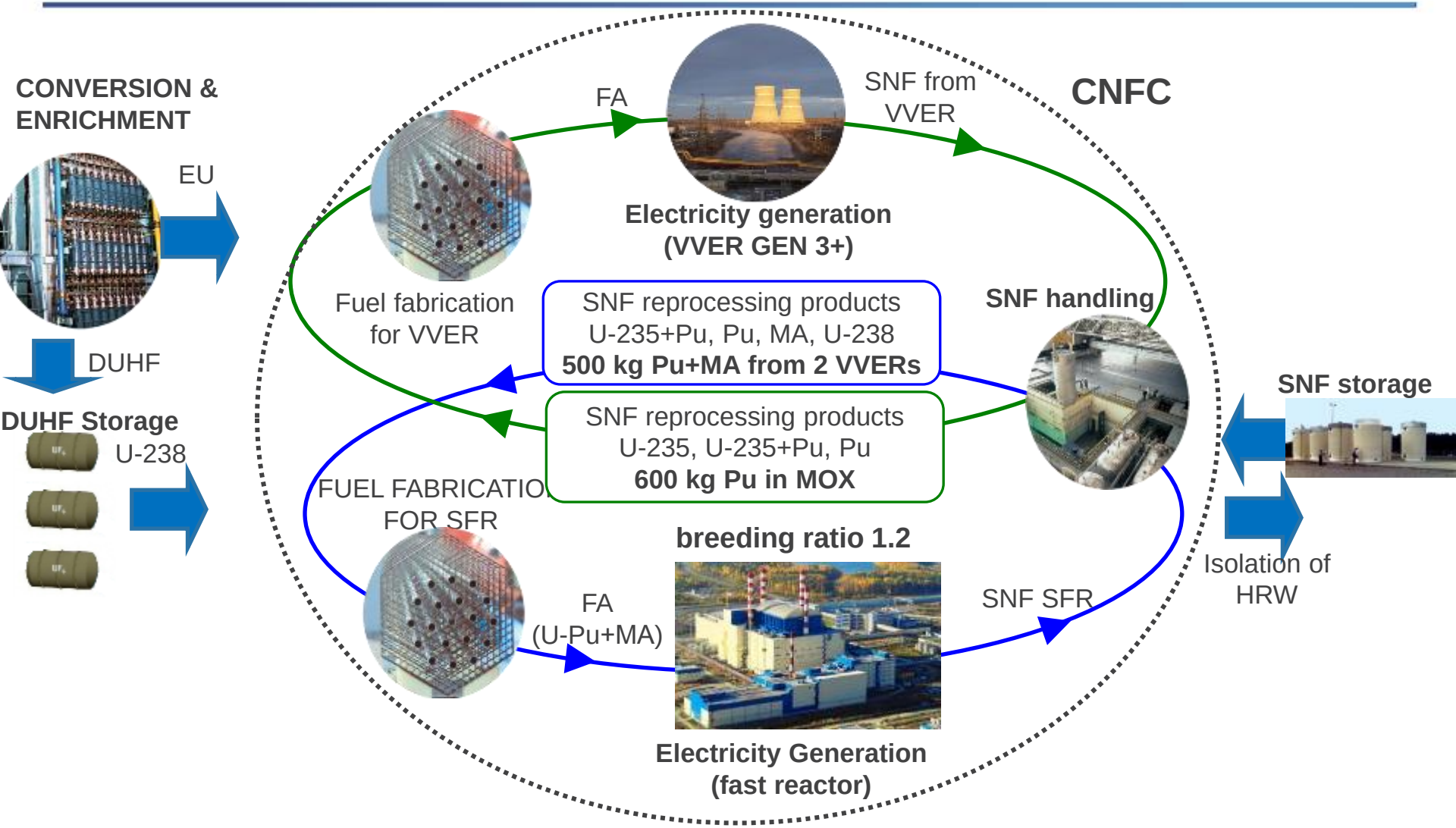
Fabrication/refabrication module (June 2017)

"PRORYV" – solution to the problems of security and SNF

The equilibrium dense fuel– exclusion of reactivity-induced accidents in reactor unit



Main idea of the two component nuclear power system (VVER and FR)



CNFC effectiveness increases in time when fuel on U-235 is substituted by U-PU fuel composition

PWR – pressurized water reactor (thermal neutrons
FR – fast reactor, or SFR – sodium fast reactor (fast neutrons)

New Developments in Back-End of the Nuclear Fuel Cycle






Mayak Plant became the only operating reprocessing plant in the world which works with every type of SNF including defective with capacity up to 400 tU/year

Pilot demonstration center on SNF reprocessing based on innovative PUREX technology was launched at Mining and Chemical Combine with capacity up to 250 tU/year. First VVER-1000 SF to be reprocessed in 2017

New electric direct heating furnace was launched at Mayak Reprocessing Plant with the designed output ~ 0,6 m^3/t SNF allowing to verify HLW generated during SNF reprocessing

First experimental **REMIX*** fuel assemblies have been installed in VVER-1000 commercial reactor on summer 2016 (Balakovo NPP, Saratov) and in parallel, irradiation of the test REMIX assemblies is starting in research reactor MR (RIAR, Dimitrovgrad)

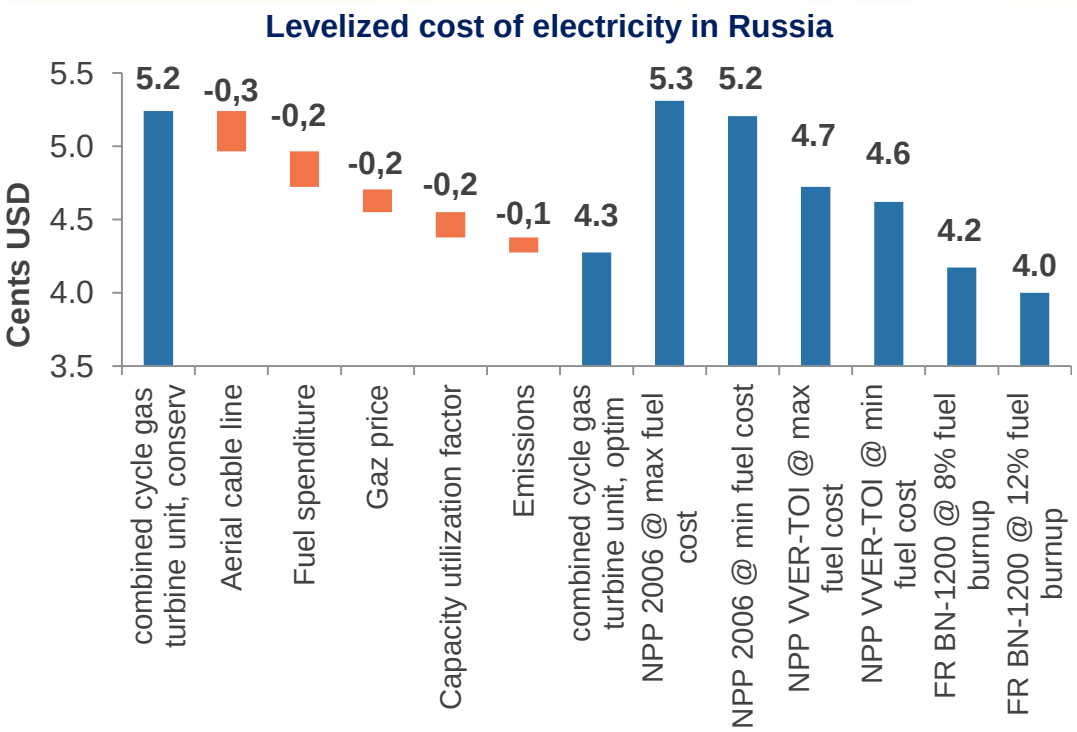
First **MOX fuel assemblies** for BN-800 reactor using power grade plutonium were developed

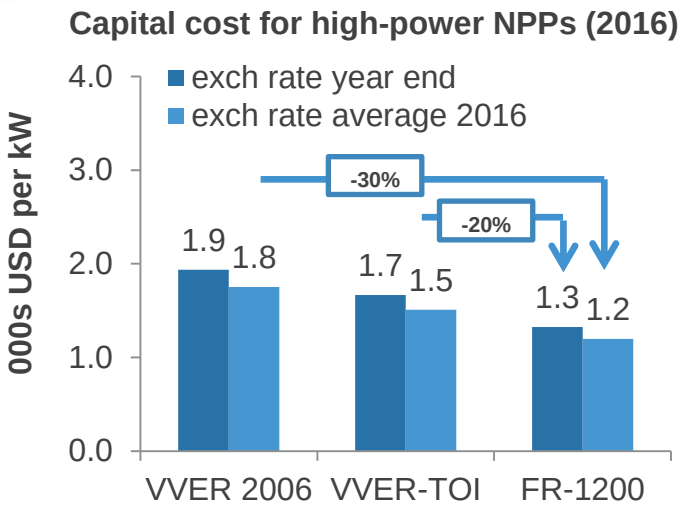
Encouraging results on **minor actinides burning** in fast neutron reactors in “PRORYV” Project

Russia goes confidently towards the practical closing of the nuclear fuel cycle

* Fuel produced from recovered uranium (4%) and plutonium (1%) with possibility of multi recycling in thermal reactors

The relative competitiveness of energy technologies in Russia



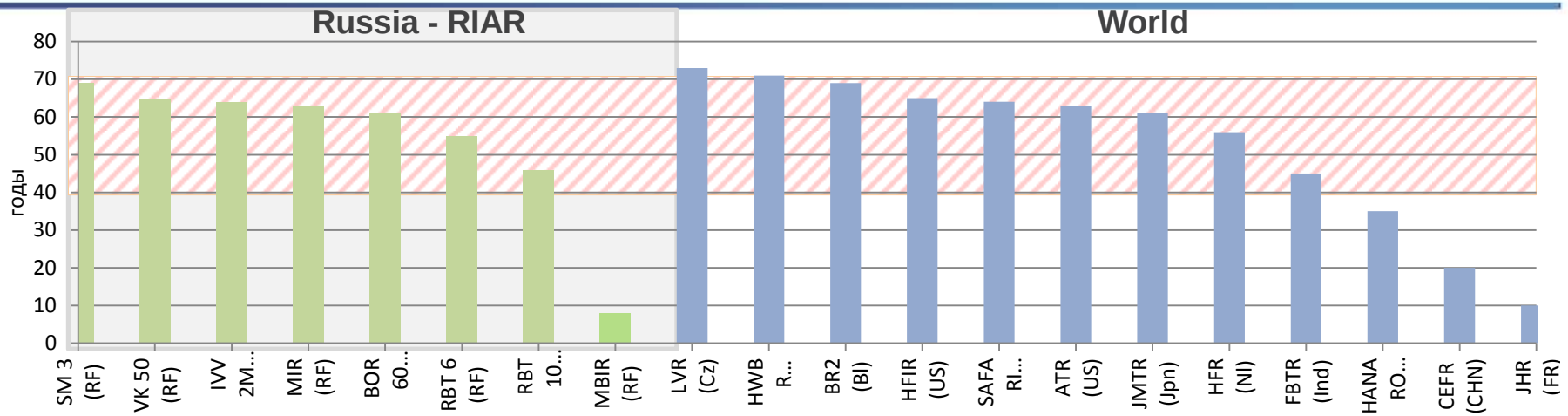


1) Reduction in specific ACL of NPP with FR compared to NPP with TR ~20-30%

2) Reducing the cost of electricity of NPP with FR compared to NPP with TR ~15-25%

1. **NPP with VVER-TOI is competitive only when performance indicators for CCGT unit are conservative**
2. **With the improvement of performance indicators for CCGT unit (the optimal values for the best analogues), NPP with VVER-TOI lose competitive position (reduction in LCOE for CCGT may reach ~20%)**
3. **The requirements for NPP with the FR-1200 maintain the competitiveness of nuclear energy even with optimal performance indicators for CCGT**

Nuclear R&D: high-flux research reactors market by 2030



Parameter		MBIR (150 MWt, Russia)	Hanaro (26 MWt, S. Korea)	CEFR (60 MWt, China)	JHR (100 MWt, France)
Avg neutron flux in the core	n/cm2·s	5.3×10^{15}	$4{,}3\times10^{14}$	3.7×10^{15}	5.5×10^{14} - 1×10^{15}
Max DPA in a single channel	DPA / year	34	3-4	11-13	16
Main purpose		Material testing, new fuel compositions for Gen 4, LOCA and other transient conditions, NAA.	Isotope production, silicon doping, material and fuel for PWR testing, NAA.	Electricity generating demonstrator, connected to the grid. Material testing is limited.	R&D for PWR, material testing, incl some for Gen 4 tech, isotope production (25% - 50% of European ^{99}Mo market)

If Russian MBIR reactor and French JHR will be commissioned by 2030 there will be only 4 high-flux reactors younger than 40 years left in the world

Neutron spectrum Fast Thermal

IRC MBIR – key infrastructure for innovative technologies research available to international scientific community

Key R&D to be performed on MBIR

Material science
- New fuels
- Structural materials
- New coolants
- Data verification

Safety
- New safety systems justification
- Studies under transient and abnormal conditions

Physics
- CNFC research;
- MA and other long -living nuclides recycling;
- Data codes verification

Endurance tests
- Fuel and its elements, absorbing substances, core elements;
- Monitoring systems & core and coolant circuits diagnostic

IRC MBIR - Sole collective user

Financial resources & in-kind contribution ↓

↑ Technical services

ROSATOM / RIAR – reactor owner & Operator

- Operating the reactor
- Liabilities, operation & maintenance
- R&D program execution
- Laboratory assistance

Rosatom solutions for non-power applications (1)

Treatment by ionizing radiation

Gamma irradiators based on Co-60

- The basic solution for processing of agricultural products
- Own production of both equipment and sources on the basis of Co-60

Rosatom gamma irradiators are installed in **7** countries

Rosatom occupies **30%** of the world market of isotope Co-60

Electron accelerators

- Allows to sterilize medical devices
- The possibility of processing production by bremsstrahlung

Electron accelerators of Rosatom established in **12** organizations around the world

Rosatom centers of irradiation in Russia

The center of the irradiation on the basis of gamma-installation at JSC "NIITFA", Moscow

- Irradiation of food and sterilization of medical devices
- Studies on the effect of ionizing radiation on different types of products
- Equipment and sources of radiation produced by GK "Rosatom"

Center irradiation "Sterion" on the basis of the electron accelerator, Lytkarino, Moscow oblast

- The provision of commercial services on the irradiation
- Sterilization of medical products, the treatment of certain types of food
- Equipment produced by GK "Rosatom"
- Production capacity* – 720 000 boxes per year

*the average density of the product is 0.13 g/CC

Rosatom solutions for non-power applications (2)

Cyclotron complexes Rosatom:

Rosatom has advanced competences in the construction of RPh production objects

- 14 cyclotrons of various models were delivered in 12 cities in the world (Turku, Debrecen, St. Petersburg, Inshas, Helsinki, Snejinsk, Moscow)
- A wide range of models of small, medium and high energies
- 2 cyclotron production management supply BRS (RPh) leading clinics of Moscow and the Urals, providing a need for treatments of PET-diagnostics

The cyclotron complex in Thailand:

- ✓ Won the tender for construction and commissioning of the cyclotron-radiochemical center
- ✓ The radiopharmaceuticals, labeled with isotopes Zr-89, Cu-64, Tl-201, Ga-67 to be developed
- ✓ The contract work period is 3.5 years
- ✓ The lifetime of the object 20-25 years

The nuclear medicine centers

Rosatom implements complex projects of construction of nuclear medicine centers on a turnkey basis

September 2017 - concession agreement signed between Rosatom and Administration of Primorsky Krai.

Center equipment:

The unit of radionuclide diagnostics: PET/CT, SPECT studies
Department of radionuclide therapy (RNT): RNT chamber with iodine-131 usage

Isotopic complex of Rosatom

- Supplies products for medical, industrial and research centers in more than 30 countries
- 5% of the world market for Mo-99 (up to 2016).

Q2 2017 - supply of therapeutic iodine-131 to the international market