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Proliferation resistance of fuel cycle of fast reactors in the Proryv project

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Motivation for increasing nuclear power share in Russia's energy balance

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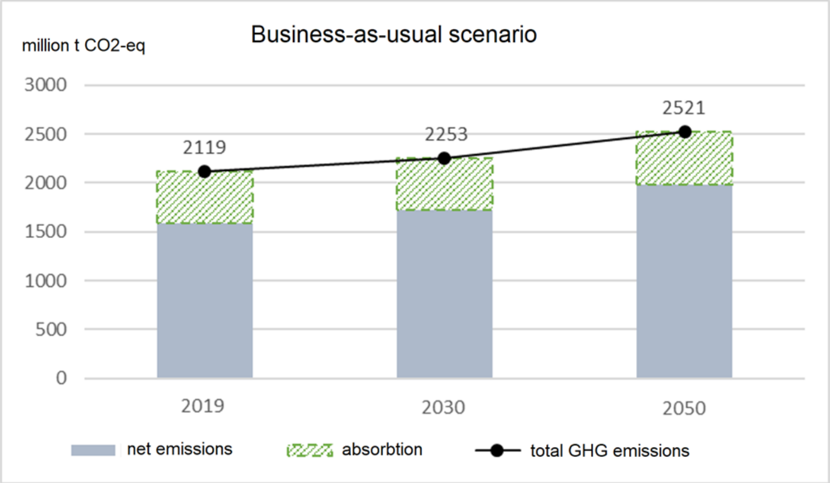
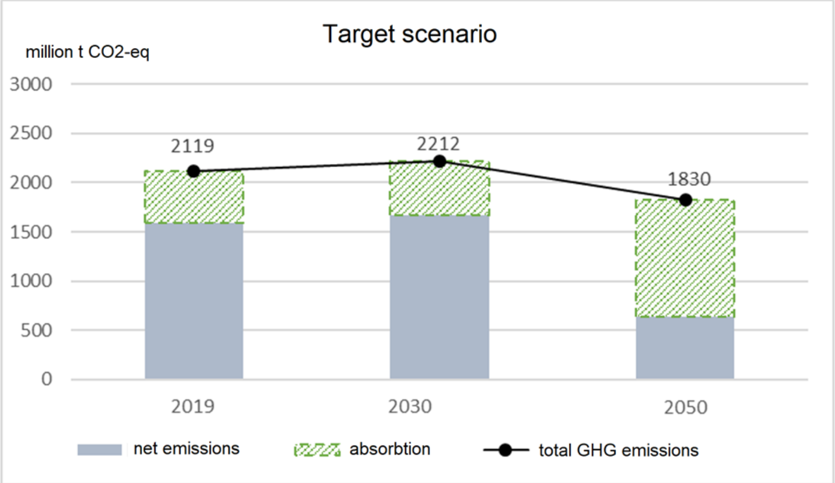
- Achieve target indicators of the lStrategy for Socio-economic Development (SED) of the Russian Federation with a ow level of greenhouse gas emissions by 2050;
- Improve ecological indicators in regions with a high share of coal generation;
- Support the competitiveness of Russia's export products by increasing the share of carbon-free electricity used in production;
- Conserve natural gas as a valuable resource for domestic and international markets.





Emissions and absorption figures for greenhouse gases for the «business-as-usual» and «target» scenarios in the Low-Emission Development Strategy of the Russian Federation until 2050.

The main challenges of nuclear energy

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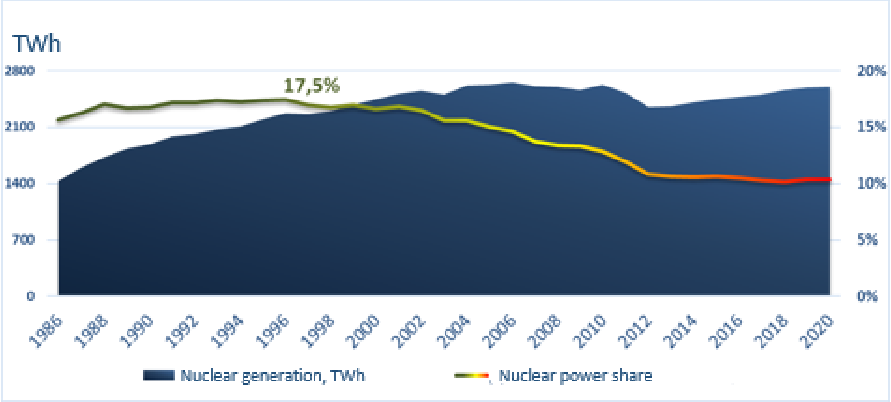
Severe accidents


Three Mile Island

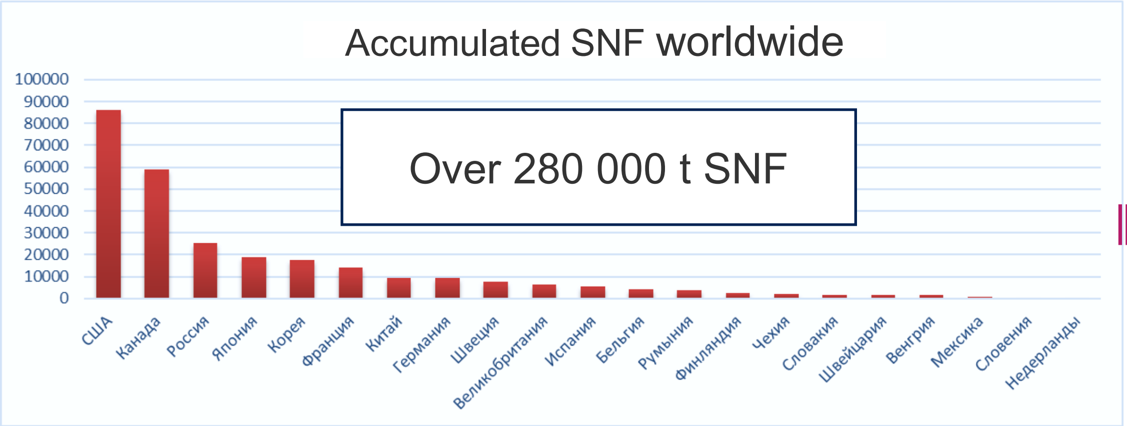

Chernobyl

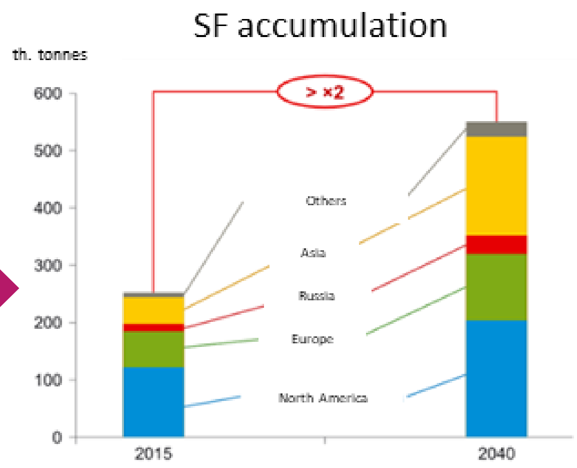

Fukushima



The main barrier to the development of modern nuclear energy is the issue of competitiveness, which hinges on the problem of safety.

Deferred solution for spent nuclear fuel (SNF)





Long-term SF storage issues

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Non-proliferation issues

SYSTEM SOLUTIONS THROUGH NEW TECHNOLOGIES

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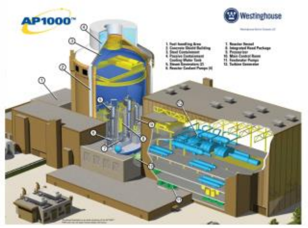
Current NPP projects



- Low resource intensity in comparison with other types of low-carbon generation;
- Long service life (service life of at least 60 years);
- Low dependence of the cost of electricity production on fuel costs.

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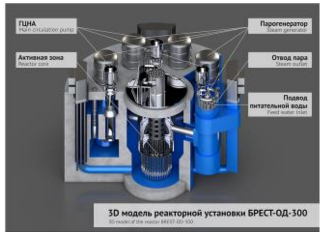
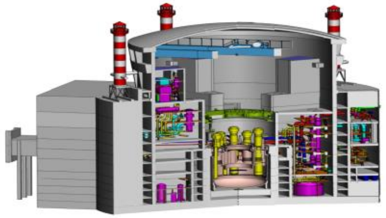
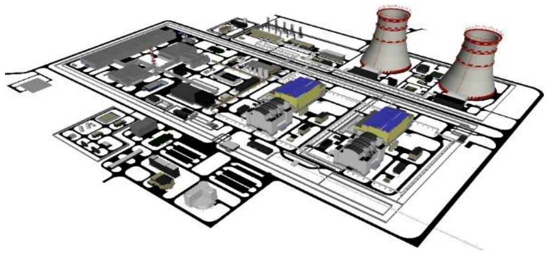
New generation nuclear power systems







- The priority of safety is the exclusion of severe accidents at nuclear power plants requiring evacuation of the population;
- Inexhaustible resource base - a closed NFC provides any scale of development of nuclear energy;
- Waste minimization – a new generation nuclear energy complex and closed NFC technologies will allow the use of already accumulated SNF and the disposal of minor actinides;
- Competitive level of capital expenditure,

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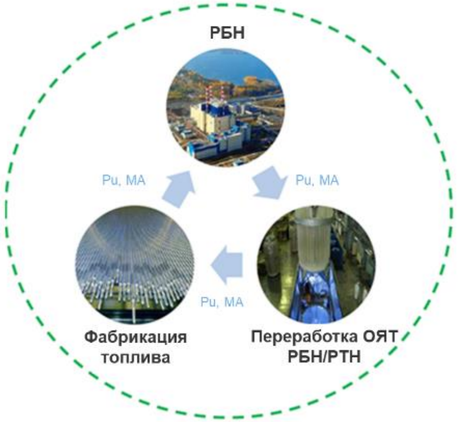
IV Generation commercial energy complex

CEC

NPP with FR and closed NFC infrastructure located on one site



Economic competitiveness

- **Lowest material use** out of all alternative NPP projects;
- **Lowers requirements** for natural resources and SNF storage for entire nuclear industrial complex;
- **Attractive LCOE under low discount factors.**

Inherent safety of nuclear energy

- **No severe reactivity induced accidents** (LMC+equilibrium MNUP fuel);
- **No loss of coolant accidents** (integral reactor design);
- **High coolant boiling temp.** (for lead coolant – 1750 °C).

Not limited by natural uranium resource base

- **Self-sufficient** after start-up load and first initial reloads;
- Runs essentially on depleted uranium – **Russia has more than enough for thousands of years**;

Minimizing the potential biohazard from waste

- **Maximum recycling of nuclear materials** from thermal reactor SNF (U, Pu, MA);
- **Minimal potential biological hazard** of waste after reprocessing.

Supports nuclear non-proliferation

- **Local on-site NFC** with Pu recycling and MA transmutation – **wastes contain no attractive materials for nuclear weapons;**
- **Self protected fuel and SNF –** incredibly hard to steal or conceal nuclear material**;**
- Large-scale scalability – can be replicated to develop a large system **without using blankets**.

Unique opportunities for expanding exports

- **Recycle nuclear materials from reprocessing foreign spent nuclear fuel in Russia;**
- **Increase energy independence** for importers of NPPs with FRs and closed NFC technology

Proliferation Critical Fuel Cycle Operations

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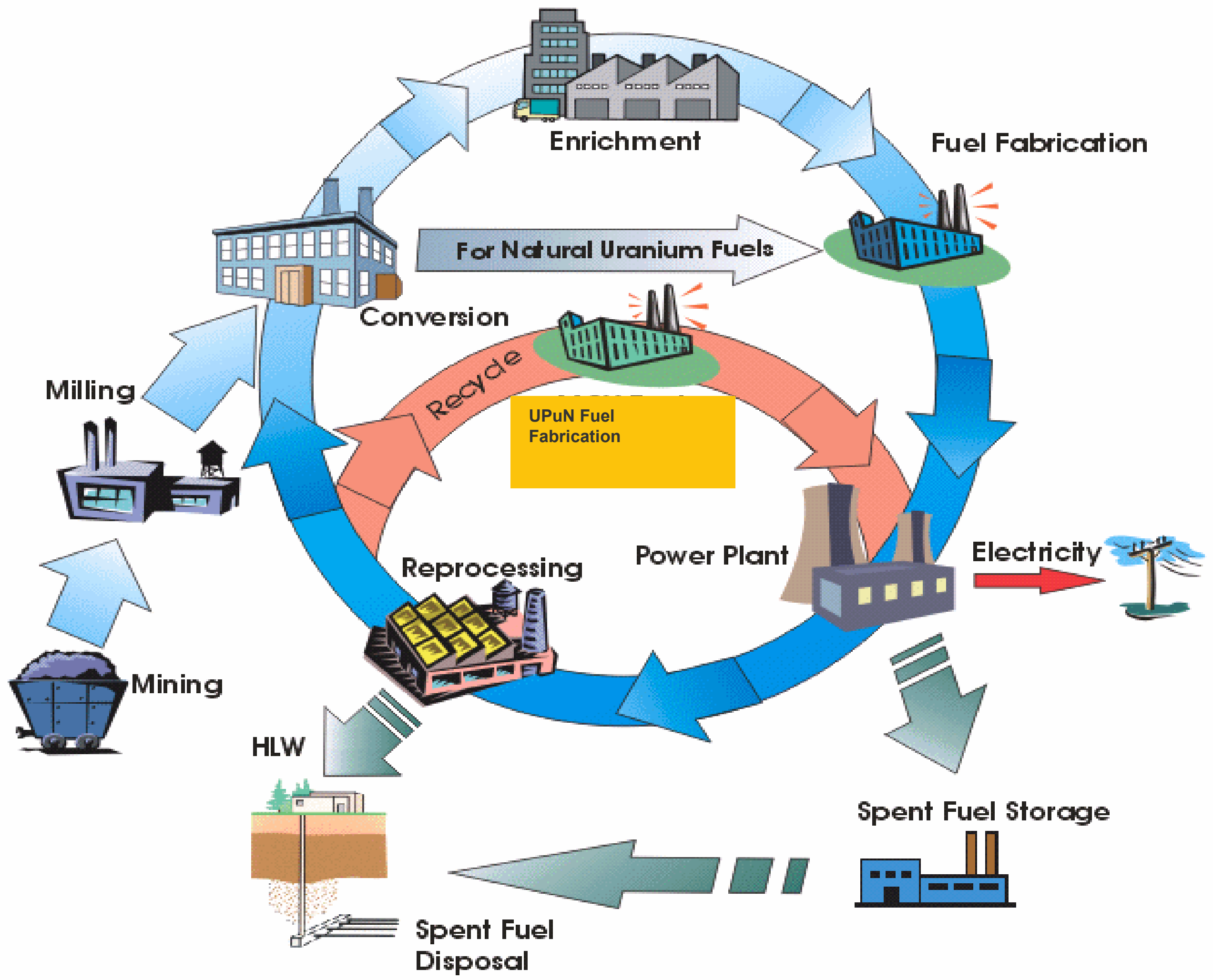

- Uranium enrichment
- Plutonium extraction during spent nuclear fuel reprocessing
- Transportation of nuclear materials
- Storage of nuclear materials

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Pilot and Demonstration Energy Complex

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The ceremony of filling the "first concrete" for the construction of BREST-OD-300 in June 2021.

NPP construction in June 2022

The SNF reprocessing module is currently being designed

Installation of MFR equipment in June 2022

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IV Generation nuclear energy system development prospects for nuclear expansion in Russia

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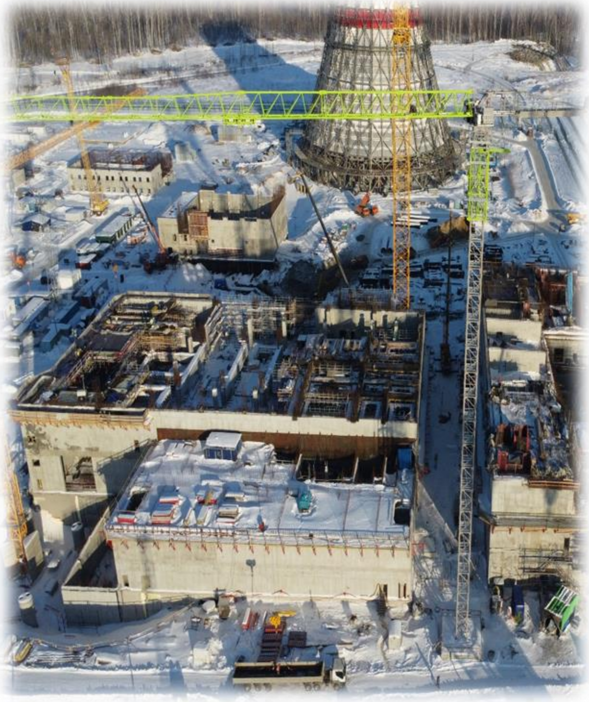
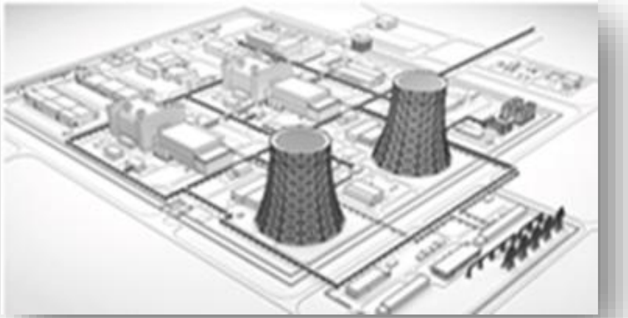


Demonstration Energy Complex
(DEC)

Commercial Energy Complex
(CEC)
Medium power plant

- Use solutions developed for DEC for serial CEC projects (small and medium sized power plants);
- Has the option of increasing thermal efficiency over 50% through superheating steam using natural gas* and installed capacity over 500 MWe ;
- Reactor and unit performance can be improved further by using advanced and innovative materials
- Ideal for replacing medium sized fossil fuel plants in the Ural and Siberia.



Commercial Energy Complex
(CEC)
Large power plant

- Unit installed capacity – up to 1300 MWe;
- Maximizing economic efficiency by using large scale design model and implementing serialized production methods;
- significant potential for replacing large fossil fuel thermal power plants

* THE CASE FOR IMPROVING THE TECHNICAL AND ECONOMIC PARAMETERS OF FR SMRS IN RUSSIA. 21st INPRO Dialogue Forum on the Deployment of Small Modular Reactor Projects and Technologies to Support the Sustainable Development Goals (SMRs for SDGs)
https://nucleus.iaea.org/sites/INPRO/Pages/df-21.aspx

The fast reactor nuclear fuel cycle

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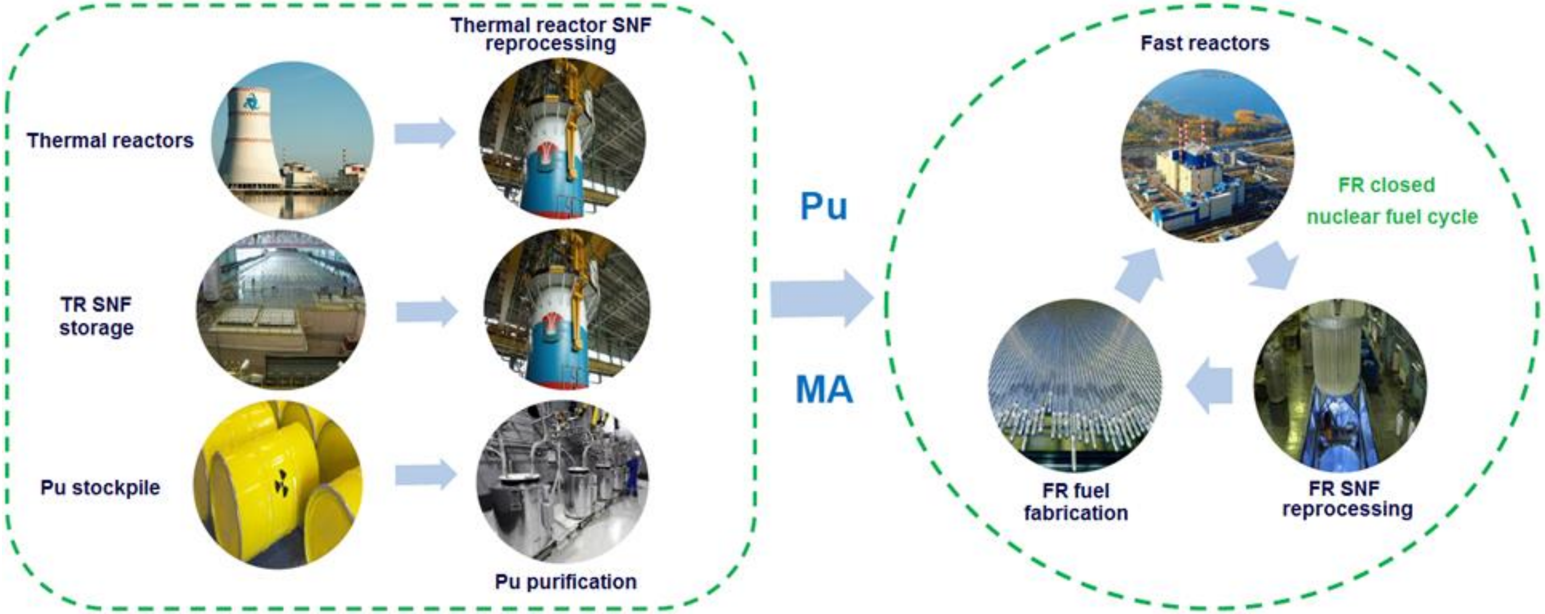
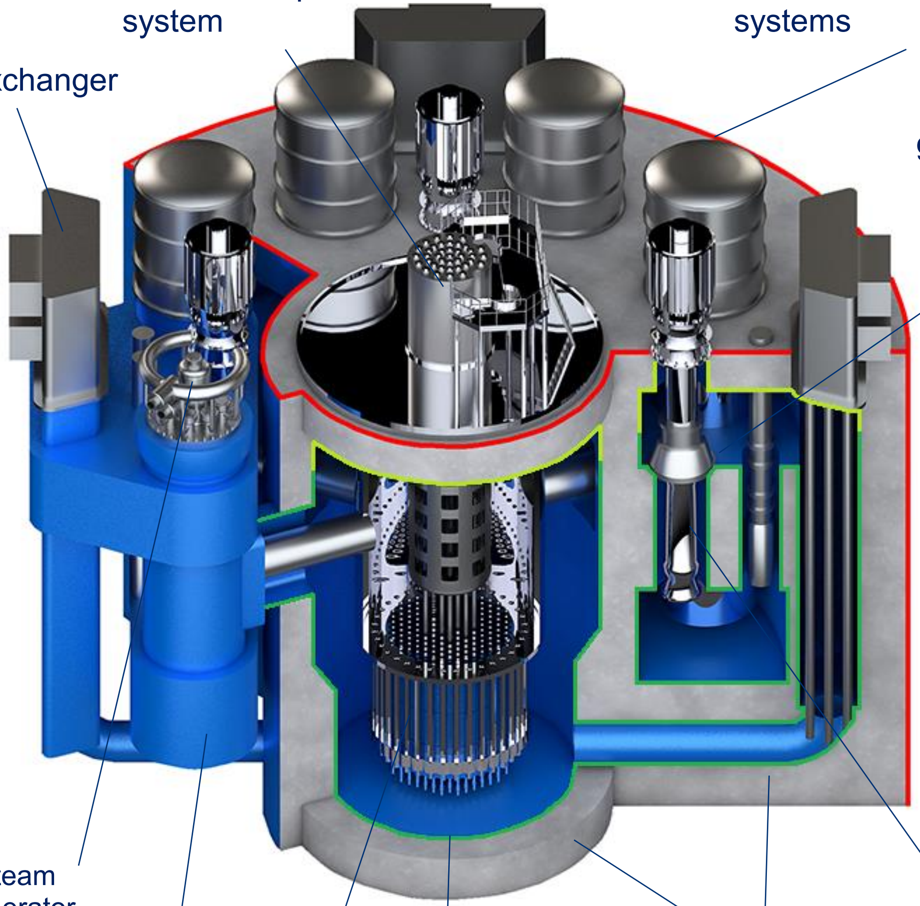
An optimal fast reactor NFC should imply:

1. Pu together with MA is recycled in the FR;
2. All MA from reprocessing thermal reactor SNF are burned in FRs.
3. Fuel consumption is balanced so no excessive Pu breeding is needed;
4. Fuel regeneration and MA transmutation are concentrated in the reactor core.



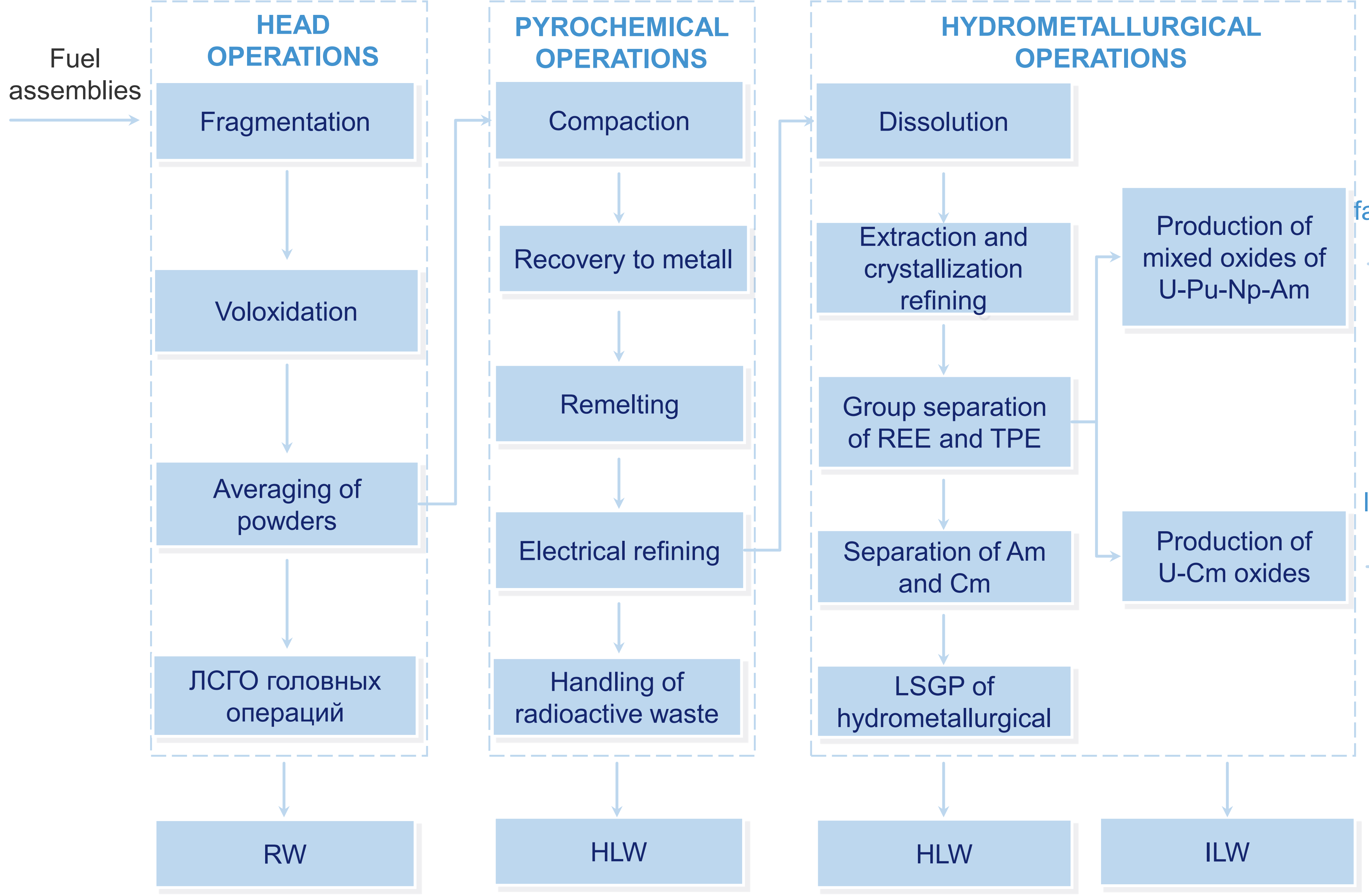
Minimizing nuclear waste is a priority for generation IV NES

BREST-OD-300 reactor: project basis



- Compliance with regulatory requirements
- Integral reactor design utilizing a multilayer metal-concrete vessel; no shut-off valves in the coolant circulation loop
- Normal operation systems and safety systems reserves
- Extensive use of passive protective and localization systems and devices
- Radiation-resistant, low-activation lead coolant with a high boiling point
- Dense, thermally conductive nitride fuel
- Minimal reactivity margin and stable physical characteristics throughout the fuel cycle
- Exclusion of prompt neutron excursion accidents
- **Homogenous core composition (no blankets)**
- No need for evacuation and resettlement of the population beyond the nuclear power plant site in event of accidents.

Combined technology for optimal results



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Key requirements:

- ✓ Non-separation of uranium and plutonium
- ✓ The burnout is 12% at.
- ✓ Cooling is not more than 3 years

- ✓ Minimization of secondary waste
- ✓ Losses are not more than 0.1 %

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THE UNIQUENESS OF THE PYROCHEMISTRY SCHEME

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The main advantages of pyrochemical technologies for the processing of SNF FR:

1. Radiation resistance of technological media – molten salts.
2. Low vapor elasticity and high thermal conductivity of process media.
3. High concentrations of TE and FP in process media.
4. High process speeds at operating temperatures.
5. Operational monitoring (sensors) and remote control of electrochemical processes.

1. The possibility of processing spent fuel with high burnout and a short shelf life (no more than 2 years).
2. Small volume of technological media.
3. The compactness of the technological scheme and equipment.
4. The possibility of reducing the volume of raw materials (a small amount of liquid RW).

High activity of products – robotization and automation of processes

EXPERIMENTAL BASE FOR TESTING INSTALLATIONS PYROCHEMICAL PROCESSING OF SNF FR

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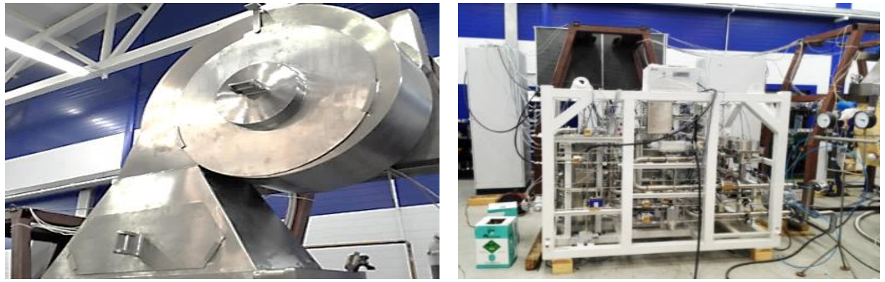
1. **A complex of equipment "Technological hot cell with an inert atmosphere" consist from:**
   - ❑ the technological hot cell with a transport system;
   - ❑ argon purification and cooling unit;
   - ❑ an electromechanical manipulator.
2. **The operations of creating and maintaining an inert atmosphere (moisture ≤ 1 ppm, oxygen ≤ 5 ppm) have been worked out**
3. **Transportation operations and the technology of remote installation of equipment in the chamber using robotics have been worked out**



Argon cooling and recirculation unit

Argon Cooling System Equipment

Equipment of the “Hot cell" section

Experimental base for testing THE MEANS OF ROBOTIZATION OF PYROCHEMICAL TECHNOLOGY

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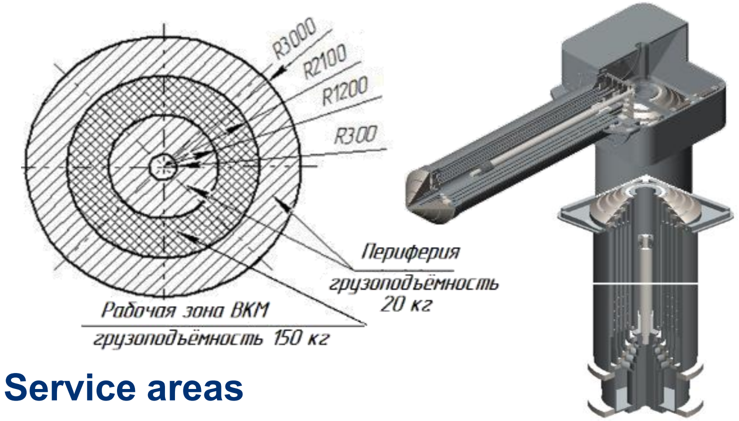
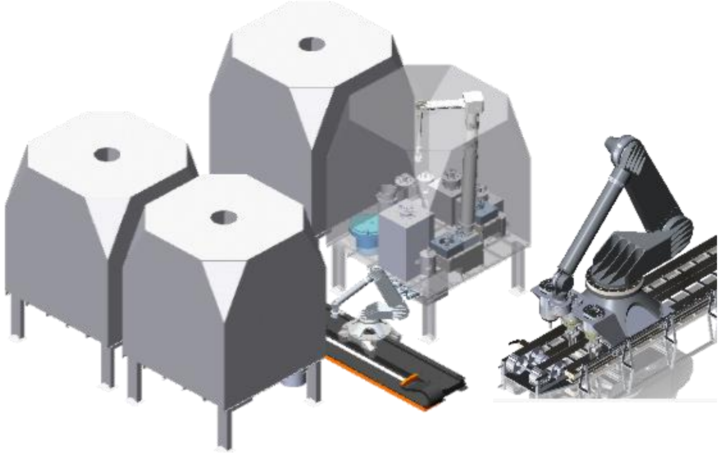
Manipulator for pyrochemical operations)



Service areas

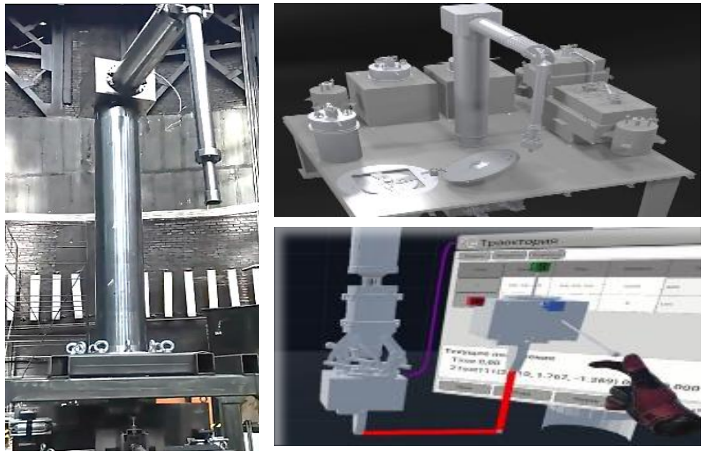


Intermodular transport system

– service area: up to 2.5 - 3.0 m;
– load capacity: up to 150 kg;
– repeatability of the trajectory : 2 ± 1 mm.

Tool Kit

Technological stand



operator's virtual environment

MODULE OF FABRICATION AND REFABRICATION OF NUCLEAR FUEL

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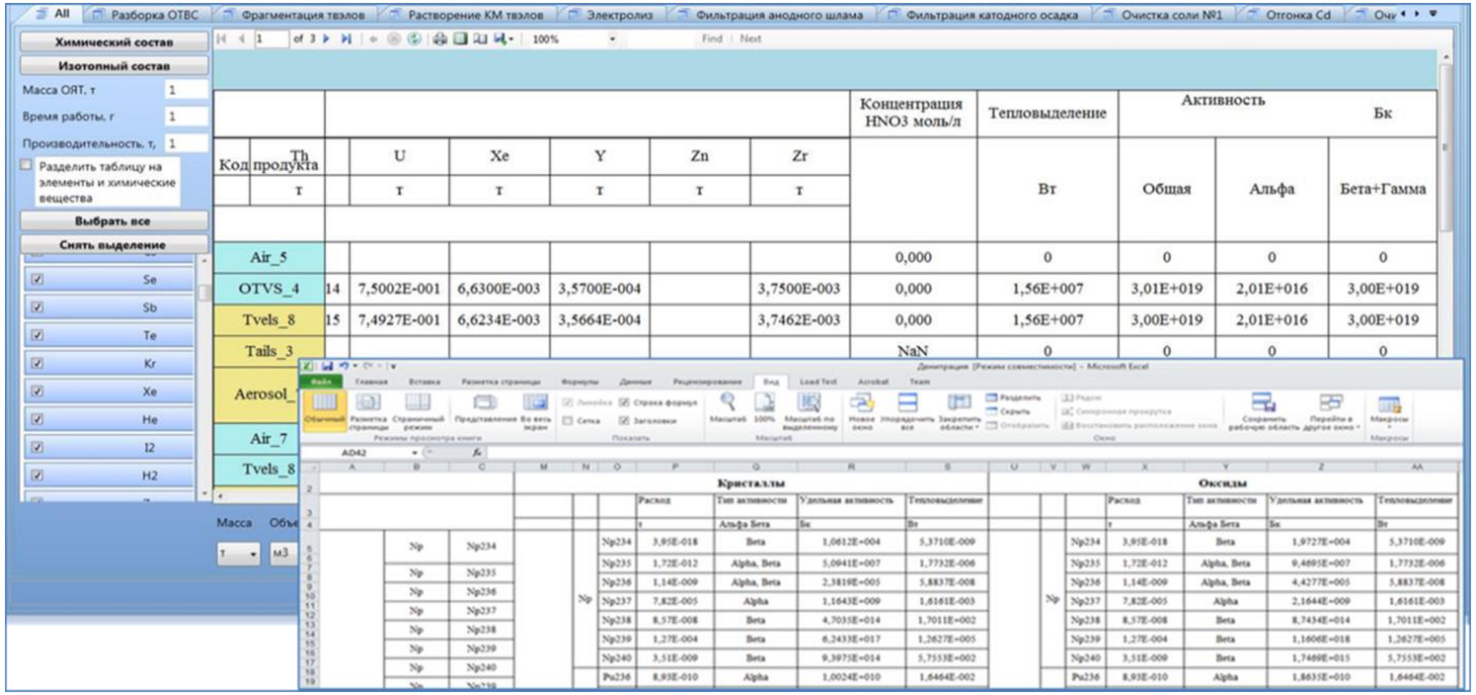
Equipment is manufactured, tested and installed and is used in the educational and demonstration stand of «Rosatom Proryv» at Sirius (Sochi, Russia)

The VISART software package



Virtual Plant of Radiochemical Technologies (VIZART) is a software package designed for mathematical modeling of the final stages of the fuel cycle (spent nuclear fuel reprocessing, fuel production and radioactive waste management).

- Calculation of material balance$
- Accounting for the evolution of nuclide compositions;
- Determination of characteristics of material flows at any point of the process flow diagram (mass, density, volume, chemical and isotopic composition, absolute and specific activity, heat release);
- Construction of equipment operation cyclograms taking into account operational characteristics (loading/unloading operations, quality control, etc.);
- Resource requirements: materials, reagents, consumables, energy, water;
- Number of intermediate tanks;
- Assessment of volumes and compositions of radioactive waste

Thank you for attention

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