# Analysis of scenarios of the inclusion of fast reactors in the nuclear power of Russia in the context of sustainable development with the use of the INPRO methodology

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# Introduction

- Currently, the world nuclear power (NP) is based on the light-and heavy-water reactors and a once-through nuclear fuel cycle (OTFC)
- It's generally acknowledged that basic technologies of NP should be further developed to meet requirements of a future large-scale sustainable nuclear energy system (NES)
- The requirements of sustainability for NES were developed under the auspices of the IAEA in the INPRO methodology as application of the UN concept to the nuclear area
- Results of simulation of a few transition scenarios from the current technological platform of NP of Russia to a new one are discussed in the presentation, and analysis of the results with key indicators established within the INPRO collaborative project GAINS is provided

# Development of transition scenarios for Russian two-component NES

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- The middle-term projections on NP deployment in Russia are determined in the Energy Strategy of Russia to 2030 (50-60 GWe)
- The Strategy of NP Development in Russia in the First Half of the 21-st Century endorsed by the government of RF defines fundamental principles and technological directions for longer perspective. Some principles are important for the long-term scenario development:
  - growth towards a large-scale NES generating up to 30% of electricity in the country;
  - deployment as a two-component system, consisting of thermal (TR) and fast reactors (FR);
  - implementation of a closed nuclear fuel cycle (CNFC).

# INS (100 GWe) FR/ALWR driven by economic, resource, waste and PR concerns

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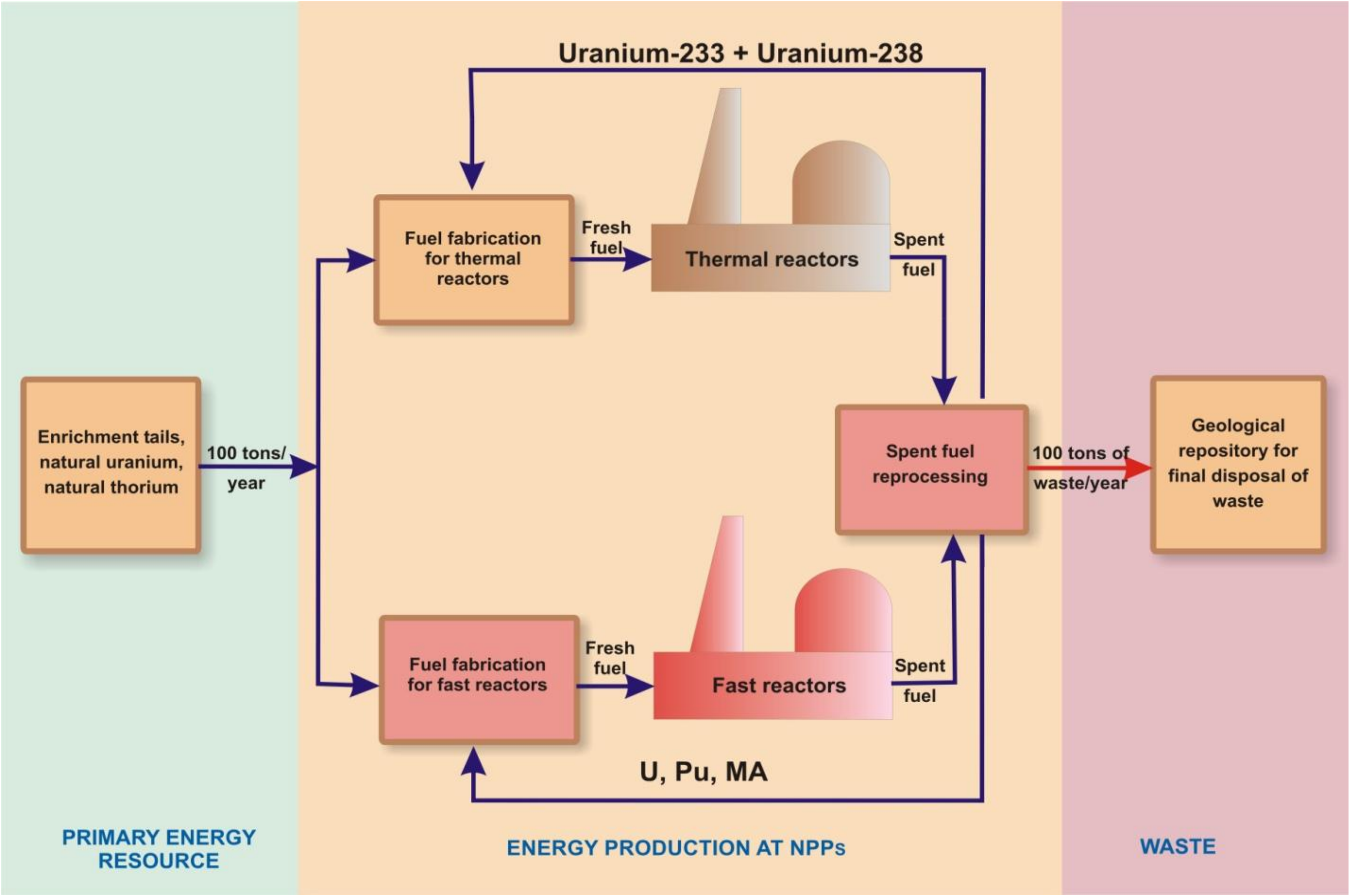
## Open NFC

- Nat U: 20 000 t/a
- Depleted U for radwaste: 18 000 t/a
- Spent fuel as HLW: 2 000 t/a

## Closed NFC

- Depleted U from TR as fuel for FR : 100 t/a
- HLW: 100 t/a




The goal is clear and agreed, while ways and timeframes for reaching it are subject for consideration and discussions

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# Selection of technological options for simulation

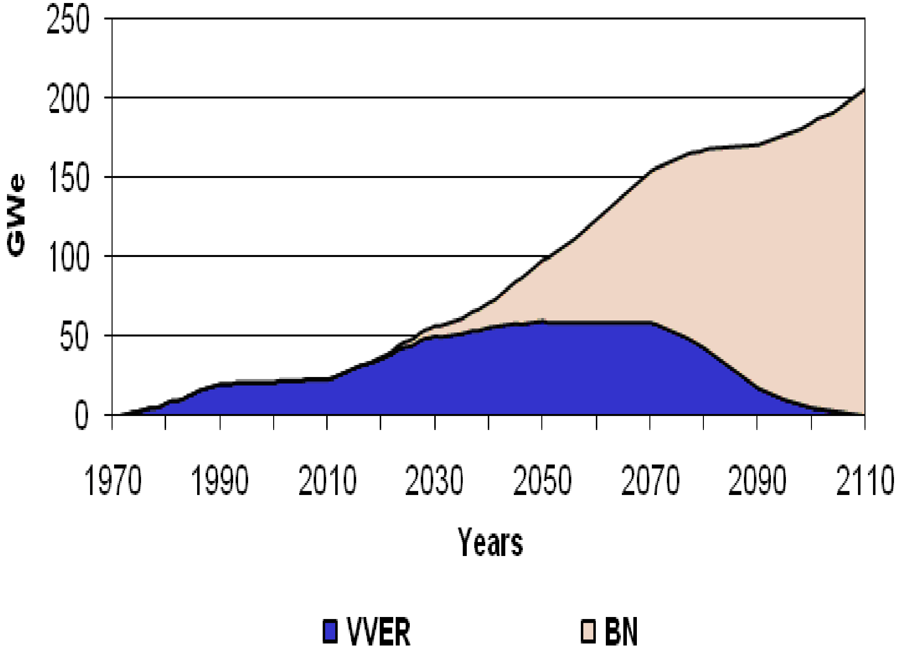
- The final decision on the choice of specific technological options for the closure of NFC and milestones for their introduction is not made

- Currently, two RD&D Federal programs are under implementation, which have to be resulted in a decision on the balance between evolutionary development and radical innovations of the NES between 2020-2040

- Three *evolutionary* scenarios are discussed in the presentation based on reactor and CNFC technologies used or demonstrated in Russia:
  - PWR type reactors (VVER);
  - sodium fast reactors (BN);
  - pellet UOX and MOX fuels,
  - aqueous technologies of spent fuel reprocessing.

- The scenarios differ by the time of FRs introduction into the NES. In the first (base) scenario the serial deployment of the SFR (BN-1200) is assumed to start in 2020 after six years of operation of the first Russian MOX fueled BN-800

# Scenarios for simulation




The first (base) scenario for the NES of Russia: 54GWe by 2030, 100 GWE by 2050

Given growth of NP electricity generation is provided by both VVER and BN units

2014 – put into operation the BN-800

Commissioning of BN-1200s:

- FOAK - 2020;
- 2020-2030 - small series;
- after 2030 – growth of the FR number until reaching the balance of Pu generation and consumption;
- maximal rate of FRs input is ~ 2.4 GWe/year.

SNF of VVER is reprocessed, extracted Pu is used in the fuel of BN

Second scenario: delay of 20 years in deployment of the BN-1200 series

Third scenario: delay of 40 years in deployment of the BN-1200 series

# Computer code for scenario simulation

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- Modeling of the scenarios was performed with a computer code CYCLE recently developed in the IPPE
- CYCLE is dedicated for mathematical modeling of the nuclide composition of the fuel of TRs and FRs at all stages of the OTFC or CNFC. It makes it possible to calculate the material balance, and to assess thermal and radiation characteristics of the fuel in the NFC
- The CYCLE code simulates loading and unloading composition of fuel in reactors and related infrastructure - storage pools at NPP, storage of irradiated fuel assemblies, and repository for the final disposal of waste
- The given function describing the input reactors in time and some technical characteristics of reactors are input data for the code.

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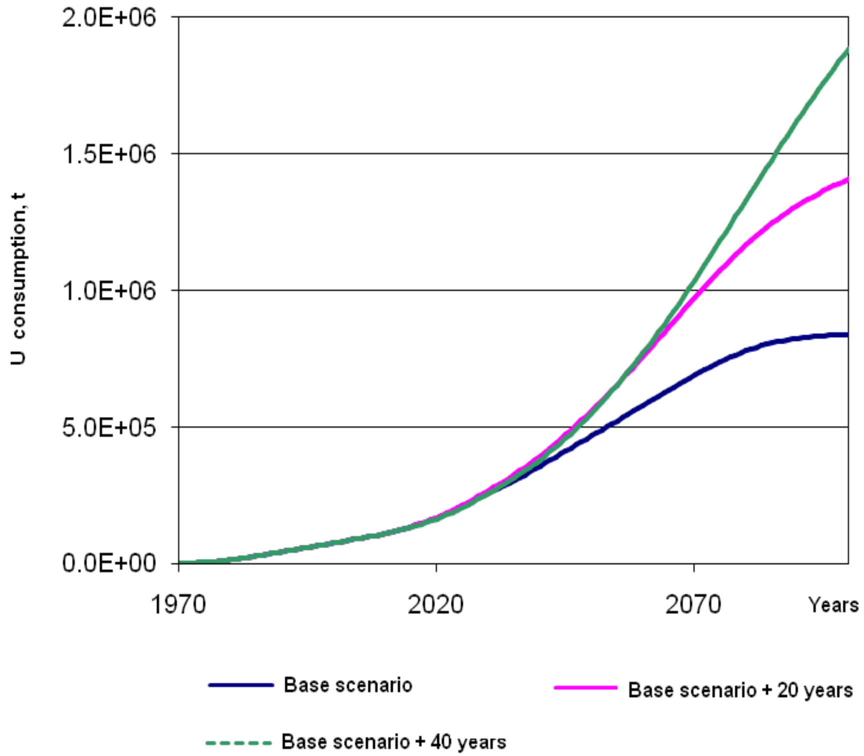
# Key indicators for the scenario study

- Several key indicators developed in the IAEA/INPRO international project GAINS for assessing sustainability features of the global NES were used to analyze results of the national scenario study
- Not all indicators from the GAINS's set can be evaluated within the scenario approach, e.g. safety assessment needs another methods and instruments
- The set of indicators used in study includes:
  - the total consumption of natural uranium;
  - capacity requirements for separation work units (SWU);
  - the amount of accumulation of spent nuclear fuel (SNF);
  - capacities for fuel fabrication and reprocessing of SNF;
  - the amount of accumulated SNF at the storages;
  - amount of plutonium and minor actinides (MA) in the storages and repositories.

# U consumption




Total consumption of natural uranium in the scenarios under consideration

**Russia is the 3d biggest holder of U reserves in the world** ~ 600,000 mln. t

However, ~80% of Russian U **reserves are within the highprice category** (over US$80 / kgU)

Even today, Russian U holding (ARMZ) is widely involved in U projects abroad through purchasing and JVs

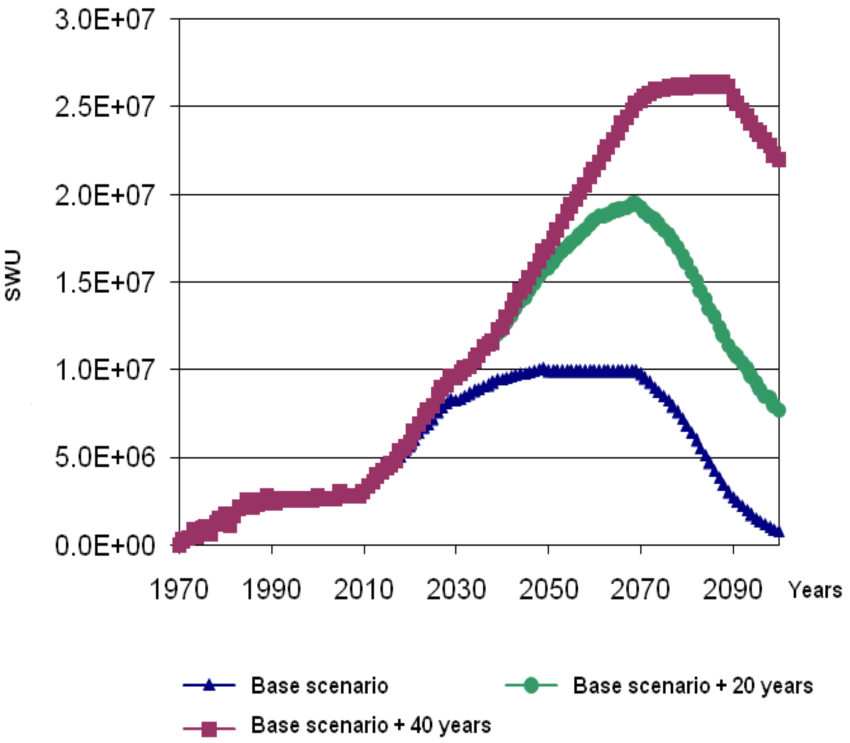
Delay of 40 and even 20 years for FR introduction may result in insufficiency of sustainable U supply after 2070

# SWU

If FRs is delayed 40 years, enrichment capacities for the VVER fuels would increase ~10 times by 2070 as compared with currently available ones

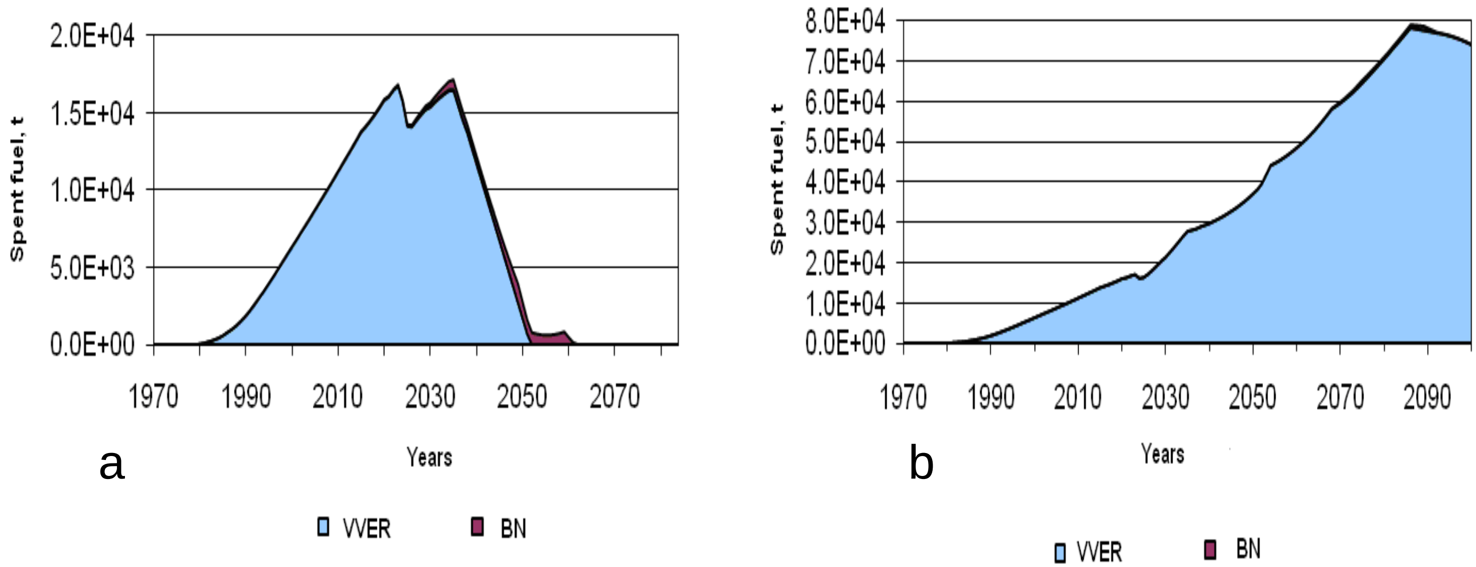
Implementation of the FR technology reduces SWU needs in the NES of TR & FR reactors

Potentially this provides an opportunity to minimize the enrichment capacities in the world thus decreasing the proliferation risks




Need in separation work

# Spent nuclear fuel

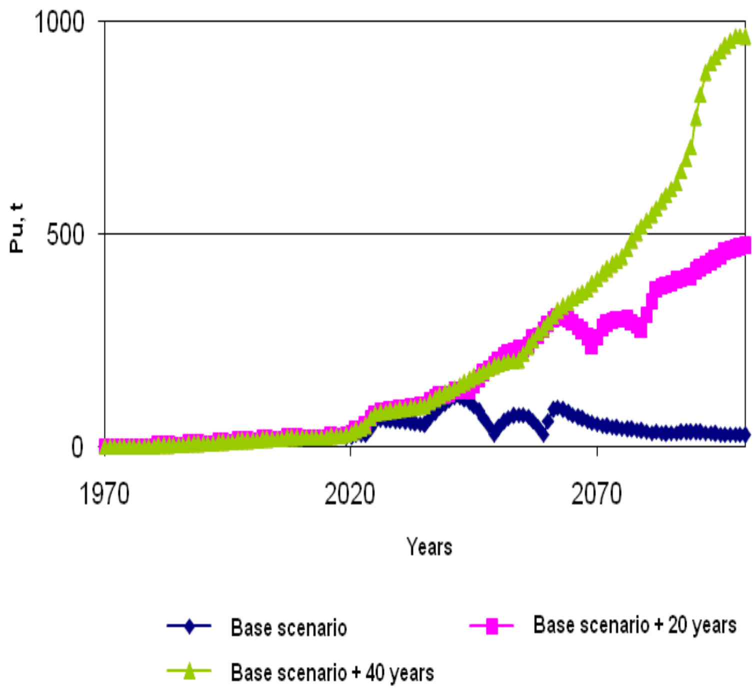



SNF of TRs & FRs in the base scenario (a) and in case of 40 years delay of FRs input

The problem of the VVER SNF accumulation **can be managed and eventually fully resolved** in the baseline scenario **by 2050** using SFRs (one BN-1200 for about ten VVER-1200)

40 years delay of the FR input would result in accumulation ~ 78 thousand tons of the VVER SNF by 2080.

# Pu management




Plutonium accumulation in the baseline scenario and scenarios with delayed introduction of SFRs

Pu accumulation in the VVER SNF **can be restrained** in the baseline scenario with using SFRs (BN-1200) and **Pu to be fully utilized** in the scenario **by 2070**

FRs provide an option for managing the Pu accumulation and enable to strengthen the non-proliferation regime

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# Economics

- BN-1200 is designed with focus on safety and economic effectiveness. One of the objectives for the construction of the FOAK BN-1200 is to reach comparable capital cost with a new VVER-TOI-1200 or at least not to exceed it by 10-15 %

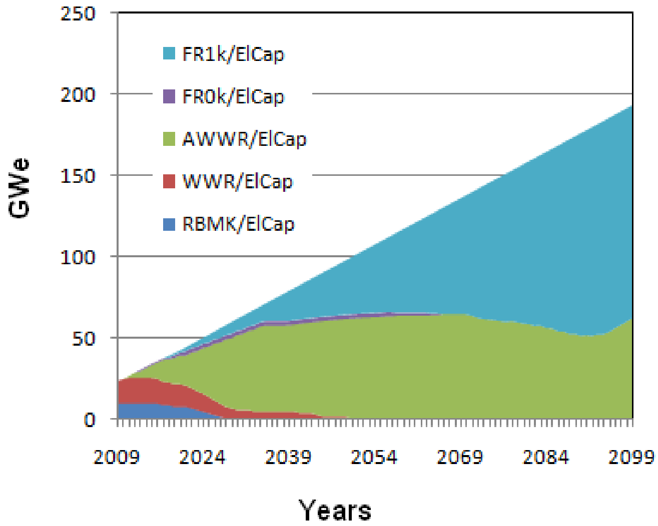
- Economic assessments made in some studies predict the fuel cost share in the total electricity cost of FRs to be lower than that of TRs

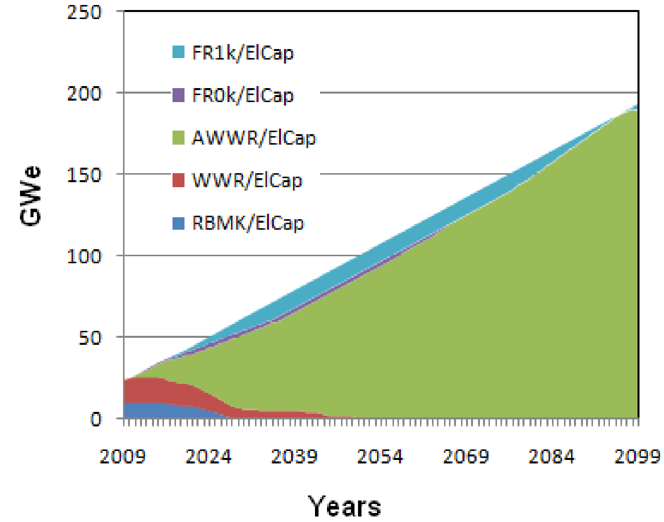
- Some of these assessments were made in EU and France which have experience in industrial scale of SNF reprocessing and MOX fuel fabrication

- Calculations performed in our study show that the ratio of fuel cost share of FR to TR is very sensitive to the boundary conditions and costs of natural U & Pu, U enrichment, SNF reprocessing and fuel fabrication, storage of SNF of TRs, etc.

- For the CNFC competitiveness, the task of reducing the costs of reprocessing and fuel fabrication along with reducing the capital costs are critical

# BN in optimal plan




An optimal plan of a NES under equal capital cost for the construction of VVER and BN (a) and under growth of capital cost of the BN by 50% over VVER (b)

- The IAEA code MESSAGE for the energy system simulation was used for assessing conditions for the BN-1200 viability. The code allows determine the optimal plan within available resources under the given technologies and boundary conditions

- BN-1200 enters an optimal plan by 2030 with a share of ~10% when its capital costs do not exceed 10-15 % of the VVER and the fuel costs of ~20% less. It would be enough for solving the SNF problem at first phase of the NFC closure

- This example shows the MESSAGE can be a useful instrument for evaluation of FR competitiveness provided that reliable data from industry are received

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# Conclusions

- The two-component NES of VVER and BN reactors can meet some critical challenges of the present nuclear industry and provide a substantial contribution to enhancing sustainability of a national NP:
  - basically to solve up to 2050 the problem of the VVER SNF accumulation by using Pu from VVER in MOX fuel for BN reactors;
  - to ensure management of Pu from VVER to reduce it by 2070 to operational reserve and thus to enhance the NES proliferation resistance;
  - to save natural U and SWU and thus to facilitate U supply and enrichment capacities for planed deployment of VVERs in Russia and abroad.
- Implementation of these opportunities might be a substance of the first phase of the NFC closure
- While some INPRO indicators have shown remarkable advantages of the NES with BNs comparing to the present system, some issues in economics and NFC technologies have not got convincing answers
- These challenges along with a crucial safety issues are addressed in the Federal target programmes on transition to a CNFC with advanced FRs which are currently run in Russia