Program for CNFC R&D using BN-800

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Abstract. Beloyarsk NPP with BN-800 reactor provides unique opportunities for the further development of fast reactor (FR) technologies and the development of the closed nuclear fuel cycle (CNFC). R&D program on the development CNFC technologies on the basis of the BN-800 are currently developed. Program is planned for both MOX and nitride fuel. The main purpose of R&D are optimization of CNFC technologies in industrial scale, getting the reference experience and testing technologies in BN-800, verification new generation computer codes. In the framework R&D program to simulate elements CNFC technologies is expected to make and demonstrate the three major step to CNFC:
– recycling of plutonium from spent fuel of thermal reactors;
– multiple recycling of fuel fast reactors;
– transmutation of minor actinides.

The presented program includes three main blocks:
– the development of technologies for reprocessing spent MOX fuel of BN-800;
– the development of technologies of mixed nitride fuel (forming BN-800 core with the insertion of the nitride fuel, the demonstration of recycle equilibrium fuel with breeding ratio ~1);
– development of partitioning and MA transmutation technologies in the FR.

It is anticipated that this Program will create the world's first industrial power complex in the fullness of implementing CNFC with FR in the 30s.

1. Introduction

Transition to closed nuclear fuel cycle based on fast neutron reactors (FNR) was adopted in Russia as a strategic direction for development of Nuclear Power industry allowing for complete solution of the problems for effective use of natural resources, disposal and elimination of spent nuclear fuel and radioactive waste accumulation [1]. It is expected that starting 2030 large-scale implementation of commercial fast neutron reactors (FNR) and transition to two-component structure of NP (nuclear power) and to integrated fuel cycle coordinating the needs of the existing thermal neutron reactors (TNR) and FNR will commence.

Understanding that development of projects with economically efficient fast neutron reactors, building of pilot units and obtaining of FNR reference operation experience require fairly long time, earlier there was made a decision on construction of power unit with BN-800 reactor unit (RU) for outrunning elaboration of Russian innovation technologies for closed nuclear fuel cycle (CNFC). It may be also noted that, by using BN-800 it was anticipated to solve the task for disposal of ex-weapon-grade plutonium within the framework of the Agreement with the USA. However, with account of political realities, the conditions for concentration of efforts on solution of scientific and technical tasks for CNFC elaboration were provided.
At present, BN-800 [2] mainly uses uranium fuel with partial use of mixed uranium-plutonium oxide fuel (MOX) composition based on low-emission plutonium specific for disposal tasks. The first step to CNFC is conversion of BN-800 RU to full loading of the reactor core with mixed uranium-plutonium oxide fuel based on energy-grade plutonium obtained as the result of recycling of spent nuclear fuel (SNF) of WWER reactors planned in 2019-2020.

Thus, all opportunities for transition to practical implementation and elaboration of CNFC basic technologies based on BN-800 were created within the framework of the program during 2019-2034 period given below.

2. Program General Characteristics
At present, the Beloyarsk NPP with two fast neutron power reactors BN-600 and BN-800 is the only NPP in the world with such type of reactors (see figure 1). Within the developed R&D framework for elaboration of CNFC elements, three large-scale steps to a closed nuclear fuel cycle are expected to be made:

- involvement of plutonium from recycling of WWER SNF into the fast reactor fuel cycle and closure by TRFC fuel;
- multiple fuel recycle and utilization of $^{238}$U power resource – fuel cycle closure by FNR fuel;
- transmutation of minor actinides (MA) and disposal of a part of long-lived fission products (FP) for the purpose of reducing the volumes and radiotoxicity of the radioactive waste (RAW) destined for dumping and ensuring the approach to radiation equivalent handling with RAW.

Given the fact that one fast reactor is insufficient for generation of fully-featured CNFC (because BN-600 is at the final stage of lifecycle), the following program objectives are defined as the basic ones:

- demonstration and obtaining of reference experience in testing of technologies in conditions of CNFC with BN-800 RU;
- optimization of technical and technological solutions for applications on commercial scale, including the framework of industrial energy complexes (IEC);
- creation of a base for FNR and CNFC licensing and verification base of new generation codes.
The Program is aimed at obtaining experimental data required for optimization and licensing of FNR and CNFC technologies. At the same time, using the data obtained at BN-800 for innovative power units and CNFC facilities is ensured by application of modern simulation tools allowing for implementation of these results without significant loss of informativeness.

The presented Program supplements the program for BN-800 conversion to full loading with mixed uranium-plutonium oxide fuel and includes three main blocks:

- elaboration of technologies for MOX SNF of BN-800 reactor (logistics and recycling of MOX fuel);
- elaboration of CNFC technologies with solid mixed nitride-uranium-plutonium (MNUP) fuel (building of BN-800 reactor core with insertion of nitride fuel, elaboration of fuel recycling and refabrication, demonstration of fuel recycle in conditions of equilibrium reactor core with breeding ratio (BR)~1);
- elaboration of RAW fractioning technologies and transmutation of MA in FNR.

Within the framework of operations, it is supposed to elaborate a number of integrated technologies solving a number of technological tasks for solution of problems presented in table 1. BN-800 is essentially important for this work. Besides it, it is supposed to use the existing Russian industrial base of the fuel cycle:

- mixed fuel production facilities of the Siberian Integrated Chemical Plant (SICP) and mining and chemical integrated plant (MCIP);
- SNF recycling facilities – RT-1 PA “Mayak”, research hot cells of Pilot demonstration facility (RHC of PDF) MCIP and Processing module (PM) of SICP, allowing for complete solution of the set tasks.

Considering the duration of reactor irradiation stages, the need for SNF ageing and development of fuel recycle, the Program covers the period up to 2034 considering the fact that the main volume of research is planned for the period up to 2025.

The results of the Program fulfillment provide the outrunning assimilation and optimization of Russian technologies and CNFC facilities for creation of IEC industrial prototype with complete implementation of CNFC technologies at 2035 level.

**Table 1. Basic tasks on elaboration of CNFC technologies within the framework of two-component NPE.**

| Task / Technology                                      | Problem under solution                                                                 |
|--------------------------------------------------------|---------------------------------------------------------------------------------------|
| Processing of WWER SNF                                 | Elimination of SNF of thermal reactors                                               |
| Production of mixed U-Pu fuel                          | Disposal of Pu from thermal reactors, emptying of Pu storage                           |
| FNR on dense mixed uranium-plutonium fuel              | Improvement of FNR safety and fuel breeding                                           |
| Processing of MOX and MNUP FNR SNF                     | Elimination of FNR SNF                                                               |
| Multiple fuel recycle                                  | Provision of fuel self-sufficiency, maximum utilization of $^{238}\text{U}$ reasourse and drastic solution of natural resources problem |
| Fractionation of RAW and transmutation of MA and long-lived FP | Reduction of RAW radiation hazard, heat output and volume of dumped RAW with step-by-step achievement of radiation-migration equivalence of RAW and natural raw materials |
| Final isolation of RAW                                  | Ensuring environmental safety during RAW dumping                                      |

The main scientific and technical tasks of the Program are:
• practical mastering of mixed uranium-plutonium fuel;
• Obtaining characteristics (reactivity effects, change of reactivity during burn-up, etc.) and operational experience of reactor core with the use of mixed oxide and dense nitride fuel;
• direct justification of fuel breeding parameters and obtaining verification data on BRC (BR);
• justification of fuel multiple recycle, operation of RU on recycled materials with provision of possibility for operation on any isotopic compositions of recycled fuel;
• obtaining data for justification of the transient mode to equilibrium mode with dense fuel;
• elaboration of handling of high-active fuel in terms of ensuring radiation safety and logistics;
• elaboration of technologies for recycling of FNR SNF;
• elaboration of technologies for RAW fractioning from SNF recycling of thermal and fast neutron reactors;
• elaboration of methods and technologies for transmutation of MA in fast power reactors;
• optimization of technologies for handling of MA with account of fuel radiation properties deterioration and economical acceptability of MA involvement into fuel cycle of power reactor.

More detailed discussion of these aspects for each Program main sections is given below.

3. Elaboration of technologies for recycling of BN-800 MOX SNF

Recycling of fast neutron reactor SNF has a number of differences as compared to fairly well-assimilated recycling of SNF of WWER reactors, such as high content of Pu, high reactivity and heat output, increased number of platinum group metals and insoluble deposits. Hydrometallurgical technology for recycling of FNR SNF was implemented for recycling of uranium SNF of BN-600 reactor and was tested during recycling of BN-600 MOX SNF at RT-1 plant at PA “Mayak”.

It is supposed to perform the pilot recycling of BN-800 MOX SNF in 2021-2023 both by means of WWER SNF co-processing and independently. In the course of work, it is supposed to specify the material balances and temporary parameters of recycling, quantity of high-activity waste (HAW) and to obtain the data for justification and optimization of technical and economical parameters of MOX SNF recycling. Following the results of work, the path to recycle of mixed uranium-plutonium fuel will be opened.

The second area of this Section of the Program is elaboration of logistics for MOX fuel. For preparation to BN-800 SNF pilot recycling it is necessary to certify transport package TP-11 designed for transportation of up to 35 spent fuel assemblies (SFA) of BN-600 and RBMK-1000 (uranium-graphite channel type reactor) with maximum reactivity up to $1.73 \times 10^{17}$ Bq.

To provide BN-800 SNF transportation after 2026, it is supposed to prepare feasibility studies for selection of TP, for transportation of BN-800 MOX SNF to location of long-term storage / recycling, to perform thermal calculations and calculations of TP radiation safety, to develop TP design documentation and to carry out the required tests.

Large-scale industrial recycling of MOX SNF is planned starting 2038 on the centralized line of recycling plant. Development of technological solutions and FS for this is expected to be executed before 2029.

4. R&D of CNFC technologies with nitride fuel

The mixed nitride-uranium-plutonium (MNUP) fuel was adopted as innovation and purpose-oriented in FNR projects within the framework of “Proryv” Project [3]. However it is worth noting that complete elaboration and demonstration of advantages for a RU operating in the equilibrium mode in CNFC, justification of integral parameters, such as BRC, change of RU reactivity, stability of power output distribution in the reactor core is possible only at prototype RU BREST-OD-300 and pilot unit with BN-1200.

BN-800 reactor does not allow for using MNUP fuel advantages to full extent. Nevertheless, a number of principal problems can be solved in BN-800 reactor ahead of the curve.
The basic idea of the approach is to locally create the conditions specific for equilibrium nitride reactor core. Demonstration of the mode with BR\(\sim 1.08\) is possible locally during placement of the fuel with \(\sim 13\%\) “equilibrium” enrichment in the reactor core. Figure 2 provides high-quality illustration of BR dependency on mass fraction of plutonium of energy isotopic composition. From this figure follows that simple replacement of MOX fuel with MNUP fuel (“BN-800 MOX” and “BN-800 MNUP” on the figure 2) leads to BR increase and approximates to its equilibrium value, but is not sufficient. In real projects of BREST-OD-300 and BN-1200 RU, BR growth up to the values exceeding 1 is also reached due to increase of fuel rod diameter from 6.9 mm to \(\sim 9.2-10.5\) mm, which is impossible to do in BN-800 presently.

Two different options for formation of the so-called MNUP “insertion” in BN-800 reactor core are given in figure 2. At that, in the first option 48 FA with MNUP fuel of \(\sim 13\%\) Pu enrichment are placed in HEZ (high enrichment zone). The calculations made by OKBM showed the level of heat load on fuel elements doesn’t exceed \(\sim 41\) kW/m and reactivity effect - \(0.017\%\Delta k/k\) when single MNUP FA is installed. In this option, in 150 FA of MOX fuel it is necessary to increase the plutonium mass fraction from 23.0 to 26.2\% (by the high active plutonium). In the alternative option, 24 FA with MNUP fuel of \(\sim 13\%\) Pu enrichment are placed in LEZ (low enrichment zone) and 12 FA with MNUP fuel rod dimension-type specific for BREST-OD-300 and BN-1200 RU in BE. In this case, the heat load on fuel elements is somewhat higher – on the level of \(\sim 47\) kW/m, and the cumulative effect of reactivity is close to zero. Thus, compensation of reactivity does not require changes of FA with MOX fuel and special licensing of the reactor core. The optimal option for layout of reactor core with MNUP fuel will be determined in the course of the Program execution.

![Figure 2. Schematic dependency of BR on fuel enrichment (mass fraction of Pu).](image-url)
Thus, the nitride fuel insertion in BN-800 reactor core is the tool for indirect simulation of equilibrium mode when using MNUP fuel with specific mass fraction of plutonium for the specified mode. The problems, which can be solved during testing of nitride fuel in BN-800 reactor:

- demonstration of fuel recycle in CNFC and the mode for provision of fuel self-sufficiency in nitride subzone with local BRC close to 1 (~1.08);
- determination of isotopic composition of equilibrium fuel and evolution of nuclide composition of the mixed uranium-plutonium nitride fuel in the mode for provision of fuel self-sufficiency;
- studying of technological aspects for manufacture of fuel, handling generated non-recyclable scrap;
- elaboration of technological scheme, equipment and processes (technologies) recycling of nitride SNF with various burn-up of fuel and ageing time;
- elaboration of technological aspects for provision of required parameters of fuel during different isotopic composition of plutonium with account of process tolerances;
- elaboration of pilot industrial technology for manufacture of mixed nitride fuel;
- studying of nitride fuel and fuel element properties in recycle conditions;
- justification of RAW actual composition and process loss in fuel handling conditions;
- expanded verification of fuel technological codes applicable to nitride fuel.

FA with MNUP fuel for this Program will bear the status of experimental and will be manufactured by one of these options:

- on the upgraded Fabrication and Refabrication Module (FRM) of fuel for pilot-demonstration complex (PDEC) of SICP;
- manufacture of fuel pellets at the FRM of PDEC engineering support section with subsequent supply to the fuel rod and FA process line assembly of FSUE “MCIP” plant.

Formation of the insert with MNUP fuel in BN-800 reactor core is expected by means of replacement of FA with MOX fuel in the part of reactor core for EFA (experimental fuel assembly) with MNUP fuel in 2021-2022 step-by-step:

- it is supposed to irradiate the first EFA batch prior to 7.5% t.a. burn-up with the task for elaboration of technology and equipment operation modes;
it is supposed to irradiate the second EFA batch designed for studying of elaboration of technology for recycling during increased burn-up and joint output of uranium-plutonium-neptunium ligature prior to ∼9,5 % t.a. burn-up;

• the third EFA batch shall fully demonstrate the fuel cycle closure and technology for recycling with fractioning and refabrication of fuel from SNF recyclable components.

Elaboration of processing and recycle of MNUP fuel shall be carried out with account of modern requirements to recycling excluding plutonium separation, which considers RAW fractioning with output of Am-Cm fraction and their further separation.

Thorough measurements of spent nitride fuel with enrichment and changes in the course of recycle are of critical importance. With that, the gradual decrease of a number of recycled materials related to provision of required accuracy of measurements due to selection of refabricated materials with clearly known history of irradiation and recycle (dropping of “mixed” fractions with ambiguously determined source of original SNF) are allowed.

The Program considers different options of BN-800 MNUP SNF with the use of FSUE “MCIP” PDC, ME PDEC and RT-1 PA "Mayak" sites. At the first stage, the preference is given to the most practical option with the use of research hot cells MCIP PDC and hydrometallurgical technology. It is planned to implement the combined scheme for recycling with the use of pyrochemistry and hydrometallurgy on PDEC ME.

5. R&D for MA burn-up justification

The effective technology for transmutation of MA and long-lived fission products is considered as the required element for environmentally acceptable handling of RAW in CNFC. But at present the optimal technical and economical solution is absent in the world. During fairly long-time research, the alternative methods to solve the problem were considered such as special-purpose reactors (for example, molten-salt ones) or ADS (accelerated driving system) systems.

This project is up to show and demonstrate the efficiency of MA transmutation in new generation energy FNR, which will possibly solve the problem of MA prior to special-purpose reactor putting into operation. The corresponding fuel technologies and technologies for RAW fractioning were demonstrated, and their nuclear and radiation safety was justified.

By results of this Program performance, the optimal solution among the following options shall be elaborated and found:

• homogeneous use of MA in the main fuel and, correspondingly, in the main fuel production, including the one based on the principles of remote fuel manufacturing, application of unattended manufacturing and robotics;

• heterogeneous use of MA in composition of the oxide uranium or mixed uranium-plutonium fuel, or when using the inert matrices in individual fuel elements and/or FA manufactured at low-tonnage robotized production.

At the expected level, the physics of fast neutron reactors demonstrates relatively low sensitivity to content of MA in the fuel at a level of 1-2 %, which is a favorable factor from the point of view of nuclear safety requirements. Moreover, input of MA in the amounts specific for transuranium part of WWER SNF has a positive impact on the required reserve of reactivity for fuel burn-up and enables its reduction (see figure 4). However there are practically no experimental validations for this.
Figure 4. MA impact on change of reactivity during interval between refueling.

At the same time, MA inclusion in fuel, especially Am and Cm, in the standard solid fuel leads to significant (by the orders) increase of ionizing emission power from fuel compositions, which can potentially complicate CNFC technologies with regard to fuel refabrication from regenerated materials. This results in the increased radiation dose for personnel in the modern option of ceramic pellet fuel production technology, which does not exclude application of manual technological and control operations. Transition of technologies to unattended option of implementation removes this problem, but it leads to increase of costs of the fuel cycle. As a result, search for optimal solution goes on in all countries with nuclear power industry until now.

Within the framework of this Program, due to high reactivity of potential fuel with Cm, its recycle is not considered. It is considered that in this case, the best method is the storage of curium fractions up to practically complete decay of short-lived curium isotopes.

In relation to neptunium homogeneous recycle, there is practically no doubt in its optimality. However the detailed elaboration and practical (experimental) justification of all these process aspects is required. Studying of Np input-in-fuel impact on accumulation of $^{232}\text{U}$ and radiation characteristics of recycled fuel is important. By preliminary estimates, the content of $^{232}\text{U}$ reaches $\sim1.6 \times 10^{-6}\%$, and, by the dose rate, this isotope is practically equivalent to the total plutonium.

Homogeneous option combines Am transmutation and plutonium recycle smoothly, but it causes technological doubts in feasibility of the standard solid fuel fabrication due to potential Am volatility and increased by $\sim10$ times of $\gamma$-reactivity of the recycled fuel. Therefore, within the framework of this Program, both scenarios of its burn-up are considered: homogeneous and heterogeneous scenarios and the technologies associated with them.

To ensure MA burn-up and recycle, the radiochemical technologies for RAW fractionation are required. At present, HAW (whole entirety of metal salts contained in them) are jointly overglazed. However, the commonly used the borosilicate and the aluminophosphate glasses cannot serve as an optimal matrix for simultaneous localization of all radionuclides. In the long-term perspective, such matrices are not sufficiently sustainable. Moreover, radiotoxicity of the overglazed HAW with inclusion of MA and fission products, and of TRU elements is fairly high, and it results in radiotoxicity of natural uranium after 10 000 years.

The alternative strategy is based on HAW fractioning, during which the most long-lived and radiotoxic nuclides (radioisotopes of cesium, strontium, transuranium elements (TRU elements)) are disengaged from them and they are divided into individual fractions in accordance with their decay
half-life and chemical behaviour. For each fraction extra-strong matrices are developed, which provide their safe dumping in the specially selected geological formations. The strategy of fractioning and transmutation meets the environmental safety requirements to the fullest extent possible. It allows for drastic reduction of the long-lived RAW hazard and economical costs for long-term controlled storage of HAW containing long-lived radionuclides.

Extraction of minor actinides is prevented by available lanthanides with their content in the PUREX process raffinates based on degree of the fuel burn-up exceeds MA content by ~20-50 times. In this connection, disengagement of minor actinides and lanthanides from HAW and their division is the Program key task.

The strategy of fractioning allows for disengaging and using not only fissile products, but also the whole range of stable fission products. The platinum metals are of particular value. Calculations show that a recycling plant for SNF with performance capacity of 1000 t/year can extract approximately 4.5 t Ru, 775 kg Rh, 175 kg Ag, as well as about 6.0 t Mo annually. More then 20 radionuclides available in HAW (\(^{137}\)Cs, \(^{90}\)Sr, \(^{85}\)Kr, \(^{9}\)T and others) are in demand at the isotopic products market. Their disengagement and sale can let save up to 10% of SNF recycling cost by the fractionation scheme. Group disengagement and transmutation of actinides may let reduce the volume of final repository and radiation hazard during RAW dumping, thus, reducing the immediacy of the problem for RAWGR (geological repository for radioactive waste) safety justification.

As it is known, within the scope of “Proryv” project, the task for step-by-step approximation to radiation equivalent handling of RAW [4-6] during large-scale implementation of FNR in NPE is assigned. The radiation equivalence is considered on the systemic level of NPE on the whole. At the initial stage, for single RU efficiency assessment in relation to RAW, the radiation balance parameter can be used, which fixes the ratio of potential biological hazard (PBH) of produced RAW and of consumed products:

\[
RBI \ (\text{radiation balance index}) = \lg \left( \frac{\sum_i A_i^{PAO} \cdot D_{RSS (radiation safety standards)-99,i}}{\sum_i A_i^{FUEL} \cdot D_{RSS (radiation safety standards)-99,i}} \right) \leq 1 \tag{1}
\]

where \(A_i\) – reactivity of RAW components and of consumed (burn-off) fuel, \(D_{RSS-99,i}\) – radiation dose factors adopted in RSS-99 (radiation safety standards).

The estimates (see figure 5) demonstrate transmutation of “own” Am ensures practically the condition, under which RAW PBH approximates to RBH of consumed fuel, and during involvement of WWER reactors MA, RAW PBH is lower then PBH of consumed fuel, i.e. the reactor performs the function of “burner-consumer”. It is worth noting that these estimates were made for actinide part of RAW with account to migration factor.
Thus, involvement of MA at WWER reactors into the fuel cycle is important on the stage of two-component NPE. For this approach implementation, the quantity of MA at the initial stage shall be increased by ~3-4 times in relation to equilibrium value up to ~1.5-2 % t.a.

The following tasks are assigned for SNF recycling and RAW fractionation technologies:

- Recycling of the whole irradiated fuel volume at the thermal and fast neutron reactors with the set fractionation;
- Fairly deep cleaning of RAW from Pu, Am and some other long-lived nuclides (loss of actinides in RAW is max. 0.1%); 
- Provision of RAW intermediate storage ~200-300 years for reduction of their biological hazard by a factor of ~100 times.

Thus, within the framework of the considered Program, the objective is set for technical assimilation and optimization of MA transmutation, fractionation technology and demonstration of potential environmental safety of CNFC, and its expected results shall be:

- Determination of the optimal technology for MA burn-up;
- Justification and elaboration of technology for homogeneous / heterogeneous reactor Np and Am transmutation in fast power reactors for further industrial implementation;
- Elaboration and demonstration of technologies for fractionation during SNF recycling with further MA recycle;
- Justification and elaboration of fuel technologies for MA transmutation;
- Justification of the fuel radiation characteristics and radiation safety during MA recycle and logistics;
- Verification base of licensing for technologies and PSC facilities from the point of view of ensuring CNFC radiation-migration approach, environmental safety and acceptability.

6. Conclusion

The Program on practical mastering of CNFC, elaboration and demonstration of key technologies with implementation of potential for the new Russian power unit with fast neutron reactor plant BN-800 was developed. The Program contemplates three big steps to a closed nuclear fuel cycle:

1. Involvement of Pu from WWER SNF recycling into the fuel cycle – closure by SNF and fuel of thermal reactors;
2. multiple recycle of fuel and exploitation of uranium-238 energy resource – closure of the fuel cycle by fuel of fast neutron reactors;
3. transmutation of MA and disposal of a part of long-lived FP for the purpose of reducing RAW volumes and ensuring approximation to radiation equivalent handling of RAW.

In addition to BN-800, this Program implementation considers using available and developed production facilities of the fuel cycle with necessary modernization at present, including production facilities of mixed uranium-plutonium fuel (MOX at MCIP and MNUP at SICP), production facilities for SNF recycling (plant RT-1 in PA “Mayak”, PDF PDC at MCIP, ME PDEC at SICP).

The proposed Program is aimed at achievement of the following objectives:

- optimization of technology for MOX and MNUP fuel production facilities by results of its large-scale manufacture;
- demonstration of the nuclear fuel cycle closure and multiple recycle of fuel based on the regenerated components;
- determination of the mixed fuel nuclide composition degradation during transition to CNFC and elaboration of methods for its recovery, justification of the transition mode to the equilibrium condition;
- determination of MA transmutation efficiency based on FNR (without using special-purpose NPE burner-reactors and ADS systems in the structure of NE);
- creation of verification databases for provision of licensing for new generation RP projects and justification of NRS (nuclear radiation safety) and CNFC environmental safety;
- creation of the base for justification and optimization of CNFC technical and economic parameters.

It is assumed to fulfil the base volume of R&D during the period 2019-2025, assimilation and demonstration of fuel and MA recycle – up to 2034. The results of the Program execution are proposed to full extent for commercialisation at the industrial level during creation of IEC industrial prototype with CNFC complete implementation.

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