SNF MANAGEMENT IN RUSSIA: STATUS AND FUTURE DEVELOPMENT

A.V. KHAPERSKAYA
State Corporation "ROSATOM",
Moscow, the Russian Federation
Email: AVKhaperskaya@rosatom.ru

O.V. KRYUKOV
State Corporation "ROSATOM",
Moscow, the Russian Federation
Email: OVKryukov@rosatom.ru

K.V. IVANOV
State Corporation "ROSATOM",
Moscow, the Russian Federation
Email: KoVlIvanov@rosatom.ru

Abstract

At present, Russia's nuclear power industry continues its development and increases its contribution to the overall energy mix, which reached 18.9% in 2017. The basis of nuclear power generation is formed by LWR, in the same time Russia operates two industrial-size fast reactors – BN-600 and BN-800. It is expected that from the year 2030 there will be the large-scale implementation of fast neutron power reactors and the transition to a two-component nuclear system with unified fuel cycle, linking the needs of both existing thermal reactors and fast neutron reactors. Solving the problems associated with the accumulation of SNF and radioactive waste in this regard is becoming a priority.

As a basic approach to SNF management in Russia, the concept of its reprocessing with the nuclear materials recycling in a two-component nuclear power energy system (with thermal and fast neutron reactors) has been adopted. The main purposes are an efficient use of natural uranium resources, SNF non - accumulation, recycling nuclear materials, and reducing the radiotoxicity and volume of the generated radioactive waste.

Russia has many years of experience in safe management of spent nuclear fuel from power reactors including storage, reprocessing and recycling. The reprocessing plant RT-1 has been operating since 1977. To date, over 6,000 tons of SNF have been reprocessed. At the same time, an integrated complex for SNF management is being created at the site of the Mining Chemical Combine, which includes: centralized water cooled ("wet") SNF storage; centralized air-cooled ("dry") SNF storage; a pilot-demonstration centre for the reprocessing of SNF based on innovative technologies; MOX fuel fabrication for fast neutron reactors (BN-800 type). An underground research laboratory will be set up here to develop the technologies for the HLW final isolation.

The recycling of repU is currently being fully implemented during the fabrication of fuel for thermal reactors. Separated plutonium from LWR SNF starts involving in NFC as a component of MOX fuel for FR (for starting loading and feeding during the first 10 years of operation of fast reactors). At the same time, the technology of multi-recycling in thermal reactors of plutonium and repU from LWR SNF is being developed (REMIX-concept).

To reduce radiotoxicity and the volume of ultimate wastes to be disposed of, HLW partitioning technologies are being developed with MA and heat-generating fission products recovering. Russia already has industrial experience in HLW partitioning.

The technology of MA transmutation is planned for studying using both solid-fuel fast reactors (like BN-800 type) and MSR.

1. INTRODUCTION

The Russian Federation has 35 operating nuclear power reactors (thermal reactors: VVER-1000/1200: 15 units, RBMK-1000:10 units, VVER-440: 5 units, EGP-6: 3 units, Fast reactors: BN-600 - 1 unit, BN-800 - 1 unit); 6 units VVER-1200 type. The first unit of Floating NPP (SMR) are under commissioning. 7 units of nuclear power reactors different types are in various stages of decommissioning. The planned layout of future NPPs at the territory of the Russian Federation has been set out by the Government Order of the Russian Federation №

1634-r of August 1, 2016. List of nuclear power plants scheduled for construction until 2030 includes 11 new power units.

As a basic approach to SNF management in Russia, the concept of its reprocessing with the nuclear materials recycling in a two-component nuclear power energy system (with thermal and fast neutron reactors) has been adopted for the purpose of efficient use of natural uranium resources, SNF non - accumulation, recycling nuclear materials, and reducing the radiotoxicity and volume of the generated radioactive waste.

2. SNF MANAGEMENT IN RUSSIA: STATUS OF INFRASTRUCTURE

The core principle of the state policy of the Russian Federation in the field of SNF management involves SNF reprocessing to prevent SNF accumulation, to recycle the nuclear material with recovering the remaining energy resource of the SNF and reducing the uranium demand, and to ensure the environment-friendly management of RW (FP& MA). The task of ensuring the safe management of RW is considered to be, on the one hand, a key element of the national security and safety, and, on the other hand, an essential precondition for present and future use of atomic energy.

The Energy Strategy of the Russian Federation Until 2030, approved by the Government of the Russian Federation, provides for the following efforts in the field of Nuclear Fuel Cycle and Nuclear Power:

- Upgrading NPP capacities with thermal-neutron reactors;
- Construction of experimental and commercial power plants with fast breeder reactors;
- Implementation of a closed nuclear fuel cycle involving new technologies and new enterprises;
- Development of advanced RW treatment methods, technologies, and ensuring closed nuclear fuel cycle when the rate of waste accumulation is equivalent to the rate of waste disposal.

Centralized SNF management in Russia is providing at two sites: PA Mayak and Mining & Chemical Combine (MCC).

2.1. RT-1 plant at "PA Mayak"

Industrial-scale SNF reprocessing is performed at RT-1. Plant RT-1 at "PA Mayak" has been operating since 1977. Now, about 6 thousand tons SNF have been processed. Processed SNF inventory includes almost all existing uranium and plutonium compositions and cover all the FAs dimensions. The design capacity is 400 tons per year. At present, the SNF of VVER-440, BN-600, SNF, RR SNF, defect fuel of RBMK (which cannot be accommodate to the dry storage) is reprocessed at the RT-1 plant, the reprocessing of VVER-1000 SND has been started in 2016. Necessary infrastructure is being set to enable AMB and EGP-6 SNF reprocessing. Mixed oxide uranium-plutonium (MOX) irradiated nuclear fuel (SNF) of FN-600 reactor was reprocessed at RT-1 plant in 2012 and 2014 [1.]. Reprocessing is based on PUREX-process (“modified PUREX”) involving the extraction of recycled uranium and plutonium as target reprocessing products with a possibility of extracting neptunium, as well as a broad range of other isotopes (Cs-137, Kr-85,Am-241, Pu-238, Sr-90, Pm-147). A lot of attention to environment issues was paid in recent years for legacy sites rehabilitation, open RW pools were decommissioning, new complex of cementation and new vitrification furnace was put into operation. Alumo phosphate glass is used for the vitrification of the HLW after the reprocessing. Borosilicate glass will be also used in near future. The first in the world semiindustrial facility for partitioning of high-level wastes was put in operation at RT-1 in August 1996. SNF reprocessing is accompanied with a production of RadWastes which are subjected to treatment. Current practice for ILW and HLW management from SNF reprocessing at RT-1 plant involves HLW vitrification in EP-500 ceramic melter with design capacity 500 liter of concentrated HLW per hour. Alumophosphate matrix of the radioactive glass is produced using direct evaporation-calcination-vitrification technology. Vitrified wastes are placed in steel canister and are stored in a dry vault-type storage facility.

2.2. The integrated complex for SNF management at the mining and chemical combine

At the same time, the integrated complex for SNF management is being created at the site of the Mining and Chemical Combine, which includes: centralized water cooled ("wet") SNF storage; centralized air-cooled ("dry") SNF storage; a pilot-demonstration center for the reprocessing of SNF based on innovative technologies; MOX fuel fabrication for fast neutron reactors (BN-800 type). An underground research laboratory will be set up here to develop the technologies for the HLW final isolation.

2.2.1. VVER-1000 SNF "wet" storage.

The storage represents the facility with the high level of safety and seismic stability. Presently the newly arrived SNF is placed in "wet" storage facility, and the aged fuel is transferring from the "wet" storage facility to the "dry" one.

2.2.2. VVER-1000, RBMK-1000 SNF "dry" storage facilities

The storing complex for RBMK-1000 and VVER-1000 SNF, in its full-scale development, composed of three buildings, dry vault-type storage facilities, were put into operation and were successfully operated since 2011. Passive safety concepts are applied in SNF "dry" storing technology.

2.2.3. MOX-fuel fabrication for fast neutron reactors

Presently the facility is in operation and produces the fuel for reactor plant BN-800 (Beloyarsk NPP). The production provides a possibility of FAs fabrication with the separated Pu from power reactors SNF.

2.2.4. The Pilot Demonstration Center on SNF reprocessing based on innovative technologies

PDC is an integral component of the integrated complex for SNF management at MCC. PDC is designed to reprocessing LWR SNF (VVER-1000 type, RBMK, PWR and BWR – there is a possibility for reprocessing). The key goal of the PDC innovation technologies development is to achieve ecologically acceptance and economically efficiency of the reprocessing technologies. The PDC is constructing in two stages. In 2016, license was granted to operate first start-up complex of PDC. This unit involves hot research cells, analytical facilities, as well as other necessary infrastructure. R&D program aimed at elaborating innovative SNF reprocessing technologies has been launched in 2016. The purpose is to confirm the designed parameters of the new technological scheme, further improvement of new technologies for reprocessing of SNF; development of HLW partitioning technologies for reducing radio toxicity of ultimate disposal waste.

Construction of the second PDC section with a design capacity of 250 tons of SNF per year is underway. It is scheduled to be commissioned in 2021.The reprocessing technologies were developed (based on the Simplified PUREX process) to provide the absence of liquid radioactive wastes (effluents) discharge. The main products of PDC - mixed oxides of plutonium, neptunium and uranium for manufacturing of the fast reactor fuel, as well as repU. PDC is also ready to deliver fuel product for REMIX. HLW are vitrified in borosilicate glass for further ultimate disposal to vitrification in borosilicate glass.

3. RECYCLING TECHNOLOGIES DEVELOPMENT

Regenerated nuclear materials (repU and Pu) have been traditionally used in Russia separately. RepU is reusing in Russian commercial nuclear reactors (RBMK type, BN VVER–440 VVER–1000) since 1996. At present, Russian fabrication plant MSZ has a license for reprocessing nuclear materials based on RepU with 232U content up to 5·10-7 %.

Separated plutonium from LWR SNF starts involving in nuclear fuel cycle as a component of MOX fuel for fast reactors (for starting loading and feeding during the first 10 years of operation of fast reactors). The concept of two-component nuclear energy system has approved in Russian Federation, including both reactor types (VVER and BN). The transition period will include reusing in Russia of reprocessed nuclear materials as mixed fuel for LWRs and FR.

The technology of multi-recycling of plutonium and repU from LWR SNF in the form of fuel for the existing and future fleet of thermal reactors (VVER-1000 type) is being developed in Russia (REMIX-concept). REMIX fuel is the mixture of U and Pu from LWR SNF reprocessing, with the addition of enriched uranium (natural or reprocessed U). REMIX fuel enables multiple recycling of the full quantity of U and Pu from spent fuel, with the 100% core charge and saving of natural uranium in each cycle. Compensation accumulated even isotopes of U and Pu by the natural uranium feeding allows performing up to 7 recycles. The main advantage of REMIX this technology is that U-Pu mix can be incorporated into the reactor fuel enabling multiple recycling of uranium and plutonium in thermal reactors. REMIX composition does not require reactor modification for the thermal neutron reactor like VVER (or PWR, BWR) and replacing fuel from natural U on REMIX fuel does not require capital expenditures from NPP operator.

State Corporation ROSATOM develops a program for REMIX fuel implementation. In the framework of the program three experimental REMIX fuel assemblies; (FA) containing 18 REMIX-fuel elements have been manufactured. Since 2016, they are being irradiated at Balakovo NPP. In parallel, ampules for FA irradiation in MIR research reactor and post-irradiation investigations were manufactured and are under irradiation (up to 2020)– some of ampoules have already been removed and are being investigated. In 2018 there was the start of the safety case development program for REMIX fuel use in VVER-1000 and VVER-1200 reactors. The program includes the development and validation of computer codes for nuclear and radiation safety demonstration. There are plans for the industrial facility for REMIX-fuel fabrication construction. In 2018, the development of investment justification such facility was initiated and will be finished in 2019.

4. HLW PARTITIONING TECHNOLOGIES DEVELOPMENT

To reduce radiotoxicity and the volume of ultimate wastes to be disposed of, HLW partitioning technologies are being developing with MA and heat-generating fission products recovering. Russia already has industrial experience in HLW partitioning. Since 1996, the Mayak (RT-1) plant has operated a pilot plant for HLW partitioning. During the operation more than 1200 m3 of HLW was processed with Cs-Sr recovering. At present, a process using N, N, N ', N'-dioctyl diamide diglycolic acid (TODGA) as an extractant in a polar diluent meta-nitrobenzotrifluoride [1], followed by chromatographic separation of americium and curium has developed in the Russian Federation. This technology includes both liquid extraction and sorption processes. The "hot" dynamic tests of the technology for recovering Am and Cm from real HLW by the TODGA system were carried out. The recovery of americium is more than 99.9%. Technology for the separation of americium and curium was demonstrated in the pilot plant at Mayak PA [2].

The program for partitioning HLW technologies development includes:

- Maturing of HLW partitioning technology (with Am, Cm, RE, Cs-Sr recovering from HLLW and its separation) including modernization partitioning facility at Mayak plant,
- Developing and deployment facility of HLW partitioning facility at the MCC,
- Developing the technologies of Am, Cm oxides and mixed U-TPE oxides precipitation,
- Developing and maturing the technologies for MA-bearing fuel fabrication, fabrication, irradiation , PIE, recycling experimental Am- and Np-bearing fuel
- Complex database for fuel characteristics and codes for MA recycling.

5. THE TECHNOLOGIES FOR MA TRANSMUTATION

The technology of MA transmutation in Russia is planned for studying using both solid-fuel fast reactors (like BN-800 type) and MSR.

The following scenarios are considered when analyzing the concept of MA management in fast reactors:

- Homogeneous transmutation of MA in the fuel;
- Heterogeneous transmutation of MA in special assemblies.

The necessary efficiency can be achieved both in the homogeneous and in the heterogeneous approaches.

Currently, both schemes are deeply researched within the framework of R & D for the "Breakthrough" project [3].

The program of Development of the MA transmutation technologies in FR includes:

- Justification of neutron-physical characteristics of core with MA and efficiency of transmutation of MA in FR, development of requirements for fuel with of minor actinides (including the experiments with MA- bearing FAs in BFS, in BOR-60 and BN-800)
- Development of the technologies of Np homogeneous recycling (design, fabrication, irradiation and post-irradiation examination of mixed oxide and nitride uranium-plutonium fuel with Np in amounts of 0.1% to 1%)
- Development of the technologies of Am recyclinghomogeneous (with content of Am from 0.4% to 1.2%)- mixed nitride and oxide fuel, uranium nitride and oxide fuel; heterogeneous recycling (with a content of Am up to 10-12%)- mixed nitride and oxide fuel, uranium nitride and oxide fuel (design, fabrication, irradiation and post-irradiation examination). The result – the option with optimal performance of Am recycling in FR fuel cycle.

As an alternative option for MA burning, Russia develops the approach of burning MA in MSR [3].

The advantages of MSR as a TRU burner from SNF reprocessing are primarily due to the lack of the need to manufacture a fuel pellet and the possibility of widely varying the content of long-lived actinides in fuel salt without core modification.

The construction of a large power MSR is proposed to be preceded by the construction of 5-10 MWt Demo MSR unit to demonstrate the control of the reactor and fuel salt management with its volatile and fission products with different TRU loadings for start up, transition to equilibrium, drain-out, shut down etc. The development of the proposed technology on an industrial scale will certainly require solving of a number of technical tasks; however, there are no deadlock problems on this path.

6. CONCLUSION

Russia already operates nuclear system with thermal and fast neutron reactors and developing the new innovative technologies and infrastructure for future sustainable development with U-Pu multirecycling in thermal and fast reactors and reduction of radiotoxicity of radwaste to be disposed of. RT-1 (reprocessing facility in Mayak plant) is the Russian pioneer facility for power reactor reprocessing, with possibility of reprocessing almost all existing types of SNF. , we have full scale recycle reprocessed uranium and start using Pu in fast rector fuel . The new complex of NFC facilities with new technologies of reprocessing and recycling as integrated plant is under creation in Krasnoyarsk area. There are already exist a complex of SNF storage facilities, industrial plant for MOX-fuel fabrication, and SNF reprocessing being deployed. An underground research laboratory supporting the R&D program for RW deep geological disposal is also being constructed there. These prospects also suggest REMIX-fuel fabrication facility and, in a longer term perspective, operation of molten salt reactors to burn minor-actinides. Introduction of MA burning in FR and/or MSR into the Russian nuclear fuel cycle will allow solving the problem of utilization of long-lived actinides after SNF reprocessing.

NOMENCLATURE

PDC	Pilot demonstration centre
HLW	High level waste
MCC	Mining and Chemical Combine
VVER	Pressurized water reactor of Russian design
REMIX	Fuel for technology of multi-recycling of plutonium and repU in LWR
MSR	Molten-salt reactor

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