CLOSING THE NUCLEAR FUEL CYCLE AT FNO FSUE "MCC"

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Abstract

The FNO FSUE "MCC" is a dynamically developing high-tech enterprise of the nuclear fuel cycle, which was identified in the State Corporation "Rosatom" development strategy as the key enterprise responsible for closing the nuclear fuel cycle (NFC).

1. INTRODUCTION

At present the Mining and Chemical Combine is creating an industrial infrastructure of the closed nuclear fuel cycle that is capable of repeated and environmentally safe involvement of reprocessed fuel components in the nuclear fuel cycle.

The spent nuclear fuel (SNF) management infrastructure created presently at the enterprise involves the facilities as follows.

- A water-cooled (wet) storage facility for VVER-1000 spent nuclear fuel;
- An air-cooled (dry) storage facility for RBMK-1000 and VVER-1000 spent nuclear fuel. The dry storage facility is a unique object, being one-of-a kind in the world and using a passive cooling system;
- A start-up facility of the Pilot Demonstration Center for reprocessing spent nuclear fuel with a throughput of 5 spent nuclear fuel tons a year, which was developed on the basis of the best world process engineering solutions for SNF reprocessing;
- A MOX fuel fabrication facility, which is to fabricate fuel to be used in fast reactors and which allows recovered plutonium to be involved in the nuclear fuel cycle.

In addition, for the purpose of SNF transportation, the Combine has a necessary infrastructure and railway rolling stock, which are shipping casks and rail carriages.

2. WET (WATER-COOLED) STORAGE FACILITY FOR VVER-1000 SNF

In 1985 the FSUE "MCC" put into operation the wet (water-cooled) storage as the first facility of RT-2 Plant to reprocess SNF discharged from VVER-1000 reactors.

The Wet Storage receives VVER-1000 spent nuclear fuel assemblies (SNFAs) after their storing in at-reactor SNF pools.

The storage facility consists of 20 monolithic ferroconcrete compartments, which are filled with water and intended to house SNFA baskets. Some compartments serve for SNF reloading from shipping casks to storage baskets, some - for SNFAs transfer to the Dry Storage facility and to the Pilot Demonstration Center for reprocessing. All the compartments are connected to one another via a single passage way, which is also filled with water. The facility design allows each compartment to be isolated for inspection and repair purposes. The building walls and floors are precast concrete and metal structures.

At present the storage facility represents a contemporary process object having a high level of safety and seismic stability. After upgrading the storage equipment and several elements of the facility building structures in 2008-2010, it became possible to store the SNF of new fuel cycles having higher thermal and radiation characteristics (initial enrichment of U-235 being up to 5%, burnup - up to 58 GW-day/ U t); to

ensure seismic stability of the storage facility in case of the maximum credible earthquake of magnitude 8, and to extend the storage service life until 2045.

The facility capacity is greater than 8000 SNF tons. After having been stored for a long time in the Wet Storage, the spent fuel is sent to the adjacent Dry Storage facility. Present rates of SNF reloading to the Dry Storage are consistent with incoming SNF amounts, which will make it possible, in future, as necessary, to timely remove SNF from Russian and foreign NPPs for being reprocessed at the Pilot Demonstration Center.

3. DRY (AIR-COOLED) STORAGE FACILITY FOR VVER-1000, RBMK-1000 SNF

The RBMK-1000, VVER-1000 SNF storage complex began its operation in 2011, being now fully fledged and composed of three buildings meant for long-term technological chamber-type storage of RMBK-1000 and VVER-1000 SNFAs.

The dry SNF storage method is based on a passive method of heat removal from SNF by natural convection. SNFAs are seated in the specific storage canisters, which are placed in the storage nests located in the ferroconcrete chambers. Each chamber has discharge shafts on both sides, left and right, as well as income downtakes for free air to enter a space under chambers. The nests are cooled with free air flowing along surfaces of the storage nests. In the dry storage chambers natural ventilation takes place. Driving forces for this type of air exchange are gravitational forces and wind pressure. Unlike forced ventilation, the SNF canister cooling system for the storage nests is passive one, which increases its reliability and gives an economic gain during the facility operation.

Also, SNFAs storage is done using several safety barriers in the stainless steel leakproof canisters and the storage nests filled with inert gas. During a storage term, ampoules and canisters are inspected for their leakproofness, which makes it possible to timely identify the incipient problems and eliminate them by welding an additional seam or repacking a leaky canister.

The building structures allow it to withstand a 5-t aircraft fall and the maximum credible earthquake of magnitude 9.6. The design life time of the Storage is 50 years with its possible prolongation to 100 years. The SNF passive cooling system allows the storage facility not to depend on offsite power.

To prepare SNF for dry storage and to reload it, up-to-date lifting equipment, viz., automated manipulators and cranes are used. All SNFAs handling operations are carried out remotely with the use of hot cells, remote equipment, master/slave manipulators. The said approaches help improve safety of storage and reloading, increase the Complex throughput, and cut the SNF storage cost.

4. DESCRIPTION OF VVER-1000 SNF SHIPPING AND DISPOSITION

The primary task to be addressed in order to ensure the Complex operation is to ship SNF to the FSUE “MCC” site.

At present the MCC ships SNF discharged from RBMK-1000 and VVER-1000 reactors operated at all Russian nuclear power plants (RBMK-1000 – Leningradskaya, Kursk and Smolensk NPPs; VVER-1000 – Novovoronezh, Balakovo, Kalinin, Rostov NPPs). The Combine receives shipments of the SNFAs in their after-examination state from JSC “SSC RIAR”. Also, it removes SNF from foreign NPPs based on the Russian VVER-1000 design, viz., Yuzhno-Ukrainskaya, Khmelnitsk, Rovno NPPs of Ukraine, Bulgarian “Kozloduy” NPP.

SNF is shipped from a NPP to the FSUE “MCC” by rail road in special railway wagons designed to carry TUK shipping casks. Shipping is done by railway trains composed of up to eight wagons. While in motion, the SNF-carrying train is under convoy of armed guards.

Today TUK-10 and TUK-13 shipping casks are used to ship VVER-1000 SNF. The containers are made of stainless steel, which allows them to be repeatedly decontaminated with special solutions. A cask structure is easy to handle using standard lifting equipment both at a NPP, and at the MCC.

The arrived railway wagons housing the SNF casks, first, are to be cleaned of road dirt accumulation, and then, to be unloaded in the SNF reloading area of the Wet Storage facility. In the reloading area the cask

is removed from the railway wagon with a special lifting beam and a crane, and after cooldown it is placed in the reloading area's water-filled compartment, which connects the Wet Storage passage way.

In the reloading area's compartment, the cask lid is removed and under a layer of water SNFAs are gripped and removed from the cask on a one-by-one basis by a special crane arm and then, are placed in the storage basket. Under a layer of water, the completed SNFA-basket is transferred along the passage way by the storage area's crane to the dedicated compartment and is seated there.

After SNFAs are unloaded, the cask is taken away from the reloading area, emptied of water from its inner cavity and placed in the decontamination area. After having been decontaminated, the empty container is prepared to a future trip and then, is placed in a railway wagon being a part of a regular train.

Having been stored in the Wet Storage for the time required, SNFAs can be sent to reprocessing at the PDC or to dry storage. SNFAs are removed in the dedicated compartments equipped with inclined hoists. The storage area's crane grips the SNF storage basket and transfers it to this compartment, where under a layer of water, SNFAs are removed from the basket on a one-by-one basis and placed in the inclined hoist cavity. Then, assemblies are transferred to the place under the SNFA transfer chamber and then, using the manipulator, delivered to the Dry Storage or to the PDC.

5. INTEGRATED TECHNOLOGICAL COMPLEX FOR CENTRALIZED SNF MANAGEMENT

At present the enterprise has created the integrated technological Complex for long-term centralized SNF management.

The Complex consists of the following:

- The Water-cooled Storage Facility for SNF discharged from VVER-1000 (HOT-1);
- The Dry Storage Facility for SNF discharged from RBMK-1000 and VVER-1000 (HOT-2);
- Pilot Demonstration Center to reprocess SNF, being a prototype of the 3-rd Generation Plant for radiochemical reprocessing of SNF.

The strategic objectives of the Complex are to:

- Safely store SNF for not less than 50 years;
- Increase a level of environmental safety of SNF reprocessing due to elimination of liquid ILW and LLW discharges into environment and conversion of all radioactive wastes into a safe form suitable for long storage and disposal;
- Close a nuclear fuel cycle (recycle fissile materials).

The site housing the SNF storage facilities is equipped with the whole infrastructure necessary to manage SNF; also, it provides an opportunity to arrange reference storage of SNFA casks with the use of promising cask designs.

The Complex has a convenient logistics, with nuclear material being transferred within one area that is physically protected. The integrated Complex infrastructure makes it possible to manage all types of SNF discharged from VVER-1000/1200, RBMK-1000 and foreign reactors such as PWR, to implement different scenarios of SNF managing according to the customer's request. This means that the Complex can provide, for example, a storage service only, a storage followed by reprocessing service, as well as a whole range of services, i.e., storage, reprocessing, fuel fabrication from reprocessed materials.

6. PILOT DEMONSTRATION CENTER TO REPROCESS SNF

The Pilot Demonstration Center is meant for commercial demonstration of an opportunity of solving the SNF accumulation problem in an environmentally friendly and effective manner. The Center addresses the following tasks:

— To perfect new, low-waste, economically viable and environmentally friendly SNF reprocessing technologies, which will provide input data for development of a large-scale reprocessing plant of a new generation.
— To improve a flowsheet of process RAW treatment, which will make it possible to convert long-lived radionuclides into compact and safe storage forms.
— To test new, promising equipment to obtain engineering data to be used in future for development of an economically effective production facility.
— To develop input data for replication of SNF reprocessing and RAW managing modules.

The Pilot Demonstration Center is to be implemented in two phases. The first phase began in 2015 with commissioning the start-up facility involving a modern hot laboratory. The laboratory carries out researches related to development of new technologies of reprocessing SNF discharged from thermal and fast reactors, and those of HAW treatment followed by minor actinide recovery. The start-up complex throughput is 5 tons of reprocessed SNF a year.

The second phase scheduled for 2021 is to commission VVER-1000 SNF radiochemical plant with a throughput of 250-400 SNF tons a year.

To improve VVER-1000 SNF reprocessing modes, the start-up facility has recently completed reprocessing of spent nuclear fuel assemblies, which has proven viability of the PDC engineering solutions related to Plant of Generation 3+.

The important tasks addressed at the PDC's hot laboratories are as follows:

— Minimization of process operations owing to unique equipment having no analogues worldwide;
— Use of the processes making it possible not to discharge low-active wastes into environment (including tritium).

The SNF radiochemical reprocessing complex will be capable of:

— Implementing different scenarios of SNF reprocessing for a definite customer;
— Using of uranium-plutonium mix being recovered from VVER-1000 SNF as a fuel composition for REMIX and MOX fuel assemblies.

The SNF reprocessing technology applied at the PDC is based on principles providing for recovery of valuable components suitable for REMIX and MOX fuel fabrication. The process capabilities of the Center allow SNF to be variously reprocessed on request of a definite customer with the resulting RAW being returned to the customer.

The PDC technology is a prototype of the 3rd generation technology. It aims at minimizing process operations and engaging unparalleled equipment. Unlike the existing radiochemical plants, the PDC technology applies the processes preventing from tritium discharge into environment as low-level radioactive wastes. This approach decreased amounts of liquid effluents, which has led to reduction in solidified RAW volumes.

The table below shows advantages of the PDC technology as the 3-rd generation technology in terms of resulting radioactive waste volumes.

TABLE 1. PDC COMPARED TO DIFFERENT REPROCESSING PLANTS

	Generation 1	Generation 2	Generation 3	Generation 4
Liquid RAW	ILW and LLW about 50 m3/SNF t	LLW about 100 m3/SNF t	none	none

Solid HLW	0.8 m3/SNF t	0.15 m3/SNF t	0.12 m3/SNF t	Trans-Pu elements transmutation, ILW shallow disposal of 4 m3/SNF t
Plants	RT-1 (“Mayak” Production Association)	UP-2, 3 (France), Rokkasho (Japan)	PDC (MCC)	RT-2 (MCC)

7. MOLTEN SALT REACTOR

A molten salt reactor (MSR) operating on a liquid nuclear fuel and allowing its fuel composition to be continually adjusted during the reactor campaign is one of the promising areas to be implemented at the enterprise.

Principal advantages of this reactor are: no need in fabrication of a fuel pellet, a fuel pin and a fuel assembly, as well as an opportunity of repeated recycling of long half-life actinides in the fuel salt.

After having been recovered from HLW reprocessing at the Pilot Demonstration Center, the long half-life actinides are planned to be utilized in this reactor unit.

Establishing of the complete MSR unit complex involving a salt processing and recycling unit within the closed NFC, with a view of long half-life actinides (Np + Am+ Cm) recycling, offers benefits in:

- Significant reduction of HAW amounts subjected to geological disposal;
- Significant reduction of costs of long-term storage and subsequent disposal of removed long half-life actinides;
- Improved safety, environmental and economic indexes of nuclear power engineering (electrical efficiency > 45%);
- Increased competitive ability of nuclear generation and commercial appeal of SNF management.

8. MOX FUEL FABRICATION TO SUPPLY FAST REACTORS

At present the unique facility is functioning to fabricate MOX fuel for BN-800-type fast reactor unit (Beloyarsk NPP).

The MOX fuel fabrication facility is located in the MCC’s underground mines. An excavation is a natural containment ensuring a reliable protection from any natural hazards (meteorites) and human impact.

The facility’s personnel has acquired a unique experience in development and improvement of new commercially-proven (not research) fabrication technologies. This experience is currently applied for establishing new fabrication plants at Rosatom enterprises.

All process operations are automated and remotely controlled, the equipment having no analogues worldwide. The facility is capable of fabricating fuel assemblies containing reactor-grade plutonium dioxide.

9. ESTABLISHING A REFERENCE REMIX FUEL FABRICATION PLANT AT THE FSUE “MCC”

The Russian atomic power engineering is developing within the framework of a two-component nuclear power system and is gradually shifting to the closed NFC, which is not just driven by the country’s domestic demands, it is also determined by the need to provide services on the international SNF management market (reprocessing of SNF discharged from foreign NPPs being based on the Russian design at a minimum).

As of today the world has accumulated 260 thousands of tons of uranium, about 2 thousands of tons of plutonium in stored spent fuel. This reusable material is enough to provide 60 years of continuous operation of 38 VVER-1000 reactors and 100 BN-800 reactors respectively.

In addition, there is a world crisis of social acceptance and public support of nuclear power engineering determined by:

— Unsettled situation with respect to SNF and RAW, suspension of SNF reprocessing by some big players (Great Britain, Belgium, Germany, Japan);
— Obvious ineffectiveness of the existing decisions on both reprocessing itself, and repu and Pu involvement in the fuel cycle;
— Choice done by a majority of NPP operators in favor of a delayed decision (interim SNF storage) due to a lack of a more favorable scenario.

All these issues could be addressed with a help of REMIX-based NFC, which offers a balanced solution involving reprocessed material recycling.

The REMIX fuel-based NFC addresses a problem of utilizing U and Pu recovered in the SNF reprocessing, allows uranium reserves to be saved (~ 25%), thus cutting a fuel charging cost; makes it possible to recycle a reprocessed nuclear material by not less than a factor of 5, i.e., a reactor could run with the same fuel for its 60-year's operation period (being fuelled with enriched uranium); provides an opportunity of REMIX fuel charging of the entire VVER core; does not require significant capital costs be incurred by power companies for equipment upgrade; and assures that nuclear material nonproliferation requirements are met, because no pure plutonium is recovered.

Therefore, a potential market of REMIX fuel products is an international one, since all countries, but for Russia, have a thermal reactor fleet. In addition, this market is potentially significantly larger in terms of sales compared to the Russian market.

Development of the reference facility for REMIX fuel fabrication at the MCC will make it possible:

— To fabricate REMIX fuel from nonseparated mix of uranium and plutonium recovered from VVER-1000 SNF, which is stored at the MCC, according to the SNF reprocessing technology applied at the PDC;
— To fabricate and qualify REMIX fuel pellets, pins and assemblies according to the uranium-plutonium fuel fabrication technology proven at the PDC.

10. INTEGRATED TECHNOLOGICAL COMPLEX

The enterprise is still developing the integrated technological complex with a convenient logistics within one industrial site, which enables the MCC to manage all types of SNF discharged from VVER-1000/1200, RBMK-1000, and in the future, from BN fast reactor, reactors on REMIX fuel, and foreign reactors such as PWR, and allows it to variously manage SNF in accordance with a customer's request (storage, SNF reprocessing followed by RAW return, reprocessing followed by fuel fabrication).

With the closed NFC infrastructure, the MCC is maturing opportunities of establishing and putting into operation of the REMIX fuel fabrication facility with a view of closing the thermal reactor-based NFC, as well as of developing the complete MSR unit complex to recycle long-lived actinides and significantly reduce HLW amounts, thus making commercial SNF managing more attractive.

11. CONCLUSIONS

The FSUE "MCC" is creating the all-embracing, integrated industrial infrastructure composed of three production stages: SNF storage, SNF reprocessing, fresh uranium-plutonium fuel fabrication.

Location of all these production stages at one site and new approaches in back-end technologies will allow:

— The two-component closure of the nuclear fuel cycle related to thermal and fast reactors on the basis of reference technologies;
— SNF reprocessing in large amounts and fabrication of fresh fuel for power reactors having different designs;

— Nuclear industry to become more effective and competitive;
— SNF management to be much safer owing to significant reduction in stored SNF and raw amounts.