COMMERCIAL POTENTIAL OF THE DUAL-COMPONENT NUCLEAR POWER SYSTEM

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Abstract

The issue of the constantly growing volume of the Spent Nuclear Fuel has turned into a serious impediment for the Nuclear Industry development. The matter of solving this problem is the key factor for the creation of the sustainable Nuclear Power System.

The most promising model for such a system now is the Dual-Component Nuclear Power System (DCNPS) which embodies both thermal neutron and fast neutron reactors. Nuclear Fuel Cycle in DCNPS is closed and self-sustained, not depending on a materialistic point of view: DCNRS could feed itself by breeding plutonium. Coupled with the thermal neutron reactors (standard PWR) and fast breeders (e.g. BN-1200) DCNRS' nuclear fuel cycle also includes spent nuclear fuel reprocessing plant with a capacity to prepare radioactive waste for disposal, and U-Pu fuel fabrication facility.

Such a system has unique advantages in ecology area (reduction of the natural uranium consumption, decrease of SNF amount), economics (cost reduction and effectiveness increase for the nuclear fuel cycle) and non-proliferation (plutonium utilization, control easing).

The main commercial peculiarity of the DCNRS is an opportunity to perform a form of leasing both for traditional uranium and uranium-plutonium nuclear fuel.

The report describes the principles of the DCNRS' nuclear fuel cycle and explains why and where it could be beneficial.

Introduction

The growing volume of Spent Nuclear Fuel (SNF) will become a significant economic burden for nuclear power generating complex in the nearest future. A radical solution to the problem of SNF, RW (radioactive waste) and problems of nuclear fuel source materials is a key element of a sustainable nuclear power system.

Today, the most promising model of such system is a Dual-Component Nuclear Power System (DCNPS), which embodies both thermal neutron and fast neutron reactors and the nuclear fuel cycle will be closed and self-sustaining from the standpoint of source materials. That (in addition to reactors in DCNPS) will also include the enterprises of the nuclear fuel cycle, which provide the production of fresh fuel, storage and reprocessing, multiple recycle of regenerated fuel, conditioning and isolation of RW.

Nuclear fuel cycle in Dual-Component Nuclear Power System

A typical cell of a dual-component system in the Russian terminology (see Fig.1) includes three units: two light-water thermal reactors (for examle VVER-1200) and one fast reactor with sodium coolant (for example BN-1200). Fuel load light-water hybrid reactors: uranium-plutonium fuel (MOX) and fuel freshly enriched with uranium oxide. Or – as alternative solution – it might even be loaded to 100% with the REMIX-fuel. The spent fuel of light water reactors is reprocessed with the recovery of uranium, plutonium, minor actinides and fission products of uranium. The plutonium produced in VVER with a large number of even isotopes (that is inconvenient for further use in VVER) is sent to fuel fabrication for BN-1200. To this fuel the minor actinides for burning and depleted uranium are added. This fuel after irradiation in a fast reactor will contain materials which enable to manufacture the fuel for its own operation and for the light water reactors: in the composition of the plutonium, removed from the BN-1200, dominate mostly even and fissile isotopes, which are easily divided by thermal neutrons. Thus, the plutonium from the SNF of the BN -1200 is directed to the manufacture of uranium-plutonium fuel (MOX or REMIX) for VVER -1200. Fission products released during the reprocessing are vitrified and are sent for disposal.

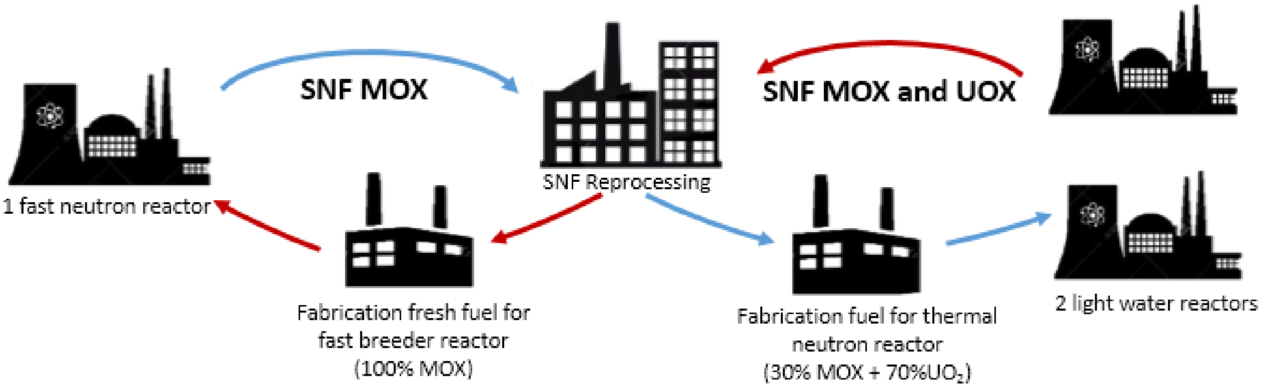

Fig.1. The Dual-Component Nuclear Power System composition.

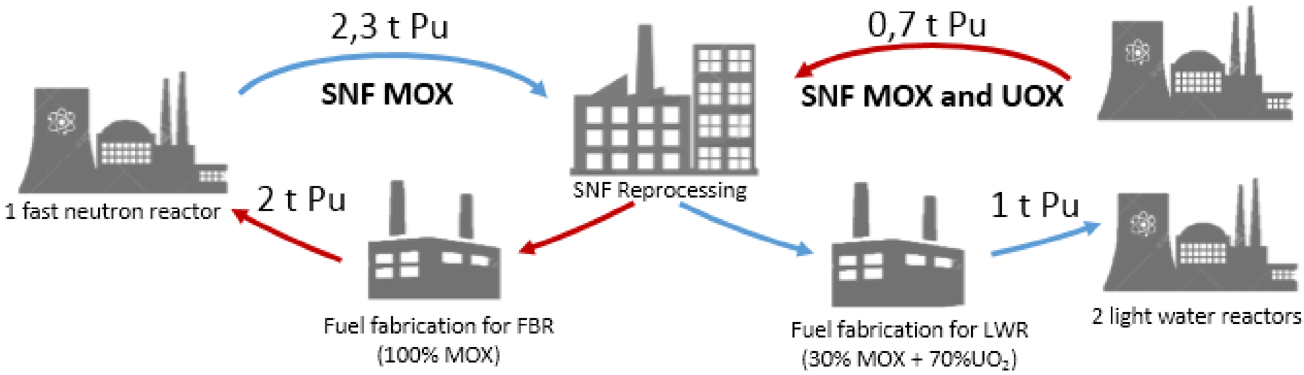

Fig.2. The balance of plutonium in the nuclear fuel cycle of The Dual-Component Nuclear Power System.

The advantages of NFC in the dual-component system

DCNPS with light water and sodium reactors and a closed NFC provide a multiple recycles of plutonium and that, therefore, on the one hand, solves the problem of disposal of SNF of light water reactors and, on the other hand, provides the nuclear energy with additional source material. The natural uranium consumption and the separation working in DCNPS are being reduced in 2,5 times in comparison with similar characteristics for the system consisting of light water reactors in the open cycle.

The main objectives of the transition to DCNPS in the future, obviously, will become its advantages and they can be formulated as stated below:

Environmental:

• minimize the consumption of natural uranium for the maximum use of the energy potential of SNF and the multiplying ability of fast reactors;

• to reduce the number of SNF in a nuclear power system with a corresponding reduction in a risk;

• lowering the potential danger of SNF radioactive waste through the allocation of minor actinides and burning them in fast reactors (described in more detailed way in the next Chapter);

Non-proliferation:

- facilitating control of nuclear materials due to their localization within the cell of DCNPS;
- waiver of reprocessed uranium and plutonium warehouses through the balance of flows within DCNPS;
- the possibility of effective utilization of already accumulated plutonium; both energy and weapon-grade (Pu-O);

Economic:

- difficult to predict cost savings for temporary storage and disposal of SNF;
- savings in the cost of natural components of the nuclear fuel cycle and work units of the division;
- involvement of the existing fleet of thermal neutron reactors in the practical circuit of the nuclear fuel cycle with the corresponding increase in the level of economic competitiveness of individual NPP and nuclear energy in general due to more efficient nuclear fuel cycle.

Thus, the implementation of DCNPS means not only increase in safety and general attractiveness of nuclear power, but also quite tangible economic benefits.

Reducing the volume and hazard for RW disposal

Most hazardous waste resulting from the operation of modern NPP in the closed (or partially closed) nuclear fuel cycle, from the point of view of radioactivity and decay heat, are the RW generated during SNF reprocessing. The reduce of their activity can be achieved by fractionation (separation into components) and afterburning of minor actinides in fast reactors. After the removal of minor actinides the activity of RW from SNF reprocessing becomes comparable to the activity of RW generated from the operation and decommissioning of NPP, as in fact only fission products of uranium, having a much smaller dissipation and half-life period, are sent for burial. The packaging of fission products, at which they will be assigned to medium-active wastes which do not require deep underground disposal, is also available.

So, today 1GW of electricity produced in the VVER-1200 has 2 m3 of HLW (high-level waste) after reprocessing of the spent fuel to remain active for 10,000 years. DCNPS, due to the extraction of the minor actinides from RW and their subsequent incineration in fast neutron reactor, can reduce the amount of RW from 1GW to 0.5 m3, with achievement of safe levels in 300 years.
Thus, the presence of fast reactors in NPP allows to reduce the risk of final waste and to reduce significantly the required volumes in an underground storage facility for final disposal of RW.

Commercial offer format

In general, DCNPS is a Russian development and will be first full-scaled implemented in Russia. Thus, the first recipients of the benefits listed above will be Russian NPP and nuclear power system. However, now there is a possibility of the use of DCNPS for the needs of foreign customers.

The typical consumer of DCNPS services is the operator of the NPPs with light water reactor on thermal neutrons, exploiting MOX fuel. Spent MOX fuel is not currently recycled, becoming a burden for the plant operator: he either keeps it by himself and at his own expense, or transfers the balance to the national operator after the done payment according to the applicable tariff. DCNPS offers such an operator to take away his MOX fuel for subsequent processing, the manufacture of fuel for a fast reactor from the reprocessing products, irradiating it in fast reactors, the new processing and new fabrication of MOX fuel (with a “fine” plutonium) for use in its own reactor on thermal neutrons. In the end, giving MOX-SFA, the customer gets back the fresh MOX fuel assemblies and vitrified fission products, prepared for burial (as an option – RW of a middle class activity).

That is, the operator-the customer and his plant actually becomes a constituent element of DCNPS, will all its advantages available: saving of natural uranium to disposal of SNF with a corresponding reduction in the cost of the nuclear fuel cycle as a whole.

Another consumer of DCNPS services may be the plant operator, which is not licensed to use MOX fuel. In this case, in exchange for a regular (not MOX) spent fuel, he will get a REMIX of the spent FA (fuel assemblies) containing ~1% plutonium, and which does not require reactor fundamental changes in design and the regulatory system.

In both cases, DCNPS allows you to implement a leasing scheme of nuclear fuel. Of course, this is not a lease in the usual sense, since fresh fuel and SNF are two fundamentally different products. However, the customer service will look like this: getting the FA after irradiation, he returns it to the supplier.

And finally, the consumer of DCNPS can be energy companies and national agencies, which already have stockpiles of plutonium. This plutonium can be directed to rewash and fabrication of MOX fuel for reactors of the customer, and for Russian reactors – the DCNPS components.

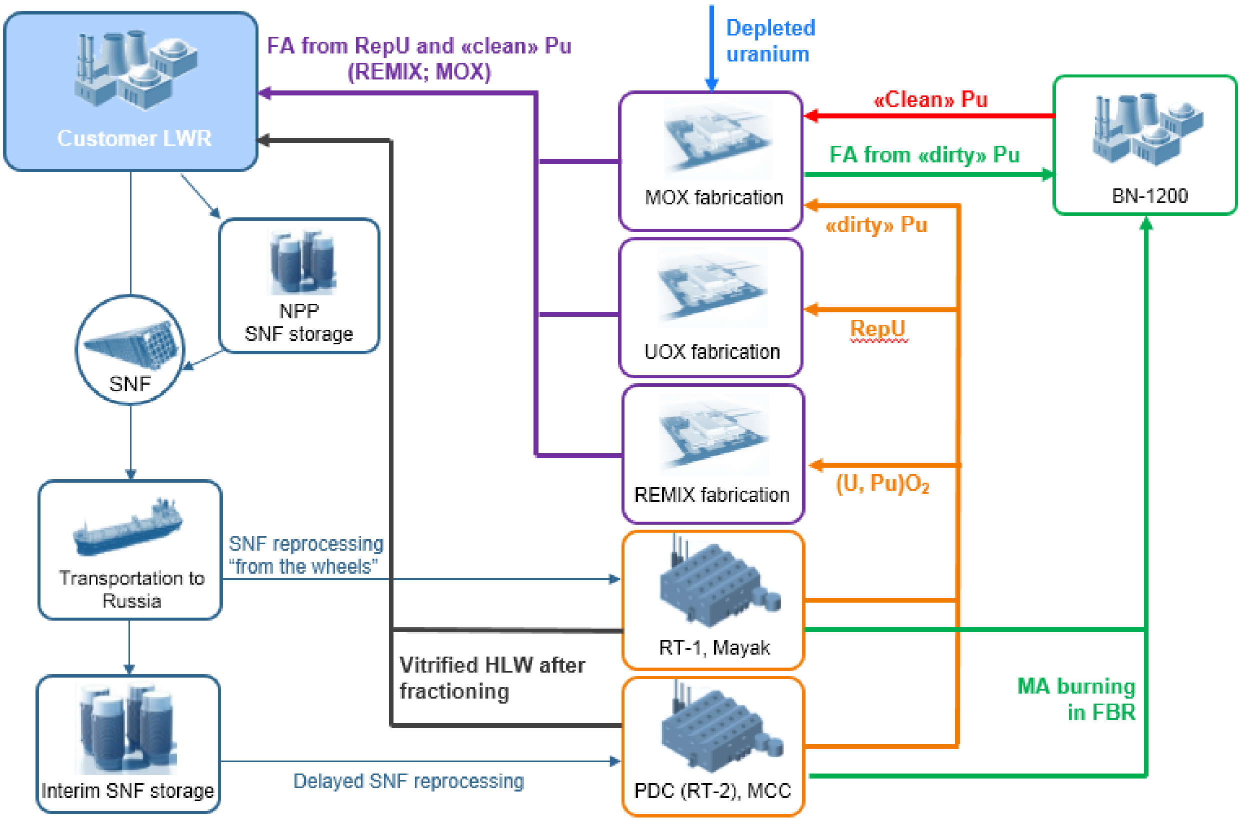

Fig.3. Customer's position in a dual-component nuclear power system

The current state of Russian infrastructure

The 15 units with VVER-1000/1200 are currently exploited in Russia while more five are being constructed. All reactors at present moment use a fuel made from enriched natural uranium. While there is an experience and the ability to transfer them to the fuel of uranium recovered from SNF. The study on the feasibility of uranium-plutonium fuel use in reactors is being held. In particular, in August of 2016 the experimental operation of fuel assemblies with uranium-plutonium REMIX-fuels in the

VVER-1000 began. It is expected that the VVER reactors will be the basic component of the Russian DCNPS.

In December, 2015, the BN-800 unit with the reactor based on fast neutron sodium cooled electrical capacity of 880 MW was commissioned at Beloyarsk NPP. Since running the process the active zone of the BN-800 was filled with MOX fuel; in 2019 it will be entirely filled with MOX fuel. Meanwhile MOX fuel for a full load of the BN-800 is made of plutonium extracted from the reprocessing of thermal reactors. With the BN-800 reactor running, we can talk about the real beginning of the creation of a dual-component nuclear power system in Russia, in which the fast reactors complement and enrich the capabilities of reactors on thermal neutrons. This primarily concerns the nuclear fuel cycle which becomes self-sufficient in the dual-component system.

An evolutionary extension of the BN-800 reactor should be the BN-1200 reactor. This reactor is considered as the basis of DCNPS. Currently the technical design of the BN-1200 DCNPS is ready, the adjustment of its economic performance is being processed, operational parameters and requirements for fuel are being optimized. In August, 2016, the Russian government has approved the scheme of territorial planning in the energy sector. It suggests that the country will build two power units with BN-1200 reactors by 2030. The first one - on Beloyarsk NPP, the second - on the site of the South Ural NPP in Chelyabinsk region. A "road map" of the project on the construction of a new commercial NPP reactor with fast neutron reactor BN-1200 in Russia is scheduled to be approved in 2017. It will contain a set of interrelated activities for the main stages of the unit life cycle until the moment of the head power unit BN-1200 start-up, including the contracting, development, coordination and approval of required documentation, permits and licenses, manufacturing, transportation and installation of equipment, commissioning and putting into operation works, personnel training. Thus, there will appear another full-fledged component of DCNPS by 2030 in Russia.

The main area of SNF reprocessing technologies development in Russia is the Mining and Chemical Combine, located in the Siberian city of Zheleznogorsk. Here is currently formed a cluster of the SNF treatment that includes a centralized SNF storage pool type, a centralized dry SNF storage, pilot demonstration center for SNF reprocessing (both for Russian and foreign type of fuel), the production of MOX fuel for BN-800 plant. In the future, a full-scale plant for SNF reprocessing (RT-2) will be built here, in Zheleznogorsk. RT-2 will be focused on SNF processing both in thermal (VVER-1200) and fast (BN-1200) reactors. Another old plant for SNF processing is located in the Production Association "Mayak" in Ozersk (RT-1). Today RT-1 processes SNF in reactors based both on thermal (VVER-440, VVER-1000/1200) and fast (bn-600) neutrons. So the processing component of DCNPS in Russia are also available.

And finally, Russia has accumulated a vast experience in the fabrication of fresh fuel from natural uranium; uranium recovered from SNF; uranium and plutonium. A large-scale production of uranium-plutonium fuel for BN-800 reactor is currently deployed at the above-mentioned Mining and Chemical combine. It is important that the so-called energy-grade plutonium, i.e., material that is extracted during reprocessing, is used here for the production of MOX fuel. This production will be the basis for the creation of another component of DCNPS – a fabrication one.

Thus, we can say that the Russian nuclear energy industry is steadily moving towards the creation of DCNPS: today we can speak about its' partial readiness, including readiness to begin testing of the above-described solutions. It is expected to create a full-fledged DCNPS by 2030.

Conclusion

1. Russia is developing a dual-component nuclear power system based on the use of reactors for thermal and fast neutrons.

2. The dual-component nuclear power system allows to create a nuclear fuel cycle with distinct advantages from an ecological (lower consumption of uranium, reducing the amount of SNF), economic (reducing costs and improving the efficiency of the nuclear fuel cycle) and non-proliferational (utilization of plutonium, the relief control) standpoints.

3. Key commercial feature of the dual-component nuclear power system is the ability to realize the similarity of leasing for a traditional uranium and uranium-plutonium nuclear fuel.

4. The State Corporation “Rosatom” responsible for the development of nuclear energy is ready to discuss options for international cooperation in the framework of the creation and use of a dual-component nuclear power system.