

The basic features of a closed fuel cycle without fast reactors

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Abstract. In this paper the basic features of a closed fuel cycle with thermal reactors are considered. The three variants of multiple Pu and U recycling in VVER reactors was investigated. The comparison of MOX and REMIX fuel approaches for closed fuel cycle with thermal reactors is presented. All variants make possible to recycle several times the total amount of Pu and U obtained from spent fuel. The reported study was funded by RFBR according to the research project № 16-38-00021

1. Introduction

Basic strategy of Russian Nuclear Energetic is propagation of closed fuel cycle on the base of fast breeder and thermal reactors. The strategy can help to solve such systematic problems as the huge quantity of accumulated spent nuclear fuel in the storages and the limited inventory of cheap natural uranium for fuel production, and to increase the economic attractiveness of the nuclear industry. There is the program which based on the development of fast nuclear reactors in Russia, but this technology is not ready for global implementation. The main element of the nuclear power fleet in Russia today is VVER reactors. The first stage for closed fuel cycle can be done with applying thermal reactors. It will help to decrease the amount of spent nuclear fuel in storages, reduce natural uranium consumption and develop modern reprocessing technologies.

This paper shows the three concepts of U and Pu multiple recycling in VVER type reactors. The first two variants differ with feeding fissile material. The first is the standard REMIX fuel [1-3] approach and the second is close to MOX fuel where regenerated uranium used instead of depleted uranium and the feeding fissile material is reactor grade plutonium. It makes possible to recycle several times the total amount of Pu obtained from spent fuel. The main difference in Pu recycling is the concept of 100% or partial fuel assemblies (FAs) loading of the core. The third variant is heterogeneous composition of enriched uranium and MOX fuel pins in the FA. These three variants of the full core loadings are balanced on zero Pu accumulation in the fuel cycle. The all Pu from the spent fuel of the core loading is used to produce new fuel for the next loading. This approach makes it possible to compare physical and economical aspects of the three variants of Pu multiple recycling in VVER core.

The neutron-physics calculations were performed by the Consul code package [4]. All calculations were performed for the standard VVER-1000 FA [5] configuration. Duration of the fuel campaign is 4 years (4X300 EFPD) with the average burnup 49.3 MW•day/kg_{HM}.



2. The fuel cycle concepts

The first variant observed in the paper based on enriched uranium addition to the recycled mixture of U and Pu. Basically the enrichment of feeding U supposed to be lesser than 20% of ^{235}U , but it will be impossible to reach 100% usage of spent fuel for the next loading in that case. The selected in the investigation first variant presumes enrichment of feeding U in the range of 50-55% of ^{235}U to achieve parameters given in the task. That is standard REMIX fuel concept. The resulting mixture consists of 3.8% of ^{235}U and 1.2% of Pu. The Pu and ^{235}U content growth with recycling number. This variant assumes 100% loading of the core with REMIX FAs.

The second variant based on Pu addition to the mixture. The necessary amount of Pu received from the pre-recycled FA with standard UOX fuel. It is possible to achieve 100% usage of spent fuel in this case. The second variant needs additional reprocessing of UOX fuel with full separation of plutonium fraction. The main difference from the standard MOX fuel is the presence of regenerated U instead of depleted one. The resulting mixture consists of 0.8% of ^{235}U and 9% of Pu. The investigation of FA depletion was done under assumption that MOX FA surrounded with UOX FAs to take into account spectral effects. The standard construction of VVER-1000 FA with 312 fuel pins was chosen for the investigation of burnup properties of new fuel compositions for the first and second variants. No burnable absorbers or Pu content profiling were taken into account.

The third variant based on the facts that during reprocessing the full FA is cut and melted down and that REMIX technology allows getting the mixture with any Pu content. The main idea was to separate UOX and MOX fuel pins in the REMIX FA to achieve better fission properties for ^{235}U . The variant of heterogeneous fuel pin positioning for VVER FA is presented in Figure 1. This concept close to CORAIL FA design for Pu multirecycling in PWR [6,7]. The main difference is MOX fuel pin amount in FA and regenerated U presence in fuel composition which helps to reduce Pu content in MOX fuel pins.

The presented FA consists of 78-90 MOX fuel pins (25%) with 0.8% of ^{235}U and 4.5% Pu and 234-222 UOX fuel pins with 4.6% of ^{235}U . Pu content in MOX fuel pin, total number and positioning of these pins in FA were chosen to meet the following tasks:

- the average burn-up of MOX and UOX fuel pins are equal;
- peaking factor does not exceed 1.2 (assembly calculation).

Total amount of Pu and MOX pins will increase with recycling number. The investigation doesn't assume the usage of regenerated uranium for UOX pin manufacturing, and they have standard design.

3. Main conclusions

The proposed above approach to the reprocessing technology has potential to improve economic parameters by reducing the number of process steps during SNF reprocessing and fuel manufacturing (reducing the several stages of fuel powder and pellets fabrication as compared to MOX fuel fabrication). New technology process can provide better quality for the mixed uranium plutonium pellet fabrication. Low Pu content in the core has negligible influence on safety parameters of the NPP.

The three options of REMIX FA fabrication proposed in the paper. All considered variants assume Pu multiple recycling. The Pu content and isotopic quality in the fuel matrix stabilized with growth of recycle number for the most variants. The better results in natural uranium savings can be achieved for the standard REMIX(UOX) approach. The regenerated materials usage in thermal power reactors gives not more than 30% saving of natural uranium consumption.

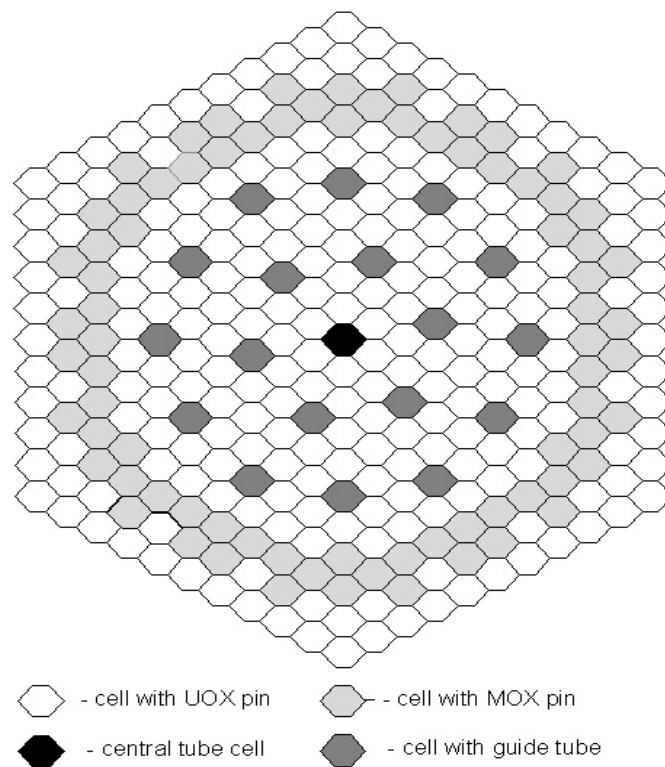


Figure 1. The REMIX (het) FA configuration for heterogeneous fuel pin positioning

Estimation of technical and economic assessment presented in the paper has demonstrated that the use of REMIX technology in the closed fuel cycle is more expensive than the open fuel cycle with direct SNF disposal. The Pu positioning in the expensive MOX FA gives better results from the economical point of view but it is worse for multiple recycling. The main idea is to place expensive fuel in the expensive fuel pins or FAs so the integral FA cost for the loading will decrease.

It is important to note that the uranium multiple recycling in the REMIX fuel form or using the reenrichment process leads to the uranium isotope composition degradation. The ^{236}U and ^{232}U concentrations in the fuel are increasing and the regenerated uranium treatment becomes more complicated.

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