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Formation of proliferation-resistant nuclear fuel supplies based on reprocessed uranium for Russian nuclear technologies recipient countries

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Abstract

The paper presents different strategies for the conversion of VVER-1000 reactors to reprocessed uranium fuel for estimating the time required to form a proliferation-resistant VVER-1000 fuel load based on uranium extracted from spent fuel of reactors of the same type cleared of minor actinides and fission products. It has been shown that the change in the proliferation resistance status of generated plutonium in the VVER-1000 spent nuclear fuel is achieved by denaturation of plutonium through the increase in the concentration of ^{238}Pu plutonium isotope in irradiated fuel. The initial presence of ^{236}U uranium isotope in fresh uranium fuel of the VVER-1000 reactor has been shown to have an effect on the accumulation of ^{238}Pu, a key isotope in the context of the barrier against unauthorized proliferation. Saving of uranium resources has been additionally analyzed for the considered strategies to convert VVER-1000 reactors to reprocessed uranium fuel for the purpose of improving the resource base of NPPs in Russia and recipient countries.

Keywords: reprocessed uranium; burnup; resources saving; spent nuclear fuel; VVER-1000.

Introduction

The present-day strategic objectives of Rosatom State Corporation are aimed at forming the Corporation's global technological leadership in nuclear industry. One of such objectives is global expansion of the VVER reactor technology platform. It is aimed at improving the Corporation's position at international market of nuclear technologies, with the associated growth in the supplies of the Corporation's products and services for all stages of the NPP lifecycle [1]. The absence of nuclear material enrichment and reprocessing technologies in newcomer countries leads to the need for the transport of fresh and spent nuclear fuel and, as a sequence, requires a great deal of effort to ensure the safeguards against unauthorized proliferation of nuclear material.

Production of reprocessed uranium from irradiated fuel repatriated from customer countries or from domestic amounts of spent fuel offers an additional capability for strengthening the resistance to unauthorized proliferation of nuclear fissionable materials. On the positive side, the use of recycled nuclear fuel (RNF) based on reprocessed uranium leads to saving of uranium resources and to a decrease in the share of the raw material component in the fuel cost. For the client countries, the use of reprocessed uranium is expected to improve the uranium resource potential for the saving at a level of about 17 to 18 % from the reactor core full loading with the fuel of an equivalent enrichment [2].

To date, a more than 30-year experience has been gained in the Russian Federation in commercial use of reprocessed uranium for the fabrication of nuclear fuel based on Russian specifications (VVER-440 spent nuclear fuel (SNF) is used to fabricate fuel for RBMK reactors), and a more than 15-year experience in the manufacturing of fuel from reprocessed uranium for NPPs with PWR and BWR reactors in Western Europe (Germany, Switzerland, Sweden, Holland, and Great Britain). Presently,

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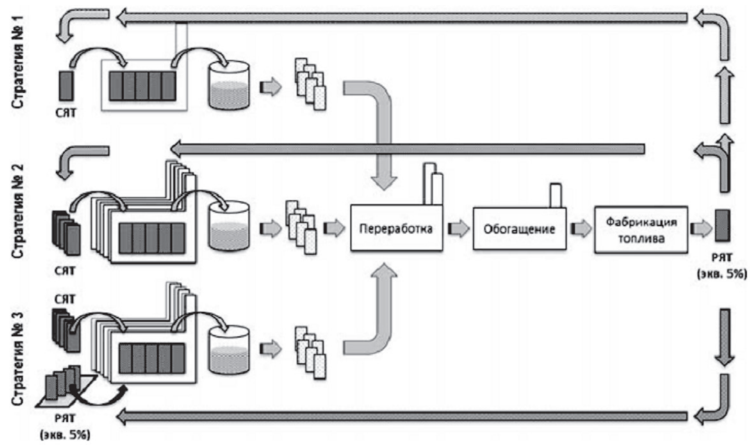

Стратегия № 1 = Strategy 1
Стратегия № 2 = Strategy 2
Стратегия № 3 = Strategy 3
СЯТ = FNF
РЯТ (экв. 5%) = RNF (5% eq.)
Переработка = Reprocessing
Обогащение = Enrichment
Фабрикация топлива = Fuel fabrication

Fig. 1. Flowchart for the VVER-1000 reactor conversion to reprocessed uranium for the three strategies.

over 3000 FAs have been fabricated for supplies under a contract with AREVA NP [3].

Given that one fifth of the reactor core is refueled annually with the current scheme of refueling [4], the time required to form the VVER-1000 reactor fuel loading based on reprocessed material is estimated. Different strategies have been considered for converting the VVER-1000 reactors to reprocessed uranium depending on the available resources of reprocessed uranium: from one reactor (a newcomer country), from six reactors (a country with sufficiently developed nuclear power), from six reactors with reprocessed material formed from onsite-stored SNF (838 FAs) [5] (a country with developed nuclear power and accumulated SNF). A change in the proliferation resistance status of the plutonium generated in the VVER-type reactor SNF depending on the time of the reprocessed material use in the fuel cycle has been demonstrated and the uranium resources saved have been estimated.

Formation of VVER-1000 fuel loads based on reprocessed uranium

Fig. 1 presents the flowchart for the formation of fuel loads based on reprocessed material for the three strategies.

In strategy 1 for the conversion of VVER-1000 reactors to reprocessed uranium, spent ENU (Enrichment Natural Uranium) fuel, following the five-year cooling in the cooling pool, is placed in storage with the required quantity of material accumulated for forming one fifth of the reactor core loading, and is then shipped to the SNF processing plant. The extracted uranium (RepU – Reprocessed Uranium) is additionally enriched to the needed level, with the presence of ^{236}U taken into account, and shipped for the fabrication of ERU (Enrichment Reprocessed Uranium) nuclear fuel. The assemblies equipped with such fuel are loaded into the reactor core. The compensation for the initial presence of ^{236}U was taken into account as described in [4].

It takes six years to accumulate the material for the fuel formation to refuel one fifth of the core with reprocessed-uranium assemblies and another six years to reprocess the accumulated material; therefore, the initial loading with reprocessed-uranium fuel may take 12 years (Fig. 2). In this strategy, the share of the raw material component in the fuel cost is reduced insignificantly due to a small number of the reprocessed assemblies involved.

In an analysis for strategy 2, spent fuel from six VVER-1000 reactors was reprocessed using the same flowchart as in strategy 1. The so equipped fuel assemblies are loaded into the core of one of the six reactors. It shall be taken into account when forming the fuel to be loaded that the SNF from six reactors is not used in full to form one fifth of the loading for the core of one reactor. Throughout the operating time, a sufficient amount of material is accumulated to form several refueling batches for the second reactor's core (Fig. 3).

In strategy 3, thanks to the involvement of onsite-stored spent fuel in the fuel cycle, it is possible to cut the time for the ENU fuel use in one of the six reactors by four years (Fig. 4).