POSSIBILITY OF USING MIXED DIOXIDE FUEL IN THE VK-300 REACTOR

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The problem of utilizing the plutonium accumulated in spent fuel from power reactors has become more acute in the last few years for reasons including the existence of excess weapons plutonium which appeared as a result of nuclear disarmament. Any plutonium is a valuable energy resource, which should be burned with the highest efficiency in fast reactors, but the relatively high construction and operation costs is postponing the commercial utilization of such reactors indefinitely. At the same time, the quite wide prevalence of thermal reactors in power production that are capable of utilizing plutonium in a mixed oxide fuel makes it possible to tackle the solution of this problem now.

Substantial practical progress in this respect has been achieved in some countries in western Europe [1]. They include France, Germany, Switzerland, and Belgium, where together with investigations on closing the fuel cycle on fast and thermal reactors [2], recycling of mixed oxide fuel in light-water reactors is being successfully implemented. At the end of 1997 the number of such reactors reaches 25, while in France the number reached 14. The total load of mixed oxide fuel in these reactors is about 700 tons with respect to the heavy metal (h.m.).

In our country practical experience in utilizing mixed oxide fuel has been gained only for fast reactors [3], but the possible use of this fuel in thermal BBER and RBMK reactors is under investigation [4, 5]. The problems of recycling fuel are not being considered for the time being. Primarily very simple schemes for adding plutonium to the fuel cycle of these reactors are being examined. These schemes essentially consist of replacing some of the uranium fuel with uranium-plutonium fuel without any large changes in the construction of the fuel assemblies and the core. The investigations show that the use of plutonium in water-moderated water-cooled reactors, such as the VK-300 reactor, changes the neutron-physical characteristics of the core:

The efficiency of absorbers (control rods and boric acid) decreases because of hardening of the neutron spectrum. The energy of the thermal neutrons approximately doubles when $^{235}$U is replaced by plutonium.

The temperature coefficient of the reactivity with respect to the moderator becomes more negative (approximately by 40%), while the Doppler coefficient remains almost unchanged.

The delayed-neutron fraction decreases by a factor of 1.5–2.

The coefficient of nonuniformity of energy release increases.

These changes can complicate the reactivity compensation system and the transient and accident operating regimes and they can also decrease the thermotechnical reliability of the reactor plant.

At the same time, analysis of variants of BBER-1000 and RBMK cores with up to 1/3 of the fuel assemblies containing mixed oxide fuel showed that the reactivity coefficients and the nonuniformity of energy release in such reactors remain within admissible limits. Similar conclusions can also be drawn with respect to foreign PWRs (see, for example, the investigations in [1, 6]). The difficulties of adding a large fraction of mixed fuel to the load are due to the need to increase the water-fuel ratio, which, as a rule, can be achieved by substantial redesign of the construction of the fuel assemblies and the structure of the core.

The neutron-physical indicators of the VK-300 reactor, which is being contemplated, are close to those of the BBER reactor, and the considerations presented are valid for VK-300 as well. However, in this case a favorable circumstance is that the reactor can be made to operate on mixed oxide fuel. In addition, the required water-fuel ratio and other required neutron characteristics of the reactor can be achieved by changing only the construction and the structure of the fuel assemblies while maintaining the same exterior dimensions of the fuel assemblies. In so doing, the following are admissible:
Fig. 1. Transverse cross section of the fuel assembly with uranium dioxide fuel: 95 BBER-type fuel elements with \( \phi \, 9.1 \times 0.65 \) mm (\( \bigcirc \)) cladding and 12 fuel elements with 5% gadolinium oxide in the fuel (\( \bullet \)).

change in the enrichment of the fuel in the fuel elements;
redistribution of the number of fuel elements in the fuel assemblies and the number of fuel elements with gadolinium, changing their relative arrangement in the fuel assemblies, and also the content of gadolinium oxide, including over the height of the core;
correction, within certain limits, of the size of the central water cavity of the fuel assemblies and the dimensions of the absorbing rods;
replacement in the fuel assemblies of some fuel elements by water pipes; and,
change in the diameter of fuel elements, which is possible in principle, but is undesirable.

It is important to note that the use of weapons plutonium, as compared with reactor plutonium, in water-moderated water-cooled reactors results in less favorable neutron-physical characteristics because the former contains much less \(^{240}\text{Pu}\) which is a unique absorber that is burned up. For this reason, the present investigation, following a conservative principle, was performed for mixed oxide fuel with weapons plutonium. We kept in mind the fact that the conclusions drawn in this work are also valid for mixed fuel with reactor plutonium.

**Methodological approach to solving the problem.** As already noted, the replacement of \(^{235}\text{U}\) with plutonium in the fuel of thermal reactors can result in appreciable deformation of the neutron spectrum. As is well known, this is due to the wide resonance in the absorption and fission cross sections of \(^{239}\text{Pu}\) at thermal neutron energies (~ 0.3 eV). At the same time, in boiling-water reactors, which VK-300 reactors are, a substantial fraction of the reactivity margin for burnup is compensated by the gadolinium absorber, which is burned up and is placed directly in some of the fuel elements. In this case, the use of gadolinium, whose isotopes \(^{155}\text{Gd}\) and \(^{157}\text{Gd}\) have large thermal (below 0.3 eV) neutron absorption cross sections, in the fuel can also transform the thermal part of the spectrum in both the fuel elements containing gadolinium and in the fuel assemblies containing gadolinium.

Taking account of these two circumstances, i.e., the presence of plutonium and gadolinium in the fuel, imposes greater requirements on the computational model for the spectral problem of the reactor. Specifically, a more detailed spatial-energy representation of neutron transport, specially in the thermal part of the spectrum, is required. The spectral problem was solved using the well-known WIMS-D4 program [7] in the PIJ+PERSEUS option. Investigations showed that at least 16 groups of thermal neutrons (energy below 0.625 eV) are required to achieve acceptable accuracy.

A two-group diffusion program FACT in the X, Y geometry was used to take account of the design structure of the VK-300 core in a four-cycle reload regime and to establish (and check) reactor criticality in the main states. The spatial calculations of the reactor were performed only for the design configuration of the core, i.e., in all variants with mixed oxide fuel the core structure, with respect to the number and arrangement of the fuel assemblies, was assumed to be unchanged.

**Optimization of water-fuel ratio.** The calculations of a cell of the fuel assembly (Fig. 1), being contemplated, with uranium replaced by mixed uranium-plutonium fuel showed a large increase in the multiplying properties of the freshly-loaded cell, an increase in nonuniformity of energy release, and a decrease in the neutron-migration area \(M^2\).