The results of a numerical simulation of an experiment on measurement of the steam coefficient of the reactivity of a RBMK reactor are presented. The “inverted variation of the reactivity” effect is explained. The computational results show that this effect is due to the nonuniformity of the load and coolant flow rate in the channels in the core.

The steam coefficient of the reactivity is an important parameter for assessing the state of a RBMK reactor. It is given by the relation $\alpha_\varphi = \frac{\partial \rho}{\partial \varphi}$, where $\varphi$ is a small change in the reactivity and $\rho$ is a small change in the volume fraction of the steam content. According to the standard method for measuring the steam coefficient of the reactivity, the flow rate of the feed water changes, which changes the steam content in the reactor. The steam content increases as the flow rate of the feed water decreases, which introduces positive reactivity and, conversely, the steam content decreases as the flow rate of the feed water increases, which introduces negative reactivity. Often, “inverted variation” of the reactivity is observed during the measurements. For example, immediately after the flow rate of the feed water increases (introduction of negative reactivity) the reactor power increases for several seconds and only then starts to decrease. This effect is also observed in computational simulation of this experiment using the nonstationary version of the computer code STEPAN/KOBRA [1]. The purpose of the present work is to explain the inverted variation of the reactivity.

The fuel present in the channels differs by the degree of burnup. As the burnup increases, the steam coefficient of reactivity of a cell increases. It is well known that the fuel cells in an infinite uniform lattice, which contain low-burnup fuel with an absorber (2.6% U + 0.41% Er and 2.8% U + 0.6% Er), have a negative steam coefficient of reactivity (Fig. 1). The calculations were performed for an infinite cell using the computer code WIMS-D4 [2].

In reactor calculations, the inverted variation of the reactivity becomes even stronger because an increase of the coolant density decreases the neutron leakage from the high-power channels. As a result of this effect, the steam effect for any fuel channel with fresh fuel (even without erbium) is negative. At the present time, only uranium–erbium fuel is loaded into RBMK reactors. Ordinarily, the high-power channels are the channels with fresh fuel. Thus, the channels with the maximum power are the channels with relatively fresh fuel, which have a large negative effect of dehydration.

The coolant flow rate is high (6–8 kg/sec) in channels with the maximum power. The effect is that coolant velocity in these channels reaches its maximum value. Thus, high-power channels are more rapidly filled with cold coolant, which has a high density (with increasing flow rate of the feed water). The result is an initial growth of the reactivity and power of the reactor. Figure 2 shows the time dependences of the reactivity and power initially, obtained in simulations of the measurements of the steam coefficient of the reactivity in the No. 4 unit of the Leningrad nuclear power plant on November 18, 2002. The variant 1 is the standard calculation with a realistic distribution of the coolant flow rate in a channel; variant 2 is a calculation of the the same state but with a constant coolant flow rate 6 kg/sec at the entrance into each channel.
In the second variant, the coolant velocity is the same in all channels. Therefore, all channels are filled with cold water simultaneously. Consequently, there is no initial growth of reactivity. To shed more light on the inverted variation of the reactivity during the initial interval, after perturbation of the flow rate of the feed water in the calculation of variant 1, the contribution of high-power and other channels to the reactivity was determined (Fig. 3). The contribution of all other channels also includes the contribution of nonworking channels. This separation of the contribution occurs in a block of the STEPAN/KOBRA code where the reactivity is calculated using perturbation theory. The high-power channels are the channels whose power exceeds $1.2Q_{av}$, where $Q_{av}$ is the average power of a channel (1.88 MW). Channels with the average power are considered to be all other channels.

Fig. 1. Steam coefficient of reactivity versus burnup of fuel 2.8% $^{235}$U + 0.6% Er (1), 2.6% $^{235}$U + 0.41% Er (2), 2.4% $^{235}$U (3), 2% $^{235}$U (4).

Fig. 2. Time dependences of the reactivity and power for variants 1 and 2.