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# Feasibility of using $Gd_2O_3$ particles in VVER-1000 fuel assembly for controlling excess reactivity

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**Abstract**

Neutronics feasibility of using $Gd_2O_3$ particles for controlling excess reactivity and pin power peaking factor of the VVER-1000 fuel assembly has been investigated. The motivation is that the use of $Gd_2O_3$ in form of micro-particles would increase the thermal conductivity of the $Gd_2O_3$ bearing fuel pellet which is one of the desirable characteristics for designing future high burnup fuel. Neutronics calculations have been conducted for the fuel assembly with the $Gd_2O_3$ particles distributed randomly using the Monte Carlo neutron transport MVP code. The results show that the $Gd_2O_3$ particles with the diameter of 60 µm could control the reactivity similarly to the homogeneous distribution of $Gd_2O_3$ with the same total amount. The power densities at the fuel rods with $Gd_2O_3$ particles increase by about 11%, leading to the decrease of the power peak and a slightly flatter power distribution. The power peak appears at the periphery fuel pins at the beginning of burnup which decreases slightly by 0.9%. Investigation has been performed to reduce the pin power peaking factor by increasing the number of $Gd_2O_3$-dispersed fuel rods and optimizing the particle diameter. The results show that by using 18 $Gd_2O_3$-dispersed fuel rods (instead of 12 $Gd_2O_3$-bearing fuel rods) with the same total amount of $Gd_2O_3$ and the particle diameter of 300 µm, similar reactivity curve can be obtained as the reference one while the pin power peaking factor at the beginning of burnup is decreased by about 5%.



*Keywords:* Fuel assembly; VVER; $Gd_2O_3$ particle; reactivity; power distribution

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## 1. Introduction

In a light water reactor (LWR), burnable absorbers are usually used for controlling excess reactivity of the fresh fuel and the reactor core at the beginning of burnup stage, and flattening the power distribution to avoid an excessively high power peak at some fresh fuel assemblies. Integral burnable absorbers (IBAs) are the most common type in which burnable absorbing materials are integrated in a fuel assembly. The IBA is designed so that the reactivity of the fuel assembly remains relatively constant or slowly decrease in the early burnup stage until the IBA is almost depleted. This is to avoid a peak of reactivity during burnup, and consequently, avoid the appearance of a power peak during burnup. In the fuel assembly of VVER-1000 reactor, 12 gadolinium bearing fuel rods are loaded into a fresh fuel assembly to control the reactivity of the fuel assembly almost constant from the beginning of burnup to about 10-15 GWd/t. After this burnup level, the main absorbing isotopes are depleted completely and the reactivity decreases linearly with burnup similar to an assembly without gadolinium bearing rods. Gadolinia ($Gd_2O_3$) is one of the common burnable absorber materials to be used as the IBA in the fuel assembly of LWRs because of its high absorption cross section to neutrons in thermal energy range. In natural gadolinium, $Gd^{155}$ and $Gd^{157}$ are main absorbing isotopes which are about 30% of the natural isotropic compositions.

In conventional design, an amount of $Gd_2O_3$ within a few percent is mixed homogeneously with $UO_2$ fuel in several fuel rods of a fuel assembly. Since $Gd_2O_3$ has a smaller thermal conductivity than that of $UO_2$, one of the disadvantages is that the additional content of $Gd_2O_3$ leads to the decrease of the thermal conductivity of the fuel pellet [1]. For the purpose of the reduction of fuel costs, power upgrade and advanced fuel design with high burnup are desirable, which lead to the increase of the power density. Therefore, the increase of the thermal conductivity of the fuel pellets is one of the desirable characteristics. In order to avoid the problem of the decrease of the thermal conductivity due to the additional content of $Gd_2O_3$, the use of $Gd_2O_3$ in form of micro-particles in the $UO_2$ matrix could be a solution. It was reported that the thermal conductivity of $Gd_2O_3$-dispersed $UO_2$ fuel pellet is larger than that of $(U,Gd)O_2$ solid solutions with the same $Gd_2O_3$ content [3]. Iwasaki et al. [4] conducted experiments to investigate the effect of $Gd_2O_3$ dispersion on the thermal conductivity. The results showed that 10 wt% $Gd_2O_3$-dispersed $UO_2$ pellet with the diameter of the $Gd_2O_3$ particles of about 25-53 μm has the thermal conductivity of about 5.8-2.7 W/mK in the temperature range from 300 to 1273 K. This is larger than that of homogeneous mixed solid solutions (3.8 to 2.6 W/mK) with the same $Gd_2O_3$ content [4]. This means that the use of $Gd_2O_3$ particles could improve the thermal conductivity of $Gd_2O_3$-dispersed fuel pellets effectively. As mentioned in Ref. [4], the fabrication of the $Gd_2O_3$-dispersed fuel pellet would not be so complicated. It was processed similarly to the traditional fuel pellet with $Gd_2O_3$ powder. $Gd_2O_3$ particles are weighted and mixed with $UO_2$ powder in a mortar. The mixture was then pressed into a form of fuel pellet and sintered under a high pressure and high temperature condition.

In the present work, we aim at investigating, in neutronics point of view, the feasibility of using $Gd_2O_3$ particle type for reactivity controlling and the effect on the neutronics performance of the VVER-1000 fuel assembly. Spherical $Gd_2O_3$ particles were distributed randomly in the $UO_2$ matrix of fuel pellet instead of homogeneous distribution of $Gd_2O_3$ powder. The diameter of the $Gd_2O_3$ particles was determined for controlling the reactivity of the fuel assembly during burnup so that the target is to obtain the $k_\infty$ curve similarly to that of the conventional fuel assembly. Comparison of the pin-wise power distribution between the new design and the conventional assembly has also been presented. In order to optimize the pin power peaking factor, a design of fuel assembly with 18 $Gd_2O_3$-dispersed fuel rods instead of 12 $Gd_2O_3$-bearing fuel rods of the reference design has been investigated. The locations of the 18 $Gd_2O_3$-dispersed fuel rods in the assembly and the diameter of the $Gd_2O_3$ particles were determined for obtaining the similar $k_\infty$ curve but lower pin power peaking factor compared to the reference assembly.

## 2. Calculation models

Numerical calculations have been performed based on the low enriched $UO_2$ fuel assembly of the VVER-1000 reactor core using the Monte Carlo neutron transport MVP code and the JENDL-3.3 library [6,7]. The configuration and the detailed design parameters of the fuel assembly are displayed in Fig. 1 and Table 1 [5]. The assembly consists of 300 $UO_2$ fuel rods with the $^{235}U$ enrichment of 3.7 wt% and 12 $Gd_2O_3$ bearing fuel rods as shown in Fig. 1. In the numerical calculation model, spherical $Gd_2O_3$ particles are assumed to be distributed randomly in the $UO_2$