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INVESTIGATION OF THE MULTIPLYING PROPERTIES OFVVER-1000 CELLS

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Abstract: This work aims to analyze the properties of VVER-1000 cells. The objectives of this paper are to calculate the burn-up of fuel with enrichments of 4.4% and 5% with a central hole at fuel for 2, 3, and 4 burn-up cycles.

Keywords: GETERA-93, VVER (Water-Water Energetic Reactor), Fuel element (fuel element), HWR (Heavy Water Reactor), LWR (Light Water Reactor), IAEA (International Atomic Energy Agency), FA (fuel assembly), BCs (Burn-up cycles)

Introduction

The GETERA program is designed for the neutron-physical calculation of cells and polycells of nuclear reactors, both fast and thermal, in spherical, cylindrical, and flat geometry. This program represents high-quality calculations for modeling a large number of components in reactors and is comparable to simulation programs MCNPA4Candothers used by the IAEA [1].

Using a computer program GETERA-93 in this work, a computer simulation was performed in the loaded program, when nuclear fuel was introduced for theVVER-1000 reactor configuration.

Currently, uranium dioxide UO_2 is the most widespread and well-developed type of ceramic nuclear fuel used in nuclear power plants in industrial production. This fuel is used in almost all modern water-cooled reactors, including boiling and heavy-water ones, as well as in fast neutron reactors.

Uranium dioxide is a substance of dark brown color, has high hardness and brittleness, and differs from other oxygen compounds of uranium in its ability to evaporate without decomposition. At operating temperatures, the vapor pressure is low, at temperature 2360 ℃, it is about 1 mm Hg (133.3 Pa). UO2 is a semiconductor, its specific thermal conductivity at 20°C is very low, but increases with increasing temperature.

Uranium is a relatively common element that is found all over the world. It is mined in several countries and must be reprocessed before it can be used as a nuclear fuel and used nuclear reaction energies [2].

Uranium-235 is used as an energy source in various concentrations. Some reactors, such as HWR, can use natural uranium with a uranium-235 concentration of only 0.7%, while other reactors require more significant uranium enrichment to levels of 3% to 5%.

Nuclear fuel burn-up is the process of converting fissionable nuclei into non-fissionable nuclei when interacting with neutrons^{235} [3]. As a rule, this occurs due to the processes of nuclear fission and radiation capture of neutrons by fissionable nuclei.

One of the most important indicators of the efficiency of a nuclear reactor, nuclear^{235} power plant, and the nuclear fuel cycle is **nuclear fuel burn-up depth**. Nuclear fuel burn-up depth – this is the amount of energy received for the entire period of operation of nuclear fuel in the core (for the nuclear fuel campaign), perunit mass of loaded nuclear fuel.

If a nuclear reactor with a loaded nuclear fuel mass m (kg or t) has producedQ $(MW*day)$ of energy,thenthe burn-updepthisas

p_{H_2}

$\bar{B} = Q/m = Nt/m \quad (MW*day/kg \text{or} MW * day/t)$.

ρ_u

$=(1-0{,}044)\cdot 0{,}02341111=0{,}0223810212[1/cm^3\cdot 10^{24}]$

x=0,05

ρ_u

$=(1-0{,}05)\cdot 0{,}02341111=0{,}0222405545[1/cm^3\cdot 10^{24}]$

The isotopic concentration of oxygen (in nuclear fuel):

$p_O=2*p_{fuel}p_O=2*0.02341111=0.046822222[poison/cm^3*10^{24}]$

The isotopic nuclear concentration of oxygen (in the moderator):

$=2\times p_{mod}p_{H_2}$

$=2\times0.023912778=0.047825556[1/cm^3\times10^{24}$]

The isotopic nuclear concentration of hydrogen (in the moderator):

$$p_0=p_{zam}p_0=0.023912778[yd/\text{см}^{cm^3}\times10^{24}]$$

After performing these calculations, we enter the isotopic concentrations of materials into the input file "VVER1000.dat".

In the output file, we can find the multiplication factor values K_{inf}, thecoefficientsofthefour-factorformula,theaverageburn-updevelopedinincrements of 50 days, we also get the isotopic compositions of all the isotopes in each sequence.

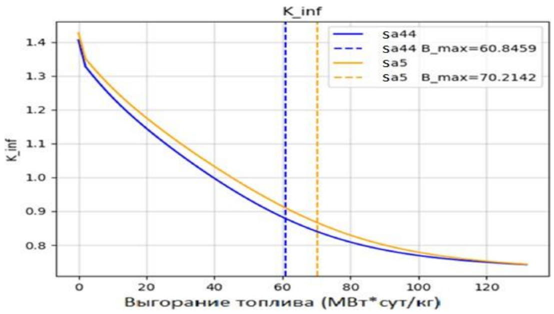

Figure 2: *Dependence of the multiplication factor $Kinf$ on the average fuel burn-up*

The fuel assembly with its characteristic dimensions is shown below. The VVER – 1000 reactor configuration of a water-cooled reactor cell has the following parameters: the cell radius is 5 mm, the fuel $UO2$ is Uranium dioxide with an enrichment of 4.4% and 5%, the shell material is zirconium with a density of 6,531 g/cm3, and the moderator is water with a density of 0.715 g/cm3.

The boundary conditions represent the total reflection of neutrons at the cell boundary.

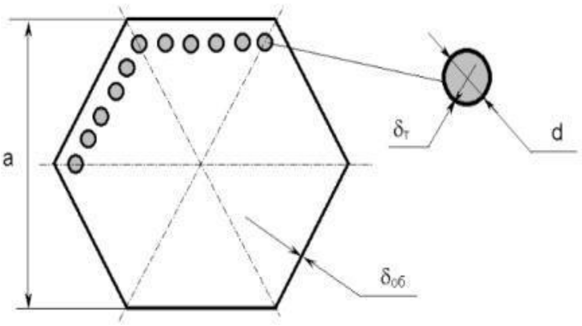

Figure1: Diagram of VVER reactor fuel assemblies with the required dimensions

The reactor can be considered on unit cell models with certain boundary conditions that water is a good absorber of thermal neutrons [5].

Continuing the calculations, we can obtain the values of nuclear isotope concentrations:

Isotopic nuclear concentrations of U^{235} is calculated as follows

$x = 0.044$

$\rho u235$

$= \text{x} \cdot \rho fuel$

$\rho u235$

$= 0{,}044 \cdot 0{,}02341111 = 0{,}0010300884$ [1

$cm3$

1024]

x = 0,05

$\rho u = 0{,}05 \cdot 0{,}02341111 = 0{,}001170555[1/cm3 \cdot 1024]$

The isotopic nuclear concentration of $U238$ is calculated as follows

$x = 0.044$

$\rho u238 = (1 - \mathrm{x}) \cdot \rho fuel$

$\rho u = (1 - 0{,}044) \cdot 0{,}02341111 = 0{,}0223810212[1/cm3 \cdot 1024]$

x = 0,05

$\rho u = (1 - 0{,}05) \cdot 0{,}02341111 = 0{,}0222405545[1/cm3 \cdot 1024]$

The isotopic concentration of oxygen (in nuclear fuel):

$pO = 2 * pfuel\ pO = 2 * 0.02341111 = 0.046822222[poison/cm3 * 1024]$

The isotopic nuclear concentration of hydrogen (in the moderator):

$pH2$
$= 2 \times pmodpH2$
$= 2 \times 0.023912778 = 0.047825556\ [1/cm3 \times 1024]$

The isotopic nuclear concentration of oxygen (in the moderator):

$p0 = pzam\ p0 = 0.023912778[yd\ /\text{см}cm3 \times 1024]$

After performing these calculations, we enter the isotopic concentrations of materials into the input file "VVER1000.dat”.

In the output file, we can find the multiplication factor values $Kinf$, the coefficients of the four-factor formula, the average burn-up developed in increments of 50 days, we also get the isotopic compositions of all the isotopes in each sequence.

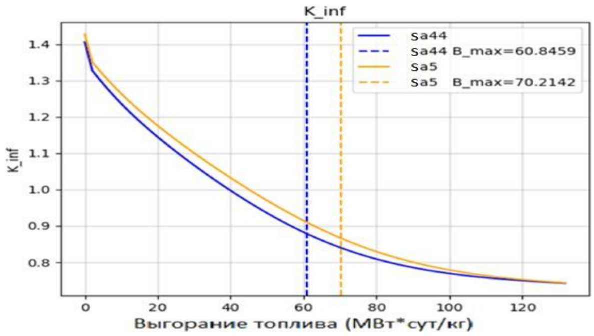

Figure 2: Dependence of the multiplication factor $Kinf$ on the average fuel burn-up

For the enrichment of 4.4%

Time in days
burn-up depth
Two BCs
1224
54.853
Three BCs
1378
60,8459
Four BCs
1471
64,9023

For 5% enrichment

Time in days burn-up depth Two BCs
1414
62,4126
Three BCs

1592 1699
70,2142 74,8951
Four BCs

For the enrichmentof4.4%		
	Timein days	burn-updepth
TwoBCs	1224	54.853
ThreeBCs	1378	60,8459
FourBCs	1471	64,9023
For5%enrichment		
	Timein days	burn-updepth
TwoBCs	1414	62,4126
ThreeBCs	1592	70,2142
FourBCs	1699	74,8951

Table 1: Burn-up depth for 2, 3, and 4 BCs with increased fuel enrichment.

Thus, from the values obtained in the table, we can see in Figure 2, that the dependence of the multiplication factor decreases as the nuclear fuel burn-up increases to a certain point at which this value becomes subcritical. We can say that at the beginning the fresh fuel has a multiplication factor of 1.40575, and when it starts to burn nuclear fuel, it decreases. Analysis of the calculations shows an increase in the burn-up depth with an increase in enrichment from 4.4% to 5%.

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