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Research Of The Multipliing Properties Of Vver Cells

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Abstract
The purpose of this work is to analyze the properties of VVER cells at elevated nuclear fuel contents using the GETERA-93 program.
The objectives of this work are the following:
2. Calculation of fuel burnup with 2, 3 and 4 overloads with a central hole at fuel enrichments of 4.4% and 5%.
1. Calculation of fuel burnup with 2, 3 and 4 overloads with increased fuel content at fuel enrichments of 4.4% and 5%.
2. Analysis of changes in the concentrations of the isotopes 235U, 239Pu, 240Pu, 241Pu during fuel burnout with a central hole and without a central hole at fuel enrichments of 4.4% and 5%.

Key words: GETERA-93, VVER (water-cooled power reactor), TVEL (fuel element), NPP - nuclear power plant, IAEA (International Atomic Energy Agency), TVS (fuel assembly). ECCS - emergency zone cooling systems.

Introduction

The limiting values of the parameters have almost been reached: almost 5% enrichment in uranium-235, all possibilities for increasing the height of the fuel column have been used, the diameter of the central hole in the fuel pellet has been reduced as much as possible (in some modifications of the fuel assembly there is no hole in the pellet).
To carry out the neutronics calculation, the GETERA program was used. The GETERA program is intended for neutronics calculations of cells and polycells of nuclear reactors, both fast and thermal, in spherical, cylindrical and flat geometry.
VVER is a pressurized water-water pressurized nuclear power reactor, a representative of one of the most successful branches of development of nuclear power plants that have become widespread in the world. The common name for reactors of this type in other countries is PWR; they are the basis of the world's peaceful nuclear energy[1].
The fuel assembly of the VVER-1000 reactor is an active structure of 312 fuel rods, 18 guide channels, 15–12 spacer grids and one lower grid [2]. In Fig. Figure 1 shows a general view of the fuel assembly: a part of the spacer grids is conventionally shown and a part of the fuel rods is not shown in height (to visualize the guide channels).

1. General view of fuel assemblies

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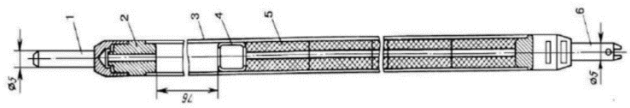
Modern fourth-generation fuel for VVER-1000 reactors (TVSA-12 Plus and TVS-2M) allows consumers to reduce the fuel component of the cost of electricity by 2-4% and increase the technical and economic characteristics of nuclear power plants by increasing the operating time and introducing extended fuel cycles [3].

2. Fuel assembly for the VVER-1000 reactor.



3. Fuel rod: 1 - upper plug, 2 - spacer, 3 - shell, 4 - spring insert, 5 - tablet, 6 - lower plug.
The fuel element (fuel element) of the VVER-1000 nuclear reactor (Fig. 3) is a tube filled with CSG uranium dioxide pellets and hermetically sealed with welded end parts. The tube is made of zirconium alloyed with 1% niobium, alloy density 6.55 g/cm3, melting point 1860 °C.

2. Materials and methods
Uranium is a relatively common element that is found throughout the world. It is mined in a number of countries and must be processed before it can be used as nuclear fuel and harness the energy of a nuclear reaction [2].
Uranium-235 is used as an energy source in various concentrations. Some reactors, such as the heavy water pressurized water reactor, can use natural uranium with a concentration of uranium-235 as low as 0.7%, while other reactors require more significant uranium enrichment to levels of 3% to 5%.
Burnup of nuclear fuel is the process of transformation of fissile nuclide nuclei into non-fissile nuclei when interacting with neutrons [7]. As a rule, this occurs due to the processes of nuclear fission and radiative capture of neutrons by fissile nuclei.
One of the most important indicators of the efficiency of a nuclear reactor, a nuclear power plant and the nuclear fuel cycle as a whole is the burnup of nuclear fuel. The burnup of nuclear fuel is the amount of energy received during the entire period of operation of nuclear fuel in the core (during a nuclear fuel campaign), per unit mass of loaded nuclear fuel. Most often, when determining the efficiency of a nuclear fuel cycle, they operate on the average burnup depth (B), which can be called specific energy release [4].
If a nuclear reactor with a mass of loaded nuclear fuel m (kg or t) has generated Q (MW·day) energy, then the burnup depth (or)
For metallic uranium, the burnup depth of nuclear fuel ranges from 3 to 3.5 (MW day/kg), and for its compounds it can be significantly greater. In modern VVERs with enrichment up to 5%, the burnup depth of nuclear fuel is about 50 (MW day/kg), and in the most stressed fuel rods it is even more. In energetic fast and high-temperature nuclear reactors, the burnup depth is about 150 (MW day/kg). In an experimental fast reactor (France), a burnup value of 210 MW·day/kg was achieved. The maximum burnup depth in individual fuel elements is always greater than the average value for the core by an amount proportional to the coefficients of heat release unevenness and, accordingly, to the neutron flux density. The maximum burnup depth is determined by the technological resistance of fuel elements depending on fuel enrichment, type of coolant, cladding material and fuel element design.
The burnup depth can be expressed through the ratio of the masses of burnt and loaded nuclear fuel: (kg/t).
By burning 1.23 g of 235U in the nuclear reactor core, one can obtain an energy of 1 MW·day, thus we obtain:

$$1(\text{Мвт}\cdot\text{сут}/\text{т}) = 1,23\cdot 10^{-3}(\text{кг}/\text{т}) \;;$$

$$1(\text{Мвт}\cdot\text{сут}/\text{кг}) = 1,23(\text{кг}/\text{т}) \;;$$

$$\overline{B'} = 1,23\overline{B}(\text{кг}/\text{т})$$

If expressed in ($\text{М}_{\text{вт}}$·сут/кг).

3. Results and discussion
Below is the fuel assembly with its characteristic dimensions. The configuration of the VVER reactor - 1000 reactor cell, cooled by water, has the following parameters: cell radius 5 mm, fuel - enriched 4.4% and 5%, shell material - zirconium (0.715 g/cm3), moderator - water with a density of 0.715 g/cm3 cm3. The boundary conditions represent the total reflection of neutrons at the cell boundary.
1. Calculation of fuel burnup with 2, 3 and 4 overloads with a central hole at fuel enrichments of 4.4% and 5%.
In the shown file we can find the values of the multiplication factor, the coefficients of the formula of four factors, the

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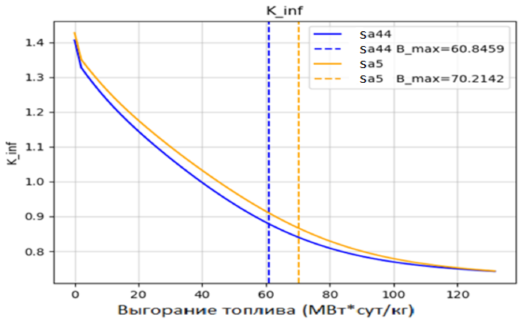
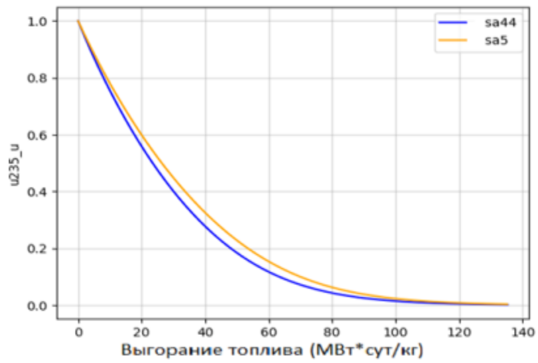
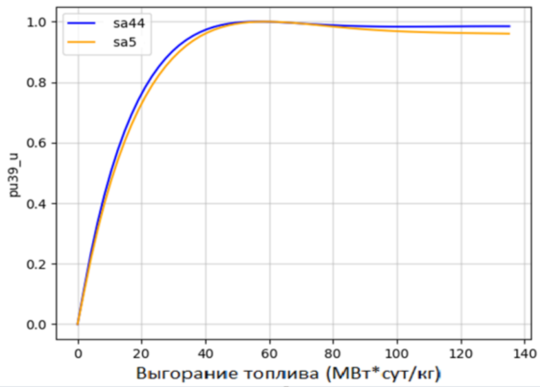
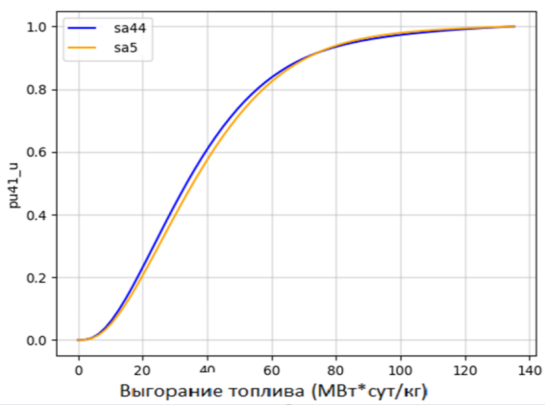
average of the burnt manifestation in increments of 50 days, in addition, we obtain the isotopic compositions of all nuclides in each sequence.
During this period, we will analyze the properties of neutron reproduction, so we obtained values for each time step, as well as the isotopic composition of nuclei , , , , which previously interested us in the described properties.
All that is highlighted in purple, please enter text, not formulas.



4. Dependence of the neutron multiplication factor based on the average fuel burnup.







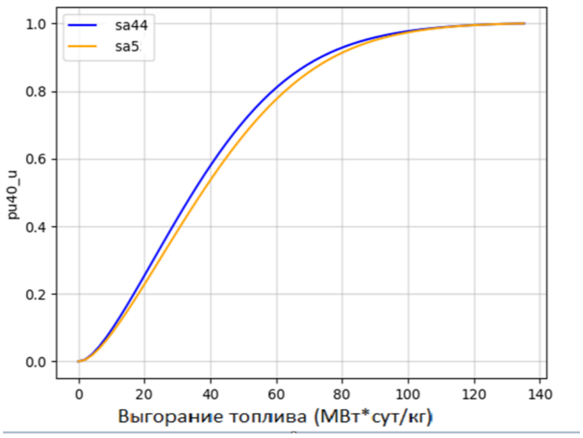
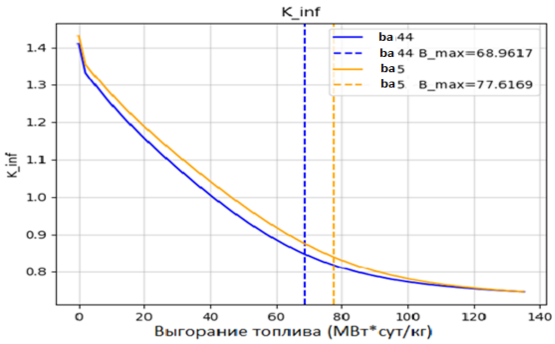


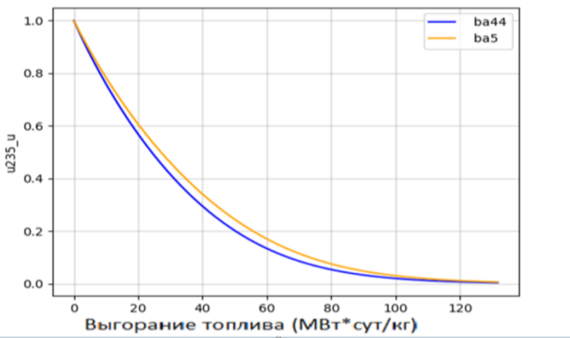
Table 1 Burnup depth with 2, 3 and 4 overloads for 4.4% and 5% enrichment.

For enrichment 4.4%		
–	Time in days	burn-up depth
Two overloads	1224	54,0853
Three overloads	1378	60,8459
Four overloads	1471	64,9023
For enrichment 5%		
–	Время в днях	глубина выгорания
Two overloads	1414	62,4126
Three overloads	1592	70,2142
Four overloads	1699	74,8951

1. Calculation of fuel burnup with 2, 3 and 4 overloads with increased fuel content at fuel enrichments of 4.4% and 5%.



6. Dependence of neutron multiplication factor based on average fuel burnup.



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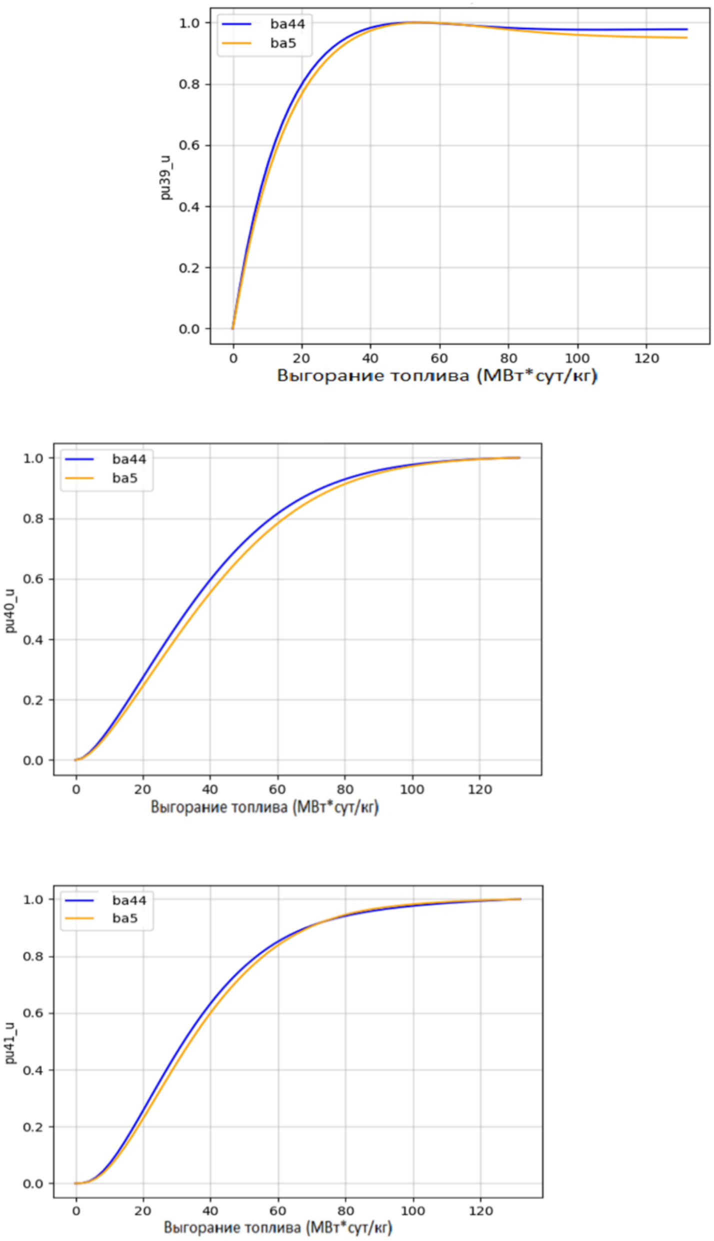

7. Relative behavior of isotope concentrations of isotopes ^{235}U , ^{239}Pu , ^{240}Pu , ^{241}Pu , depending on fuel combustion.

Table 2 Burnout depth with 2, 3 and 4 overloads with increased fuel content.

For enrichment 4.4%		
–	Time in days	Burn-up depth
Two overloads	1354	61,2993
Three overloads	1524	68,9617
Four overloads	1626	73,5591
For enrichment 5%		
–	Time in days	Burn-up depth
Two overloads	1525	68,9928
Three overloads	1717	77,6169
Four overloads	1832	82,7914

4. Conclusions

From Fig. 4, 6 we can say that at the beginning the new fuel has a multiplication rate of 1.40575 and 1.42699, and when it starts to burn nuclear fuel, it decreases (the number of fissioned isotopic sheets due to fission reactions occurs inside

the nucleus).
Analysis of the calculations performed shows an increase in burnup depth with increasing enrichment from 4.4% to 5% and with increasing amount of fuel (with and without a central hole).
Also in the graph of isotope concentration ratio values (Figures 5 and 7), it can be noted at first glance that as fuel burns, the isotopic concentration of uranium 235 decreases, and the isotopic compositions of plutonium 239, 240 and 241 increase simultaneously as uranium decreases.

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