Uncertainty analysis in the physical calculations of VVER cells in the daily maneuvering schedule

Rahman SK Anisur¹, M A Uvakin ¹

¹National Research Nuclear University (MEPhI), City-Moscow, Kashira Highway, House-31, 115409. Tel:+7(495) 788-56-99, Fax: +7(499) 324-21-11, E-mail: info@mephi.ru)

Abstract. This work is oriented to actual problems resolving of VVER reactor. The problem of reactor core is- how many zone is needed in both, fuel rod and fuel rod with gadolinium (tveg). Work contains deviation of multiplication coefficient and burnup estimating approach. To solve this problem, program GETERA 93 was used, and for data preparing program SIMPLE FORTRAN was used.

1. Introduction

Fuel assembly FA is the main part for any type of reactor. It is a machine-building product containing fissile materials and intended to generate thermal energy in a nuclear reactor through the implementation of a controlled nuclear reaction. It is usually a four-sided (PWR) or hexagonal (VVER) beam of fuel elements 2.5-3.5 m long (approximately equivalent to the height of the core) and 30-40 cm in diameter, made of stainless steel or zirconium alloy (to reduce neutron absorption) [1].

The fuel elements are assembled in the fuel assemblies to simplify the registration and transfer of nuclear fuel in the reactor. One fuel assembly usually contains 150-350 fuel rods, usually 200-450 fuel assemblies are placed in the reactor core. Fuel assembly (FA) formed with a rigid frame by six corners and spacing gratings. The main emphasis was placed on increasing the burnup depth, increasing the operational reliability and increasing the flexural rigidity of the fuel assembly [2]. The completed modernization of the assemblies allowed to extend the period of their operation to 4-5 years, and also provided the opportunity to work in the maneuvering mode (daily change in the power unit's capacity).

2. State of the problem

At present, the possibility of working in a maneuverable load mode is considered as one of the promising competitive advantages of modern projects of water-and-water power reactors. Therefore, the rationale for the security of the reactor installation. When working in maneuver mode is an urgent task. A feature of this operating mode of the reactor is a change in power, which in turn leads to a constant change in other neutron-physical and thermal-hydraulic parameters during the process. Therefore, in justifying the security of the reactor installation, the problem arises of choosing the most unfavorable time for the origin of the initial event.

As a result, it is possible to obtain the dependence of the criteria parameters as a function of the regulatory parameters. This allows us to analytically solve the problem of finding an extremum with
allowance for a given space of values of the regulatory parameters for the maneuvering period. As a result, the most unfavorable initial state and the corresponding moment of time are determined, when the occurrence of the initial event will be the most conservative. Since the calculation of all possible states is rather difficult, the development of this technique seems to be an urgent task.

Maneuvering is a process in which change the power of a reactor. In the pick hour, reactor needs to work by 100% power, but in the off pick hour need to change the power of a reactor. For this reason, at the present time maneuvering load mode is considered one of the most advantages for the VVER power reactors. One the other hand maneuvering is very important for the safety assessment. For the maneuvering and without maneuvering regime mode which is shown below.

![Figure 1. Without maneuvering mode](image1)

![Figure 2. With maneuvering mode](image2)

In pick hour reactor work by 100% power (figure 1). On the other hand, in off pick hour, 8 hours reactor works by 50% power and 16 hours work by 100% power figure 2.

3. Description of calculation model
The GETERA-93 program can be used to solve a wide range of tasks, both research and applied. With its help, it is possible to study the neutron-physical characteristics of the reactors at the cell and poly cell level. The algorithm for the multiplicity of the cell makes it possible to simulate sufficiently large fragments of the reactor on a small number of cells. In addition to calculations of the fragments of the reactor, the built-in algorithms allow modeling the burnup processes in the reactor and calculating the characteristics of fuel cycles: for example, the coarse fuel burnup in reactors with cyclic and in reactors with continuous fuel overload.
Another large area of application of this program is the preparation of libraries of small sections so that they can later be used in full-scale models. The program allows you to take into account the environment of the cell when preparing sections, which is important when preparing the correct constants for small programs. The program prepares both macromicrosequences and constants for dynamic software complexes.

Fuel assembly FA contains four types of rod:
1. Fuel rod
2. Fuel with gadolinium rod (tveg)
3. Central rod
4. Guide channel

Fuel with gadolinium rod (tveg) is fabricated by 8% gadolinium and (3.6%- 4%) \( \text{U}^{235} \). Fuel rod and fuel with gadolinium rod figure 4 are divided into five zones. The first zone, which is contains “He” gas. The second zone, which is contains fuel (\( \text{U}^{238} \)). The third zone which is contains clearance zone. Forth zone contains shell zone and the fifth zone is coolant zone.
Figure 4. Fuel zone or Fuel with gadolinium zone position in 0.39 cm radius

But when the fuel zone and the fuel with gadolinium zone were divided into five sub-zones, then the calculated figure which is shown below figure 5 and figure 6.

Figure 5. Position of the fuel in different radius in the fuel rod
4. Calculation of the result

When in the fuel rod only one zone is fuel, then the deviation of multiplication coefficient vs burnup which is calculated by the program GETERA-93 shown in the figure 7. This calculation for the fuel assembly type 1 (when in the Fuel assembly has 6 fuels with gadolinium rods and enrichment of uranium 4.95%).

![Figure 6. Position of the fuel with gadolinium in different radius in the fuel with gadolinium rod](image6)

![Figure 7. Deviation of multiplication coefficient VS burnup, when in the fuel rod only one zone is fuel (fuel assembly type 1)](image7)
In figure 8, the calculated result showed that the presence of additional fuel zone (2, 3, 4, and 5) the deviation of multiplication coefficients are not changed.

![Figure 8](image)

**Figure 8.** Deviation of multiplication coefficient VS burnup, the position of fuel in different radius in the fuel rod (fuel assembly type 1)

In the figure 9, for the fuel assembly FA type 2 (when in the Fuel assembly has 27 fuels with gadolinium rods and enrichment of uranium 4.4%) and in the Figure 10, the fuel assembly type 3 (when in the Fuel assembly has 27 fuels with gadolinium rods and enrichment of uranium 4.95%) were the same result. The same result means: Presence of additional fuel zone in the fuel rod, deviation of multiplication coefficients are not changed.

![Figure 9](image)

**Figure 9.** Deviation of multiplication coefficient VS burnup, the position of fuel in the fuel rod in different radius (fuel assembly type 2)
Figure 10. Deviation of multiplication coefficient VS burnup, the position of fuel in the fuel rod in different radius (fuel assembly type 3)

On the other hand, when the fuel with gadolinium rod (tveg) zone was divided into five sub-zones figure 6 and put the fuel with gadolinium, then the deviation of multiplication coefficient vs burnup which is calculated by the program GETERA-93 shown in the figure 11. But in this calculation shown that the presence of additional fuel with gadolinium zone (2, 3, 4, and 5), the deviation of multiplication coefficients are decreasing. This result for the fuel assembly type 1 (when in the Fuel assembly has 6 fuels with gadolinium rods and enrichment of uranium 4.95%).

Figure 11. Deviation of multiplication coefficient VS burnup, the position of fuel with gadolinium zone in different radius in the fuel with gadolinium rod (fuel assembly type 1)
In figure 12 for the fuel assembly FA type 2 (when in the fuel assembly has 27 fuels with gadolinium rods and enrichment of uranium 4.4%) and in the Figure 13- for the fuel assembly type 3 (when in the fuel assembly has 27 fuels with gadolinium rods and enrichment of uranium 4.95%) were the same results. The same result means: Presence of the additional fuel with gadolinium zone in the fuel with gadolinium rod, the deviation of multiplication coefficients are decreasing.

**Figure 12.** Deviation of multiplication coefficient VS burnup, the position of fuel with gadolinium zone in different radius in the fuel with gadolinium rod (fuel assembly type 2)

**Figure 13.** Deviation of multiplication coefficient VS burnup, the position of fuel with gadolinium zone in different radius in the fuel with gadolinium rod (fuel assembly type 3)
5. Calculate the fuel temperature reactivity coefficient

Research work was applied in the field of fuel temperature reactivity coefficient vs burnup, which is shown in the figure 14.

5.1 Without maneuvering step:

Burnup for the 300 days when the temperature was 1000k, then the multiplication coefficient $K_{\infty 1}$ was calculated. After that, the temperature was changed to 990k and again the multiplication coefficient $K_{\infty 2}$ was calculated. In the next step, the fuel temperature coefficient $\alpha_{\text{fuel}}$ calculated by using formula

$$\alpha_{\text{fuel}} = \frac{\Delta \rho}{\Delta T} = \left( \frac{1}{k_{\infty 1}} - \frac{1}{k_{\infty 2}} \right)/(T_2-T_1).$$

5.2 Maneuvering step:

In the same way, the maneuvering step was calculated. But in the fuel temperature reactivity coefficient ($\alpha_{\text{fuel}}$) is always negative. To calculate this condition the next steps were followed. Firstly, one burnup and his multiplication coefficient $K_{\infty 1}$ was taken in the output file from the fuel assembly type (1). This multiplication coefficient was the density ($\rho$). Secondly, this density ($\rho$) was put in the input file with temperature 990k and got the multiplication coefficient $K_{\infty 2}$. In the same way, 7 points were calculated. Then the calculated result of fuel temperature reactivity coefficient ($\alpha_{\text{fuel}}$) vs burnup which is drawn in figure 14.

![Figure 14. Fuel temperature reactivity coefficient VS burnup](image)

6. Result analysis

6.1 For the fuel rod

In figures 7,8,9,10 the result for the same burnup was calculated, but it is known that burnup time is not same for the maneuvering and without maneuvering mode. For this reason, the peak was shown. But in the figure 7 and figure 8 peak is small than the fuel assembly type 2 (figure 9) or fuel assembly type 3.
figure 10. Because in fuel assembly FA type 1 has 6 fuel with gadolinium rods. For this reason, burnup time is small than fuel assembly type 2 or fuel assembly type 3. On the other hand, figure 9 in fuel assembly type 2, and figure 10 fuel assembly type 3, has 27 fuels with gadolinium rods. For this reason, the difference of burnup time is greater than fuel assembly type 1. For this reason, in these two figures, the big peak was shown. Presences of additional fuel zones in the fuel rod, the deviation of multiplication coefficients are not changed. Because in the fuel rod has not gadolinium fuel. For this reason, fuel may be burned more evenly.

6.2 For the fuel with gadolinium rod
For the same reason, the small peak figure 11 and the big peak figure 1 and figure 13 were the presence, which is discussed in the above. But in the fuel with gadolinium rod presence of additional fuel with gadolinium zone, the deviations of multiplication coefficients are decreasing. Because, more gadolinium fuel rod absorbed the more neutrons, for this reason, $\Delta K_{\infty}$ decreasing.

6.3 Reactivity coefficient of the fuel temperature
In figure 14 it is the reactivity coefficient of the fuel temperature vs burnup figure. In the reactor core when the temperature is increasing at that time U$^{238}$ more absorbed the neutron and energy is decreasing. For this reason, temperature reactivity coefficient is always negative. It is a very important parameter for the reactor. Because, if the temperature in the reactor core is increased, then the negative reactivity is added to the core. This negative reactivity decreases the thermal power. In this time the reactor power stabilizes itself and stays safe.

7 Result
In the present work, it was found that when creating a design model of the VVER reactor fuel assembly, then in the fuel rod only one fuel zone is sufficient, but five zones are needed in the fuel with gadolinium rod. If used more zones in the fuel rod or the fuel with gadolinium rod, the result will not change, but the calculation will be more complicated.

8 Conclusion
The program GETERA 93 allows the model conditions of neutron-physics experiments correctly and calculates the measured parameters: reaction rates, resonance integrals, multiplication coefficient and various indices. The multiplication coefficient is one of the most important parameter for the nuclear power reactor. To reduce the deviation of multiplication coefficient is the main goal for the nuclear power plant safety. In this work, it is understood that to use the more zone in the fuel with gadolinium rod will be fruitful to safe the nuclear power plant.

References
[1] Kurchenkov A Yu, Kovel A I and Chapaev V M, Account for the burnout of the parental rpz in the VVER-1000. Questions of atomic science and technology. Series: Physics of Nuclear Reactors, 2012, No 1. Page 43-53
[2] Gerasimchuk O G, Orlov V I and Ukrainstev V F, Analysis of physical states of VVER-1000 reactor and control of emergency situation. Proceedings of high educational institutions. Nuclear power, 2003 No 1. Page 57-69.
[3] Getya S I, Krapivtsvet V G, Markov P V, Solonin V I and others. Modeling temperature nonuniformities in a fuel-element bundle of a VVER-1000 fuel assembly. Atomic energy, 2013. Volume 114, No 1. Page 69-72.
[4] Melikhov V I, Melikhov O I, Yakush S E and others. A study of boron dilution in VVER-1000 reactor. Thermal Engineering, 2002. Volume 49, No 5, page 372-376.

[5] Bikeev, A., Kalugin, M., Shcherenko, A. et al. Annals of Nuclear Energy (2018) 117:60 https://doi.org/10.1016/j.anucene.2018.03.001

[6] Nikulina, A.V., Peregud, M.M., Vorob’ev, E.E. and others. Atomic Energy (2018) 123:235. https://doi.org/10.1007/s10512-018-0332-6

[7] Dubov, A.A. Atomic Energy (2018) 123: 365. https://doi.org/10.1007/s10512-018-0354-0

[8] Alekseev, A.V., Goryachev, A.V., Izhutov, A.L. and others. Atomic Energy (2018) 123: 159. https://doi.org/10.1007/s10512-018-0318-4