**ЭКСПЛУАТАЦИЯ ОБЪЕКТОВ АТОМНОЙ ОТРАСЛИ**

*УДК: 621.039.5:004*

# СРАВНЕНИЕ РЕЗУЛЬТАТОВ АНАЛИЗА НЕОПРЕДЕЛЕННОСТИ В ФИЗИЧЕСКИХ РАСЧЕТАХ ЯЧЕЕК ВВЭР В СУТОЧНОМ ГРАФИКЕ МАНЕВРИРОВАНИЯ ДВУМЯ ПРОГРАММАМИ GETERA И WIMS

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Работа ориентирована на решение реальных задач реактора ВВЭР. Решается проблема моделирования ТВЭЛа и ТВЭЛа с гадолинием в ВВЭР, а именно, анализируется на какое количесвто расчётных слоёв необходимо разбивать топливный стержнь и топливо с гадолиниевым стержнием. Работа содержит зависимость отклонения коэффициента размножения нейтронов от выгорания. Для решения данных задач использовались программы GETERA-93 и WIMS. Для подготовки данных была использована SIMPLE FORTRAN.

*Ключевые слова:* топливный стержень, выгорание, топливная зона, топливный стержень с гадолинием (твэг), GETERA-93, SIMPLE FORTRAN.

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## 1. Introduction

In first article [http://iopscience.iop.org/article/10.1088/1742-6596/1133/1/012048] it was showed that in fuel rod only one zone is sufficient but in fuel with gadolinium rod five zones are needed. In this article fuel zone (in the fuel rod) and fuel with gadolinium zone (in the fuel with gadolinium rod) are divided about five sub-zones and tried to prove the first article by another program WIMS. The WIMS program (Winfrith Improved Multigroup Scheme) is designed to calculate the neutron-physical characteristics of reactor cells on thermal neutrons, including burnout calculations. The program uses its own 69-group library of micro constants. A characteristic feature of the program is a two-step approach to the calculation of the spatial energy distribution of neutrons in a cell. At the first stage, a detailed spectrum is calculated in 69 groups in each of the zones specific for the cell (PIN-CELL): fuel, shell, coolant, and retarder, which is shown in the Figure 1.The collision probability method is used.

On the second stage- the sections are reduced to a certain small-scale approximation, in which spatial distributions of neutrons along the cell are calculated. At the same time, it is possible, if desired, to choose either the method of discrete ordinates or the collision probability method. Further, the solution, taking into account the leakage, is modified and small-scale flows unfold into 69 groups to calculate the reaction rates of the given isotopes. The collision probability method is implemented in WIMS to solve the transport equation in one-dimensional cylindrical geometry.

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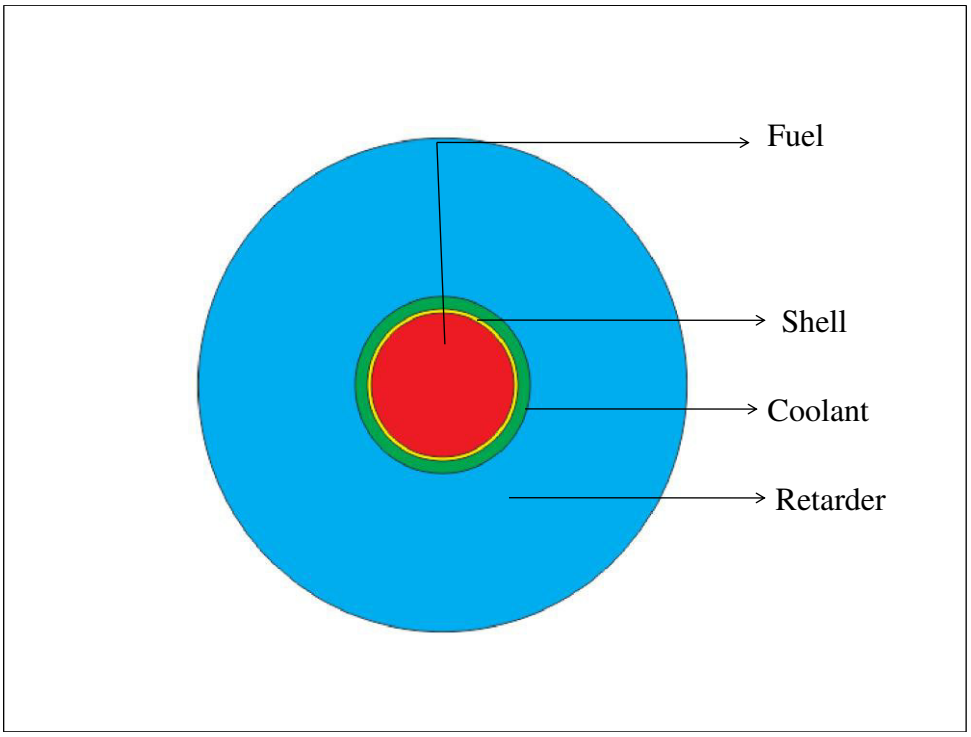



Fig. 1 – Pin cell

## 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 is shown below.

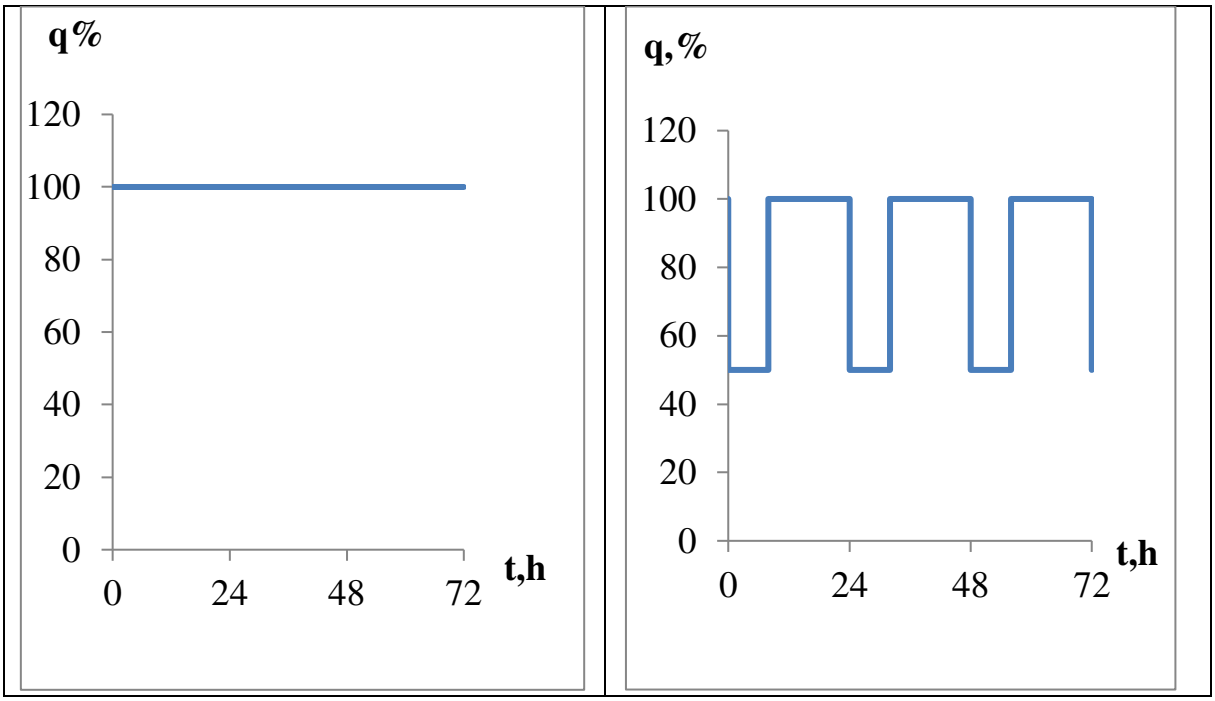



Fig. 2 – Without maneuvering and with maneuvering mode

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

### 3. Descriptionof the calculation model

The Winfrith improved multigroup scheme (WIMS) is a general code for reactor lattice cell calculation on a wide range of reactor systems. In particular, the code will accept rod or plate fuel geometries in either regular arrays or in clusters and the energy group structure has been chosen primarily for thermal calculations. The basic library has been compiled with 14 fast groups, 13 resonance groups and 42 thermal groups, but the user is offered the choice of accurate solutions in many groups or rapid calculations in few groups. Temperature-dependent thermal scattering matrices for a variety of scattering laws are included in the library for the principal moderators which include hydrogen, deuterium, graphite, beryllium and oxygen.

The treatment of resonances is based on the use of equivalence theorems with a library of accurately evaluated resonance integrals for equivalent homogeneous systems at avariety of temperatures. The collision theory procedure gives accurate spectrum computations in the 69 groups of the library for the principal regions of the lattice using a simplified geometric representation of complicated lattice cells. The computed spectra are then used for the condensation of cross-sections to the number of groups selected for the solution of the transport equation in detailed geometry. The solution of the transport equation is provided either by use of the Carlson DSN method or by collision probability methods. Leakage calculations including an allowance for streaming asymmetries may be made using either diffusion theory or the more elaborateB1-method.The output of the code provides eigenvalues for the cases where a simple buckling mode is applicable or cell-averaged parameters for use in overall reactor calculations. Various reaction rate edits are provided for direct comparison with experimental measurements.

Isotope $^{238}$U is described in the library by the recommended nuclide 2238 and has three

versions with different tables of resonance parameters - 2238.2, 2238.3, 2238.4. Resonance tables 2238.2 were obtained from the UKNDL files, which are close to the corresponding ENDF / B-4 data. Correction of this nuclide by the authors in the direction of decreasing the resonant integral uniformly in all groups outside the connection with the files of the estimated data led to the nuclide 2238.4. Calculations with its use gave more satisfactory results on the criticality of experimental assemblies. In the library there are two versions of the resonance tables of the 235U - 235.2 and 235.4 isotope. The authors recommend to use nuclide 235.4. Source of nuclide 235.2 is the UKNDL estimated data system. Nuclide 235.4 differs from the nuclide 235.2 by a correction toward a decrease in the fission source in the resonant groups by ~ 15%.

In the reactor active zone has 163 fuel assemblies. In every fuel assembly contains 312 fuel rods (Fig-3). 312 fuel rods are divided into four types.1) Fuel rod, which only contains $U^{235}$ fuel.2) Fuel with gadolinium rod, which contains $U^{235}$+Gd. (Percentage of gadolinium is shown in the table. 3) Central rod, which contains Fe, Sn, Nb, Zr alloy. 4) Guide channel, which also contains the same alloy.

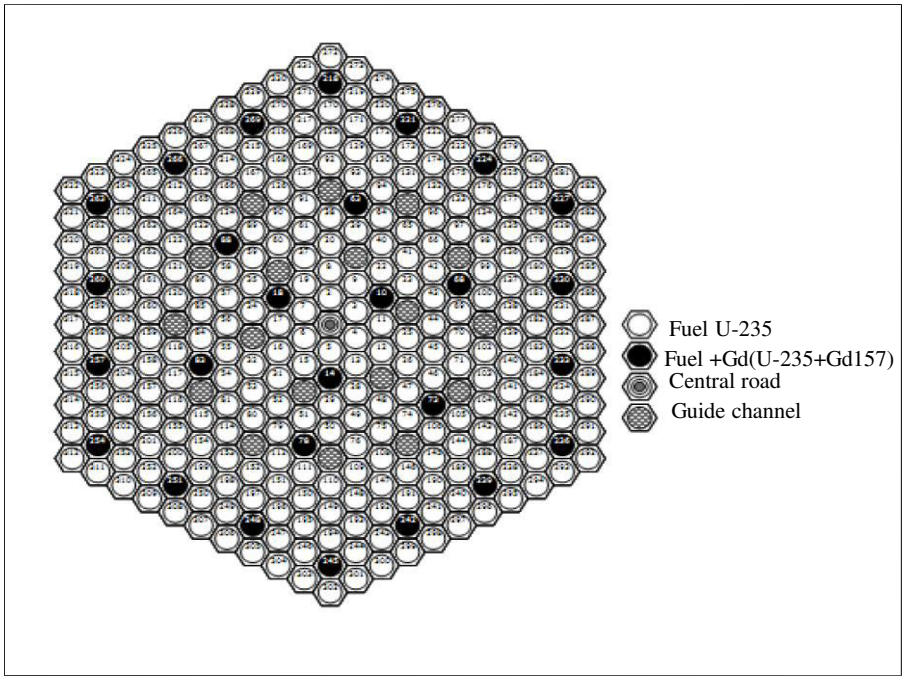



Fig. 3 – 312 fuel rods assembly

Table 1 – Characteristics of fuel U235 and gadolinium Gd

| Fuel assembly type | Average fuel enrichment 235U, wt.% | The number of fuel rods of various types and their enrichment, 235U, weight. % | Characteristics of fuel cells with gadolinium | | |
|---|---|---|---|---|---|
| | | | Number of fuel with gadolinium | Fuel enrichment of fuel with gadolinium, 235U, weight. % | Content$Gd_2O_3$, weight. % |
| Fuelassembly Type-1 | 4,93 | 306/4,95 | 6 | 4,0 | 8 |
| Fuelassembly Type-2 | 4,33 | 285/4,40 | 27 | 3,6 | 8 |
| Fuelassembly Type-3 | 4,87 | 285/4,95 | 27 | 4,0 | 8 |

Every fuel rod and fuel with gadolinium rod is divided by four zones which are in Figure 1. In this article, 7 fuel rods taken form 312 fuel rods and calculated simple model by

the program WIMS. Which is drown in the Figure 4(left) and Figure 5(left). Central fuel rod ($U^{235}$) is surrounded by six fuel ($U^{235}$) rods which is in figure 4 (left). Central fuel with gadolinium rod is surrounded by six fuel ($U^{235}$) rods which is in figure5 (left). Central fuel rod and fuel with gadolinium rod are divided into five sub-zones, which is shown in the figure 4 (right) and figure 5 (right) respectively.

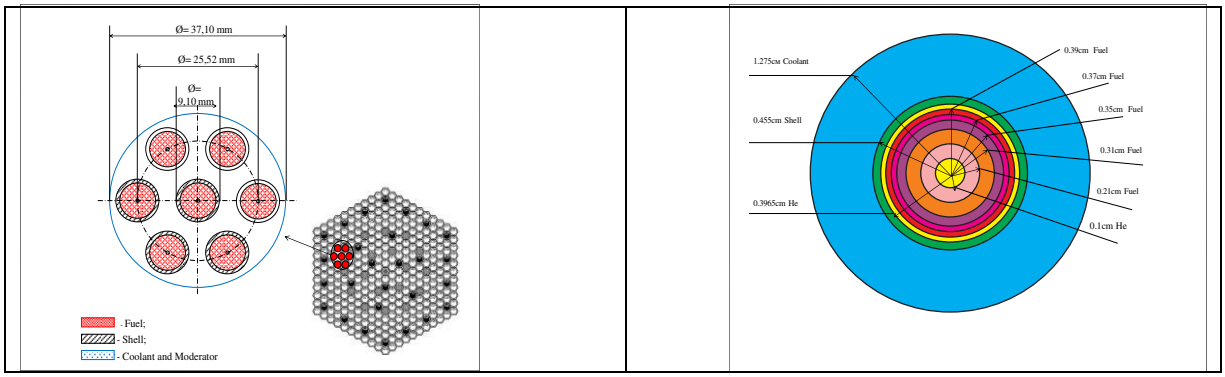



Fig. 4 –The central fuel rod is surrounded by six fuel rods (left) and the central fuel rod is divided by five sub-zones (right)

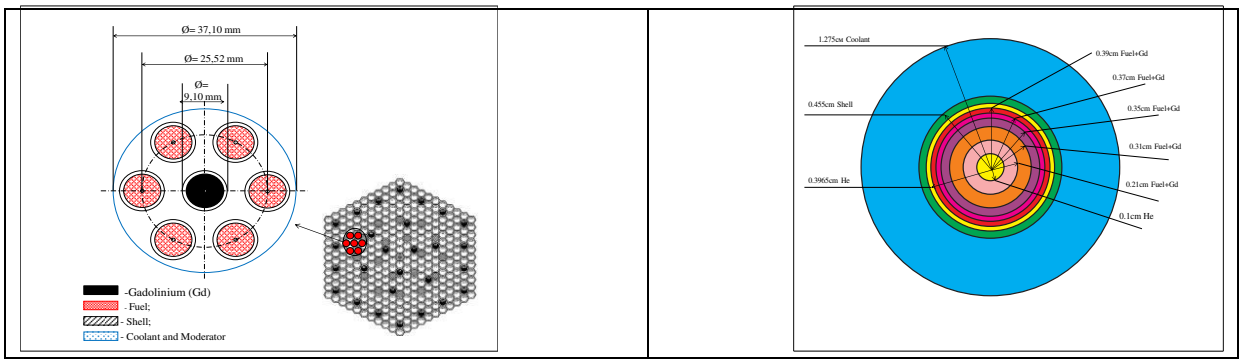



Fig. 5– Fuel with gadolinium rod surrounded by six fuel rod (left) and Central fuel with gadolinium rod is divided by five sub-zones (right)

## 4. Calculation of the result

When in the fuel rod only one zone is fuel Figure 1, then the deviation of the multiplication coefficient vs burnup which is calculated by the program WIMS shown in the Figure-6.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%).

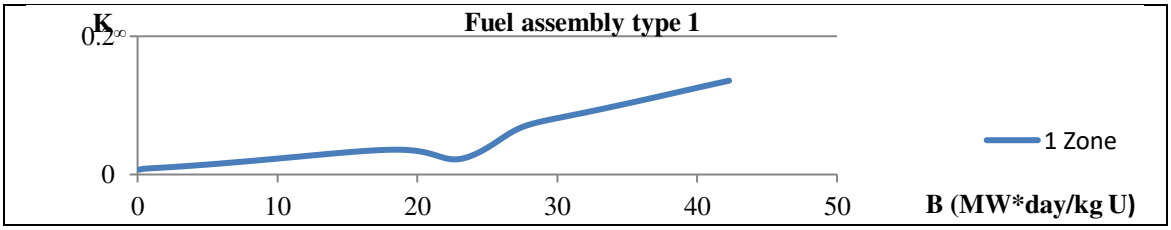



Fig. 6 – Deviation of multiplication coefficient VS burnup, when in the fuel rod only one zone is fuel (fuel assembly type 1)

But when the fuel zone was divided into five subzones is in Figure 4 (right) then the deviation of the multiplication coefficient vs burnup which is calculated by the program WIMS and GETERA-93 shown in the Figure 7 (A). But in this Figure 7(A), the calculated result showed that the presence of additional fuel zone (2, 3,4and 5) the deviation of multiplication coefficients are not changed by the program WIMS and GETERA-93 respectively.

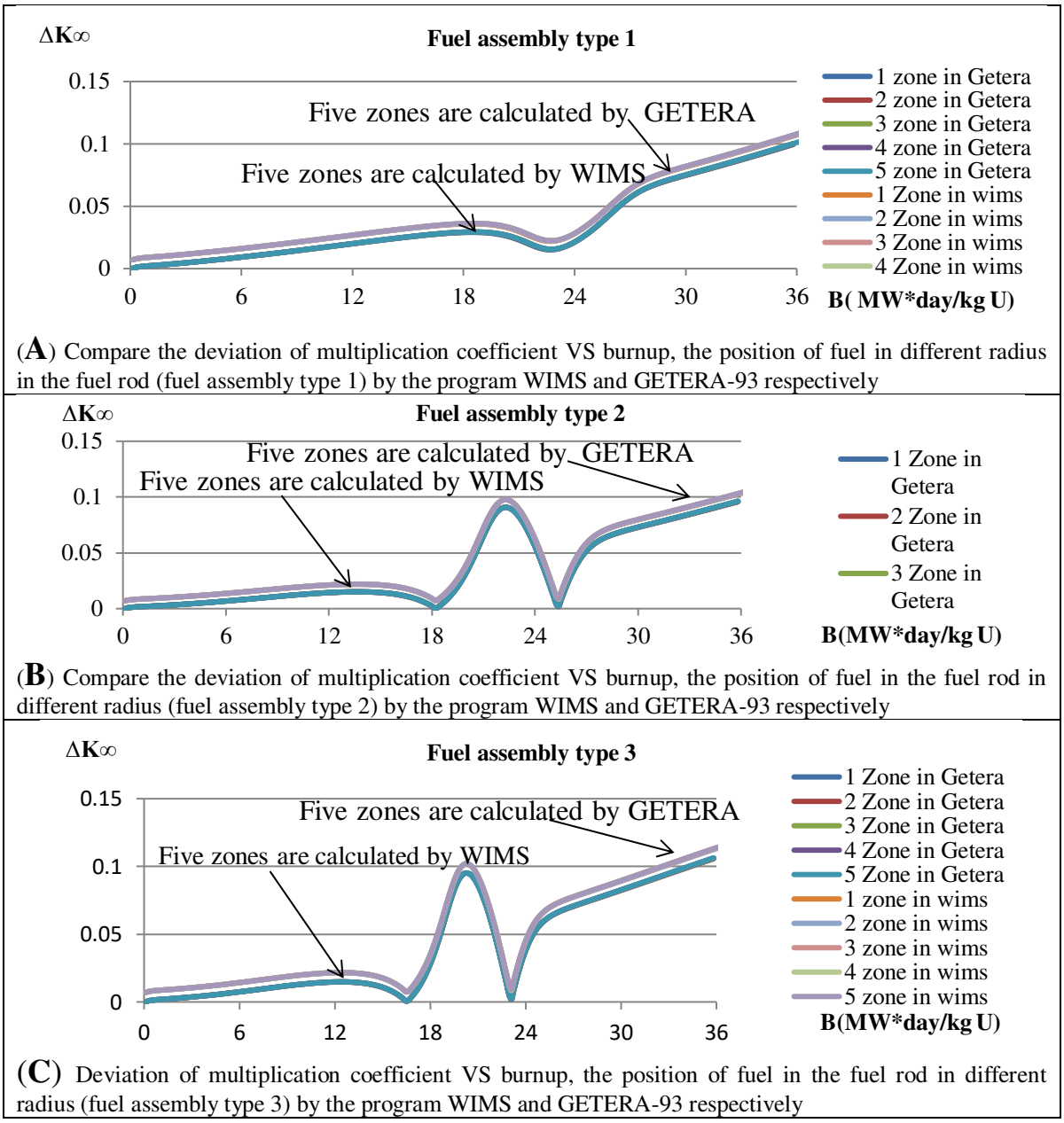
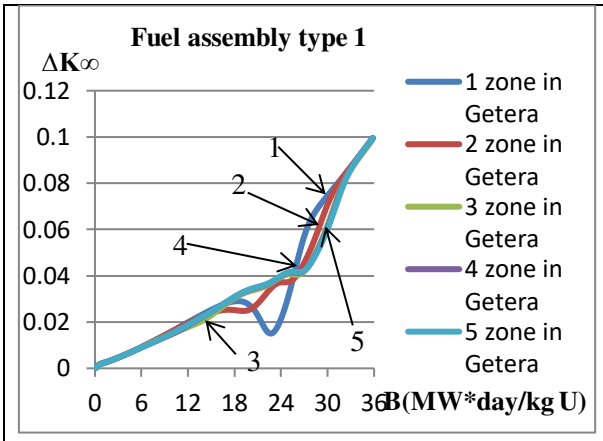
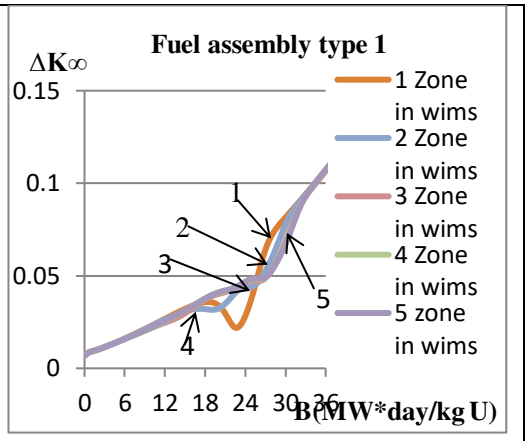



Fig. 7 – Deviation of multiplying coefficient VS burnup for different types of fuel assembly

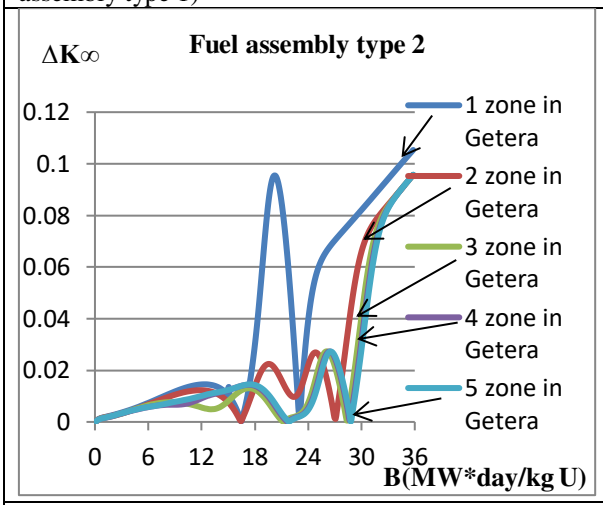
In the Figure-7 (B), for the fuel assembly (FA) type-2 (when in the Fuel assembly has27 fuels with gadolinium rods and enrichment of uranium 4.4%) and in the Figure -7 (C), the fuel assembly type- 3 (when in the Fuel assembly has 27 fuels with gadolinium rods and enrichment of uranium 4.95%) were the same result. The same result means: - Presence of additional fuel zone in the fuel rod Figure 4 (right), deviation of multiplication coefficients are not changed. It was calculated by the WIMS and GETERA-93 accordingly.

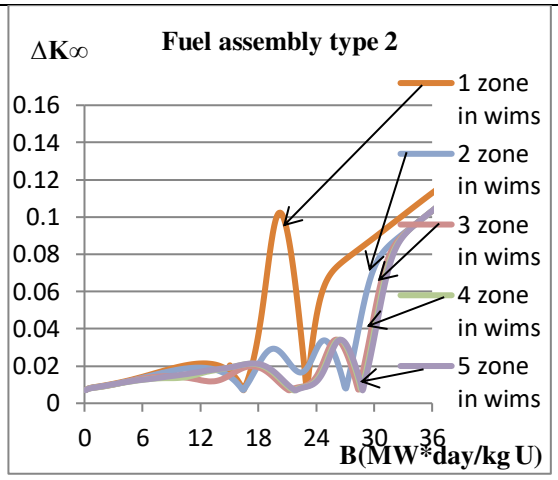
On the other hand, when the fuel with gadolinium rod zone was divided into five sub-zones Figure-5 (right) and put the fuel with gadolinium, then the deviation of multiplication coefficient vs burnup which is calculated by the program WIMS and GETERA-93 shown in the Figure-8 (A). But in this calculation it is 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%).



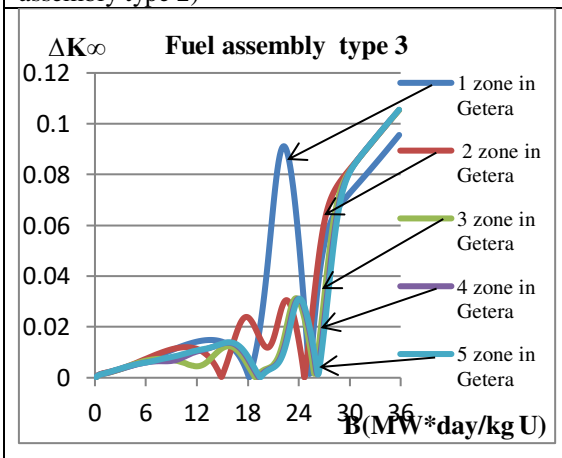



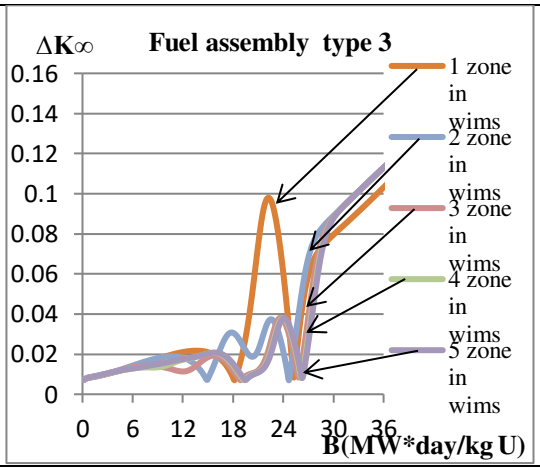

(**A**) Compare the deviation of multiplication coefficient VS burnup,) by the program WIMS and GETERA-93 respectively. The position offuel with gadolinium zone in different radius in the fuel with gadolinium rod (fuel assembly type 1)




**B**) Compare the deviation of multiplication coefficient VS burnup, by the program WIMS and GETERA-93 respectively. The position of fuel with gadolinium zone in different radius in the fuel with gadolinium rod (fuel assembly type 2)




(**C**) Compare the deviation of multiplication coefficient VS burnup, by the program WIMS and GETERA-93 respectively. The position of fuel with gadolinium zone in different radius in the fuel with gadolinium rod(fuel assembly type 3)

Fig. 8 – Deviation of multiplying coefficient VS burnup for different types of fuel assembly

In Figure 8 (B) – for the fuel assembly (FA) type – 2 (when in the Fuel assembly has 27fuels with gadolinium rods and enrichment of uranium 4.4%) and in the Figure 8 (C) – for the fuel assembly type – 3 (when in the Fuel assembly has27 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. It was calculated by the program WIMS and GETERA-93 accordingly.

## 5. Calculate the fuel temperature reactivity coefficient by WIMS and GETERA-93

Research workwas applied in the field of fuel temperature reactivity coefficient vs burnup, which is shown in the Figure-9.

### 5.1 Without maneuvering step:

Burnup for the 300 days- when the temperature was 1000k, then the multiplication coefficient $K_{\infty 1}$ was calculated by the program WIMS and GETERA-93 respectively. After that, the temperature was changed to 990k and again the multiplication coefficient $K_{\infty 2}$was calculated by the program WIMS and GETERA-93 accordingly. In the next step, the fuel temperature coefficient $\alpha T_{fuel}$calculated by the using formula $\alpha T_{fuel} = \frac{\Delta\rho}{\Delta T} = (\frac{1}{k\infty 1} - \frac{1}{k\infty 2})/(T_2\text{-}T_1)$.

### 5.2 Maneuvering step:

In the same way, the maneuvering step was calculated. But in the fuel temperature reactivity coefficient ($\alpha T_{fuel}$) 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 (ρ).Secondly, this density (ρ) was put in the input file with temperature 990k and calculated the multiplication coefficient $K_{\infty 2}$ .In the same way;7 points were calculated by the program Getera and WIMS accordingly. Then the calculated result of fuel temperature reactivity coefficient ($\alpha T_{fuel}$) vs burnup which is drawn in figure 9.

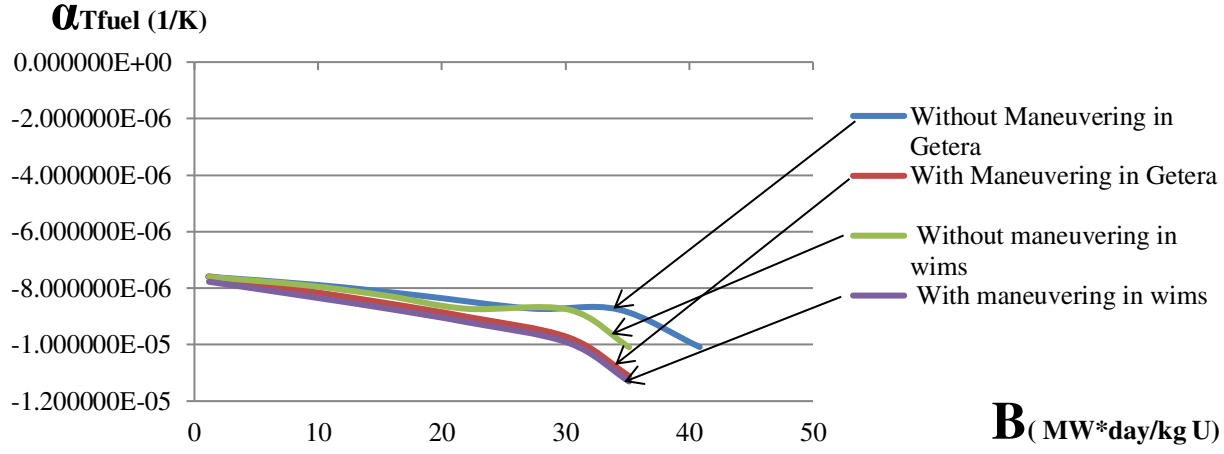
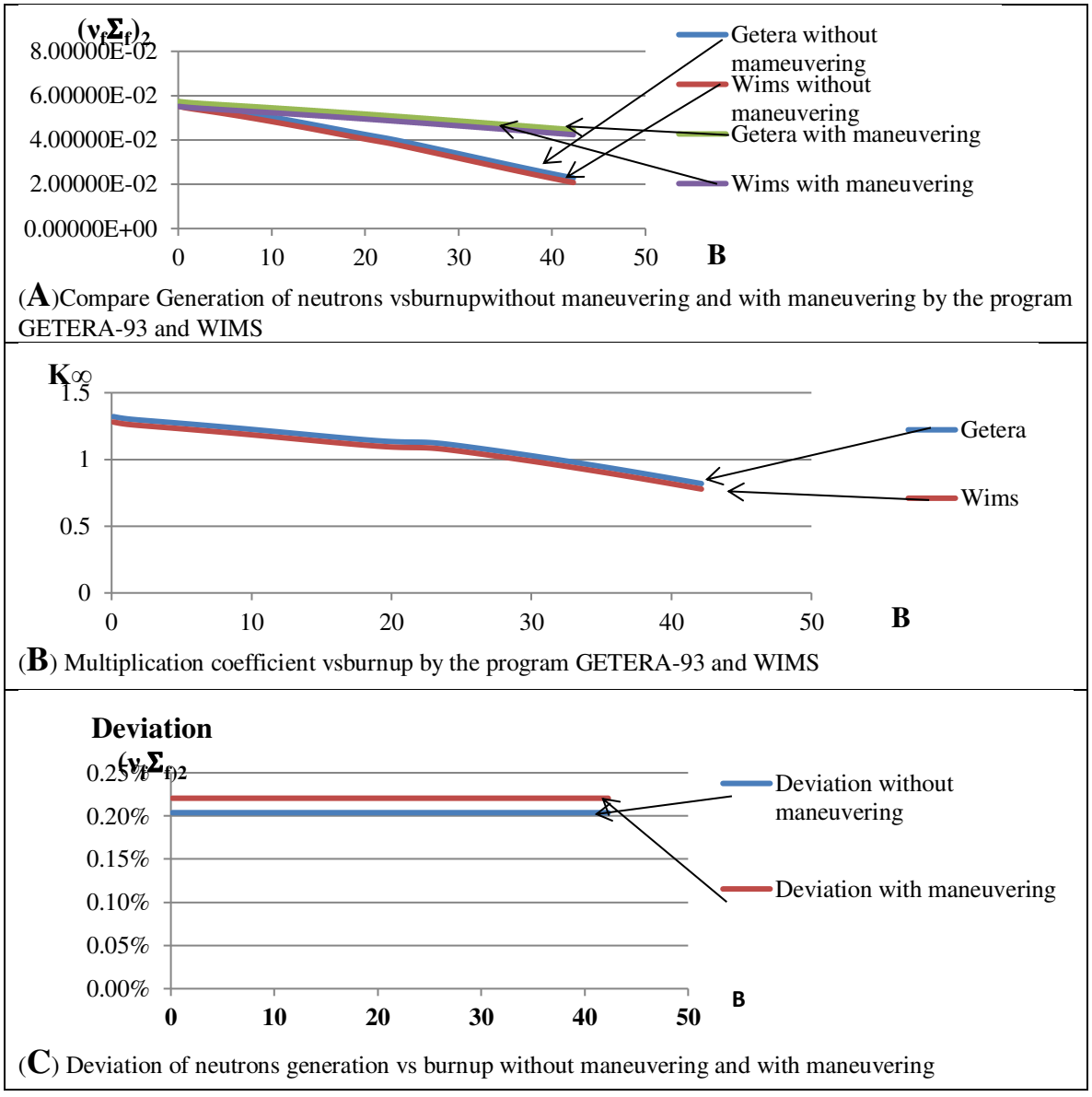



Fig. 9 –Compare the fuel temperature reactivity coefficient VS burnup by the program WIMS and GETERA-93 respectively

## 6. Result analysis

### 6.1 Compare the program Getera and Wims

Generation of neutrons $(\nu_f\Sigma_f)_2$ vs burnup without maneuvering and with maneuvering and multiplication coefficient vs burnup. It was calculated by the program Getera and WIMS which shown in the Figure 10 (A) and Figure 10 (B) accordingly. On the other hand deviation between without maneuvering and with maneuvering which is shown the Figure 10 (C).




(**A**)Compare Generation of neutrons vsburnupwithout maneuvering and with maneuvering by the program GETERA-93 and WIMS

(**B**) Multiplication coefficient vsburnup by the program GETERA-93 and WIMS

(**C**) Deviation of neutrons generation vs burnup without maneuvering and with maneuvering

Fig. 10 – Compare the program Getera and Wims

In figure 10 (B) the program GETERA-93 and WIMS showed the same characteristics. In figure 10 (C) it is shown that deviation of without maneuvering and with maneuvering are the same. That means, the program Getera and Wims are calculated the general code for reactor lattice cell on a wide range of a reactor but they have their own library system.

### 6.2 For the fuel rod

In Figure 6,7(A),7(B),7(C) – the result for the same burnup was calculated, but it is known that burnup time is not the same for the maneuvering and without maneuvering mode. For this reason, the peak was shown. But in the Figure 6 and Figure 7(A) – peak is small than

the fuel assembly type-2 Figure 7(B) or fuel assembly type-3 Figure 7(C). Because fuel assembly (FA) (type-1) has 6 fuel with gadolinium rods. For this, burnup time is smaller than the fuel assembly type-2 or fuel assembly type-3. On the other hand Figure 7(B) in fuel assembly type-2, and Figure 7(C) fuel assembly type-3, has 27 fuels with gadolinium rods. For this reason, the difference of burnup time is greater than the 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, the fuel rod has not gadolinium fuel. For this reason, fuel may be burned more evenly.

### 6.3 For the fuel with gadolinium rod

For the same reason, the small peak Figure 8(A) and the big peak Figure 8(B) and Figure 8(C) 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, so $\Delta K\infty$ decreasing.

### 6.4 Reactivity coefficient of the fuel temperature

In figure 9 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

The program GETERA-93 and WIMS allows the model conditions of neutron-physics experiments correctly and calculates the measured parameters: reaction rates, resonance integrals, multiplication coefficient and various indices. They give the same result but a little bit different. Because every program have their own library system. Result of WIMS has a good agreement with the result of GETERA-93. For this reason at last it may be say that first work was correct.

## 8. Conclusion

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 than five zones in the fuel rod or the fuel with gadolinium rod, the result will not change, but the calculation will be more complicated. In this work two programs are used but it was found that results are the same. At long last it seems that this research work is more correct which is proved by two programs.

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## Compare the Result of Uncertainty Analysis in the Physical Calculations of WWER Cells in the Daily Maneuvering Schedule by GETERA and WIMS Programs

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**Abstract –** This work is focused on solving real problems of a WWER reactor. The problem of simulating a fuel rod and a fuel rod with gadolinium in WWER is solved, exactly, it is analyzed for how many design layers is necessary in the fuel rod and fuel with gadolinium rod. The work contains the dependence of the deviation of the multiplication factor of neutrons from burnout. To solve these problems, the GETERA-93 and WIMS programs are used. SIMPLE FORTRAN was used for data preparation.

*Keywords:* Fuel rod, burn up, fuel zone, fuel rod with gadolinium. GETERA-93, SIMPLE FORTRAN.