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Investigation of the power peaking factor K_r in the fuel assembly during the maneuvering mode of the VVER-1000 reactor

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Abstract: The aim of this thesis paper is to analysis the power peaking factors K_r of the VVER-1000 reactor. Power peaking factor is important for the safety operation of the VVER-1000 power reactor. The maintenance of the core power distribution in a nuclear power plant is a precondition for the safety operation of a reactor. In this investigation used boron carbide. Boron carbide is a compound that contains boron and carbon, especially B_4C ; an extremely hard, non-metallic, black crystalline compound or solid solution. Only diamond is harder. In addition to its hardness property, boron carbide has the physical properties of corrosion resistance, heat strength, low specific gravity and high elastic modulus. It is used as an abrasive, neutron absorber for nuclear reactors, and as an alloying agent in composite structural materials. For this reason, when need to change the power of a reactor then the boron carbide (B_4C) control insert the reactor core. In this step investigated the power picking factors and its deviation using the Boron carbide (B_4C). Power peaking factors are connecting between the thermal-hydraulics and the nutronics of the nuclear power plant core. This power peaking factors was calculated by the comprehensive nutronics calculation program GETERA-93.

1. Introduction

The power distribution in the reactor core needs to be calculated meticulously to protect the nuclear fuel rods melting. Power distribution is related by the power peaking factors K_r . It is mentioned that the fuel rods are divided into several types. In all types rods are the same materials and same radius. But different they have different multiplicity figure 1. For this reason, power peaking factors are different from center to the periphery. It needs to estimate accurately in order to prevent the fuel rod from melting in the reactor core. Peaking factors very throughout an operating cycle, even at steady-state fuel power operation, because peaking factors are affected by withdrawal of control rods to compensate for fuel burnup. In this work it was investigated that, power peaking factors will be influenced or not in the mode of daily maneuvering (power change in 100-50-100%) of the VVER-1000 reactor. Power distribution calculations are performed by the program GETERA-93. Fuel rods are contained 4.95% wt of uranium and 5% wt of gadolinium enrichment and 300 days burnup. In the previous work [1], [2] calculated macroscopic cross-section, fuel and coolant concentration, multiplication factor, etc and investigation of absorber (B, Dy, Ag, etc) concentration changes during maneuvering operation of the VVER reactor.



2. Calculation models

Fuel assembly contains four types of cell. 1) 285-Fuel cells (UO_2) 2) 27-Fuel with gadolinium cells 3) 18-Guide tube cells 4) 1-Central tube cell (figure 1). For the neutronic physical calculation in the reactor core by the program GETERA-93, need to same parameters, which are shown in the Table 1.

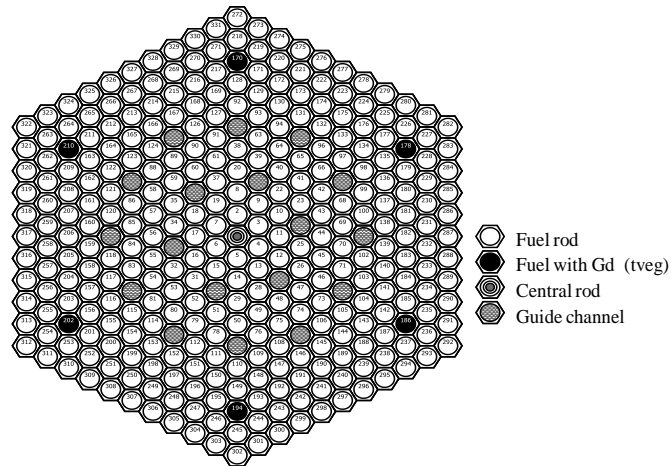


Figure 1. Fuel assembly.

Table 1. Fuel composition of VVER-1000 reactor.

Parameter Name	Value
Fuel enrichment ^{235}U , wt. %	4.95
The number of fuel rods, material, internal and external diameter of the cladding of the fuel rod accordingly	285, Alloy E110, $7.80 \cdot 10^{-3}$ m, $9.10 \cdot 10^{-3}$ m
Number of teigs (fuel+Gd), material, internal and external diameter of the cladding of the teigs (fuel+Gd) rod accordingly	27, Alloy E110, $7.80 \cdot 10^{-3}$ m, $9.10 \cdot 10^{-3}$ m
The internal diameter of the cladding of a fuel rod / teg (Fuel+Gd)	$7.93 \cdot 10^{-3}$ m
Fuel enrichment of teigs, ^{235}U , wt. %	4.0
Content Gd_2O_3 , wt. %	8
Lattice pitch of fuel elements,	$12.75 \cdot 10^{-3}$ m
Guide channel: Its materials, internal and external diameter accordingly	Alloy E635, $13.0 \cdot 10^{-3}$ m, $11.0 \cdot 10^{-3}$ m
Central rod : Its materials, internal and external diameter accordingly	Alloy E635, $13.0 \cdot 10^{-3}$ m, $11.0 \cdot 10^{-3}$ m

In this calculation model, for the power distribution in the reactor core, 285-fuel rods are divided into 6 types and 27 fuels with gadolinium rod into 3 types accordingly. In the fuel type-1, fuel type-2, fuel type-3, fuel type-4, fuel type-5, fuel type-6, and (Fuel+Gd) type-1, (Fuel+Gd) type-2, (Fuel+Gd) type-3, 285-number of fuel cells 51, 49, 41, 42, 42, 60 and 27-(Fuel+Gd) cells divided into 3, 6, 18 accordingly, shown in figure 2. All these type of cells neutron transport calculation shown below.

3. Leakage matrix

Using the multiplicity, it can quite simply describe a poly cell consisting of hexagonal cells identical in the corresponding rows figure 2. In the picture it also shown that one type of cell surrounded by a large number of another cells. In such a poly cell, it can be said with sufficient accuracy that the cells in the same row have the same boundary conditions. The multiplicity of fuel cells 51, 49, 41, 42, 42, 60, (Fuel+Gd) cells 3,6,18, Number of guide tube cells 18 and 1 central tube cells. Correspondingly, the hexagonal of the cells are- 306, 294, 246, 252, 252, 240, 18, 36, 108,108, and 6. Multiplicity of the hexagonal cells of the VVER-1000 reactor is shown in the table 2.

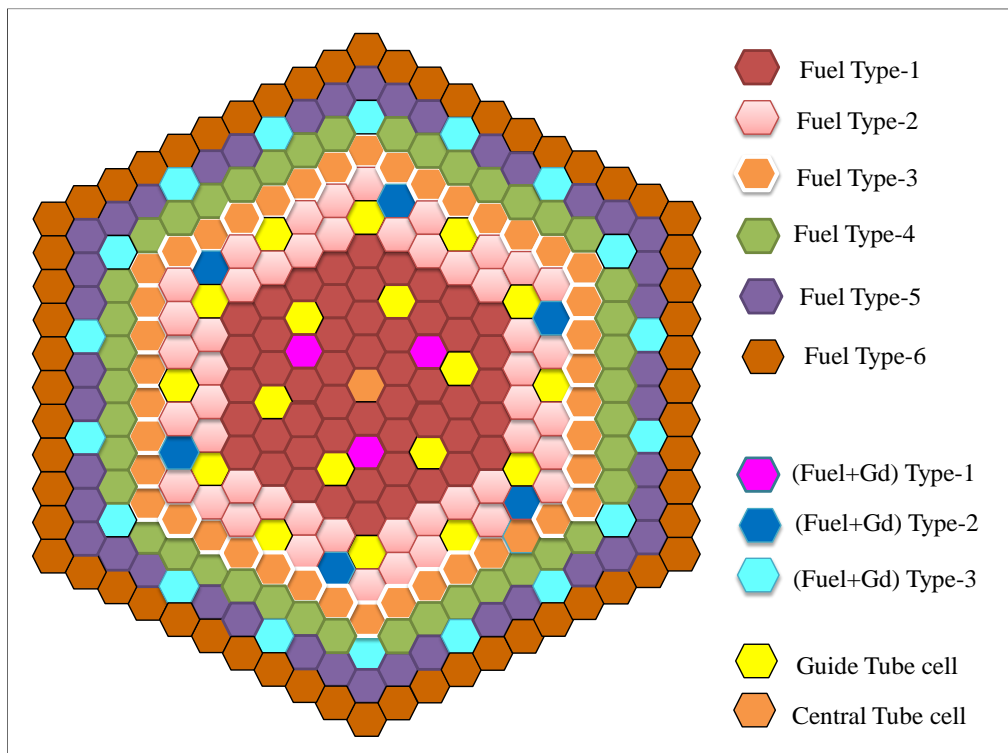


Figure 2. Symmetrical configuration of the VVER-1000 fuel assembly.

Table 2. Multiplicity of the poly cells of VVER reactor.

		Fuel type-1	Fuel type-2	Fuel type-3	Fuel type-4	Fuel type-5	Fuel type-6	(Fuel +Gd) type-1	(Fuel +Gd) type-2	(Fuel+ Gd) type-3	Guide channel	Central
Cells		51	49	41	42	42	60	3	6	18	18	1
Cell area		(51*6)=306	(49*6)=294	(41*6)=246	(42*6)=252	(42*6)=252	(60*6)=360	(3*6)=18	(6*6)=36	(18*6)=108	(18*6)=106	(1*6)=6
Fuel type-1	C.C	198	48	0	0	0	0	15	0	0	39	6
	C.M	198/306	48/294	0	0	0	0	15/18	0	0	39/108	6/6
Fuel type-2	C.C	48	129	54	0	0	0	0	17	0	48	0
	C.M	48/306	129/294	54/246	0	0	0	0	17/36	0	48/108	0
Fuel type-3	C.C	0	0	84	78	0	0	0	12	6	12	0
	C.M	0	0	84/246	78/252	0	0	0	12/36	6/108	12/108	0
Fuel type-4	C.C	0	0	78	78	60	0	0	2	36	0	0
	C.M	0	0	78/246	78/252	60/252	0	0	2/36	36/108	0	0
Fuel type-5	C.C	0	0	0	60	66	90	0	0	42	0	0
	C.M	0	0	0	60/252	66/252	90/360	0	0	42/108	0	0
Fuel type-6	C.C	0	0	0	0	90	246	0	0	24	0	0
	C.M	0	0	0	0	90/252	246/360	0	0	24/108	0	0
(Fuel+Gd) type-1	C.C	15	0	0	0	0	0	0	0	0	3	0
	C.M	15/306	0	0	0	0	0	0	0	0	3/108	0
(Fuel+Gd) type-2	C.C	0	15	12	0	0	0	0	0	0	5	0
	C.M	0	15/294	12/246	0	0	0	0	0	0	5/108	0
(Fuel+Gd) type-3	C.C	0	0	6	36	36	24	0	0	0	0	0
	C.M	0	0	6/246	36/252	36/252	24/360	0	0	0	0	0
Guide channel	C.C	39	48	16	0	0	0	3	5	0	0	0
	C.M	39/306	48/294	16/240	0	0	0	3/18	5/36	0	0	0
central	C.C	6	0	0	0	0	0	0	0	0	0	0
	C.M	6/306	0	0	0	0	0	0	0	0	0	0
Total	C.M	1	1	1	1	1	1	1	1	1	1	1

Here, C.M- contact matrix and C.C- Contract of cells

4. Power peaking factors

Power peaking factors are very important for the safety assessment for the reactor core. This factor is connected between neutronics and thermal hydraulics of a power reactor. Power peaking factors are defined by this formula $K_r^i = \frac{Q^{i(max)}}{Q(ave)}$. Here, $Q^{i(Max)}$ is the maximum power of the each type fuel cell and \bar{Q} is the average power of the fuel assembly. Power peaking factors in the reactor core was calculated by the program GETERA-93 using multiplicity, concentration of materials (table-1) and other information's.

5. Maneuvering Mode

Maneuvering is the process in which change the power of a reactor. In the peak-hour, reactor worked by 100% power. On the other hand, in the off peak-hour, need to change the power of a reactor figure 3.

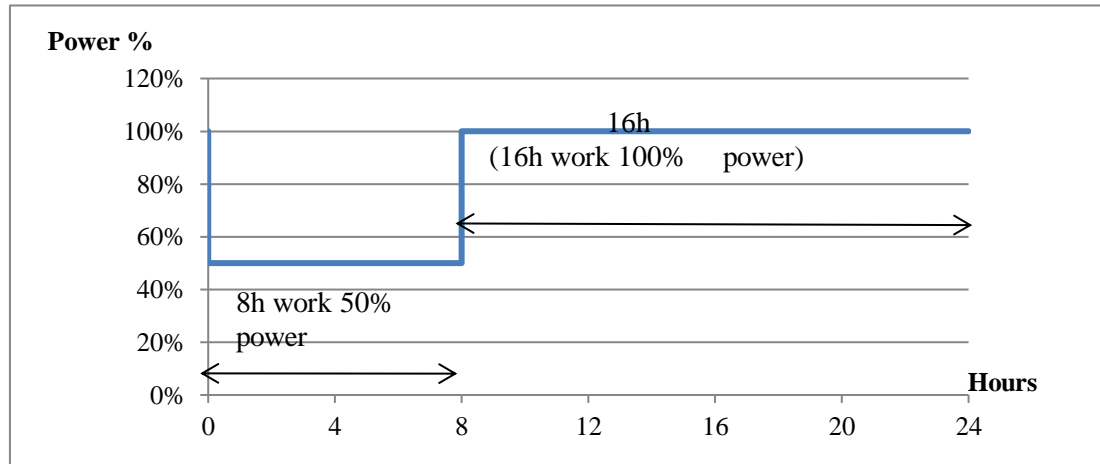


Figure 3. Power vs Time.

The maneuvering method will allow operating a nuclear power plant to maintain the balance of power in the energy system of a country weekly, monthly and yearly. For this reason, now a day's maneuvering is very important for the VVER reactor. In this investigation work, need to find out during maneuvering of a power reactor how to change the distribution of power in a reactor core. Power peaking factors K_r^i is calculated the power distribution in the reactor core, which shown in the figure 4.

6. Calculation result

6.1 Without Boron carbide (B_4C) absorber

Using GETERA-93, power peaking factors K_r^i and time was calculated figure 4. In this figure 4 it is shown that, power peaking factor for every fuel types are decreased. Because of, in the fuel rods have only the fuel element U^{235} . For this reason, in the time of burning concentration fuel U^{235} was decreased and power peaking was also decreased. On the other hand, (fuel with gadolinium rod) when gadolinium was burned, then power peaking was increased. Maneuvering result also showed figure 4. But maneuvering mode shows the same character but a little bit different from without maneuvering.

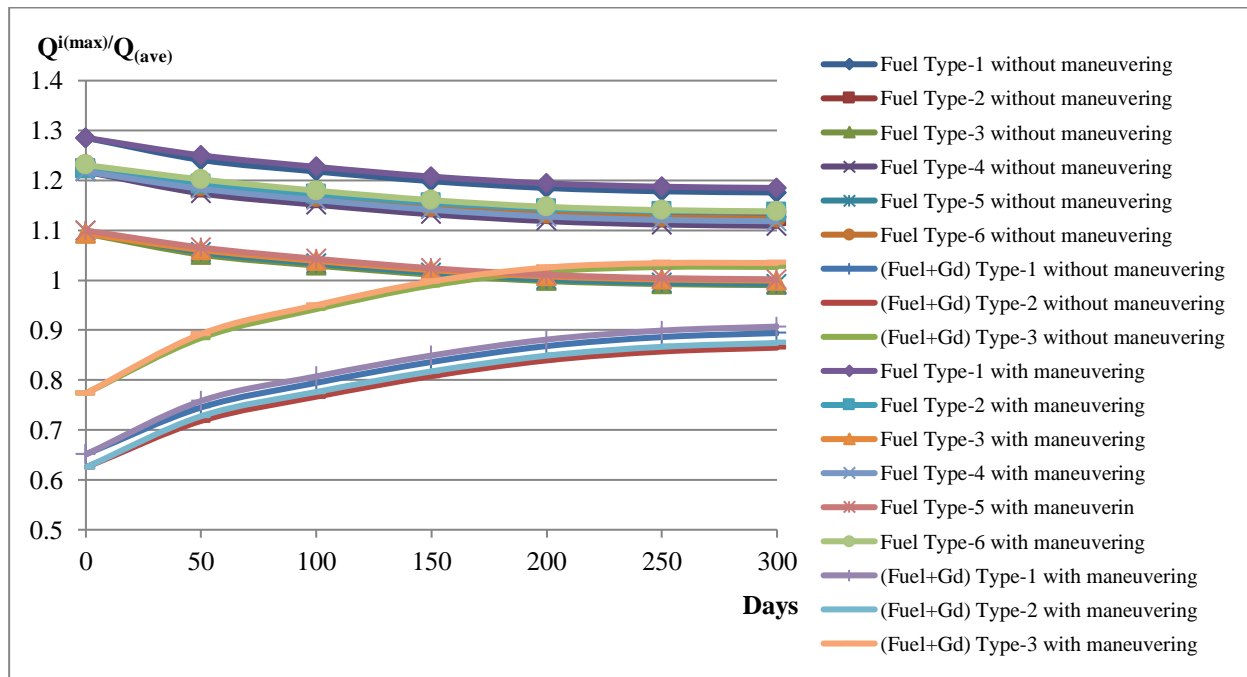


Figure 4. Power peaking factors vs days without Boron carbide (B₄C) absorber for different types of fuel without and with maneuvering.

6.2 Deviation of power peaking factors

Deviation of power peaking factors was calculated by this formula:

$$\Delta K_r^i = \frac{K_r^{i \text{ without maneuvering}} - K_r^{i \text{ with maneuvering}}}{K_r^{i \text{ without maneuvering}}} \tag{1}$$

Using this formula, without Boron carbide (B₄C) absorber deviation of power peaking factors result was shown in the figure 5.

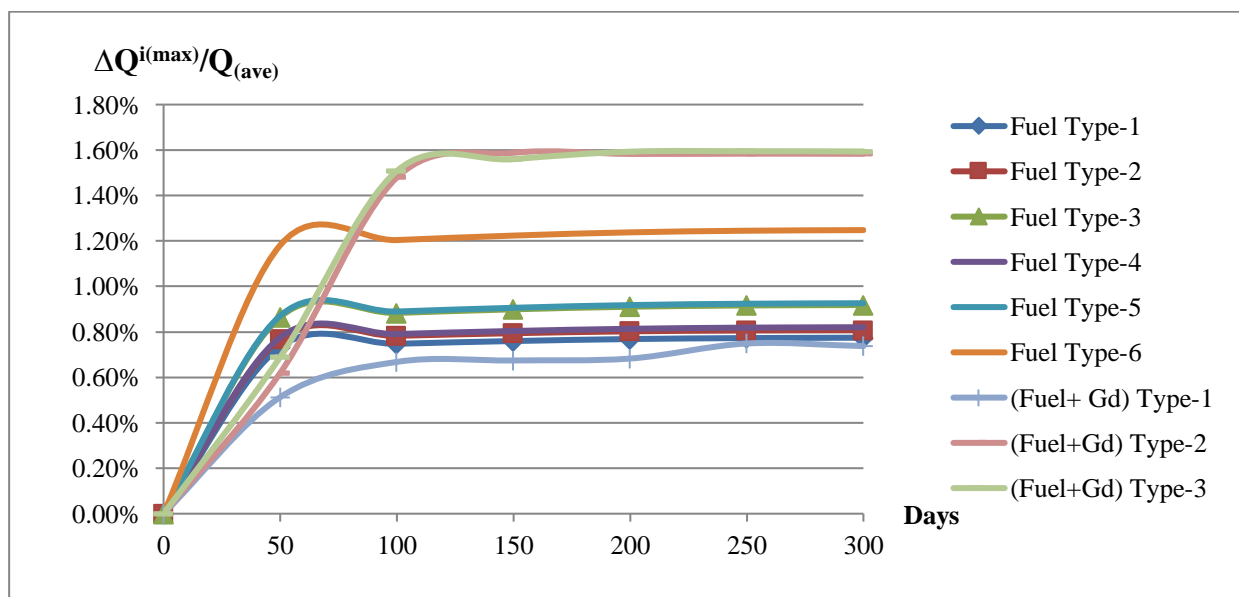


Figure 5. Deviation of power peaking factors vs days without Boron carbide (B₄C) absorber.

6.3 With Boron carbide (B₄C) absorber

Boron has two principal isotopes, ¹⁰B and ¹¹B the effectiveness of boron as neutron absorber is due to the high absorption cross-sections. The thermal neutron absorption cross-section for ¹⁰B and ¹¹B are 3837 barns and 0.005 barns respectively. The neutron absorption of natural boron-containing 20% ¹⁰B is sufficiently high ~ (4000 barns) in the low neutron energy range to make it an excellent candidate for use in VVER reactors. For this reason, when need to change the power of a reactor then the boron carbide (B₄C) control insert the reactor core. In this step investigated the power picking factors and its deviation using the Boron carbide (B₄C) absorber in the figure 6 and figure 7 respectively.

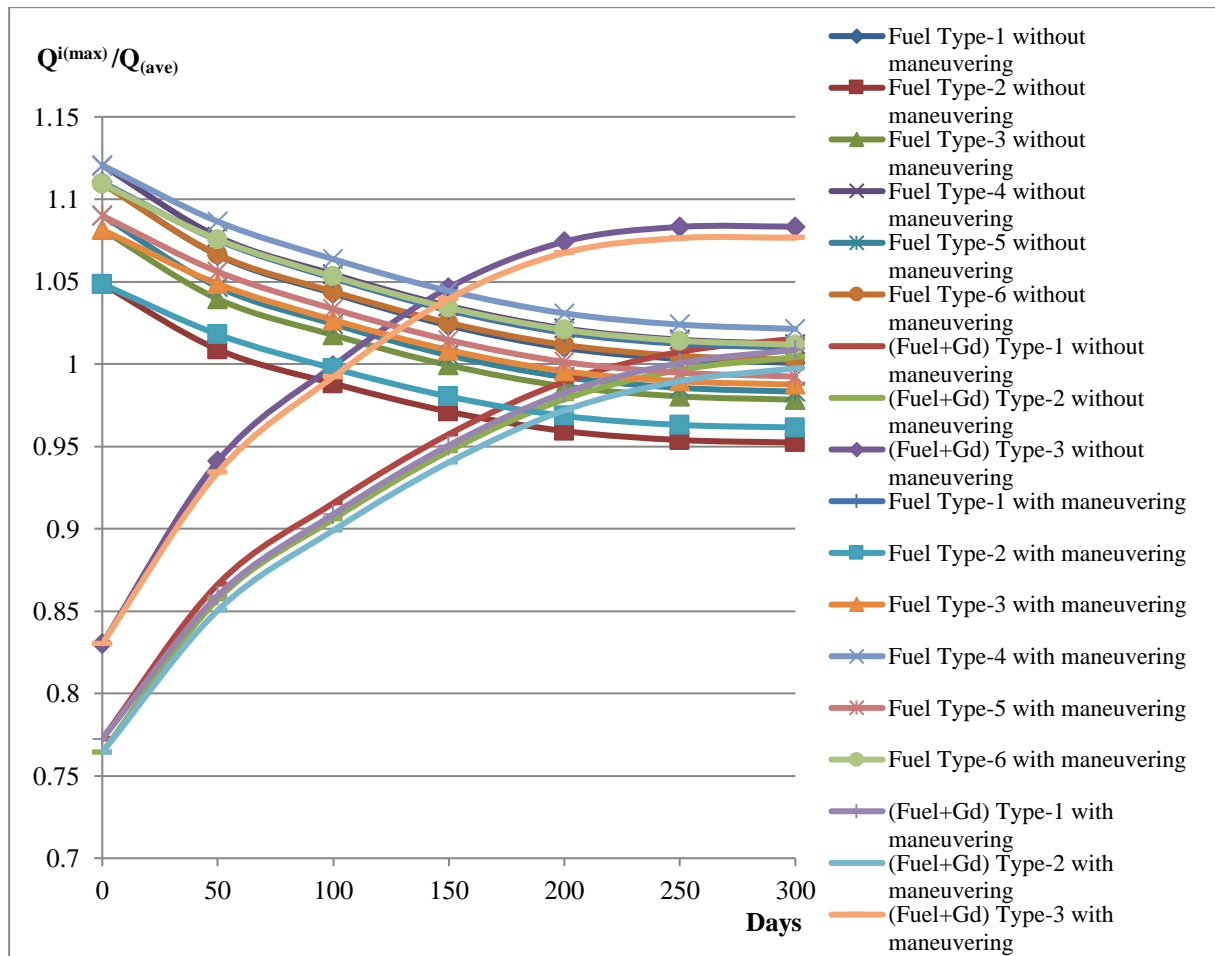


Figure 6. Power peaking factors vs days with Boron carbide (B₄C) absorber for different types of fuel without and with maneuvering.

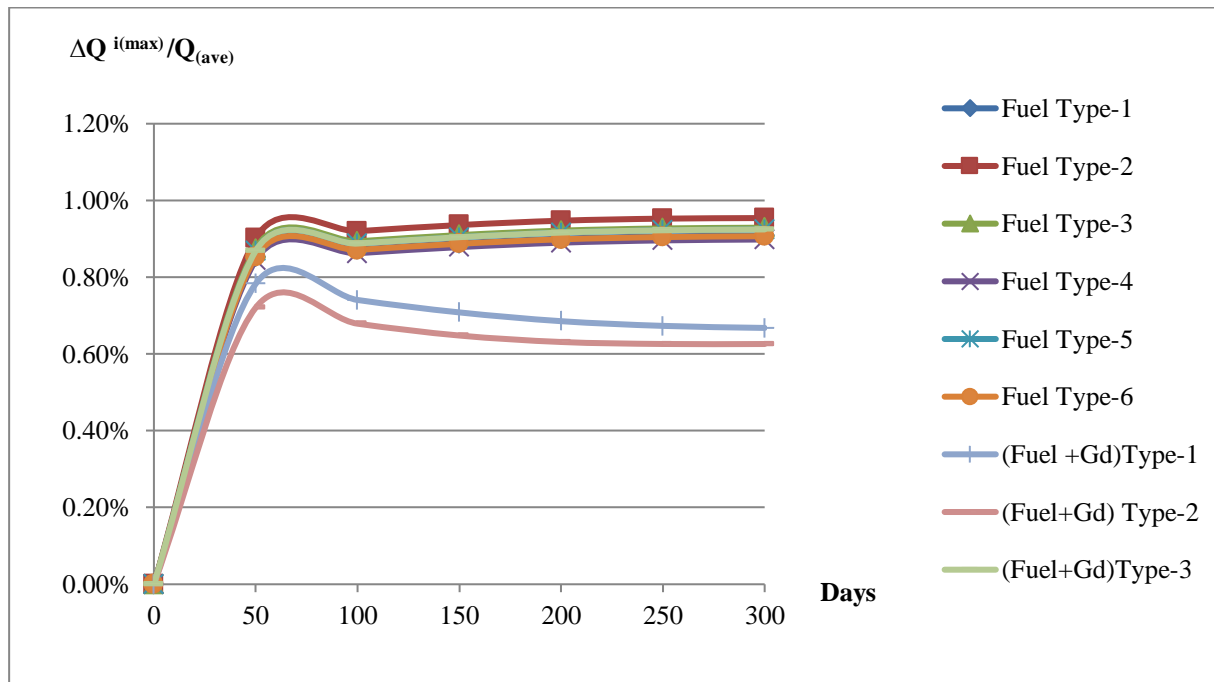


Figure 7. Deviation of power peaking factors vs days with Boron carbide (B_4C) absorber.

6.4 Graph analysis

With Boron carbide (B_4C) absorber element power peaking factors and its deviation is smaller than without absorber element. Because of, boron carbide (B_4C) absorber element absorbed more neutrons.

7. Results

Accounting for maneuvering showed an effect on the relative power of the fuel element: $\sim 1.6\%$ in the case of without control rod, and $\sim 1\%$ in the case of control rod. Most fuel assemblies are operated without control rods. Therefore, the coefficient of uneven energy release is very important for assessing safety. Because safety margins may be 1.6% less for the hottest fuel rod.

8. Conclusion

In this work investigated the power peaking factors during maneuvering period of VVER reactor. Investigation shows the following results:

- Power peaking factors K_r^i for different types of fuel rods
- Deviation of power peaking ΔK_r^i factors for different of fuel rods
- Boron carbide (B_4C) absorber effect on the power peaking factors

The maneuvering method solves operating a nuclear power plant to maintain the balance of power in the energy system of a country. But it is very important to know that during maneuvering how to change the power distribution in the reactor core. In this work it is clear that deviation of power peaking factors change during maneuvering which is shown in the result is very negligible. For this reason, it is understood that during maneuvering method VVER reactor work with safety.

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