ЭКСПЛУАТАЦИЯ ОБЪЕКТОВ АТОМНОЙ ОТРАСЛИ

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ИССЛЕДОВАНИЕ ИЗМЕНЕНИЯ КОНЦЕНТРАЦИИ ПОГЛОТИТЕЛЯ ПРИ РАБОТЕ РЕАКТОРА ВВЭР–1000 В РЕЖИМЕ МАНЕВРИРОВАНИЯ

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В работе исследуется изменение нейтронно-физических свойств поглощающих материалов, применяемых в органах регулирования РУ ВВЭР с учетом маневренных режимов. Основным из таких материалов является карбид бора. В случае продолжительного применения режимов суточного маневрирования мощностью концентрация основного поглощающего элемента – бора – будет существенно снижаться. Это может приводить к изменению эффективности органов регулирования, что будет влиять как на алгоритмы маневрирования, так и на эффективность всей аварийной защиты. В работе приведены оценки снижения эффективности органов регулирования, а также исследован ряд других материалов, для которых такой эффект существенно снижается. Расчеты выполнялись на уровне моделей ТВС при помощи программных кодов GETERA, WIMS и SERPENT.

Ключевые слова: карбид бора, нейтрон, сечение поглотителя, эффективность, ВВЭР-1000, стержень управления, маневрирование, реактор, GETERA, WIMS и SERPENT.

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Introduction

The main requirement associated with the development and operation of nuclear reactors is the control and containment of neutrons that sustain, and are also produced during fission reaction. Boron is one of the few elements to possess nuclear properties, which proves its consideration as neutron absorber material. Boron and its compounds boric acid, boron carbide, rare-earth etc. Boron has two principal isotopes, ^{10}B and ^{11}B the effectiveness of boron as neutron absorber is due to the high absorption cross-sections. The thermal neutron absorption cross-section for ^{10}B and ^{11}B are 3837 barns and 0.005 barns respectively. The neutron absorption of natural boron-containing 20% ^{10}B is sufficiently high ~ (4000 barns) in the low neutron energy range to make it an excellent candidate for use in WWER reactors. In addition to a high absorption cross-section, boron has another advantage over other potential neutron absorber materials. The reaction products, helium and lithium are formed as stable, non-radioactive isotopes. As they do not emit nuclear radiation, decay heating problems during reactor shutdowns and transfer of depleted control rods are minimal. The (n α) reaction

$$_5B^{10}+{}_0n^1\longrightarrow {}_2He^4+{}_3Li^7+2.4MeV$$

Short description of using program GETERA-93, WIMS-D/4 and SERPENT

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.

On the other hand, WIMS – the Winfrith improved multigroup scheme 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 a variety 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 the 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 elaborate B1-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 isotopes. The authors recommend using 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%.

The SERPENT – Serpent code is written in standard ANSI-C language. The code is mainly developed in the Linux operator system, but it has also been compiled and tested in MAC OS X and some UNIX machines. The Monte Carlo method is a computing-intensive calculation technique and raw computing power has a direct impact on the overall calculation time.

Serpent was originally developed to be a simplified neutron transport code for reactor physics application. The urnup calculation capability for the reactor was included. In present time Serpent is used in a wide range of applications from the group constant generation to coupled multi-physics application.

Description of the calculation model:

Active zone of the WWER-1000 contains 163 fuel assemblies. Every fuel assembly contains 312 fuel rods. These 312 fuel rods are divided in four types Figure 1a. 1) Fuel rod (UO_2). 2) Fuel with gadolinium rod (UO_2+Gd). 3) Guide channel. 4) Central tube. Absorber materials (B, Dy, Ag etc) are put through the guide channel Figure 1b. In this calculation model only calculated two dimensional cells without any height and compare the characteristics of Boron with Dysprosium, Silver etc. Fuel composition, which is used in the calculation of reactor cell by the programs (GETERA, WIMS and SERPENT) shown in the table 1.

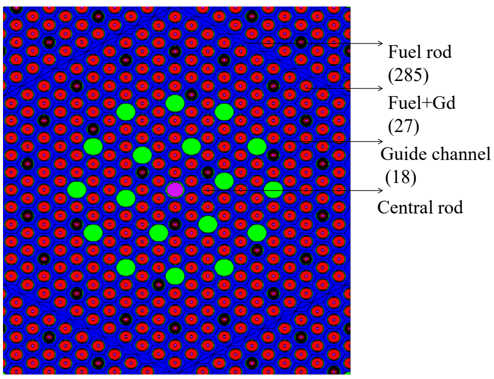


Figure 1a: Fuel assembly

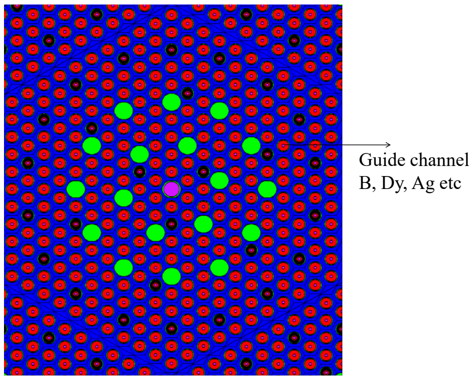


Figure 1b: Fuel assembly with absorber element

Table 1 – Fuel composition

Parameter Name	Value
Fuel enrichment ^{235}U, вес. %	4.95
The number of fuel rods, material, internal and external diameter of the cladding of the fuel rod accordingly	285, Alloy E110,7.80·10^{-3} m, 9.10·10^{-3} m
Number of tegs (fuel+Gd), material, internal and external diameter of the cladding of the tegs (fuel+ Gd) rod accordingly	27, Alloy E110,7.80·10^{-3} m, 9.10·10^{-3} m
The internal diameter of the cladding of a fuel rod / teg (Fuel+Gd)	7.93·10^{-3} m
Fuel enrichment of tegs, ^{235U}, вес. %	4.0
ContentGd_2O_3, вес. %	8
Lattice pitch of fuel elements,	12.75·10^{-3} m
Guide channel: Its materials, internal and external diameter accordingly	Alloy E635, 13.0·10^{-3}m, 11.0·10^{-3}m
Central rod : Its materials, internal and external diameter accordingly	Alloy E635, 13.0·10^{-3}m, 11.0·10^{-3}m

Calculation of the problems

In normal operation, the WWER-1000 reactor is operated by a nominal 100% power (q_v = 110 MWt/m^3). It means that in 1m^3 volume power is approximately 110 MWt. If in this time control (B_4C) rods are inserted the reactor core then (^{10}B) absorbs neutrons strongly. For this reason, ^{10}B absorber concentration is very low after 300 days. But when changed the nominal power 90% (q_v = 99 MWt/M^3), 80% (q_v = 88MWt/M^3) and 50% (q_v = 55MWt/M^3) accordingly (Figure 2a), then in the reactor core number of neutrons are decreasing. Consequently, the concentration of boron (^{10}B) was burned slowly. The result was calculated by the program GETERA, WIMS and shown in Figure 2b.

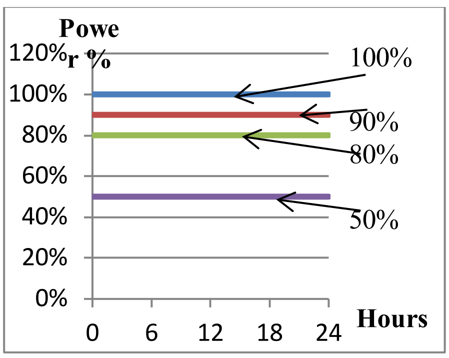
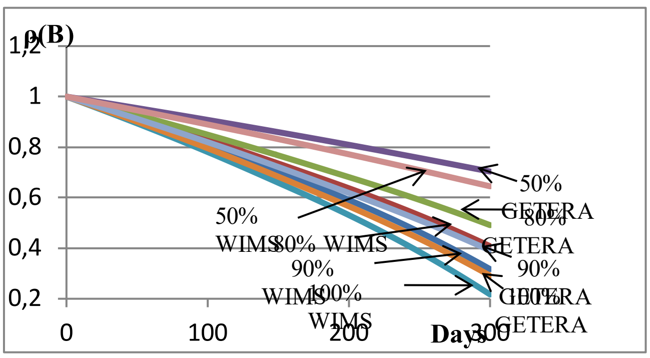


Figure 2a: Power vs time Figure

Boron carbide control rod



2b: Boron concentration in different power vs time by the programs GETERA and WIMS

When inserting the boron control rod in the reactor core, then strongly occurred the “α” radiation (${}_5B^{10}+{}_0n^1 \longrightarrow {}_2He^4+{}_3Li^7+2.4MeV$). This “α” radiation heated and scrammed the boron control rod. That is why; Boron carbide is very good for scram. For this reason in the emergency situation all boron carbide control rods insert the reactor core and stop the fission reaction. But in the case of maneuvering mode heating up the boron control rod and destroyed it. Consequently, the control rod needed the elementally change in the maneuvering mode.

Maneuvering is the process in which changes the power of a reactor. Without maneuvering operation, in the reactor core, all control rods stay top level of the reactor core. But in the maneuvering mode control rods are inserted in the reactor core. In maneuvering mode within 1 day (24h), 8h insert the control rod in the reactor core as a reactor work by 50% power (55 MWt/m^3); another 16h lifts up the control rod as a reactor work by 100% power (110 MWt/m^3) which is shown in Figure 3a. For the full company (300 days) result was calculated by the program GETERA and WIMS and shown in Figure 3b.

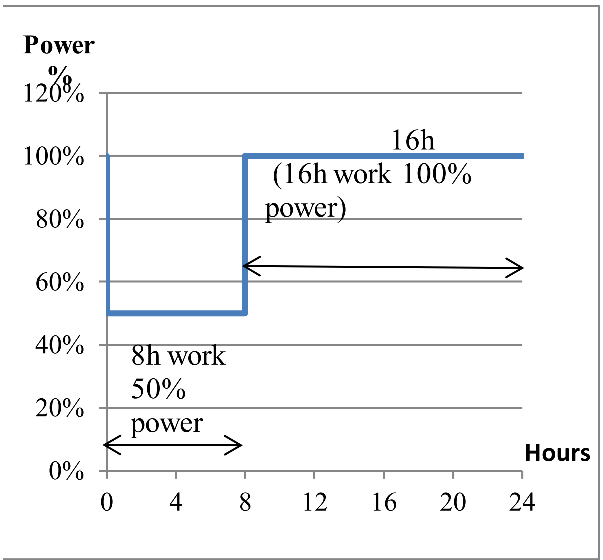


Figure 3a – power vs time

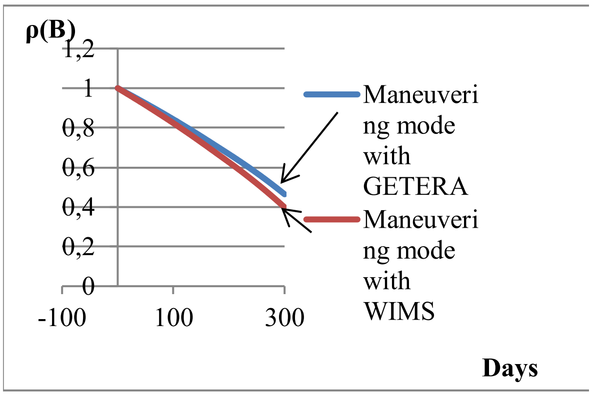


Figure 3b – Boron concentration vs time by the programs GETERA and WIMS

But in this graph, it was seen that, if the control rod was made of only boron carbide (B_4C) and it was used in the maneuvering mode then the concentration of boron in the boron control rod also lower after the full company. It is unpleasant for the reactor which discussed above. For this reason, in the control rod mixed another chemical element Dysprosium (Dy) Silver (Ag) etc.

Dysprosium (Dy) acts as a neutron absorber in nuclear fuel or in a reactor control rod; moreover, Dy isotopes after neutron capture have a large capture cross-section. Therefore, Dy can absorb neutrons continuously and effectively. This slow-burnout property is necessary for a reactor control rod material. Dysprosium has seven isotopes, ^{158}Dy, ^{159}Dy, ^{160}Dy, ^{161}Dy, ^{162}Dy, ^{163}Dy, and ^{164}Dy have 0.056, 0.095, 2.34, 18.9, 25.5, 24.9, and 28.2% in natural abundance respectively. The thermal capture cross-sections of Dy isotopes range from; 60 b ~^{158}Dy to 2500 b ~^{164}Dy. In the present time in the WWER reactor’s control rod used 50 cm Dy_2O_3 as a neutrons absorber Figure 4a.

Silver (Ag) is used in the control rods of nuclear reactors, acting as a very effective neutron poison to control neutron flux in nuclear fission. When silver rods are inserted in the core of a nuclear reactor, silver absorbs neutrons, preventing them from creating additional fission events, thus controlling the amount of reactivity. As like Dysprosium; Silver is used 50 cm in the control rod Figure 4a.

Absorber result for the B_4C was calculated by the programs GETERA and WIMS (Figure 4b). On the other hand Dysprosium and Silver absorber result was calculated by the programs SERPENT and WIMS (Figure 4b).

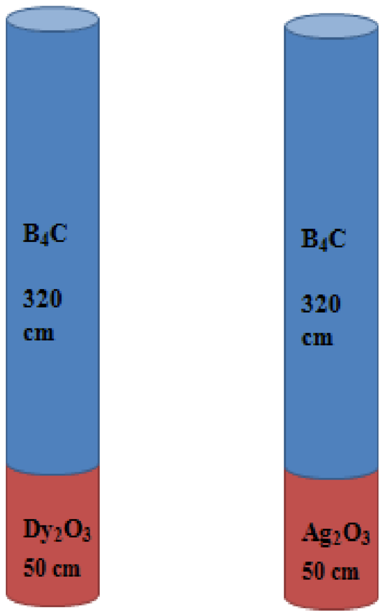


Figure 4a – Boron carbide and Silver oxide control rod with Dysprosium oxide

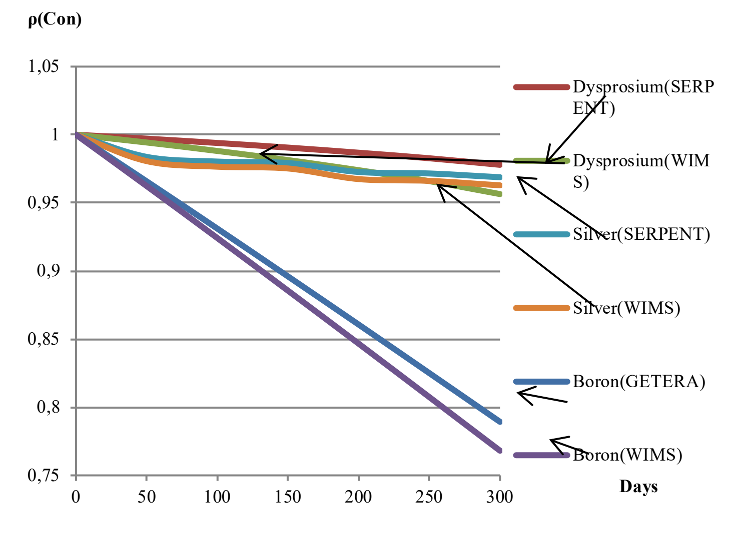


Figure 4b – Concentration of absorber (B, Dy and Ag) vs time by the programs SERPENT, WIMS and GETERA

Compare of the scram efficiency

Boron carbide has a high absorption cross-section. So scram efficiency is also high. It is used in the safety purpose. On the other hand, Dysprosium or Silver has low absorption cross-section and scram efficiency is also low. For this reason control rod, which is used in the maneuvering mode, is made of Dysprosium or Silver (Figure 4a). To compare the scram efficiency of these elements need to calculate the next step.

In the first time without (B_4C) absorber (Figure 5a) multiplying coefficient $K_{\infty}^{Without\ absorber}$ was calculated for the (300 days) full company and the calculated result was shown in Figure 6a. Then with (B_4C) absorber (Figure 5b) multiplying coefficient $K_{\infty}^{With\ absorber}$ was calculated for the full company and the result was shown in figure 6b.

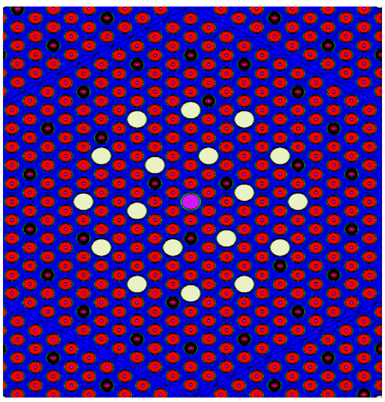


Figure 5a – Fuel assembly without absorber (in around central circle 18 big circles are empty absorber)

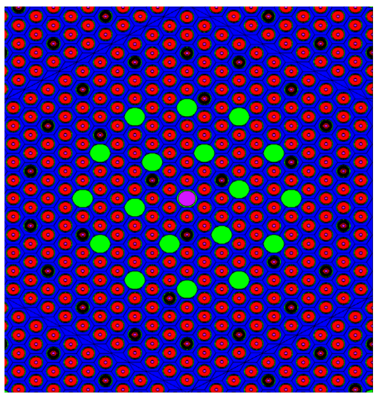


Figure 5b – Fuel assembly with absorber (in around central circle 18 big circles are absorber)

Then the scram efficiency of boron was calculated by the formula

$$\Delta K = \left(\frac{K_{\infty}^{With\ absorber} - K_{\infty}^{Without\ absorber}}{K_{\infty}^{With\ absorber}}\right)\%,$$

and the result was calculated by the program GETERA and WIMS and shown in Figure 6c. In the same way; multiplying coefficient and scram efficiency for the Dysprosium and Silver was calculated by the programs SERPENT and WIMS and shown in Figure 7a,7b,7c, and 8a,8b,8c accordingly. In here calculated only for a cell, not for the full reactor.

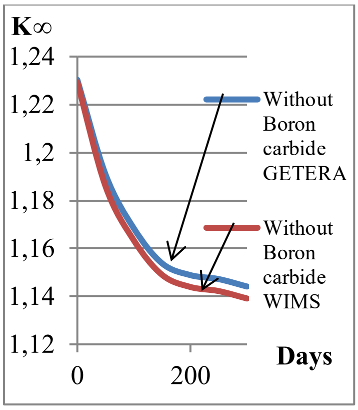


Figure 6a – Multiplying coefficient without Boron carbide vs time by the program GETERA and WIMS

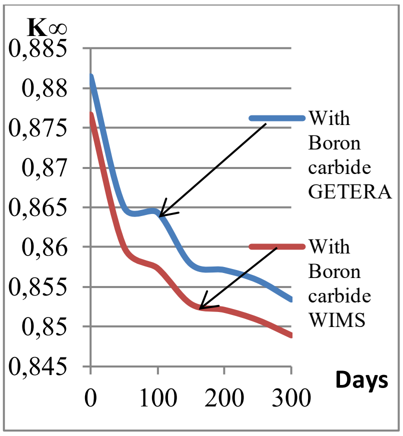


Figure 6b – Multiplying coefficient with Boron carbide vs time by the program GETERA and WIMS

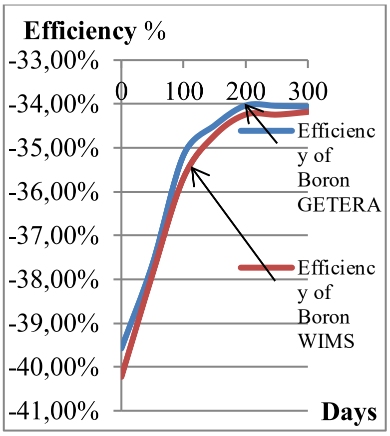


Figure 6c – Efficiency of Boron vs time by the program GETERA and WIMS

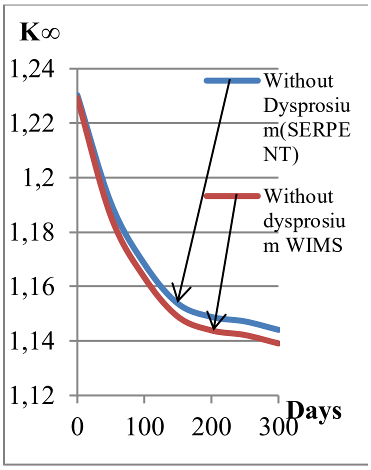


Figure 7a – Multiplying coefficient without Dysprosium oxide vs time by the program SERPENT and WIMS

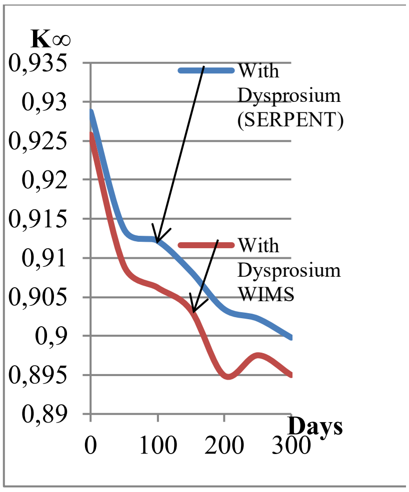


Figure 7b – Multiplying coefficient with Dysprosium oxide vs time by the program SERPENT and WIMS

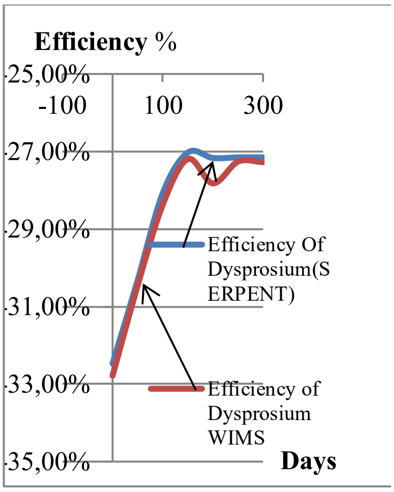


Figure 7c – Efficiency of Dysprosium vs time by the program SERPENT and WIMS

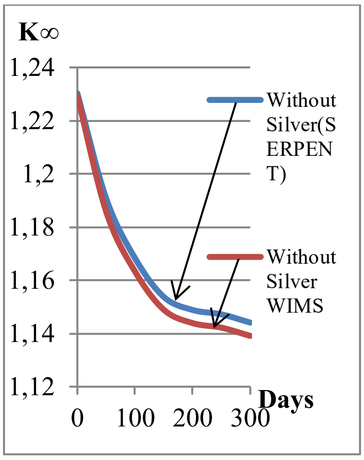


Figure 8a – Multiplying coefficient without Silver oxide vs time by the program SERPENT and WIMS

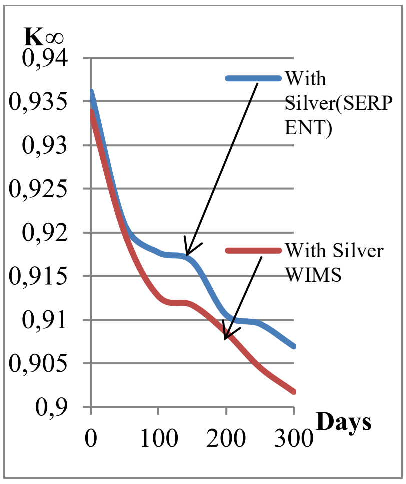


Figure 8b – Multiplying coefficient with Silver oxide vs time by the program SERPENT and WIMS

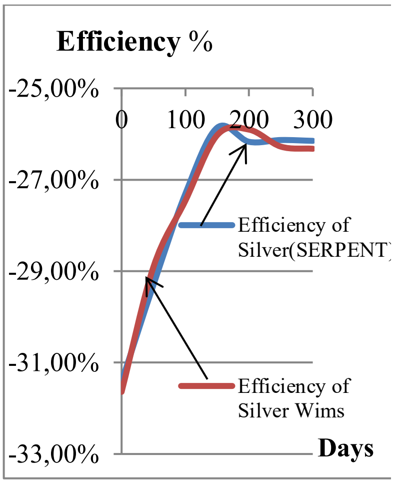


Figure 8c – Efficiency of Silver vs time by the program SERPENT and WIMS

Resultant Graph

The efficiency of Boron, Dysprosium and Silver are presented in one graph (Figure 9). But in here seen that efficiency of Boron at the end of the company (EOC) is approximately similar to the beginning of the company (BOC) of Dysprosium or Silver. In this point, it is clear that in the bottom part of the control rod use the Dysprosium or Silver in the view of maneuvering mode of a reactor.

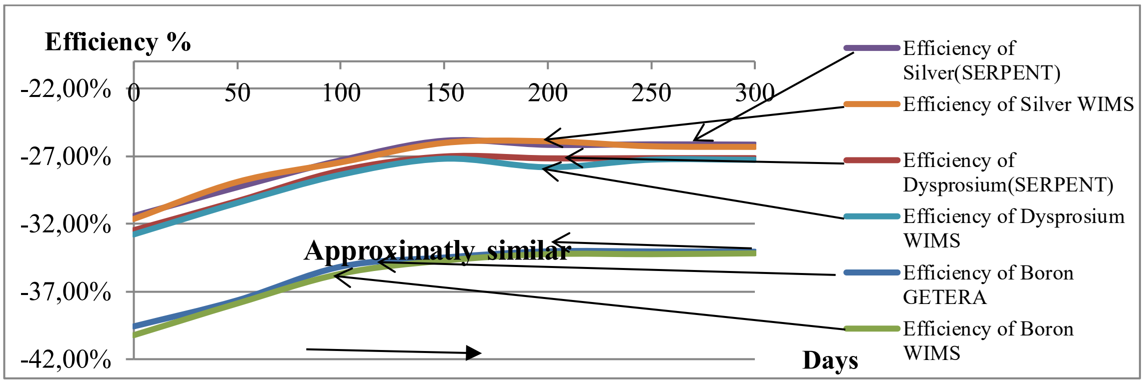


Figure 9 – Efficiency of Boron, Dysprosium and Silver vs Time by the programs SERPENT, WIMS and GETERA

Observation

In this work was used three programs GETERA, WIMS and SERPENT. The GETERA program is used to calculate neutron physics at department No. 5 of the Moscow Engineering Physics Institute (MEPhI). On the other hand, WIMS and SERPENT is an international program. But the result shows that GETERA, WIMS and SERPENT are the same programs, but slightly different for their own library system.

Result

The result shows that only the boron carbide (B_4C) control rod (Figure 3b) is also stronger absorber neutron in the maneuvering mode. That is why it is needed to modify the control rod with the chemical element Dysprosium oxide (Dy_2O_3) or Silver oxide (Ag_2O_3) or other chemical elements.

Conclusion

In this paper investigated the control rod burring in the maneuvering mode. In here used two dimensional models. Calculation shows the flowing result-

- Boron concentration ρ(B) is decreased, for this reason effectiveness of Boron also decreased.
- Dysprosium, Silver is better, because concentration of these materials decreased slowly.
- Dysprosium, Silver is good materials for the power regulation during maneuvering.

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 WWER reactor. The calculated result was showed that boron carbide burning is very high during the maneuvering period. That is why; must improve the construction of the boron control rod with other materials Dy, Ag, etc as if burn slowly in the time of maneuvering. The VVER reactor has 12 regulator groups that maintain the power of a reactor. Group numbers 1 to 8 (made of only boron carbide) used in the emergency situation of the reactor. On the other hand, group numbers 9 to 12 (made of boron with Dy or Ag or other elements) used in the maneuvering operation (when need the change the power of a reactor).

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Investigation of Absorber Concentration Changes During Maneuvering Operation in WWER 1000 Reactor

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Abstract – Boron carbide, Dysprosium, Silver, etc have a lot of unique properties, high neutron absorption, chemical stability, high melting temperature, low density, and low price. These elements are widely using in the WWER power reactors. In this article was investigated the absorber cross-section, burring behavior and scram efficiency of these elements. If the control rod (CR) is made of only boron carbide chemical element and it will be used in the maneuvering mode then the power of a reactor will fall down drastically. But in this work main goal is that, which element will be required in the control rod, as a result, the reactor in the maneuvering mode work with different power without fall down power drastically. The result was calculated by the three programs GETERA, WIMS and SERPENT.

Keywords: Boron carbide, neutron, absorber cross-section, WWER-1000, control rod, maneuvering, reactor. GETERA, WIMS, SERPENT.