REACTIVITY EFFECT OF POISONED BERYLLIUM BLOCK SHUFFLING IN THE MARIA REACTOR

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ABSTRACT

The paper is a continuation of the analysis of beryllium blocks poisoning by Li-6 and He-3 in the MARIA reactor, presented at the 22 RERTR Meeting in Budapest. A new computational tool, the REBUS-3 code, has been used for predicting the amount of poison. The code has been put into operation on a HP computer and the beryllium transmutation chains have been activated with assistance of the ANL RERTR staff. The horizontal and vertical poison distribution within beryllium blocks has been studied. A simple shuffling of beryllium blocks has been simulated to check the effect of exchanging a block with high poison concentration, adjacent to fuel elements, with a peripheral one with a low poison concentration.

Introduction

In the earlier papers [1-3] the problem of beryllium poisoning in the MARIA reactor was approximated using constant reaction rates to predict average flux dependent He-3 and Li-6 content. This enabled to show the influence of the poisoning on reactivity. Besides, a strong dependence was shown of the amount of He-3 and Li-6 created on reactor operation history, i.e. duration of the on-power and off-power periods. It was concluded, that prediction of reliable values of beryllium poisoning in each block is necessary to properly evaluate the poisoning and its influence on fuel burnup, power distribution and reactivity. As the consequence, the REBUS-3 code [4] was adapted at IEA on HP-C360 to calculate burnup of fuel elements and accumulation of poisons in beryllium blocks in MARIA reactor.

The vertical and horizontal poison distributions were obtained in a simplified reactor geometry to evaluate heterogeneous effects and the amount of work required to simulate burnup history of the MARIA reactor. The effect of poisoned beryllium blocks shuffling was also evaluated in a simplified geometry showing the possible reactivity gain from the operation. The available data on first period of reactor MARIA operation [5] have been used to evaluate the poison distribution average for each beryllium block accumulated and to compare them with the previous results obtained by simpler methods.

Reactions for beryllium transmutations in the REBUS-3 code

The reactions simulated in the calculations of beryllium poisoning are given in Table 1.

The reaction shown in row 7 refers to the transfer of microscopic cross sections from WIMS-ANL to REBUS-3. The reaction shown in row 10 involves the short lived ^{6}He and beta decay. 'Dump' means that the resulting number density is no longer tracked.

The values of reaction cross sections are taken from the WIMS-ANL [6] calculations together with the whole set of effective microscopic cross sections calculated in 7 energy groups.

Table 1

Reactions for beryllium transmutations in REBUS-3

No	Isotope undergoing reaction	Reaction type	Product isotope
1	^{3}H	(n,γ)	Dump
2	^{3}H	(β^{-})	^{3}He
3	^{3}He	(n,p)	^{3}H
4	^{3}He	(n,γ)	Dump
5	^{3}He	(n,^{2}H)	Dump
6	^{6}Li (n,γ)	(n,γ)	Dump
7	^{6}Li	(n,^{3}H)	^{3}H
8	^{6}Li	(n,p)	^{6}Li
9	^{9}Be	(n,γ)	^{9}Be
10	^{9}Be	(n,α)	^{6}Li
11	^{9}Be	(n,2n)	Dump

3 dimensional calculations of the core fragment

The calculations were performed for one row of four beryllium blocks starting at the core center and two blocks of the graphite reflector and with one fuel element. In vertical direction 20 cm top and bottom water reflector was added. Thus the geometry was symmetrical with respect to the middle of the fuel element and only one half of the element had to be represented in the vertical direction. The fuel and beryllium were divided into 5 vertical regions. It is worth noting, that usually only two beryllium blocks separate fuel channels from the graphite reflector, while in the geometry considered we have three of them. The reflective boundary conditions are applied at all the 6 boundaries. The geometry is shown in Fig. 1.

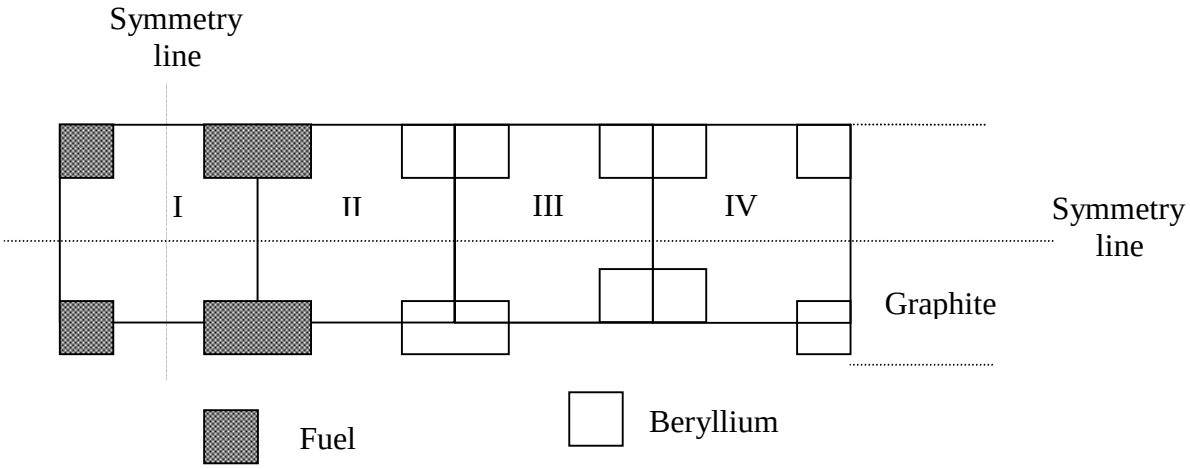


Fig. 1. Geometry of the core fragment for 3D calculations

The average power of fuel element was 1.15 MW. The system was burned for 9 cycles of: 94.5 days on power and 236.7 days off power. This corresponds to the period from 1977 to 1985 of the MARIA operation, when the cores contained, on average, 24 elements and the reactor was on power for 20414 hours. Fresh fuel was loaded at the beginning of each cycle and the beryllium block was not changed for the whole 9 cycles. It should be mentioned that the reactor was operated on a weekly basis, approximately 100 hours on power a week. Therefore the number of cycles should be much larger, with shorter periods off power. The length and number of breaks in operation affects the decay of H-3 i.e. production of He-3, as was discussed in [2].

The average total flux distributions at the beginning and after the 9-th cycle of reactor operation are shown in Figs. 2a and 2b. It can be seen that the total flux is practically not affected by beryllium poisoning.

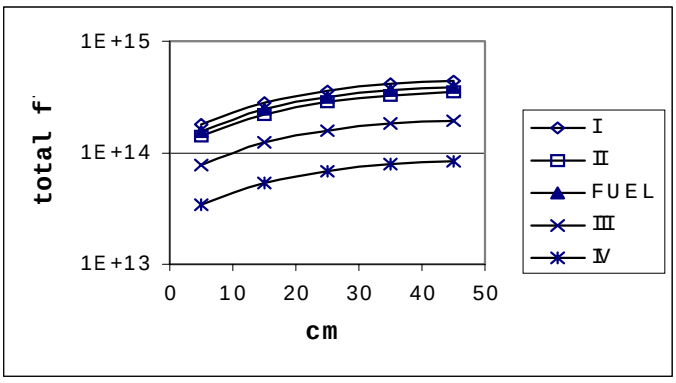


Fig. 2a.. Vertical total flux distribution in beryllium blocks and fuel for the system without poison.

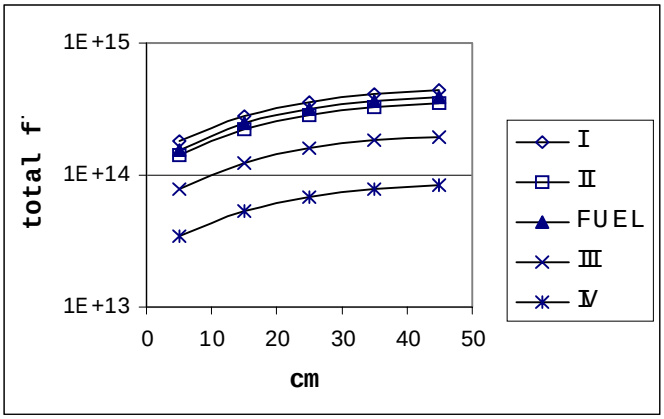


Fig. 2b. Vertical total flux distribution in beryllium blocks and fuel after 9 cycles.

The poison distribution after 9 cycles is shown in Figs. 3 and 4. The results show that the flux level is of similar order in the first two blocks and hence the poison buildup in those blocks is significant.

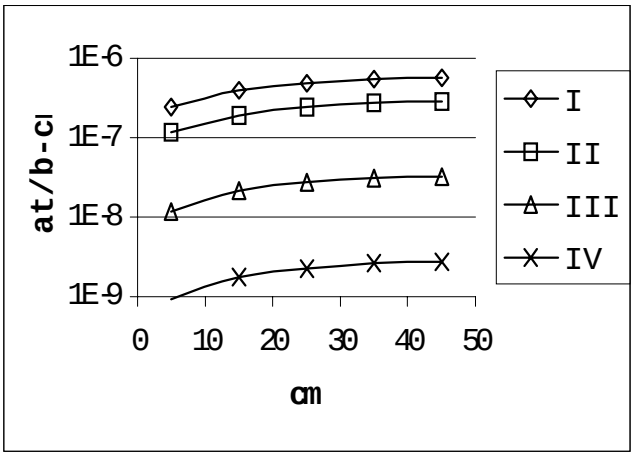


Fig. 3. The vertical He-3 distribution in 4 beryllium blocks.

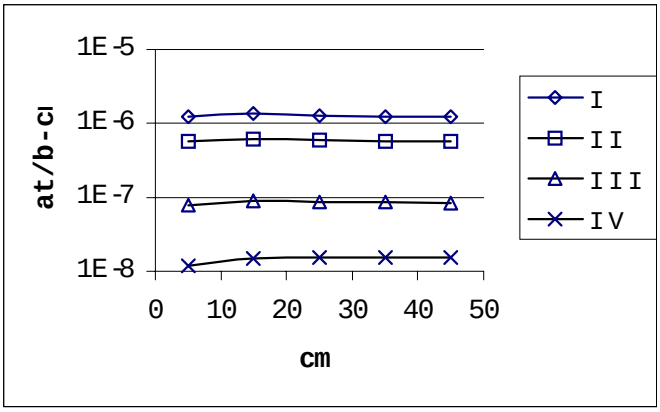


Fig. 4. The vertical Li-6 distribution in 4 beryllium blocks.

It can be seen that the Li-6 distribution is practically flat with maximum not necessarily in the block center.

2D model for the first period of reactor MARIA operation

The first period of reactor MARIA operation lasted from June 24.1975 to July 5.1985. During this period eight core configurations were operated, ranging from 9 to 26 fuel elements. To simplify the computer analysis of that period, the configurations, which have been operated for few days only, were removed from the consideration. In order to preserve the energy produced, the energy obtained from more representative basic configurations was suitably increased. Finally, four configurations have been selected for the computations of beryllium block poisoning. Fuel element positions, defined by respective letters and digits, as well as 2D mesh layout are shown in Fig.5. The four configurations considered are schematically shown in Fig.6. The full power days for a given configuration were obtained as the ratio of their output energy in MWd divided by the average reactor power during the period of their operation. The period of outage for each configuration was calculated as a difference between the real time of life of that configuration and its operation time.

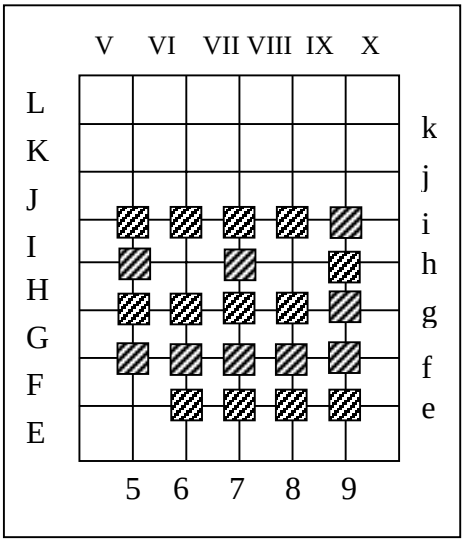
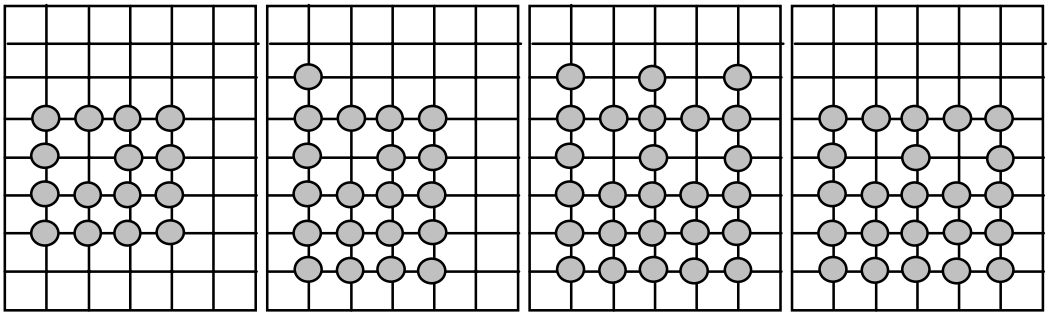


Fig 5. Mesh layout for 2D calculations.



Power: 19.8MW	19.4MW	21.0MW	21.7MW
FPD : 16.05days	256.4days	318.6days	252.9days
Shutdown: 655.9days	1179.6days	648.4days	336.1days

Fig 6. Basic configurations of reactor core in years 1975 -85.

The initial core consisted of only 9 fresh fuel elements. The reactor was operated for a short time on a low power and therefore in the next configuration (the first one in Fig.6) the depletion of the same fuel elements has been continued with new fresh elements added. Starting from the second configuration from Fig.6 the longer operation times had to be considered with scarce information on the fuel management history. For that reason the third configuration initial burnup distribution has been taken from the well-documented configuration from the year 1995, as it was operated with the same number of fuel elements. The fuel composition corresponding to a given burnup level has been obtained by separate runs of REBUS. The fuel management strategy consisted in

moving the elements following the decreasing U-235 content in the element was applied. The fresh fuel was always entered at the position 'g6' and the fuel element has been discharged from the position 'i7'. The length of consecutive cycles has been chosen to simulate the 5-day working week and the breaks following each cycle have been calculated by dividing the whole outage period for a considered configuration by the number of cycles. The total burnup depth of the fuel element and the total number of fuel elements used has been also suitably adjusted.

The resulting poisoning is given for each beryllium block in Figs. 7 and 8.

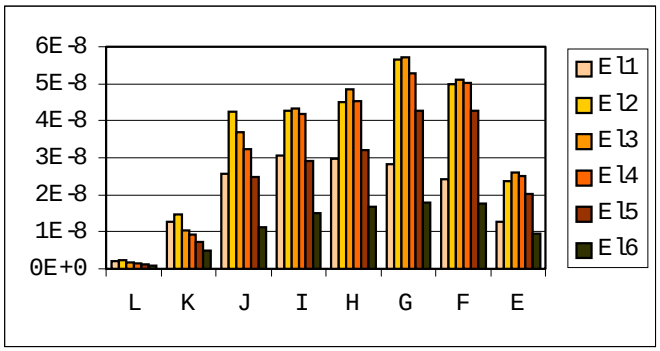


Fig. 7. Number densities [at/b-cm] of He-3 in beryllium blocks for 6 July 1985.

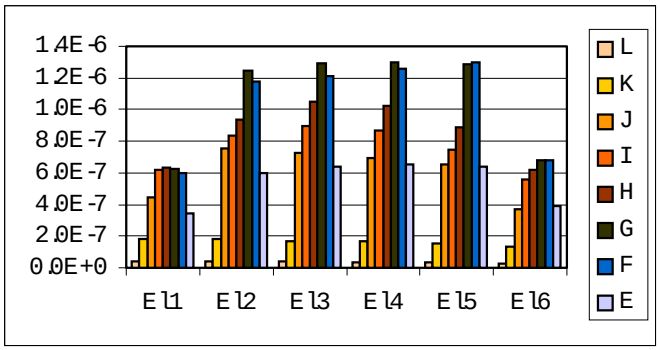


Fig. 8. Number densities [at/b-cm] of Li-6 in beryllium blocks for 6 July 1985.

It is worth mention that the estimate of the poison in two beryllium zone calculations and lumped yearly time of operation and related outages was given in Ref.[2], cf. Table 2:

Table 2.
Two-zone estimate of beryllium poisoning [2]

Isotope	Central blocks	Peripheral blocks
He-3	4.503E-7	6.528E-9
Li-6	1.230E-6	3.955E-7

The effect of the block shuffling for the core fragment

After the 9 cycles of burning, the blocks I and IV, cf. Fig. 1, were interchanged, and another 9 cycles of reactor operation were performed. It should be noted that in the given geometry it corresponds to reloading a row of Be blocks. Table 3 shows the values of k-effective after the 9-th cycle, after the interchange and after the 18-th cycle. It can be noted that the gain in k-eff resulting from the reloading is 50mk.

Table 3.
The effect of beryllium block shuffling

	Fresh Be	**After 9 cycles**	**After reload**	After 18 cycles
k-eff	1.33608	**1.23135**	**1.28124**	1.19811
Δ%	-7.83		-6.4	

The comparison of He-3 and Li-6 number densities, in the reloaded central block (originally No I) after 9-th and 18-th cycle is given in Table 4. It shows that moving the central block to the periphery results in the substantial reduction of Li-6 because of its smaller production at the location [2]. The density of He-3 is higher as a result of H-3 decay and low burnup rate of He-3 in peripheral flux. The effect needs further investigation.

Table 4.
Number densities [at/b-cm] of Be poisons before and after 'detoxication'

Vertical zone [cm]	He-3		H-3		Li-6	
	9 cycles	18 cycles	9 cycles	18 cycles	9 cycles	18 cycles
0-10	2.390E-7	4.459E-7	5.779E-6	6.597E-6	1.222E-6	2.272E-7
10-20	3.877E-7	5.802E-7	9.781E-6	1.088E-5	1.353E-6	1.121E-7
20-30	4.880E-7	6.542E-7	1.251E-5	1.365E-5	1.295E-6	6.122E-8
30-40	5.494E-7	6.985E-7	1.417E-5	1.531E-5	1.248E-6	4.296E-8
40-50	5.781E-7	7.193E-7	1.495E-5	1.608E-5	1.225E-6	3.681E-8
Average 0-50	4.484E-7	6.196E-7	1.144E-5	1.250E-5	1.269E-6	9.606E-8

The effect of the block shuffling in the 2D model

In the 2D representation of the MARIA core the effect of a single block shuffling could be calculated. The blocks L-IX and G-VII have been chosen, because the former was the least and the latter the most poisoned. It has been found that the reactivity effect of the exchange is 4 mk gain in k-effective. It should be noted that relatively large cores have been operated in the analyzed period 1975-1985, which contributes to the week effect of the block shuffling. It is expected that in the second period of reactor operation, 1993-2000, the effect should be more pronounced because smaller cores have been operated in this period.

ACKNOWLEDGMENTS

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