AGEING MANAGEMENT OF BERYLLIUM AND GRAPHITE BLOCKS IN RESEARCH REACTOR MARIA

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ABSTRACT

In the paper the phenomenon of beryllium moderator poisoning by thermal neutron absorption and the method and results of this phenomenon control is presented. Also the phenomenon of graphite blocks damage due to fast neutrons accumulation and the methods and results of this process supervising is described. These methods refer especially to: visual inspection of their state and radiography of graphite blocks. Special attention is paid to permanent estimate of fast neutron fluency accumulated in blocks and methods of their shuffling in the reactor core. The shuffling makes possible to increase the lifetime of beryllium and graphite blocks and decrease the cost of reactor operation.

1. Introduction

In Polish research reactor Maria the beryllium blocks constitute moderator and graphite blocks are reflector. In the past for the reason of graphite blocks swelling it was necessary to shut down the reactor and perform the reactor core reconstruction because graphite blocks caused blockage movement of fuel elements. Fuel elements were situated in the vicinity of graphite blocks. After examination of graphite blocks the decision of evacuation them from the vicinity of fuel element and replacing by beryllium blocks was taken. From this time very strict limits for fast neutrons fluency accumulated in beryllium and in graphite blocks were imposed and procedure for its control was introduced.

2. Poisoning of beryllium moderator

The main role of beryllium moderator is to slow down the fast neutrons a portion of these neutrons is absorbed. As the result of this reaction ^{6}Li is generated and the following reactions with thermal neutrons occur:

$$^{9}_{4}Be(n,\alpha)^{6}_{2}He \xrightarrow[0{,}8\,sec]{\beta^-} {}^{6}_{3}Li$$

$$^{6}_{3}Li(n,\alpha)^{3}_{1}H$$

$$^{3}_{1}H \xrightarrow[12{,}35\,y]{\beta^-} {}^{3}_{2}He$$

$$^{3}_{2}He(n,p)^{3}_{1}H$$

Two of the above radioisotopes have very large cross-section for thermal neutrons absorption, i.e. ^{6}Li and ^{3}He. These radioisotopes decide over beryllium poisoning.
Concentration of ^{3}He is to be linearly increased in time and the relevant reactivity effect may be higher than the poisoning by ^{6}Li. This effect is more significant if there are long break in

reactor operation. Growth of beryllium poisoning is to be a function of $\frac{\emptyset f}{\emptyset th}$ ratio in beryllium and also causes in beryllium irradiation increase of the ^{3}He concentration. During reactor shutdown, generation of ^{3}He from ^{3}H decay is carrying out but the mechanism of ^{3}He reduction due to burnup is stopped. The effect is more significant during long period of reactor shutdown (a few years). In this case the concentrations of ^{6}Li, ^{3}He and ^{3}H have been changing in a following way, as function of time:

$$N_{Li}(t) = N_{Li}^0 = const$$

$$N_{He}(t) = N_{He}^0 + N_H^0 \, (1 - e^{-\lambda_H t})$$

$$N_H(t) = N_H^0 \cdot e^{-\lambda_H t}$$

where:

$N_{Li}(t)$ – concentration of lithium
$N_{He}(t)$ – concentration of ^{3}He as the function of time
$N_H(t)$ – concentration of ^{3}H as the function of time
N_{Li}^0 , N_{He}^0 , N_H^0 – adequately the concentration in the time $t = 0$
λ_H – decay constant of ^{3}H

If t_c is defined as period of reactor shutdown so the growth of macroscopic cross-section on thermal neutrons absorption is described as:

$$\Delta\Sigma_a(t + t_c) \cong \frac{N_b \cdot \sigma_t \cdot \emptyset_t}{\emptyset_{th}} \, (1 + \lambda_H(t - t_0) + \sigma_{He}\emptyset_{th}(t - t_0)\left(1 - e^{-\lambda_H t_c}\right))$$

where:

N_b – beryllium concentration inside elementary cell of core
σ_t – microscopic cross-section of Be on reaction (n, α)
$\emptyset_f$ – average fast neutron flux in Be
$\emptyset_{th}$ – average thermal neutron flux in Be
σ_{He} – microscopic cross-section of He on reaction (n, p)

For example 10 years period of reactor shutdown brings about a 15 times increasing of beryllium poisoning due to He in comparison to poisoning during reactor operation.
The reactivity effect of beryllium poisoning can't be measured directly beside the changing of the poisoned beryllium over fresh one and comparison the reactivity effect. This effect is estimated by calculation using REBUS-3 code [1] which was adapted at NCBJ to calculate beryllium poisoning in reactor MARIA.

3. Minimization of reactivity effect due to beryllium blocks poisoning

Poisoning of beryllium, as it was presented in p. 1, is influenced strongly by mode of reactor operation. It should be very important to avoid long periods of reactor shutdown but it is not always possible because at least some periods for maintenance or modernization are to be necessary.
Any longer reactor shutdown period causes increase of poisoning concentration in the beryllium and the loss of reactivity which is to be recovered after long period of reactor operation (about 1000 hours). For this reason it's important to avoid unloading of irradiated beryllium, for longer period, out of the reactor core. Such situation would cause significant growth, depending of time to be out of core, of the concentration and after returning to reactor core would introduce negative reactivity effect for a long time. In the case of necessity to remove some beryllium blocks from reactor core it's recommended to install them in the place of graphite blocks in the vicinity of beryllium moderator. In this place the

ratio $\frac{\emptyset_{\mathrm{f}}}{\emptyset_{\mathrm{th}}}$ is small, so the beryllium poisoning will be slower and depending on thermal neutron flux.

In the case of necessity to install in reactor core of beryllium block which was some years out of the core and is highly poisoned, at the beginning it's recommended to install it in the periphery of the core for ^{3}He burning.

The main method of minimization of beryllium blocks poisoning is to perform a systematic shuffling of them. This process is carrying out every two years. This operation is based on following principle: the blocks from the places where the ratio $\frac{\emptyset_f}{\emptyset_{th}}$ is high (center of the core) are install in the places where this ratio is small (periphery of the core). In this way strongly poisoned blocks are depoisoned in the periphery of reactor core. As an example the change of fully poisoned block in the reactor center by fresh one causes around 1.1 $ of reactivity increase [4].

4. Estimate of fast neutrons fluence inside beryllium blocks [2]

Assumptions:

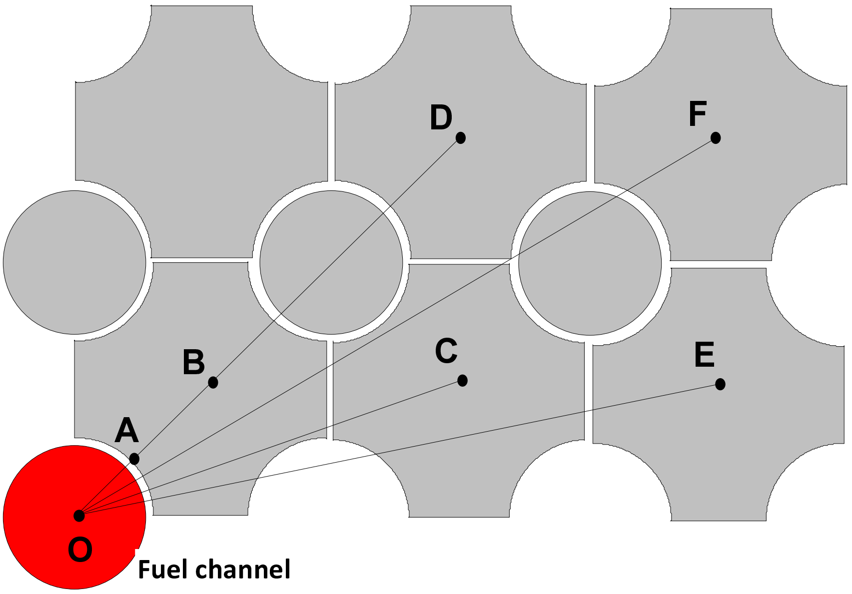
- estimate is related to medium beryllium block where the neutron flux is maximal
- estimate is done in geometrical center of block
- the total neutron fluence in geometrical center of block is generated due to fast neutrons by unscreened fuel channels in the vicinity of block.

For evaluation of fast neutron fluence accumulated inside beryllium blocks it's necessary to determine the correlation between the fuel channel power and fast neutron flux. The results of calculation achieved by using WIMS-D4 code, for fresh fuel, 1 MW power are following:

- $3{,}55 \cdot 10^{13}$ n/cm^{2}s – on block surface
- $2{,}64 \cdot 10^{13}$ n/cm^{2}s – in geometrical center of block.

For comparison the measured value in the center of block is $2{,}54 \cdot 10^{13}$ n/cm^{2}s.

The fast neutrons flux generated by one fuel channel and accumulated in beryllium block depends on fuel channel power and its distance from the block:



AO – 41,0 mm
BO – 91,9 mm
CO – 207,5 mm
DO – 278,6 mm
EO – 335,4 mm

Fig. 1. Distances between the centers of beryllium blocks and fuel channel center

This correlation is presented on the figure below:

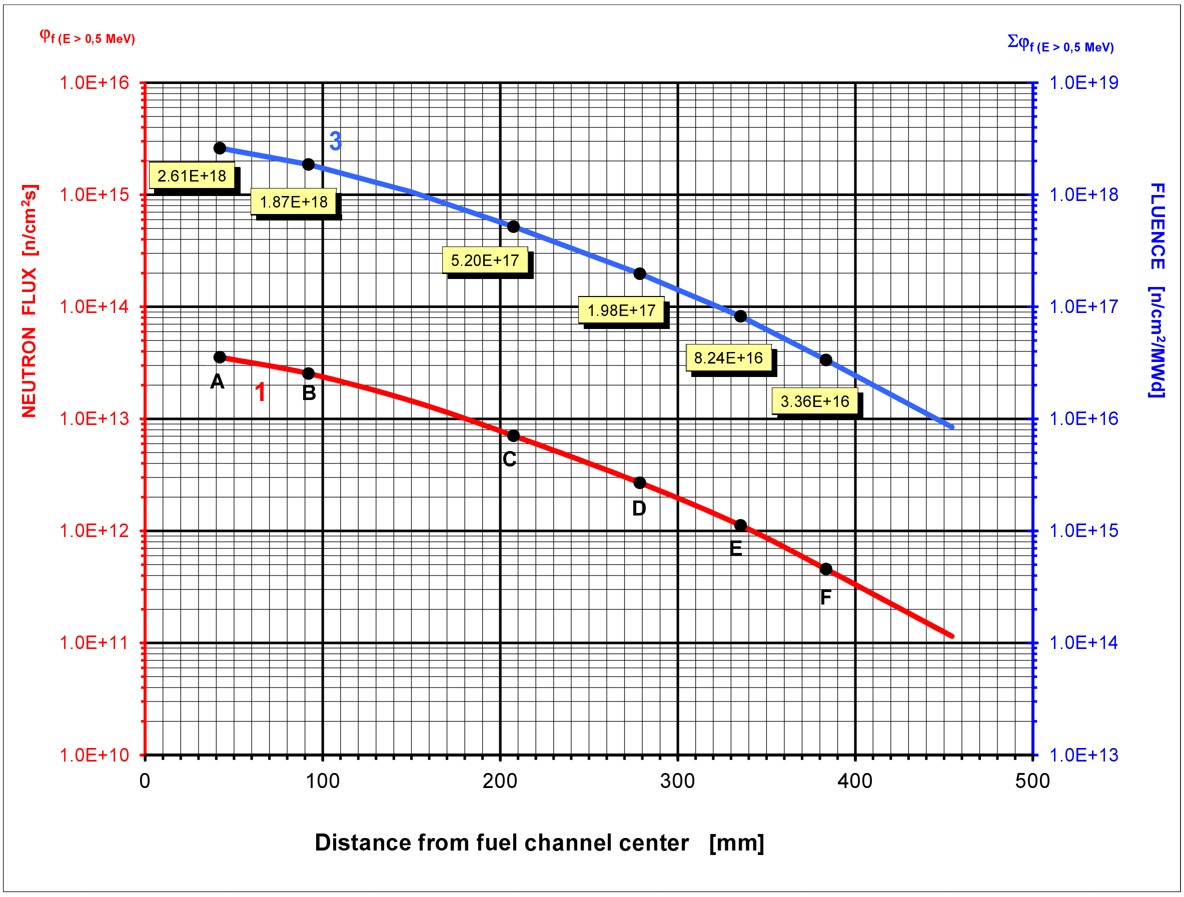


Fig. 2. Dependence of fast neutron flux and fluence as a function of distance of beryllium block center from fuel channel center

Based on this curve the fast neutron fluence in the center of beryllium block for different distances from one fuel channel center generated 1 MW energy, has been determined. The total fluence is determined as the summe of fluences generated by all fuel channels which directly “see” the beryllium block. Knowing correlation between energy generated by related fuel channels and fluences in the center of beryllium blocks the total fluence accumulated in the block can be determined.

5. Estimation of graphite blocks physical state

The scheme of graphite block is presented in Fig. 3.
Graphite damage due to fast neutrons accumulation influences strongly on its physical properties. Irradiation of graphite causes the change of its dimensions in the direction perpendicular to the direction of pressing are increasing whilst in the parallel direction are decreasing.
The core configuration from the year 1974 and actual are presented in the Fig. 4.

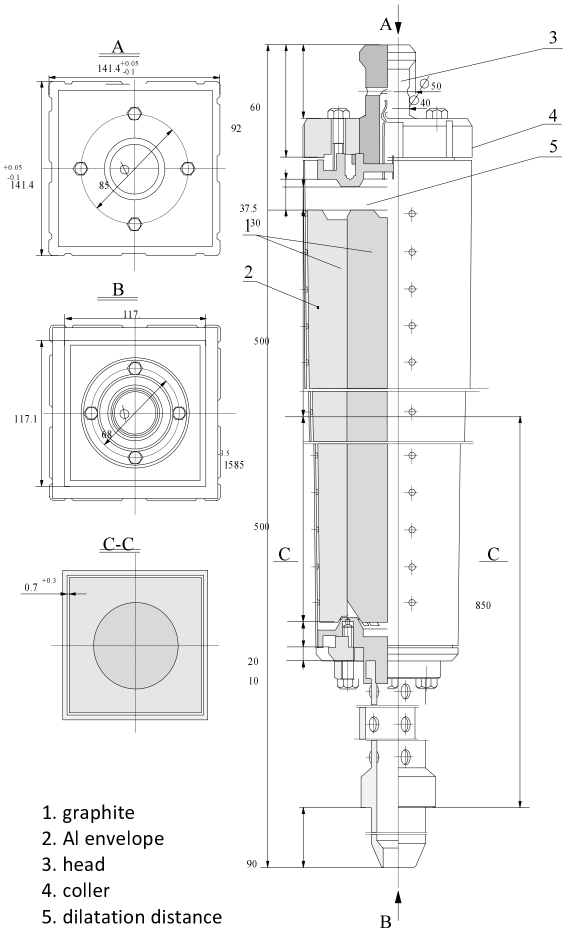
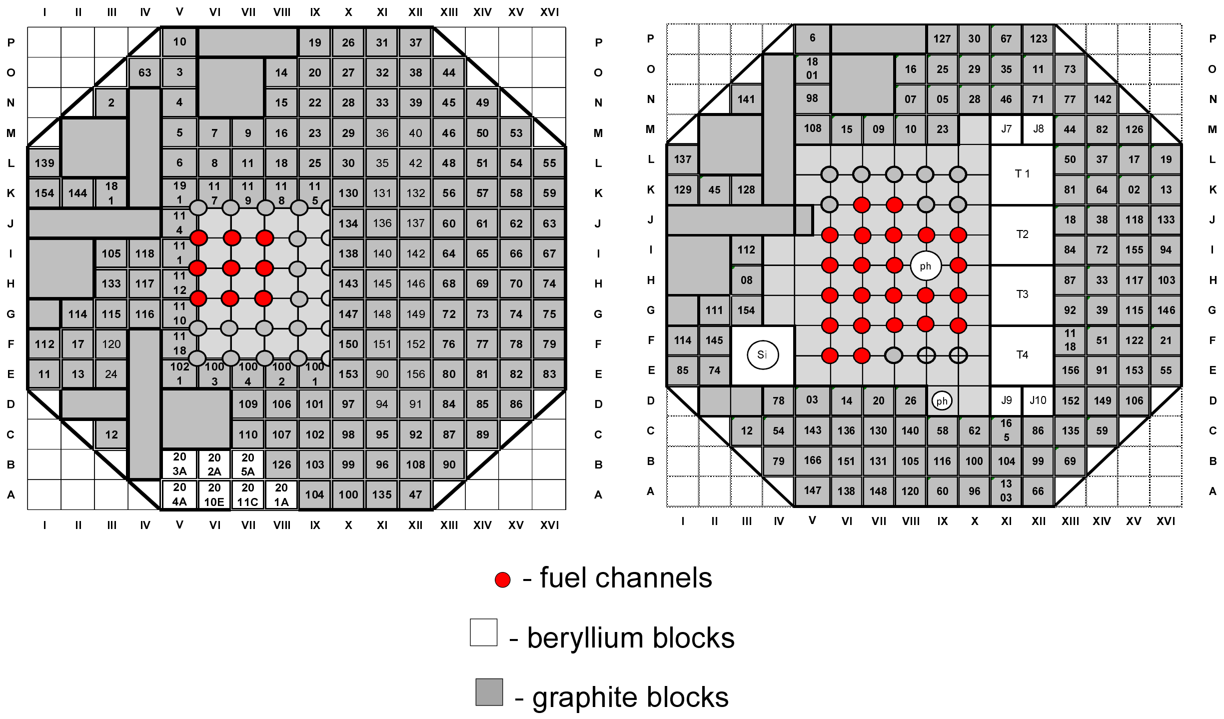


Fig. 3. Scheme of graphite block



a) year 1974

b) year 2013

Fig. 4. Reactor core configurations

After 10 years of reactor operation with configuration a) when graphite blocks were situated in the vicinity of fuel channels caused important deformation of some graphite blocks. The radiography of these blocks indicated the lack of dilatation distance (see Fig. 3) what was the reason of block deformation. In Fig. 5 the results of the dilatation distance measurements in function of the fast neutrons fluence being accumulated inside the blocks is presented [3]. These measurements were performed in the year 1986 and in this time maximum fluence of fast neutrons accumulated in some blocks was 1,56 · 10^{22} n/cm^2. In the consequence it was decided to remove the graphite blocks from the vicinity of fuel channels and the core configuration presented in Fig. 4 b) was established. The new radiography and measurements of dilation distance was carried out in July this year. The results of this examination indicated that in all verified blocks the dilatation distance is presented and the minimal value in block which accumulated the fast neutron fluence is 15 mm. The radiography of this block is presented in Fig. 6.

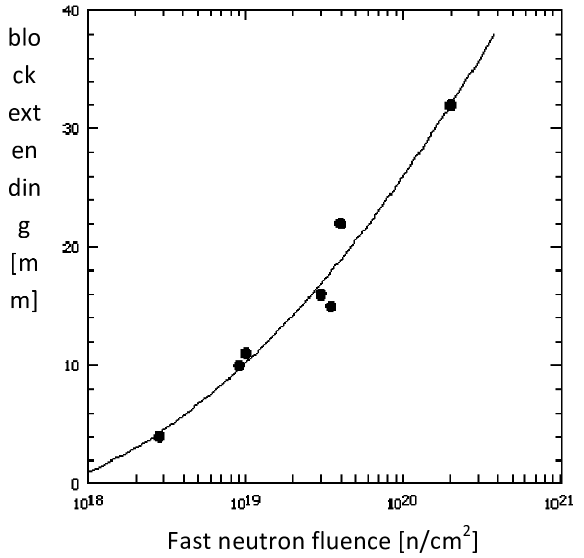


Fig. 5. Dependence of block extending as a function of fast neutron fluence

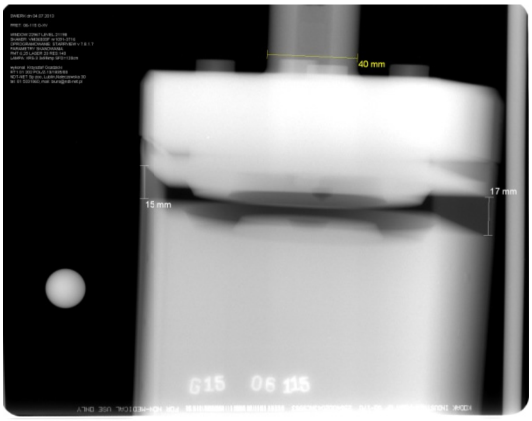


Fig. 6. View of the graphite block

6. Conclusion

Ageing management of beryllium and graphite blocks, in research reactor Maria is very important issue due to very high value of fast neutron flux (E > 0,5 MeV). Especially beryllium blocks which are the moderator have to be very carefully examined and estimated. Actual method of their fast neutron fluence estimate is not sufficiently precised and the work for doing this by using Rebus code is carried out. Nevertheless presented in the report ageing management programme fulfill its role and is sufficiently good.

REFERENCES:

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