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An Evaluation for Reactivity Loss of B_4C Control Absorber in a Small Research Reactor

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1. Introduction

A conceptual small research reactor has been studied and irradiation effects for several control rods including Hf, Ag-In-Cd, and B_4C have been investigated.[1] The previous study shows that the B_4C control absorber has less reactivity loss than those of other control rods. The B-10 has strong absorption cross section and it will be changed into Li-7 with (n,α) reaction. However after 30 years irradiation, the weight of B-10 does not decrease significantly. It was concluded that the low level of thermal flux does not give a large effect on B-10 depletion due the low power.

In this study, a more detail calculation has been carried out concentrating on B_4C control rod for the small research reactor. The previous calculation has been carried out with constant flux irradiation up to 30 years, whereas time dependent flux is used to estimate reactivity loss due to B_4C depletion. The flux is obtained at every 3 years. The depletion analysis has been done with the ORIGEN-S code[2] and the neutron flux estimation and the reactivity worth analysis have been carried out with the MCNP5 code[3].

2. Core Configuration of Small Research Reactor

The small research reactor is to enhance the beam tube neutron flux by shifting fuel assemblies toward the beam tube as shown in Fig. 1. The core consists of nine (9) square fuel assemblies in a 3x3 arrangement. Its fission power is assumed to 3 MW and the reflector is Be square block. The specification of the fuel assembly is given in Table 1. Fig. 2 shows the configuration of control absorber. Square absorber shroud surrounds the fuel assembly.

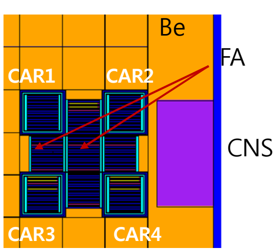

Figure 1. Core configuration of the small research reactor

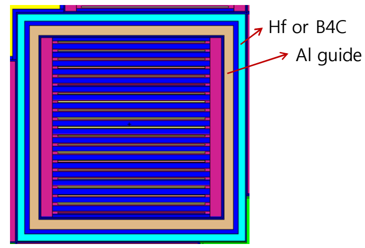

Figure 2. Configuration of control absorber

Due to a single type of fuel assembly, it provides more easy fuel management. Hf is chosen as the reference control absorber in the small research reactor. In this study, B_4C is taken into consideration with enriched B-10 and its density is 1.25 g/cc.

Table I. Fuel Data for the Small Research Reactor

Item	Value
Fuel Meat Material	U_3Si_2-Al
U density (g/cc)	4.8
Meat thickness (mm)	0.76
Meat width of standard FA(mm)	~64
Cladding thickness (mm)	0.38
Moderator channel thickness (mm)	~2.5
Number of plates in standard FA	20
FA size (mm)	81x81x600

3. Analysis Results

In order to analyze depletion effect of control absorbers, thermal neutron fluxes are estimated in the control absorber by using the MCNP5 code. All the fuels are assumed in the fresh states and the bottom of all control absorbers is positioned at +150 mm from the center of fuel assembly, which is overall average control rod position during operation. In order to obtain more accurate results, control absorber is split into three regions such as 150 mm, 200 mm and 300 mm from the bottom. The average thermal fluxes for three different control absorbers at the inserted region are 2.72E+12 n/cm^{2}s and 6.38E+10 n/cm^{2}s for Hf and B_4C, respectively. The bottom thermal flux is used for the flux irradiation analysis to assure enough margin. As the next step, a depletion analysis with flux irradiation calculation has been carried out with the ORIGEN-S code. Irradiation time is extended to 30 years and the inventories of depleted control absorbers are directly used for the next step analysis. The reactivity loss of depleted control absorbers is estimated again with MCNP5 calculation. The reduced reactivity worth is reported about 99 mk and 32 mk for Hf and B_4C, respectively.

But B-10 has a high neutron capture cross section thus it is necessary to re-visit the problem for B_4C depletion and a time dependent flux irradiation option is used instead. If the flux level of B_4C increases up to that of Hf, the concentration of B-10 decreases significantly as shown in Fig. 3. It means that more detail calculation should be done in B_4C depletion analysis. Total 10 irradiation steps are divided into and the flux was obtained at every 3 years. Each step, the composition of depleted B_4C control absorber is used to obtain new flux. The concentration of B-10 with time dependnet flux irradiation exhibits almost same as constant flux irradiation case as shown in Fig. 3. Table II shows reactivity differences between constant flux irradiation and time dependent flux irradiation options. The difference of two cases is about 5 mk, which is not significantly large. The main reason of this reactivity loss of depleted B_4C control absorber just comes from low fission power of the small research reactor. If the power level increases, then the flux increases too. Thus, the depletion of B-10 will be accelerated further. However, in this small research reactor, B_4C depletion is almost negligible and it may be a good option to use as control absorber.

4. Conclusions

In this study, the reactivity losses of B4C control absorber in the small research reactor is investigated with time dependent flux irradiation approach. ORIGEN-S and MCNP5 code is used to carry out depletion analysis of control absorber. Up to 30 years irradiation, the estimated reactivity losses of depleted B4C control absorbers are not significant when constant flux irradiation and time dependent flux irradiation are used.

The calculation procedure with constant flux irradiation is directly to apply the general research reactor in order to analyze depletion effect of control absorbers. And reactivity loss data will be utilized to estimate lifetime of control absorber including thermal and mechanical deformation by irradiation damage.

Acknowledgement

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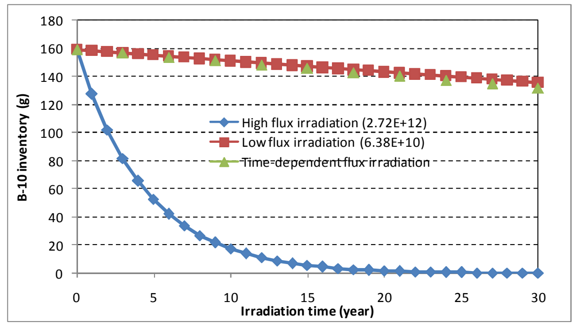

Figure 3. B-10 inventory change as a function of irradiation time.

Table II. Reactivity Loss of Depleted Control Absorbers

Control Absorber	Hf	B_4C	B_4C
Flux Irradiation	Constant	Constant	Time dependent
Thermal Flux (n/cm^2s)	2.72E+12	6.38E+10	6.38E+10~ 8.16E+10
Irradiation Time (year)	30	30	30 (10 steps)
Total CAR Worth (mk)	444.7	893.8	888.9
Fresh Reactivity Worth (mk)	543.8	925.6	925.6
Reactivity Loss (mk)	99.1	31.8	36.7