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Nuclear Analysis for Application of Boron Burnable Absorber in the HANARO Fuel Assembly

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1. Introduction

The HANARO research reactor of 30 MW uses rod type fuel composed of U_3Si dispersed in the Al matrix. This rod type fuel has been used at NRU, MAPLE 1 and 2 in CANADA. Unlike MTR (Material Testings Reactor) type reactor such as OPAL, CARR, etc., those reactors of rod type fuel do not use burnable absorber. Burnable absorber is used for reducing reactivity swing and power peaking in high performance research reactors.

Development of the HANARO fuel element with burnable absorber was started in the U-Mo fuel development program at HANARO [1], and the first full core analysis was performed last year [2]. In the analysis, cadmium in the form of CdO was considered as the most promising burnable absorber for the current HANARO element. The U-Mo fuel with CdO was successfully irradiated at the HANARO core, but it was found that the thermodynamic stability of CdO is questionable under the higher temperature condition than the current manufacturing environment [3]. Prior to application of CdO, further studies are required.

Traditionally, boron has been used as burnable absorber at the high performance research reactors such as ATR, FRM-II, etc. The power density of HANARO is lower than those reactors, and the residual reactivity effect by boron is not negligible in the core. Nevertheless, boron is still one of attractive materials as burnable absorber for the HANARO fuel element and neutronics study is done for application of boron in the HANARO fuel assembly in this study. The McCARD [4] code with the ENDF/B-VII library was selected and the detailed HANARO core model [5] was used for the full core analysis.

2. Nuclear Analysis

HANARO uses hexagonal and circular fuel assemblies. Two types of fuel assemblies are loaded in the inner and outer core of HANARO. There are 23 hexagonal channels and 8 circular channels in the inner core of HANARO. Those 8 circular channels are surrounded by 4 control absorber rods (CARs) and 4 shut-off absorber rods (SORs). 8 channels located in the outer core are also circular. 3 hexagonal channels in the inner core and 4 circular channels in the outer core are used as irradiation holes. The core consists of 32 fuel assemblies and 7 irradiation holes. Other irradiation holes and beam tubes are located in the D_2O reflector region surrounding the core.

2.1 Homogeneous Mixing of Boron

The hexagonal fuel assembly consists of the standard and reduced fuel rods, but the circular fuel assembly only consists of the standard fuel rods. The reduced fuel rods were used to suppress power peaking. When a low power peaking can be achievable by burnable absorber, large residual reactivity effect could be overcome by replacing the reduced fuel rods into the standard fuel rods. Fig. 1 shows reactivity swing and the excess reactivities at EOC (End Of Cycle) in the HANARO core.

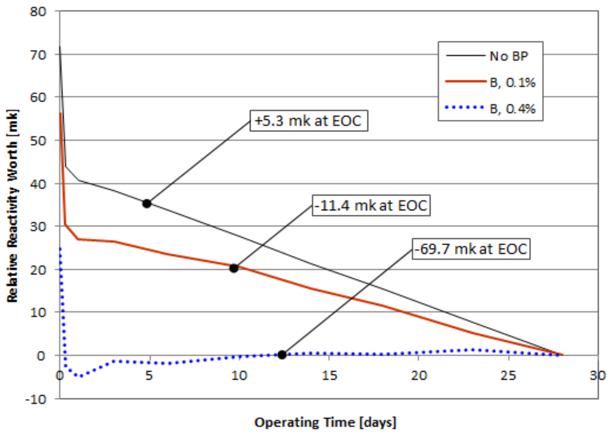

Fig. 1. Reactivity Swing vs. Boron Concentration in the HANARO Core

Boron can control the reactivity swing almost completely, but the residual reactivity effect become large. As shown in Fig. 1, complete reactivity flattening requires additional reactivity worth of 75.0 mk in the core. Replacing the reduced fuel rods into the standard fuel rods extends the current cycle length of 28 days into 34.5 days. For the current cycle length, reactivity swing and the excess reactivity at EOC were evaluated as shown Fig. 2. Complete reactivity flattening is not possible, but the result of ‘B, 0.175%’ is a very good case. Maximum excess reactivity after 1 day is 9.8 mk for the case of ‘B, 0.17%’, which is lower than the CdO case of 15.8 mk [2].

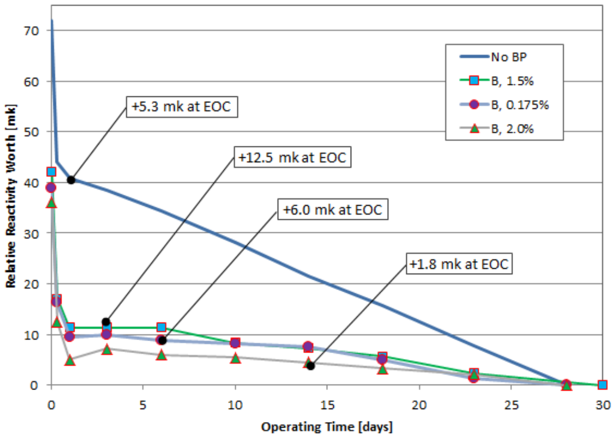

Fig. 2. Reactivity Swing vs. Boron Concentration in the HANARO Core Consisting of All Standard Fuel Rods

Fig. 3 shows the peak power distribution for the case of 'B, 0.175%'. The power peaking factor, Fq is reduced from 2.37 of 'No BP' case to 2.30.

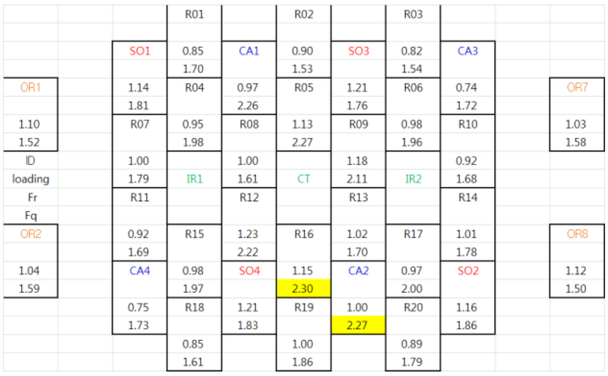

Fig. 3. Power Distribution for the Boron 0.175% Case

2.2 Heterogeneous Mixing of Boron

Boron can be used for the HANARO fuel assembly, but the uranium loading became increased about 10.8%. It is necessary to reduce the residual reactivity effect by boron. The burnable absorber was homogeneously mixed with the fuel material within the fuel rod, but the thermal flux within the rod drops rapidly by the self-shielding effect. If we disperse burnable absorber particles in the outer region within the fuel rod homogeneously, burnout rate of burnable absorber could be raised.

Infinite array of the hexagonal fuel assembly was modeled for evaluating the self-shielding effect. Relative power distributions within the outer fuel rods of the hexagonal fuel assembly were evaluated using the MCNP [6] code. Each outer fuel rod was segmented into 50 regions and the relative power distribution averaged over the outer rods of each case is depicted in Fig. 4. Physical density, 5.4 g/cm^3, of the current HANARO fuel is not high, but the minimum and maximum relative powers are 93.0% and 110.7%, respectively. The case of 'B, 0.2%', in which the burnable absorber particles are homogeneously mixed within the rod, shows that minimum and maximum relative powers are 86.7% and 111.5%, respectively. The homogeneous mixing of the burnable absorber makes the self-shielding effect larger, but the heterogeneous mixing cases, 'B, 0.4~10.0%', mitigates the effect as shown in Fig. 4.

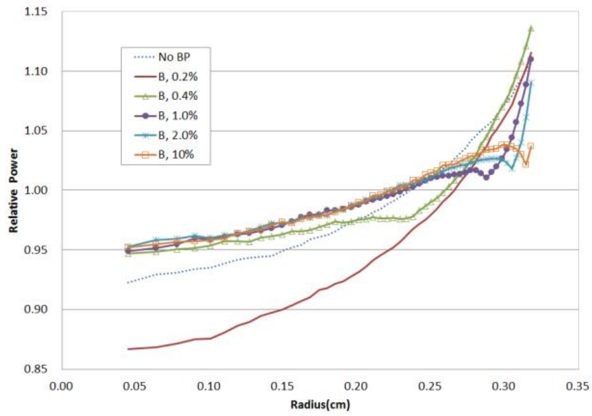

Fig. 4. Relative Power Distribution with the Fuel Rod for Each Boron Concentration

Fig. 5 shows the reactivity rundown curves calculated by the HELIOS [7] code. The partial calculation results are summarized in Table 1. The amount of boron was maintained to be constant, but the multiplication factors are different on concentration of boron.

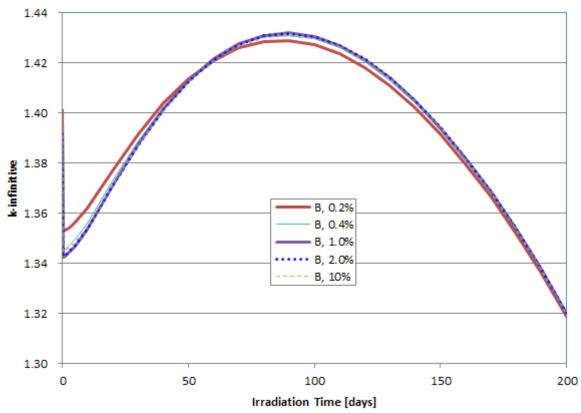

Fig. 5. Reactivity Rundown Curves for Each Boron Concentration

Fig. 5 shows that the heterogeneous cases, 'B, 0.4~10%', are better than the homogeneous case, 'B, 0.2%'. Among the heterogeneous cases, we can find that 'B, 1.0%' is best from Table I. In the case of 'B, 1.0%', the burnable absorber particles within the outer fuel rods are mixed from 0.2840 cm to 0.3175 cm in radius.

Table I: Irradiation Time Dependent Multiplication Factors for the Several Boron Concentrations.

Irradiation Time [days]	Inner Radius of the BP Region (cm)				
	0.0	0.2245	0.2840	0.3012	0.3143
	Boron Concentration in the BP Region (wt%)				
	B, 0.2%	B, 0.4%	B, 1.0%	B, 2.0%	B, 10%
0	1.40148	1.39355	1.39104	1.39143	1.39359
1	1.35327	1.34558	1.34291	1.34311	1.34498
10	1.36221	1.35611	1.35380	1.35376	1.35488
20	1.37727	1.37278	1.37092	1.37069	1.37114
40	1.40415	1.40240	1.40158	1.40120	1.40073
60	1.42123	1.42145	1.42154	1.42123	1.42034
80	1.42878	1.43016	1.43090	1.43073	1.42978
100	1.42750	1.42938	1.43045	1.43042	1.42961

Based on the analysis results for the fuel assembly, the full core calculation results are compared at Fig. 6. The heterogeneous cases have smaller reactivity swing and higher excess reactivity at EOC.

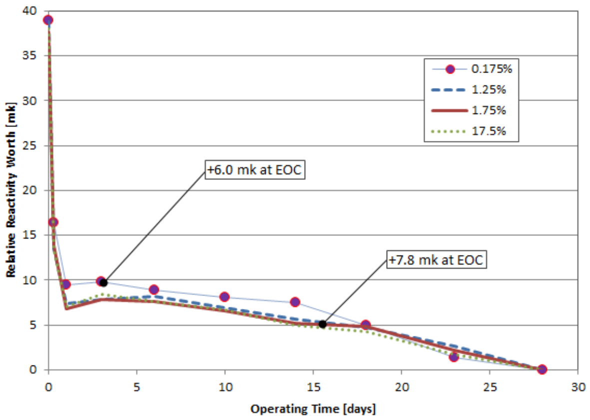

Fig. 6. Comparison of the Reactivity Swings for Several Boron Concentration Cases.

3. Conclusions

Basic nuclear analysis for application of boron burnable absorber in the HANARO fuel assembly was performed for getting a better fuel element. The residual reactivity effect can be overcome with replacing the reduced fuel rods into the standard rods. This new fuel design provides lower reactivity swing and lower power peaking.

To minimize the residual reactivity effect, a concept of heterogeneous burnable poison within the rod is introduced. The heterogeneous cases give us better results and there is an optimum boundary for the burnable absorber region. This neutronics study was limited to the boron burnable absorber in the current silicide HANARO fuel, other studies including manufacturing study are desirable for application of burnable absorber.

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