Feasibility Study on Burnable Absorber in the KiJANG Research Reactor

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has developed a new research reactor of 15 MW and submitted a preliminary safety analysis report to get a construction permit. The KiJANG Research Reactor (KJRR) adopts the MTR (Material Testings Reactor) type U-Mo fuel composed of U-7Mo fuel particles dispersed in the Al matrix. At the conceptual design stage, burnable absorber was supposed to be used in the KJRR fuel assembly. The current KJRR fuel assembly does not use burnable absorber unlike the MTR type reactors such as JRR-3M, OPAL, etc.

This paper introduces why the burnable absorber option was discarded in the KJRR fuel design and whether burnable absorber is necessary. In this nuclear analysis, the McCARD [1] code with the ENDF/B-VII.0 library was used.

2. Nuclear Analysis

The KJRR core was optimized for isotope production, NTD (Neutron Transmutation Doping) production, and the related research activities [2]. The core is located within a core box made of zircaly-4 as shown in Fig. 1.

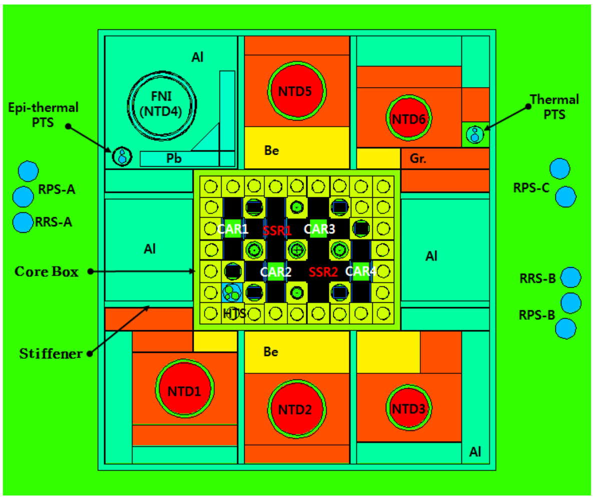

Fig. 1. Plan view of the KJRR core.

The core is composed of a 7x9 lattice with its active length of 60 cm. The nominal core consists of 22 fuel assemblies, in which 16 standard and 6 follower fuel assemblies are loaded. Each fuel assembly is filled with 19 interior fuel plates of 8.0 gU/cm^3 and 2 exterior fuel plates of 6.5 gU/cm^3 as shown in Fig. 2.

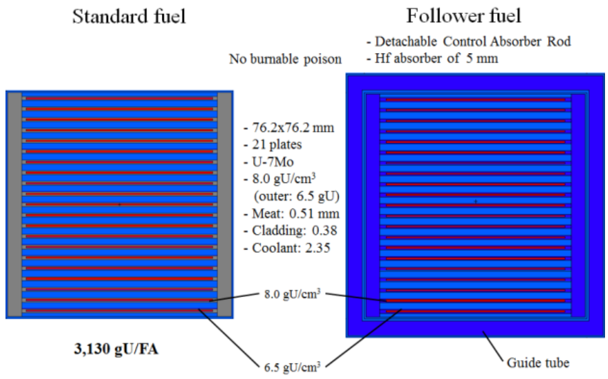

Fig. 2. Cross sectional view of the KJRR fuel assemblies.

An equilibrium core is dependent on an operation strategy, so there may be various equilibrium cores according to a reactor operating strategy. Two fuel assemblies are loaded for one cycle operation considering discharge burnup, cycle length and excess reactivity etc. The reactivity swing by fuel burnup is estimated to be 34.1 mk over the cycle length.

Traditionally, burnable absorber has been used for reducing reactivity swing and power peaking in research reactors. The current fuel design without burnable absorber fulfills all design requirements of the KJRR, but lower reactivity swing is beneficial in its utilization and lower power peaking is helpful to get more safety margin. Section 2.1 introduces the preliminary study to get a proper burnable absorber in the basic design stage of the KJRR. The study was limited to use of the proven technologies. In section 2.2, the study was extended to use of possible technologies.

2.1 Preliminary Study

KJRR uses high density U-Mo fuel of 8.0 gU/cc. U-Mo fuel is not used widely yet and the studies on burnable absorbers in the U-Mo core are not available. High density fuel gives higher fuel economy, but there are some drawbacks such as high power peaking and a difficulty on controlling excess reactivity, etc. The use of burnable absorber was considered in the fuel design. First, Cd wire wrapped with Al cladding was considered in the fuel design. The Cd wire of 0.4 mm diameter is used in the JRR-3M of 20 MW. Fig. 3 shows the reactivity rundown curves calculated by the McCARD code. The use of the Cd wire can suppress the reactivity of 8.3 mk. The Cd wire of 0.5 mm diameter can be used in the KJRR fuel, but reactivity flattening is not possible and the residual reactivity effect is severe. The use of Cd wire increases the fuel manufacturing cost and the reactivity suppression is not effective in the KJRR core.

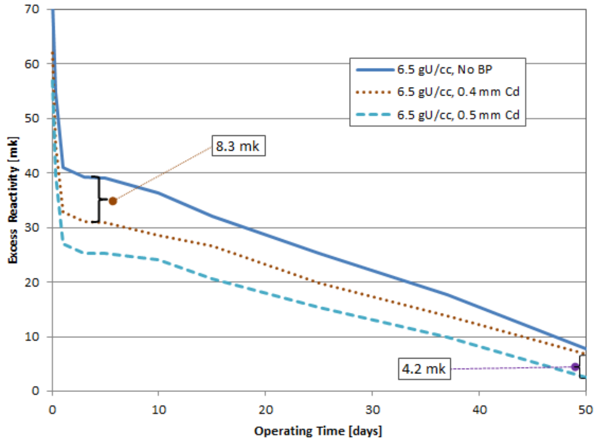

Fig. 3. Excess reactivity vs. Cd wire diameter.

Boron has been used as burnable absorber at the high performance research reactors such as ATR, FRM-II, etc. The power density of KJRR is lower than those reactors, and the residual reactivity effect by boron is not negligible in the core. Additional fuel loading at two outer plates was tried to compensate the residual reactivity as shown in Fig. 4. From this comparison, the case of '7.5 gU/cc, 0.5wt% B_4C' is better than the case of '8.0 gU/cc, 0.7wt% B_4C'.

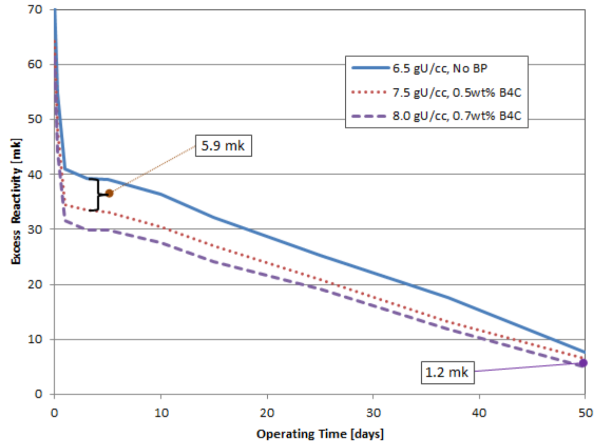

Fig. 4. Excess reactivity vs. boron concentration.

Considering the low power density of the KJRR, gadolinia (Gd_2O_3) would be proper. The 5wt% Gd_2O_3 was added in the outer fuel plates. An experiment for gadolinia in U-Mo fuel was tested up to 5wt% [3]. Fig. 5 shows the reactivity rundown curves for the case of '6.5 gU/cc, 5.0wt% Gd_2O_3' gives another reactivity effect of 11.2 mk compared with the core of '7.5 gU/cc, 0.5wt% B_4C'. Two cases have the same residual reactivity effect of 1.2 mk. From the view point of the reactivity control, gadolinia is the best burnable absorber in the KJRR fuel assembly.

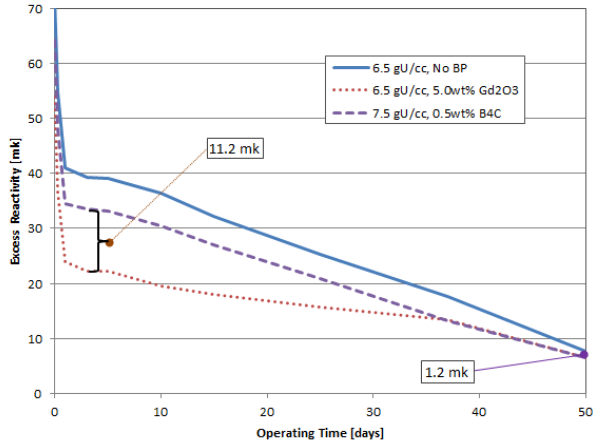

Fig. 5. Excess reactivity vs. gadolinia concentration.

Fig. 6 shows the operating time dependent neutron detector responses, which are used for the reactor power control in the KJRR. The detector response for controlling the reactor power is an average value of 'RRS-A' and 'RRS-B' in Fig. 1. The case of '6.5 gU/cc, No BP' shows that the neutron detector response by the fuel burnup increases about 3% at EOC (End Of Cycle). The case of '6.5 gU/cc, 5.0wt% Gd_2O_3' shows that the response increases about 15% at EOC. As the design limit from I&C (Instrument and Control) had been set to 10%, the case of '6.5 gU/cc, 5.0wt% Gd_2O_3' was discarded. In the design stage, the case of '7.5 gU/cc, 0.5wt% B_4C' was recommended, but small benefit of the case and unknown risk in the U-Mo fuel qualification test made us give up the burnable absorber option.

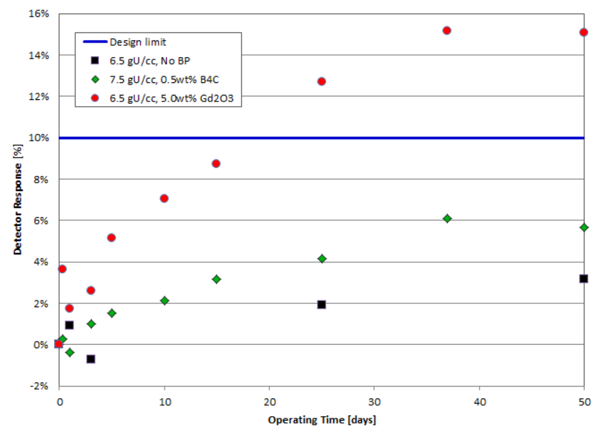

Fig. 6. Operating time dependent detector responses.

2.2 Further Study

Excluding the design limit of the detector response, the case of '6.5 gU/cc, 5.0wt% Gd_2O_3' is promising. The design limit could be removed by modifying the procedure in the power calibration. Additional gadolinia was added to the outer fuel plates for more reactivity effect, but the residual reactivity effect becomes severe as shown in Fig. 7. The reactivity effect of '6.5 gU/cc, 4.0wt% Gd_2O_3' is almost same to the effect of '6.5 gU/cc, 5.0wt% Gd_2O_3'. It is found that the 5.0wt% case is a reasonable limit for Gd_2O_3 mixed in the outer fuel plates.

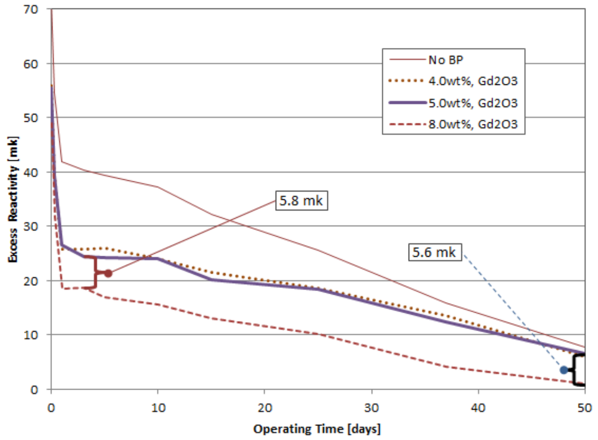

Fig. 7. Comparison of the excess reactivities for several gadolinia concentration cases.

So far, gadolinia was applied to the outer fuel plates in the KJRR fuel assembly. The addition of burnable absorber in the 8.0 gU/cc fuel was avoided for the safe fuel qualification test. If the burnable absorber is applied to all fuel plates, more reactivity effect can be obtained at low residual reactivity. Fig. 8 shows the reactivity rundown curves for several gadolinia concentration cases. At the case of '0.5wt%, Gd_2O_3', the peak reactivity swing is estimated to be 8.9 mk, which is lower than the peak reactivity swing, 17.1 mk, of '5.0wt%, Gd_2O_3' in Fig. 7. A further reactivity flattening is possible as shown in the case of '1.0wt%, Gd_2O_3', but the residual reactivity effect becomes severe.

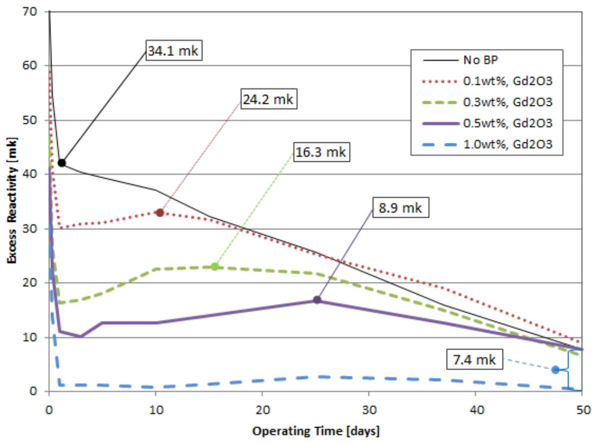

Fig. 8. Comparison of the excess reactivity for several gadolinia concentration cases.

From the viewpoint of the reactivity control, the best burnable absorber is the case of '0.5wt%, Gd_2O_3'. It is necessary that the case of '0.5wt%, Gd_2O_3' should be checked for the power peaking. At the BOC (Begin Of Cycle) state, the power peaking was evaluated and compared with the distribution at 'No BP' case in Fig. 9. The power peaking factor, Fq increases from 2.47 of 'No BP' case to 2.58. The power peaking is slightly increased by the application of the burnable absorber, but the peaking could be suppressed by its optimized fuel management.

F20	IR8	F21	IR9	F22	IR10	
1st		9th		4th		
0.99/0.35		0.94/0.94		1.19/1.37		
2.15/0.77		1.42/1.25		2.39/2.58		
F14	F15	**F16**	F17	**F18**	F19	IR7
4th	7th	6th	10th	12th	8th	
0.76/0.73	0.98/0.97	1.15/1.22	0.97/1.11	0.63/0.80	1.03/1.18	
1.74/1.49	1.81/1.68	1.99/2.05	1.80/1.84	1.53/1.45	1.85/1.80	
F10	IR5	F11	IR0	F12	IR6	F13
2nd		5th		5th		3rd
1.05/1.04		1.21/1.37		1.22/1.37		1.15/1.18
2.25/2.18		2.17/2.29		2.13/2.20		2.45/2.34
IR4	F4	**F5**	F6	**F7**	F8	**F9**
	7th	10th	11th	8th	6th	2nd
	0.85/0.97	0.67/0.85	0.85/0.95	1.07/1.11	1.18/1.13	0.93/0.84
	1.58/1.58	1.66/1.57	1.60/1.56	1.79/1.79	2.19/2.00	2.13/1.79
ID	IR1	F1	IR2	F2	IR3	F3
loading		3rd		9th		1st
F_r (No/BP)		1.04/1.19		1.00/0.97		1.14/0.38
F_q (No/BP)		2.10/2.22		1.55/1.38		2.47/0.86

Fig. 9. Power distribution in the cores of 'No BP' and '0.5wt%, Gd_2O_3'.

3. Concluding Remarks

Basic nuclear analysis for application of burnable absorber in the KJRR fuel assembly was introduced. The addition of '0.5wt%, Gd_2O_3' to all fuel plates gives the best result. This neutronics study was limited to the current core design, further studies using other fuel management schemes are desirable for application of burnable absorber.

REFERENCES

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[3] Ho Jin Ryu, et al., "Effects of Burnable Absorbers on the Fuel Fabrication and Irradiation Performance of U-Mo Dispersion Fuel," RRFM 12, Prague, Czech Republic, March, 2012.