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Nuclear Study on the Rod Type U-Mo Fuel with Burnable Absorber

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1. Introduction

The HANARO research reactor of 30 MW uses a rod type fuel composed of U_3Si dispersed in the Al matrix. The current core uses the silicide fuel of 3.15 gU/cc. The high density U-Mo fuel up to 5.0 gU/cc has been developed in the HANARO [1] and the core conversion studies were accompanied [2,3]. High density U-Mo fuel gives us higher fuel economy, but there are some drawbacks such as high power peaking and a difficulty on controlling excess reactivity, etc. Burnable absorbers were considered to overcome the difficulties in the U-Mo fuel development, but any 3-D full core analysis on the U-Mo fuel with burnable absorber was not done yet. The recent nuclear studies on burnable absorber in the rod type fuel were limited to the current silicide fuel [4,5]. This paper introduces a study on burnable absorber in the rod type U-Mo fuel using the HANARO core. In this nuclear analysis, the McCARD [6] code with the ENDF/B-VII.0 library was selected and the detailed HANARO core model [7] was used for the full core analysis.

2. Nuclear Analysis

The core conversion studies were performed to get more flexibility in reactor utilization and the nuclear analysis of the U-Mo core have unveiled the nuclear characteristics of the U-Mo fuel in the HANARO [2,3]. In this study, the same fuel management scheme for the current HANARO core was used and key parameters such as reactivity, power peaking, and burnup are presented. The equivalent U-Mo core to the current core was searched and then the U-Mo core of 5.0 gU/cc was analyzed.

2.1 Low Density U-Mo Core

HANARO uses hexagonal and circular fuel assemblies. Two types of fuel assemblies are loaded in the inner and outer core of HANARO. There are 20 hexagonal fuel assemblies and 8 circular fuel assemblies in the inner core of HANARO. 4 circular fuel assemblies are loaded in the outer core also. The reference HANARO core is maintained by loading of 3 hexagonal assemblies and 2 circular fuel assemblies. The number of loaded fuel assemblies was fixed to investigate the nuclear characteristics of burnable poison.

In the current HANARO core, the hexagonal fuel assembly consists of the standard and reduced fuel rods and the circular fuel assembly only consists of the standard fuel rods. In the U-Mo core, all fuel rods are the standard fuel rods and burnable absorber are used in the outer region to suppress power peaking. First, a U-Mo core of 3.15 gU/cc was searched. Addition of the burnable absorber, B_4C, was adjusted for the same excess reactivity with the silicide core at the EOC (End Of Cycle). The case of '0.14wt% B_4C' is equivalent to the excess reactivity of the silicide core at EOC. Fig. 1 compares the reactivity swings in the cores. The lower reactivity swing provides a larger safety margin in operation and the larger flexibilities in utilization. In this study, the reactivity swing below 15.0 mk is proposed for an upgraded HANARO.

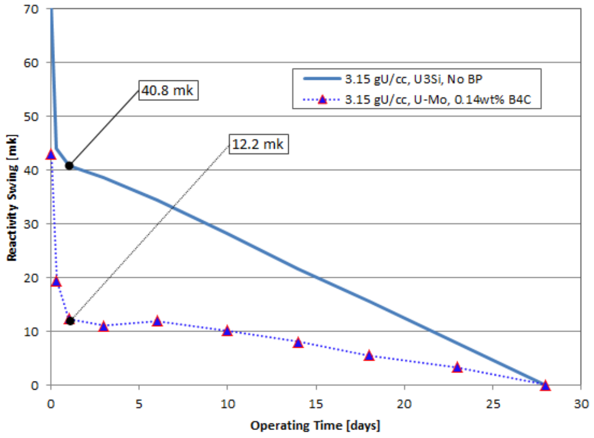
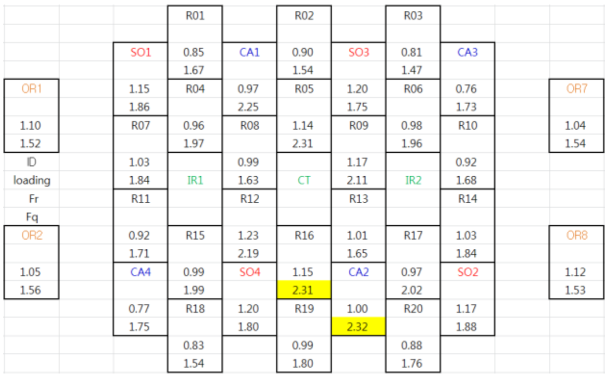


Fig. 1. Reactivity swing of the current core and the low density U-Mo core.

Fig. 2 shows the peak power distribution for the case of '3.15 gU/cc, U-Mo, 0.14wt% B_4C'. The power peaking factor, Fq, is reduced from 2.37 of '3.15 gU/cc, U_3Si, No BP' case to 2.32. Fresh fuel assemblies are loaded into R05, R07, R14, CA3, and CA4. The highest peaking factor occurs at CA2, one of the positions of once burnt fuel assemblies.



			R01		R02		R03			
		SO1	0.85	CA1	0.90	SO3	0.81	CA3		
			1.67		1.54		1.47			
OR1		1.15	R04	0.97	R05	1.20	R06	0.76		OR7
		1.86		2.25		1.75		1.73		
1.10		R07	0.96	R08	1.14	R09	0.98	R10		1.04
1.52			1.97		2.31		1.96			1.54
ID		1.03		0.99		1.17		0.92		
loading		1.84	IR1	1.63	CT	2.11	IR2	1.68		
Fr		R11		R12		R13		R14		
Fq										
OR2		0.92	R15	1.23	R16	1.01	R17	1.03		OR8
		1.71		2.19		1.65		1.84		
1.05		CA4	0.99	SO4	1.15	CA2	0.97	SO2		1.12
1.56			1.99		2.31		2.02			1.53
		0.77	R18	1.20	R19	1.00	R20	1.17		
		1.75		1.80		2.32		1.88		
			0.83		0.99		0.88			
			1.54		1.80		1.76			

Fig. 2. Power distribution of the low density U-Mo core.

2.2 High Density U-Mo Core

The U-Mo fuel has been developed up to 5.0 gU/cc in the HANARO. Addition of the burnable absorber, B_4C, was adjusted for the same excess reactivity of the current core at the EOC. Fig. 3 shows reactivity swings and the excess reactivities at EOC. The excess reactivity of '0.25wt% B_4C' is equivalent to the reactivity of the current core at EOC. Maximum reactivity swing after 1 day is 13.5 mk for the case of '0.25wt% B_4C'. The maximum discharge burnup of the fuel assemblies is 59.9%U-235 and the local peak burnup of the fuel rod is 88.5%U-235.

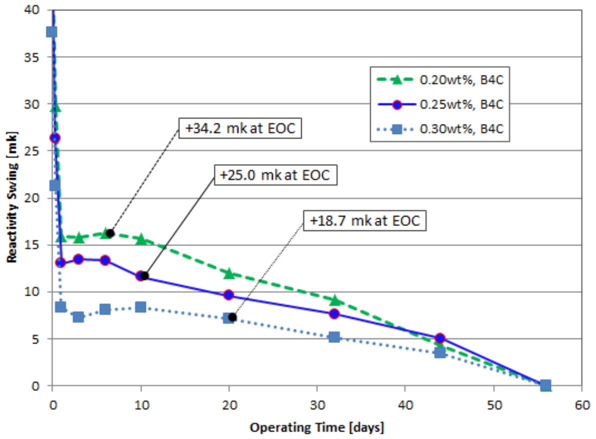
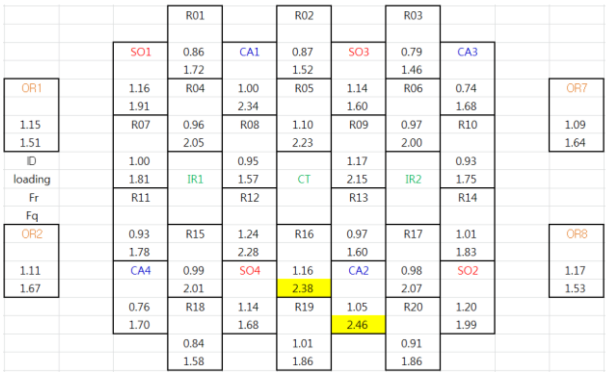


Fig. 3. Reactivity swing vs. B_4C concentration in the high density U-Mo core.

Fig. 4 shows the peak power distribution for the case of '0.25wt% B_4C'. The power peaking factor, Fq is increased from 2.37 of '3.15 gU/cc, U_3Si, No BP' case to 2.46. Comparing Fig. 2 and Fig. 4, the relative assembly powers of Fig. 4 at the first loading positions are lower than the powers of Fig. 2. A better fuel management scheme could improve the high peaking factor by balloon effect.



			R01		R02		R03			
		SO1	0.86	CA1	0.87	SO3	0.79	CA3		
			1.72		1.52		1.46			
OR1		1.16	R04	1.00	R05	1.14	R06	0.74		OR7
		1.91		2.34		1.60		1.68		
1.15		R07	0.96	R08	1.10	R09	0.97	R10		1.09
1.51			2.05		2.23		2.00			1.64
ID		1.00		0.95		1.17		0.93		
loading		1.81	IR1	1.57	CT	2.15	IR2	1.75		
Fr		R11		R12		R13		R14		
Fq										
OR2		0.93	R15	1.24	R16	0.97	R17	1.01		OR8
		1.78		2.28		1.60		1.83		
1.11		CA4	0.99	SO4	1.16	CA2	0.98	SO2		1.17
1.67			2.01		2.38		2.07			1.53
		0.76	R18	1.14	R19	1.05	R20	1.20		
		1.70		1.68		2.46		1.99		
			0.84		1.01		0.91			
			1.58		1.86		1.86			

Fig. 4. Power distribution of the high density U-Mo core.

So far, the burnable absorber was limited to B_4C, but the residual reactivity effect of B_4C is not negligible. In the KOMO-5 test [8], CdO was added to mitigate the residual reactivity effect. Fig. 5 shows that the reactivity swing can be controlled without the residual reactivity effect, in which the 3 cases have almost the same excess reactivity at EOC. Using CdO, the cycle length can be extended to 60 days with suppressing the maximum reactivity swing after the xenon equilibrium below 15 mk as shown in Fig. 6. The addition of CdO reduces the required B_4C concentration, but the application of CdO requires further studies for resolving the thermal unstability [9].

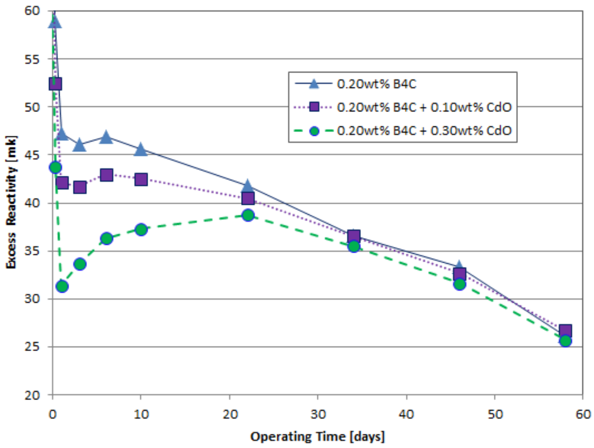


Fig. 5. Excess reactivity vs. CdO concentration.

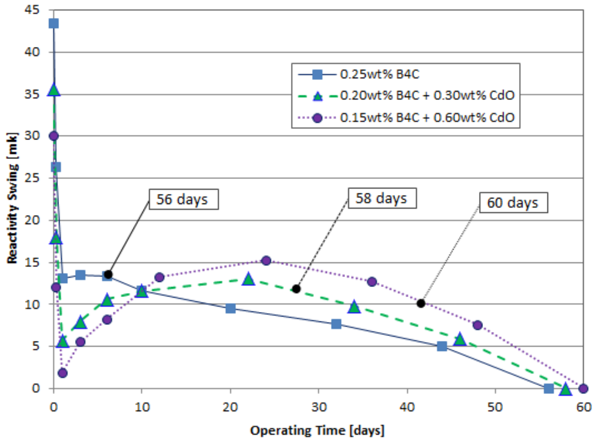


Fig. 6. Reactivity swing and cycle length vs. CdO concentration.

3. Conclusions

Essential nuclear analysis for application of burnable absorber to the rod type U-Mo fuel was performed using the HANARO core.

The current HANARO fuel can be replaceable with the 3.15 gU/cc U-Mo fuel. The maximum reactivity swing after the xenon equilibrium reduces from 40.8 mk to 12.2 mk. The U-Mo fuel of 5.0 gU/cc doubles the cycle length of the current HANARO fuel at the low reactivity swing of 13.5 mk. An optimized burnable absorber in the U-Mo fuel of 5.0 gU/cc is the B_4C addition of 0.25wt%.

In the U-Mo fuel development [8], the U-Mo fuel of 5.0 gU/cc was mixed with 0.20wt% B_4C and 0.10wt% CdO, and the U-Mo fuel was irradiated up to the burnup of 85.0%U-235. Additional irradiation test is required to qualify the proposed U-Mo fuel in this study, but the test is expected not to be challenging according to the post irradiation test result [8].

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