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Preliminary Nuclear Analysis for the HANARO Fuel Element with Burnable Absorber

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1. Introduction

HANARO of 30 MW has been contributed to various domestic nuclear research programs since its first criticality in 1991. The current HANARO uses rod type fuel composed of U_3Si dispersed in the Al matrix. Using this rod type fuel, MAPLE 1 and 2 were constructed in CANADA, and AHR (Advanced HANARO Reactor) was designed up to its conceptual design stage [1]. 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 [2], but detailed full core analysis was not performed because the current HANARO fuel management system is uncertain to analysis the HANARO core with burnable absorber. A sophisticated reactor physics system is required to analysis the core. The McCARD [3] code was selected and the detailed McCARD core models, in which the basic HANARO core model was developed by one of the McCARD developers [4], are used in this study.

The development of nuclear fuel requires a long time and correct developing direction especially by the nuclear analysis. This paper presents a preliminary nuclear analysis to promote the fuel development. Based on the developed fuel, the further nuclear analysis will improve reactor performance and safety.

2. Current Design

HANARO and AHR use hexagonal and circular fuel assemblies. Each fuel assembly consists of standard and reduced fuel rods as shown in Fig. 1. The current HANARO fuel is in the form of U_3Si dispersed in the Al matrix with a loading density of 3.15 gU/cm^3. The AHR requires a higher uranium density fuel for a higher performance without an economical loss. U_3Si_2 fuel of 4.0 gU/cm^3 was selected as a reference fuel in the core design of AHR.

In this section, core designs of HANARO and AHR are described from the viewpoint of the reactor physics.

Fig. 1. HANARO Fuel Rod and Assembly

2.1 HANARO

HANARO is a multi-purpose research reactor. 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 as shown in Fig. 2. Other irradiation holes and beam tubes are located in the D_2O reflector region surrounding the core.

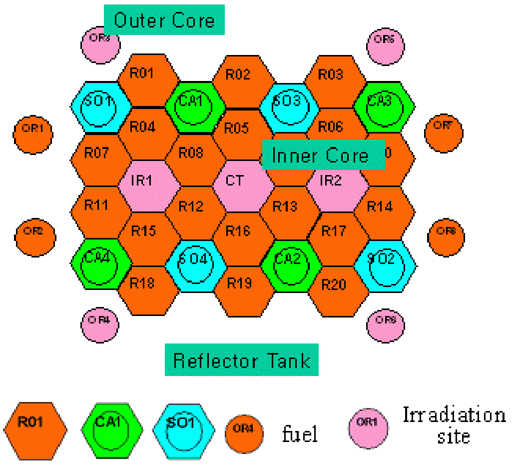

Fig. 2. The Core Layout of the HANARO

2.2 AHR

AHR is a 20 MW multi-purpose research reactor and loaded with the HANARO fuel assemblies of rod type. The core configuration was optimized according to its purpose. Various options for the reactor core had been studied and the core model in Fig. 3 was selected as the reference.

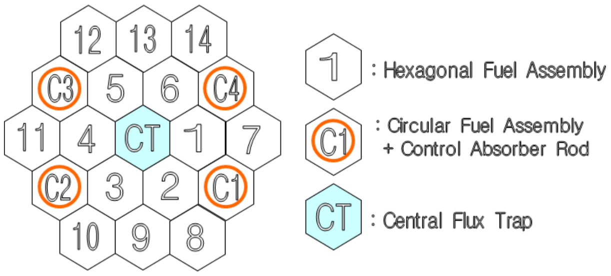

Fig. 3. The Core Layout of the AHR

14 channels are loaded by the hexagonal fuel assemblies, and four channels are loaded by the circular fuel assemblies, and one channel is devoted to the Central flux Trap (CT). The core reactivity is controlled by four CARs made of hafnium which are used as a shutdown system. The nominal fission power of AHR is 20 MW and the other design characteristics are similar to HANARO.

3. Analysis Result

AHR was designed to accommodate higher density fuel of 4.0 gU/cm^3. In this section the current HANARO fuel of 3.15 gU/cm^3 was used for a comparison.

3.1 HANARO

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. Fig. 4 shows the reactivity swing during the cycle. The reactivity swing of the reference core is estimated to be 72.0 mk by the McCARD code. For 3 kinds of burnable poison, the reactivity swings were calculated at the same fuel management scheme. This figure shows that the boron case might control the excess reactivity without increasing reactivity in the middle of the cycle. The burnout speed of boron is too slow to remove the residual reactivity effect. The burnout speed of gadolinium is too fast to suppress the excess reactivity over the cycle. Cadmium is the best element as burnable absorber for the HANARO fuel element.

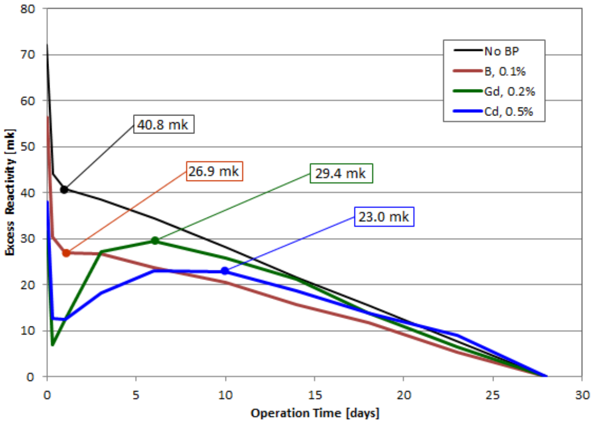

Fig. 4. The Reactivity Swing of the HANARO Core

Power peaking occurs at the peripheral region of the fuel assemblies by edge effect. Location of burnable poison can be controlled to suppress power peaking in the fuel assemblies. In the Fig. 4 case, the position of burnable absorber was selected to be at the outer ring region. The current HANARO fuel has already reduced the fuel meat diameter for controlling power peaking. A homogenous mixture of burnable absorber is enough to control the power peaking in the current HANARO fuel assemblies. Fig. 5 shows that a homogenous mixture case 'Cd, 0.4%H' was compared to a heterogeneous case 'Cd, 1.2%'. The case 'Cd, 1.2%' is slightly better than the case of 'Cd, 0.4%H', but the difference is small. From the viewpoint of the fuel manufacturer, the case of 'Cd, 0.4%H' is simple. In Fig. 5, the excess reactivity is defined as the reactivity worth between each evaluation position and the EOC (End Of Cycle) position. The excess reactivity '-1.8 mk' of the 'Cd, 0.4%H' case does not mean a negative core reactivity. The HANARO core reserves over 25 mk at the EOC for the irradiation targets. The power peaking factor, Fq is reduced from 2.37 to 2.21.

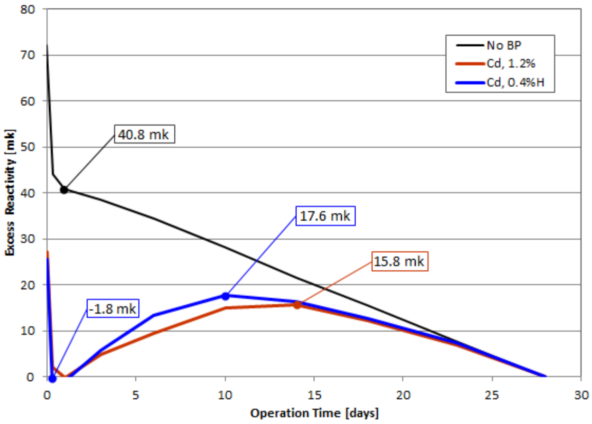

Fig. 5. The Reactivity Swing of the HANARO Cores with Cadmium Burnable Poison

3.2 AHR

The excess reactivity in the reference AHR core design is obtained by loading two new hexagonal fuel assemblies or one hexagonal fuel assembly plus two circular fuel assemblies. AHR can be operated at 20 MW without a refueling for 31 days. The cycle length of the AHR core with the current HANARO fuel can maintained to be 28 days with 3 hexagonal fuel assemblies and one circular fuel assembly. When burnable poison is mixed within all fuel rods homogenously, the ‘Cd, 0.3%’ case in Fig. 6 is the best for the AHR core. If the reactor is operated without any transient condition, the reactivity swing would be reduced from 77.7 mk to 28.4 mk. The maximum power peaking factor Fq is reduced from 2.89 to 2.58.

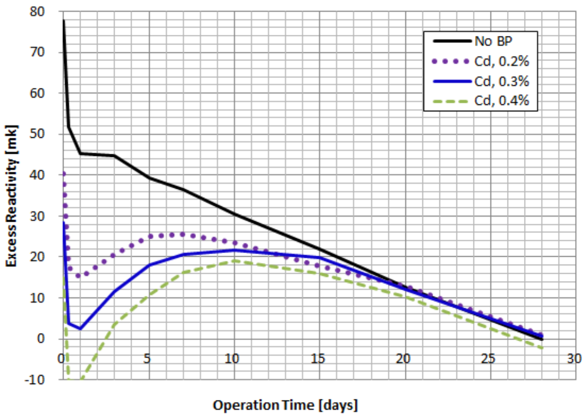

Fig. 6. The Reactivity Swing of the AHR Core

4. Conclusions

Basic nuclear analysis for the HANARO and the AHR were performed for getting the proper fuel elements with burnable absorber. Addition of 0.3~0.4% Cd to the fuel meat is promising for the current HANARO fuel element. Small addition of burnable absorber may not change any fuel characteristics of the HANARO fuel element, but various basic tests and irradiation tests at the HANARO core are required.

This new fuel design provides the lower reactivity swing and the lower power peaking. The lower reactivity swing reduces the axial neutron flux perturbation for the better utilization. The low power peaking will provide us with a higher safety margin. From this nuclear analysis, the fuel developing direction became clear.

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