Burn-up Calculation of the PBMR Core with Pebble Flow Velocity from Modified Kinematic Model

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1. Introduction

PBMR is the pebble bed reactor with the fuelling scheme that fresh fuel are added to the top of the reactor while the burned fuel pebbles are removed from the bottom of reactor. The discharge rate of fuel pebble in the fuelling system is actually 2936 pebbles per day for PBMR[1]. The pebble velocity is the function of the pebble position within the core. It is important that the pebble velocity should be accurately analyzed, because the difference of the velocity affects the criticality and the flux distribution. In the previous study, the burn-up calculation was carried out with assuming the pebbles move through the stream lines[2]. Based on a modified kinematic model developed in the following study of reference 2, the method which can evaluate more accurate the relative velocity of pebble has been developed. The burn-up calculation was pursued with MCNPX Version 2.7c in this study, after the pebble velocity calculation for PBMR by using the method developed in this work.

2. Methodology

2.1 Outline of PBMR Modeling with MCNPX

The major components of the reactor were modeled, which were 24 reactivity control systems (RCS), 8 reserve shutdown systems (RSS), 3 de-fueling chutes, 36 gas risers, 2 inlet ducts, outlet duct, 2 inlet plenums, outlet plenum, and reflectors as well as the core. Fuel and moderator pebbles in the core region were randomly packed with the ratio of 1:1. This feature was modeled using the method that body-centered cubic (BCC) unit cell was expanded throughout the volume of the core preserving the 1:1 F/M ratio and the void fraction of 0.39. Spherical fuel region of a fuel pebble was divided into cubic lattice element in order to model a fuel pebble which contained, on average, 15000 CFPs (Coated Fuel Particles). Each element contained one CFP at its center. The CFP was a TRISO-type particle and consisted of the UO_2 fuel kernel and 4 outer layers. All of these 5 concentric shells were modeled.

2.2 Description of Burn-up Calculation

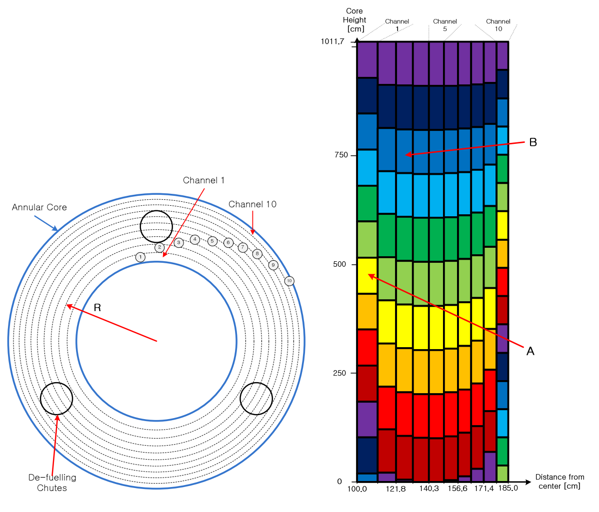
The relative velocity of the pebble flow in the PBMR core was calculated by using the method with modified kinematic model. The results normalized using the maximum value are tabulated in Table I.

Table I: The Relative Velocity of the Pebble in PBMR As a Function of Radius[1)]

Radius[cm]	100.0~111.5	111.5~121.8	121.8~131.4	131.4~140.3	140.3~148.7
Relative Velocity	0.816966	0.978474	0.994483	0.999885	1.000000
Radius[cm]	148.7~156.6	156.6~164.2	164.2~171.4	171.4~178.3	178.3~185.0
Relative Velocity	0.995467	0.986548	0.969554	0.931618	0.641911

1) The distance from the center of inner reflector

It was assumed that the core region was divided into 10 channels in a radial direction. Channel 5 in which the pebble moved at the fastest velocity was split to 10 layers axially, and the other channels except Channel 1 and 10 were split to 11 layers. Channel 1 and 10 were divided into 13 and 16 layers, respectively. This scheme is described in Figure 1. The burn-up calculation was, therefore, performed for the 116 regions in total.



(a) Horizontal View (b) Vertical View

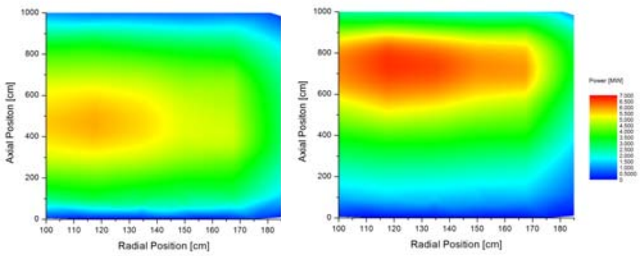
Fig. 1. The Scheme of the Divided Core Regions for Burn-up Calculation

It was also assumed that 1step was 6.67 days from the discharge rate(2936 fuel pebbles per day) of fuel pebble for PBMR [1]. Firstly, the core is filled with the fresh mixed pebbles of 1:1 F/M ratio. After 6.67 days burning, the pebbles in each layers are shifted downwards to the adjacent layer. Thermal power and the uranium enrichment are 400MWth and 5.768w/o, respectively. The burn-up calculation was pursued with ENDF/B-VI cross-section library and used SAB2002 thermal cross-section library for graphite material for the state without any control rod insertion.

3. Calculation Results

3.1 Power Calculation

The Power distributions at the end of Step 1 and Step 10 are described in Figure 2.



(a) End of Step 1 (b) End of Step 10

Fig. 2. Power Distribution

The power profile has a peak in Channel 1(position A in Fig. 1.), adjacent to the inner reflector, at the end of Step 1. It was found that the peak moved to Channel 3(position B in Fig. 1.), where the pebble flow velocity was relatively fast, as burn-up was progressed. The analysis of the power as a function of axial position shows that the peak appears in the center of the core at the beginning of burn-up. And the peak is transferred to the upper region of the core as burn-up is progressed. It was confirmed that this was caused by the facts that the fresh fuels were added to the top of the core and the burned fuels were shifted to the bottom region of the core. The peak power at the end of Step 10 was calculated to be 6.93MW.

3.2 Burn-up Calculation

The burn-up calculation result at the end of Step 10 after 66.7 burning days is shown in Figure 3. The average burn-up of the pebbles, placed in the top of the core at the beginning of burn-up, was calculated to be 12.4 GWd/MTU. Thus, it is roughly evaluated that the six refuellings are needed in order to achieve 80 GWd/MTU which is average burn-up for PBMR. This agrees with the fact that the fuel pebble at equilibrium core conditions traverses the core on average 6 times in PBMR[1]. The maximum burn-up at the end of Step 10 was 16.1 GWd/MTU in Channel 1, because the peak of power occurs in this channel at the beginning of burn-up.

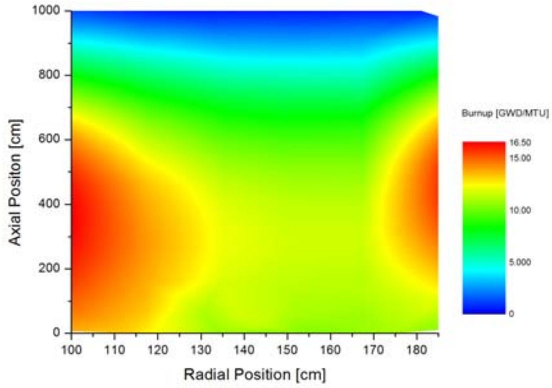


Fig. 3. Burn-up Distribution at the End of Step 10

4. Conclusion

In this study, the burn-up calculation was carried out using MCNPX version 2.7c with the result of the relative pebble flow velocity from the modified kinematic model for PBMR. The peak power appeared in the zone close to the inner reflector than the center of the core. The fresh fuel was injected and 66.7 days later the average burn-up was calculated to be 12.4 GWd/MTU. This study can be contributed and utilized directly to the establishment of benchmark problems to develop deterministic neutronics analysis tools and methods, which lagged behind the state of the art compared to other reactor technologies, to design and analyze PBMR. It is also expected that this study would be utilized in the validation of a deterministic computer code for HTGR core analysis which will be developed in near future in Korea.

Acknowledgment

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