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Monte Carlo Burn-up Calculation of the PBMR Core with Pebble Flow Velocity

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1. Introduction

PBMR core has the fuelling scheme that fresh fuel elements 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]. In the previous study, the burn-up calculation was carried out assuming the velocities of the pebbles are all the same in the whole core region[2]. 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. A method to calculate the relative velocity of the pebble flow was developed in the previous study[3]. The burn-up calculation was pursued with MONTEBURNS 2.0 code[4] in this study, after the pebble velocity calculation by using the method[3].

2. Methodology

The core modeling with MCNP code was performed to avoid the partial(broken) pebbles at the core edge by using the method in the previous study[5], as shown in Figure 1.

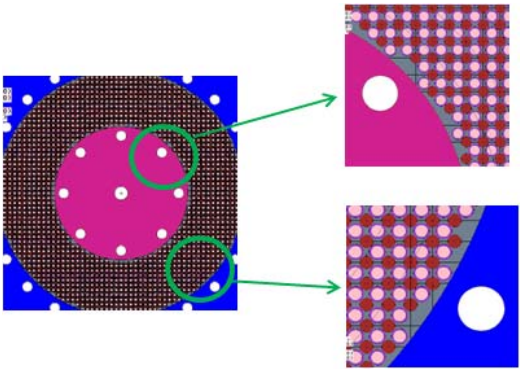


Fig. 1. Horizontal View of MCNP Modeling for PBMR

The relative velocity of the pebble flow in the core was calculated by using the method in which the pebbles moved through the stream lines[3]. The results are tabulated in Table I.

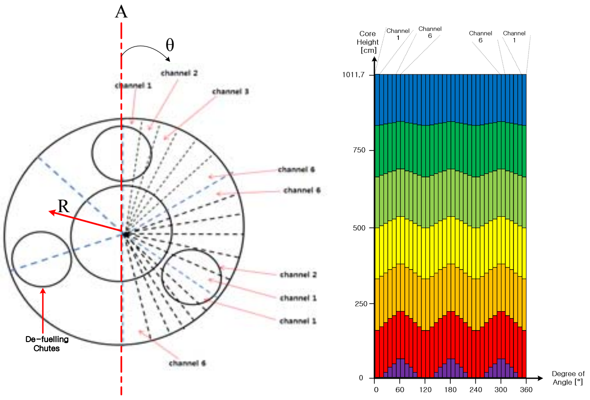
Table I: The Relative Velocity of the Pebble in PBMR as a function of the Angle$^{1)}$ and Radius$^{2)}$

Angle[°] / Radius[cm]	0~10	10~20	20~30	30~40	40~50	50~60	Avg. Value
170.8~185	0.9984	0.98337	0.97116	0.96022	0.95097	0.94261	0.96780
156.7~170.8	1	0.98354	0.96922	0.95515	0.94334	0.93356	0.96413
142.5~156.7	0.99875	0.97972	0.96357	0.94698	0.93442	0.92483	0.95805
128.3~142.5	0.99877	0.97868	0.95949	0.94243	0.92628	0.91592	0.95359
114.2~128.3	0.99701	0.97670	0.95634	0.93737	0.92150	0.90660	0.94925
100~114.2	0.99316	0.97163	0.95116	0.93372	0.91619	0.89888	0.94412
Avg. Value	0.99769	0.97894	0.96182	0.94598	0.93212	0.92040	

$^{1)}$ Angle θ from the axis A in Figure 2-(a)

$^{2)}$ The distance R from the center of inner reflector in Figure 2-(b)

It was found that the relative velocities as a function of the angle were more variable than the relative velocities as a function of the radius. It was assumed that the core region was divided into 6 channels with respect to an angular direction, Channel 1 and 2 was splitted to 6 layers axially, and the other channels were splitted to 7 layers axially. This scheme is described in Figure 2. The burn-up calculation was, therefore, performed for the 40 regions totally.



(a) Horizontal View (b) Vertical View

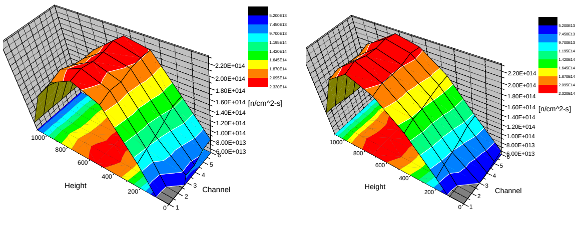
Fig. 2. The Scheme of Core Regions divided for Burn-up Calculation

It was also assumed that 1 step was 11.47 days from the discharge rate(2936 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 11.47 days burning, the pebbles in each layers are shifted downwards to the adjacent layer. Thermal power and the uranium enrichment are 400MWth and 9.6w/o which are the conditions of equilibrium core for PBMR. 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 Neutron Flux Calculation

The Neutron flux distributions at the end of Step 1 and Step 6 are described in Figure 3.



(a) End of Step 1 (b) End of Step 6

Fig. 3. Neutron Flux Distribution

The neutron flux profile has a peak in Channel 5, where the pebble flow velocity is relatively slow, at the end of Step 1. It was found that the peak moved to Channel 2, where the pebble flow velocity was relatively fast, as burn-up was progressed. The analysis of the neutron flux peak 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 neutron flux peak at the end of Step 6 was calculated to be 2.32E+14 n/cm^2·sec in the 4th layer of Channel 2.

3.2 Burn-up Calculation

The burn-up calculation result at the end of Step 6 after 68.82 burning days is shown in Figure 4.

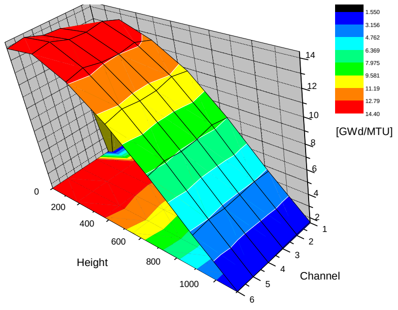


Fig. 4. Burn-up Distribution at the End of Step 6

The average burn-up was calculated to be 14.0 GWd/MTU. Thus, it is 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 6 was 14.4 GWd/MTU in Channel 5, because the peaks of power density and neutron flux occur in this channel at the beginning of burn-up.

4. Conclusion

In this study, the burn-up calculation was carried out using MONTEBURNS code with the result of the relative pebble flow velocity for PBMR. It was found that the relative velocities as a function of the angle were more variable than the relative velocities as a function of the radius. The average burn-up of the fuel pebble from the injection to the removal was calculated to be 14.0 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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