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Monte Carlo Burn-up Calculation for 400MW$_{th}$ PBMR Startup Core

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1. Introduction

A large interest in high-temperature gas-cooled reactors (HTGR) has been initiated in connection with hydrogen production in recent years. In this study, as a part of work for establishing Monte Carlo computation system for HTGR core analysis, burn-up calculations for pebble-type HTGR were carried out. As a benchmark model, the core of the 400MW$_{th}$ Pebble-bed Modular Reactor (PBMR) was selected.

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. In this study, a description of the pebble flow considered in the model was presented and some results from Monte Carlo analysis were shown for predicting the criticality, flux profile, and burn-up of core. Burn-up calculation was performed using MONTEBURNS 2.0 code [1] in which MCNP simulation was linked with a depletion system ORIGEN.

2. PBMR Modeling with MCNP Code

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.

3. Calculation Method

The scheme to model the feature of pebble flow for the start-up core was described in Figure 1. It was assumed that there were 7 layers in the fuel region axially, and a burn-up period of each step was 10 day. Firstly, 80% of core volume was filled with only graphite pebbles. At the step 1, fresh fuel pebbles were loaded to layer 7 and six below layers were full of graphite pebbles. After 10 days burning, these fuel pebbles were shifted downwards to layer 6, and layer 7 was filled with new fresh fuel pebbles on the top layer while graphite pebbles in layer 1 were removed out through 3 de-fuelling chutes. Following this way, fuel pebbles moved step by step from the top to bottom of the core. At step 7, equivalent to 70 burning days, all graphite pebbles were discharged and the core cavity contained fuel pebbles with 7 different burn-up.

The discharge rate of fuel pebble in the fuelling system of PBMR is actually 2900 pebbles per day [2], while 26000 pebbles per 10 days are removed out from the core by the assumption in this study.

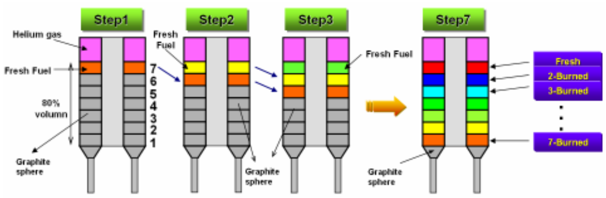

Figure 1. Continuous Reloading Scheme of Start-up Core

The annular fuel region was divided into 35 regions which consisted of 5 different radial regions and 7 axial regions as shown in Figure 2. In this model, five channels had been specified to simulate the fuel flow path through the core.

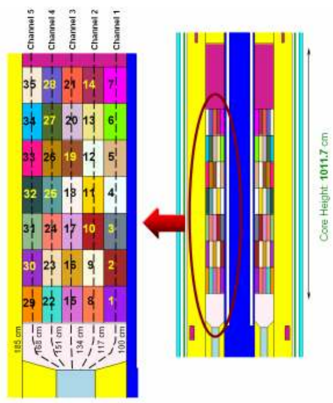

Figure 2. Modeling Geometry of PBMR Core

3. Calculation Results and Discussions

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.

The multiplication factor k_{eff} was calculated for the start-up core. The results show that k_{eff} increases gradually after each step because of the movement down to the bottom of burned fuels and the fresh fuel pebbles loaded to the top of core at the beginning of each step. Figure 3 presents the variation of k_{eff} at the beginning and the end of each step.

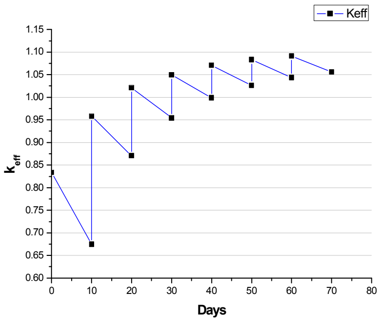

Figure 3. Variation of k_{eff} during 70 Burned Days

The neutron fluxes, divided into thermal flux (E < 1 eV) and fast flux (E ≥ 1 eV), were observed after 70 operating days of the start-up core. Figures 4 illustrate the spatial dependence of two group fluxes in the annular core. The thermal flux profile has a peak in the region (regions # 6 in Figure 2) adjacent to the center reflector due to the moderation effect of graphite.

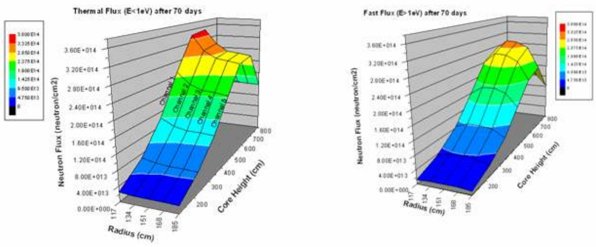

Figure 4. Thermal and Fast Flux Profiles

The burn-up profile was calculated for all fuel regions in core after 70 operating days of the start-up core and this result was shown in Figure 5. This result shows that the burn-up of regions which are adjacent to central reflector is higher than others in the same layer.

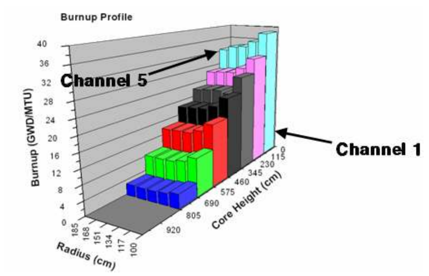

Figure 5. Burn-up Profile after 70 Operating Days

The burn-up of discharge fuel was also evaluated. This work can be an important role in classifying and deciding whether the depleted fuel is either routed to the core or discharged to the spent fuel tanks. The discharge fuel was 7^{th} burned fuel at the bottom which was firstly unloaded after the start-up process. Comparing among 7^{th} burned fuels, the maximum burn-up was 38.49 GWD/MTU for a region in channel 1 and 1.18 times as much as minimum value of 32.71 GWD/MTU in channel 5.

4. Conclusions

Considering pebble flow, the burn-up calculation was carried out for the startup core of $400MW_{th}$ PBMR using MONTEBURNS code in this study. It was found that k_{eff} increased step by step as expected in the operation of start-up core, and the moderation effect by the center reflector caused the thermal flux peak. It was also investigated that the maximum burn-up of fresh fuel pebble was calculated as 38.49 GWD/MTU.

Based on these results, as a consequence, the study has some recommendations for the future work. The equilibrium cycle after the start-up state will be applied for the burn-up dependent core neutronic calculation. Especially, a more detailed streamline of pebble flow in real system will be built to get more accurate results.

This study can be contributed and utilized directly in 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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