A Study for Burn-up Calculation applied on 400MW_{th} PBMR Core

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1. Introduction

The 400MW_{th} Pebble-bed Modular Reactor (PBMR) is an advanced high temperature gas cooled-reactor (HTGR). It possesses a very high efficiency and attractive economics without compromising the high levels of passive safety expected of advanced nuclear designs. With this reason, PBMR is a target which researchers especially in nuclear engineering field study carefully and therefore it is regarded as the leader in the power generation field. There are many research results about benchmark problems but results of the burn-up process are still poor. Hence, in this study a burn-up calculation was performed with PBMR using MONTEBURNS[1] code in which MCNP modeling linked a depletion systems is used.

2. Description of Burn-up Code

MONTEBURNS 2.0 developed in Los Alamos Laboratory is chosen in this study. It is designed to link the Monte Carlo transport code MCNP with the radioactive decay and burn-up code ORIGEN through MONTEB utility which is an executable Fortran 77 program and a PERL procedure. MONTEBURNS produces a large number of criticality and burn-up results based on various material feed/removal specifications, power(s) and time intervals. MONTEBURNS processes an input from the user that specifies the system geometry (a complex 3-D geometry), initial material compositions, feed/removal specifications and other code-specific parameters. The main function of MONTEBURNS is to transfer one-group cross section and flux which are results from MCNP to ORIGEN, and then transfer the resulting material compositions (after irradiation and/or decay) from ORIGEN back to MCNP in a repeated, cyclic fashion.

3. System Modeling

PBMR essentially comprises a steel pressure vessel and core which consists of approximately 452,000 pebbles in annular core with an inner radius of 1.0m and an outer radius of 1.85m. The height of the core is 10.117 m. There are three de-fueling chutes and three de-fueling cylinder at the bottom of the bed.

The annular fuel region is divided into 35 regions which consist of 5 different radial regions of 17 cm each (equal width), 7 axial regions of 140 cm (6 regions) and 171.7 cm in this study. Hence, the whole core totally includes 37 regions (1 region of three de-fueling chute and 1 region of 3 de-fueling cylinder). In order to achieve the random packing core model, the repeating lattice structure is applied to each region. Elements in lattice are pebbles that are the fuel of reactor.

It assumes that the core is filled with fresh fuel (9 grams HM and 5.768 $^{w}/_{o}$ enriched). Cold condition (300K) is employed for all materials. And there is no control rod inserted.

A fuel pebble contains on average 15,000 coated fuel particles (CFPs) within the central region of 2.5 cm radius. A coated particle consists of a kernel of uranium dioxide surrounded by four coating layers. This spherical region is divided into cubic lattice elements. The remaining volume of each lattice element was filled with graphite.

4. Calculation Results and Disscussion

Burn-up calculation is applied with 10 days burned and the computational result of keff value is calculated for 4 steps by 2.5 days (Table 1). The keff value decreases gradually with respect to time. Comparing with keff at BOC (beginning of cycle), it decreases 4960 pcm after 10 days. At the end of each step, the nuclear characteristics are evaluated in each region.

Table 1: keff results at each step

Burned Time [days]	keff
0 (BOC)	1.28036 ± 0.00105 (68%)
2.5	1.22899 ± 0.00102 (68%)
5.0	1.22320 ± 0.00100 (68%)
7.5	1.22176 ± 0.00091 (68%)
10	1.21686 ± 0.00100 (68%)

Figure 1 shows the power profile in core at BOC and after 10 days. The power peak was found axially in the middle of the core but radially close to the central column.

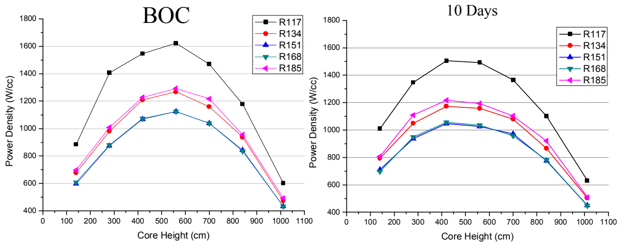

Figure 1. Power Distribution at BOC & after 10 Days

Fluxes profiles with E<1eV and E>1eV inside the core are illustrated in Figure 2 and Figure 3, respectively. These fluxes have axial peaks at the middle of core as expected. But the radial flux (E<1eV) close to 2 reflector regions is higher than that at the middle, while the flux (E>1eV) is completely inverse.

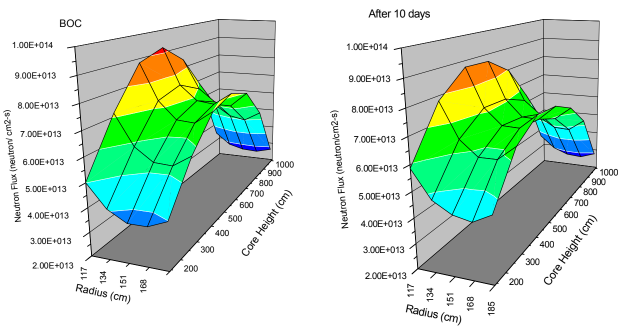

Figure 2. Flux (E<1eV) Profile at BOC & after 10 Days

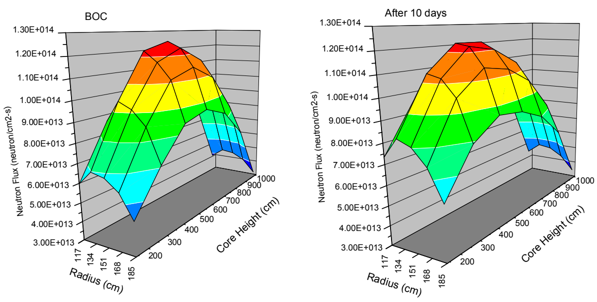

Figure 3. Flux (E>1eV) Profile at BOC & after 10 Days

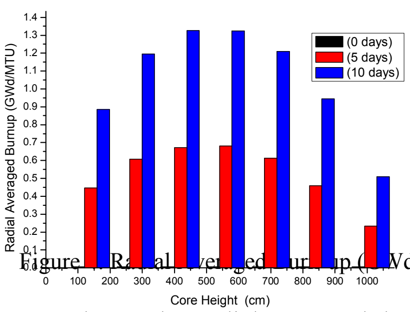

Figure 4. Radial averaged burn-up (GWd/MTU)

Figure 4 shows the radial averaged burn-up which depends on the core height at different time periods. It is clear that the burn-up is proportional to the flux in core. So, it also gets the high value at the middle of core.

Finally, a study about the isotopic concentration in fuel is performed. Some important isotopes are quantified in region by region. Inventory of isotopes at the regions of 560 cm core height were shown in Figure 5.

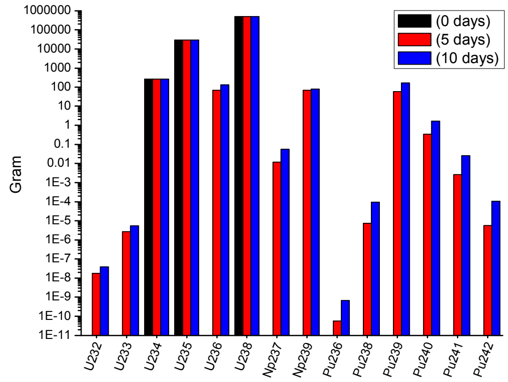

Figure 5. Inventory of isotopes in the middle of core

5. Conclusion

The burn-up calculation was carried out for PBMR using MONTEBURNS code and gave evaluations about the burn-up process. The keff, flux profile, burn-up and inventory of isotopes toward burning for PBMR were searched in this study. These results are going to be sufficiently verified and validate in near future. This study can be contributed and utilized in an estimation of the detailed burn-up and fuel management for operating process of PBMR.

Acknowledgment

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[1] D.L.Poston, and H.R. Trellue, "User's Manual, version 2.0 for MONTEBURNS version 1.0. LANL Report LA-UR-99-4999, PSR-0455/01 (Los Alamos National Laboratory, Los Alamos, NM) (1999).