Effect of Single and Multi Burnup Zones Model in ENHS Core Calculation

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1. Introduction

The ENHS (Encapsulated Nuclear Heat Source) is a small lead-bismuth or lead cooled novel reactor concept. Its core contains uniform composition fuel rods without blanket elements. The special features of ENHS are as follows ; module fabricated , fueled and weld sealed in the outside factory, over 20 effective full power years (EFPY) of operation without refueling and fuel shuffling, 100% natural circulation, nearly constant power shape throughout life, autonomous operation and superb safety. It is designed to have nearly constant fissile fuel contents, very small reactivity swing along with burnup, hence, and very simple control system. The core region is homogenized to a single annular cylindrical region. The thermal power of the ENHS core and the average heat generation rate are assumed to be, respectively, 125 MWth and 101.4 W/cm. Figure 1 shows the core configuration when the fuel rod pitch to diameter ratio (P/D) is 1.44.

The basic design of ENHS is assuming the once-through fuel cycle for which the initial feed fuel comes from the spent fuel of light water reactors (LWR). Currently, the envisioned fuel cycle of ENHS based on the closed, fuel-self-sustaining Pu-U cycle by reusing the initial feed fuel is investigating.

In this study, we evaluate the the effect of single and multi burnup zone model in ENHS core calculation and investigate the reason why they shows difference.

2. Calculation Model

In this study, the ENHS core uses IFR type metallic fuel, whose composition is: 10 $^{w}/_{o}$ Zr and 90 $^{w}/_{o}$ HM, which is 12.89 $^{w}/_{o}$ (of the HM) of Pu from LWR spent fuel that underwent a burnup of 50 GWd/t HM and was cooled for 20 years and the remaining part is depleted U (0.2 w/o of U235). The nominal density is 15.85 g/cm3, but the fuel smear density is taken equal to 75% of the nominal density.

The core calculations by REBUS-3 code were performed using the combined 80-group cross sections including the lumped FP XS. The decay chain is spanned in the range from ^{234}U to ^{246}Cm. In this study, the following calculation model cases are used, only different from the number of burnup zones in the core;

Case-1 : 1x1 single burnup zone,

Case-2 : 3x3 multi burnup zones (3 radial and 3 axial zones with equal volume),

Case-3 : 5x5 multi burnup zones (5 radial and 5 axial zones with equal volume).

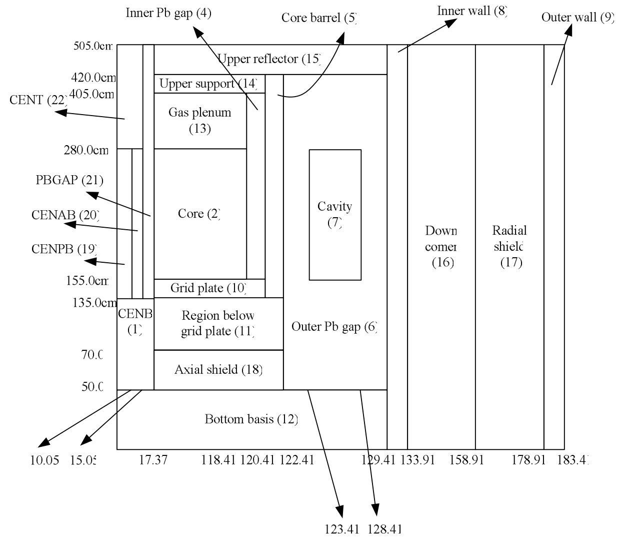

Figure 1. Configuration of the ENHS reactor with P/D=1.44; not to scale.

3. Effect of Single and Multi Burnup Zone

The calculation results for case-1(BU 1x1), case-2(BU 3x3) and case-3(BU 5x5) are shown in Figure 2 on the k-eff evolution versus burnup, Figure 3 on the core average power density versus burnup and Figure 3 on the conversion ration versus burnup. The core power comes from the fission power and the gamma heating. So there is small portion of gamma heating (~5%) in the fuel, coolant and structure material. Therefore, if the neutron leakage varies with time, then the fission power in the core will be changed and also the gamma heating will be changed to the amount of gamma heating due to the leakage variation. But the total reactor power (125 MWt) should be constant with time.

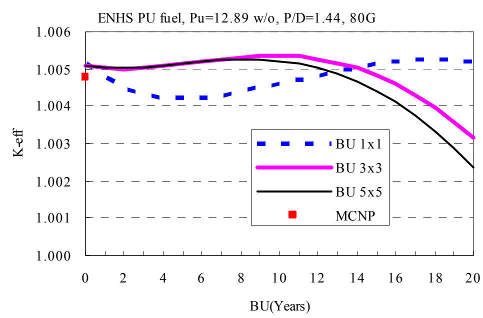

Figure 2. K-eff evolution versus burnup

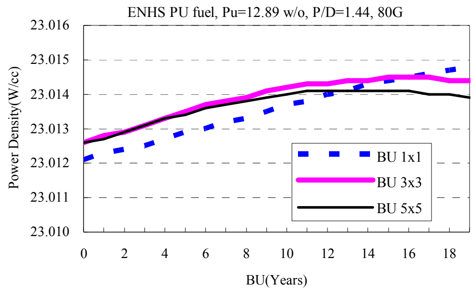

Figure 3. Average power density versus burnup

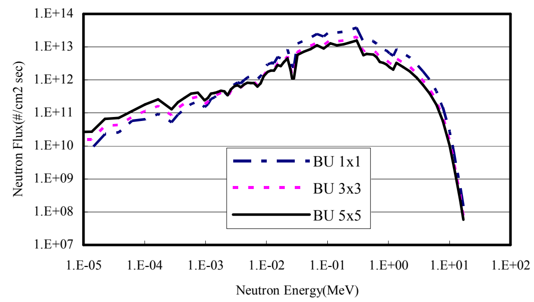

Figure 4. Comparison of neutron spectrum at the outer bottom of core, BOC

4. Analysis

Depending on the core model, the neutron flux spectrum is different at the edge of core. The high energy neutrons can easily leak from the core at the edge of core. Figure 4 shows the neutron energy spectrum depending on the core burnup model at the outer bottom part of core, beginning of cycle (BOC).

Figure 5 shows the total net neutron leakage of core versus burnup. At the beginning of cycle, the neutron leakage is almost same regardless of number of burnup zones. But if we take the multi burnup zones, then the neutron flux is higher at the area of core inside. The neutron flux at the edge of core is lower than the average neutron level, so the neutron leakage is smaller than the single burnup zone model. These estimations will affect the neutron balance including the reaction rate calculation and the conversion, also the active isotopes and fission product isotopes number density calculation. Figure 6 shows the total Pu atom density along with the burnup at the outer bottom part of core.

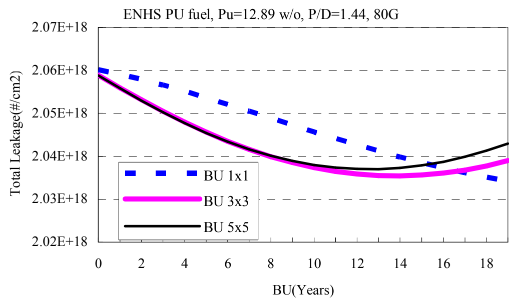

Figure 5. Total Leakage versus Burnup

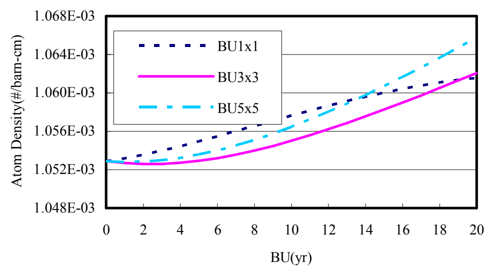

Figure 6. Total Pu Atom Density versus Burnup

5. Conclusion

According to the investigation for the effect on the number of burnup zones in ENHS core model, the calculation results such as k-effective evolution, average power density and conversion ratio show difference depending on the single and multi burnup zones. It is mainly caused by differences of total leakage, fission product buildup and the conversion of fissile material along with the burnup depending on the number of burnup zones. On the basis of this study, the multi burnup zone model of small reactor core like ENHS should be highly recommended in the core design studies and will be used in the closed fuel cycle study.

6. Acknowledgement

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REFERENCES

[1] Ser Gi Hong, Ehud Greenspan and Yeong Il Kim, "The ENHS Reactor Core Design," Nuclear Technology, Vol. 149, Jan. 2005.

[2] B. J. Toppel, "User's Guide for the REBUS-3 Fuel Cycle Analysis Capability," ANL-83-2, Argonne National Laboratory (March 1983).

[3] Lanfranco Monti, "Validation of ENHS Core Neutronics Design," 2006.

[4] E. Greenspan, P. Hejzlar, H. Sekimoto, G. Toshinsky, and D. Wade, " New Fuel Cycle and Fuel Management Options in Liquid Metal Cooled Reactors," Nuclear Technology, 141, 2005.