Decay Heat Analysis of a PMR200 VHTR Core by Using McCARD and ORIGEN2 codes

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1. Introduction

The decay heat of radioactive isotopes is one of main concerns in designing a reactor core as well as designing a spent fuel repository. In particular, the effective removal of the decay heat during accidents such as high or low pressure conduction cooling events is a crucial factor which determines the main design parameters of a very high temperature gas cooled reactor (VHTR) core.

In a previous work[1], the applicability of the ORIGEN2 code[2] for the analysis of VHTR core decay heat was demonstrated. The one-group cross-sections of major actinides in the ORIGEN2 code were replaced with those generated from the HELIOS[3] model for a PMR200 fuel block in the work.

In this study, the decay heat of the PMR200 VHTR core was analyzed by using McCARD[4] and ORIGEN2 codes and the accuracy of the decay heat calculation by the HELIOS/ORIGEN2 codes was verified by comparing it with those from McCARD/ORIGEN2 calculation.

2. Methods and Results

2.1 PMR200 Core Design Parameters

A 200MWth prismatic VHTR (PMR200) core [5] which is one of the candidate cores of the Nuclear Hydrogen Development and Demonstration [6] (NHDD) reactor was taken as the reference core. Figure 1 and Table 1 show the up-to-date PMR200 VHTR core configuration and the major design parameters

2.2 Analysis Methods

Figure 2 shows the HELIOS/ORIGEN2 calculation procedure proposed in reference 1. The one-group actinides cross-sections generated in the previous work were also used in this work.

Figure 3 shows the McCARD/ORIGEN2 calculation procedure in which the McCARD code performs Monte Carlo core depletion calculation and the ORIGEN2 code performs decay cooling calculation after shutdown. The PMR200 core reached equilibrium after 10 cycles with the design parameters listed in Table 1. . The cycle length of the equilibrium cycle is 440 days with the EOC burnup of 70.1GWd/tHM and the discharge burnup of 99.0GWd/tHM.

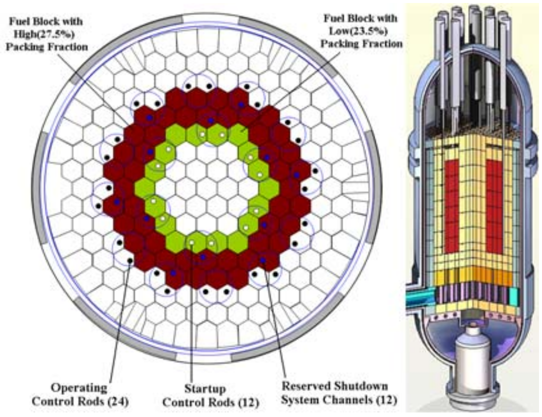

Fig. 1. PMR200 VHTR core configuration

Table 1. PMR200 Design Parameters

Parameters	Values
Thermal power of core (MWth)	200
UO2 enrichment (w/o)	12.0
Number of Axial Layers and blocks/layer	6 / 66
Fuel block height (cm)	79.3
Active core height (cm)	475.8
Top/bottom reflector height (cm)	120/160
Compact height and radius (cm)	5.0 / 0.6225
Kernel diameter (cm)	0.0500
TRISO volume fraction in compacts (%)	27.5 / 23.5
Specific power density (W/g)	74.96
Power Density (W/cc)	5.67

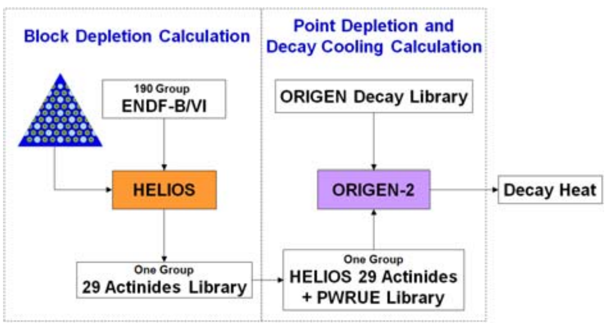

Fig. 2. HELIOS/ORIGEN2 Calculation Procedure

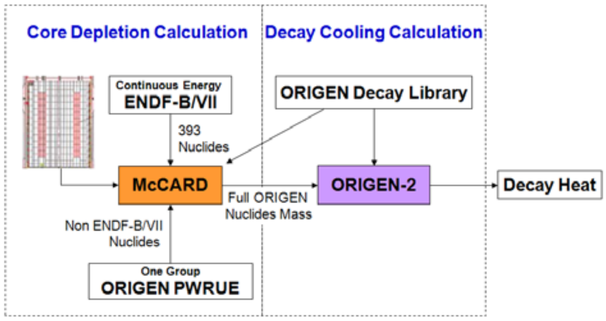

Fig. 3. McCARD/ORIGEN2 Calculation Procedure

2.3 Results and Discussions

The ORIGEN2 point depletion calculation was performed till 70.1GWd/tHM in the HELIOS/ ORIGEN2 analysis. Three shutdown scenarios, at the beginning of cycle (BOC) equilibrium Xe state, at the middle of cycle (MOC) and at the end of cycle (EOC), were considered in the McCARD/ORIGEN2 analysis.

Figure 4 compares the decay curves of the four cases until 1000 hours within which most of the accidents of the VHTR are expected to be finished. We observe that all the decay curves except for that of BOC case are relatively close to each other. The decay heat curve of BOC case is much lower than the others because one third of the fuel blocks in the core are almost fresh at that state. But once it gets burnt, the fuel burnup has a little effect on the decay heat for a short period of decay time. Figure 5 shows the cumulative decay heat for the four cases to magnify the differences between them. We also observe that the HELIOS/ORIGEN-2 combination overestimates the cumulative decay heat untill 1000 hours after shutdown at EOC by 4.1%.

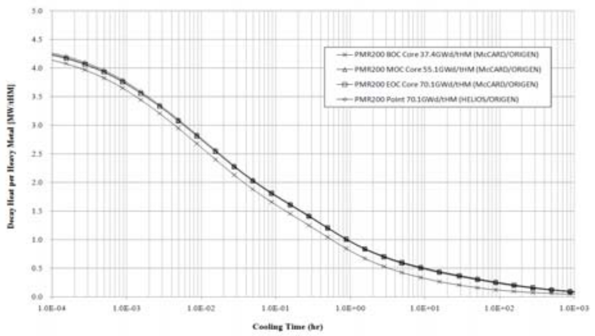

Fig. 4. Comparison of Decay Heat Curve

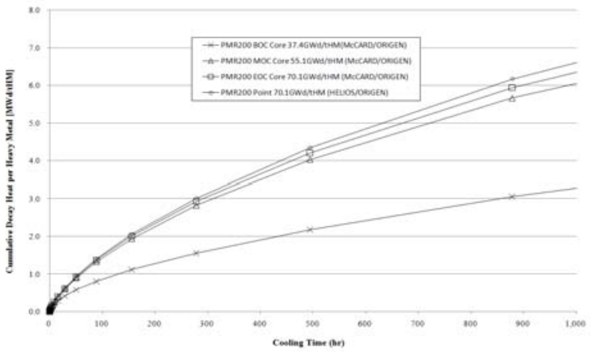

Fig. 5. Cumulative Decay Heat

A longer-term decay heat behavior should be considered for a spent fuel repository. Figure 6 shows the cumulative total decay heat of the three cases. The decay heat analysis with McCARD single block depletion underestimates the decay heat in the early stage of the cooling time (<300yr) while it overestimates the decay heat in the late stage of the cooling time (>300yr). The cumulative total decay heat with McCARD single block depletion is about 14% larger than that with McCARD core depletion at 1000yr. It is definitely due to the spectrum difference between the single block with reflective boundary condition and the core surrounded by graphite reflector. The decay heat with ORIGEN-2 point depletion is much larger than that with McCARD core depletion all over the cooling time. The large error of the decay heat in the point depletion case is due to the fact that the cross-sections of the fission products in ORIGEN-2 code cross-section library are not changed from the original ones for PWRs while the cross-sections of the actinides were replaced with those generated from HELIOS single block depletion calculation.

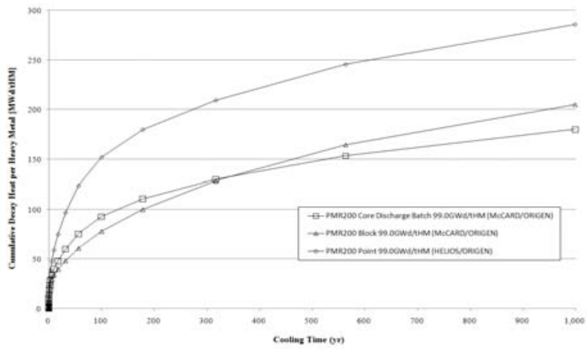

Fig. 6. Cumulative Decay Heat for a Long Period

3. Conclusions

A sophisticated decay heat analysis by using McCARD and ORIGEN2 codes was performed for the PMR200 VHTR core and the accuracy of the decay heat analysis procedure developed in the previous work by using HELIOS /ORIGEN2 codes was verified.

A relatively good agreement between the results of two analysis procedures was achieved for a short period of decay time within which most of the accidents of the VHTR are expected to be finished. However, a relatively large discrepancy was observed for a long period of cooling time during which the decay heat is important for spent fuel repository design.

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