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Preliminary Core Design Analysis of a 200MWth Pebble Bed-type VHTR

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1. Introduction

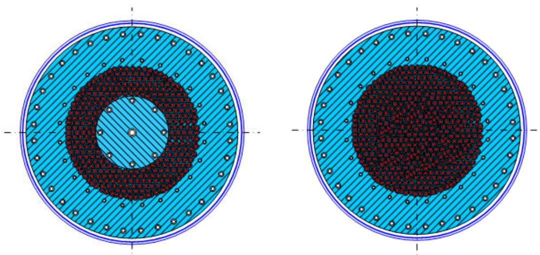
This paper intends to suggest the preliminary core design analysis of a VHTR for a hydrogen production. The nuclear hydrogen system that utilizes the high temperature heat generated from the VHTR is a promising candidate for a cost effective, safe and clean supply of hydrogen in the age of hydrogen economy. Among two candidate VHTR cores, that is, a prismatic modular reactor (PMR) and a pebble bed-type reactor (PBR), we focus on the design of a 200MWth PBR (hereinafter PBR200) in this paper. Here, the 200MWth power is selected for a demonstration plant. The core configuration of the PBR200 is similar to the PBMR (Pebble Bed Modular Reactor, 400MW_{th}) of South Africa[1], but the overall dimension of the reactor system is scaled-down.

This paper is to suggest two candidate PBR200 cores. One is an annular core with an inner reflector (PBR200-CD1) which was presented at IWRES07[2], and the other is a cylindrical core without an inner reflector (PBR200-CD2).

Table 1 shows the main design specifications of the PBR200 cores, and Fig. 1 shows the cross section view at the vessel midplane of the PBR200 cores. The system pressure is 7.0MPa and its inlet and outlet temperatures are 490 and 950℃, respectively. The PBR200 reactors use sphere type (pebble) fuels. Each pebble has a 6cm diameter and contains nominally 15,000 UO_2 TRISO coated micro-spheres imbedded in a graphite matrix. Each pebble contains 9g of U, and the fuel enrichment is 9.76w/o for the equilibrium cycle. The employed fueling scheme is the continuous on-line multi-pass method similar to the designs used in the PBMR reactor. The active height of the core is 8.73m for the two candidate cores. The thickness of the outer graphite reflector is 90cm. The average power density of the core of PBR200-CD1 is 4.79w/cc, while that of PBR200-CD2 is 3.56w/cc. If 4.79w/cc is used for the average power density of PBR200-CD2, the maximum temperature is over 1600℃ which is the limit of a maximum temperature in the safety analysis.

Table 1. Main design specifications

Design Parameter	PBR200 CD 1	PBR200 CD 2
Thermal power (MW)	200	200
Inlet/outlet temperature (℃)	490/950	490/950
Active core inner/outer radius (cm)	80/147	0/143.18
Thickness of outer reflector (cm)	90	90
Effective core height (cm)	873	873
Average power density (W/cc)	4.79	3.56
U235 enrichment (w/o)	9.76	9.76



(a) PBR200-CD1 (b) PBR200-CD2

Fig. 1 Configuration of PBR200 Cores

2. Results of Core Analysis

The preliminary core analysis for the PBR200 cores was performed by using the VSOP94 code system[3]. Four-group diffusion calculations were performed for the core in an r-z geometry. The core characteristic parameters including the power and temperature distributions, and the temperature coefficients were evaluated for the equilibrium cycle condition of the core at zero power and full power operating conditions.

The Doppler coefficient is the reactivity change due to a change in the average fuel temperature. As shown in Fig. 2, the Doppler reactivity coefficients of the equilibrium cycle of the PBR200 CD1 and CD2 cases at the zero power condition are negative for any operating condition and range in magnitude from -5.0 to -2.0 pcm/^{o}C.

Figure 3 shows that the fuel temperature coefficients of the equilibrium cycle of the two candidate cases are also negative for any operating condition.

The isothermal reactivity coefficients of the equilibrium cycle for the PBR200 CD1 and CD2 cores were also calculated to be always negative for any operating condition, which are shown in Fig. 4 for all the cases. It is indicated that the isothermal temperature coefficients are always negative from cold to hot conditions, which means inherently safe.

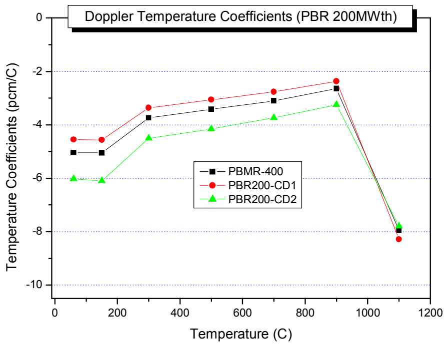


Fig. 2. Doppler temperature coefficients

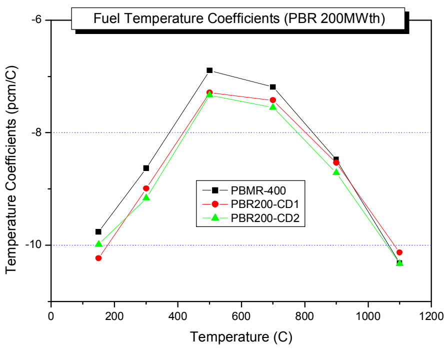


Fig. 3. Fuel temperature coefficients

The temperature coefficients at the full power operating condition are shown in Table 2. This table shows that the contribution of the moderator in the fuel part of the core to the temperature coefficient is largely negative, while the contributions of the inner and outer reflectors are positive. It also shows that the Doppler temperature coefficient is largely negative. It is noted that the overall temperature coefficients of the PBR200 candidate cores are negative at the full power operating condition.

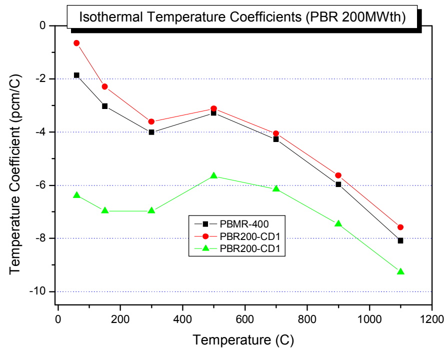


Fig. 4. Isothermal temperature coefficients

Table 2. Temperature coefficients at full power condition

Temperature Coefficients ($\delta\rho$/C, pcm)	PBR200 CD1	PBR200 CD2
1. Inner (central) reflector	1.58957	N/A
2. Outer reflector	1.84405	1.29317
3. Moderator in fuel part of the core (C, O)	-4.73397	-3.60930
4. Fuel (Doppler Coefficient of U238)	-2.91488	-3.98207
Total	-4.21523	-6.29820

3. Conclusion

In this paper, two candidate cores for a 200MWth pebble bed-type VHTR were suggested. One is an annular core and the other is cylindrical core. From the results of the temperature coefficients analysis for the two candidate PBR200 cores, it is shown that the Doppler coefficients, fuel and isothermal temperature coefficients of the cores are all negative for any operating condition at an equilibrium cycle.

ACKNOWLEDGEMENTS

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