Development of the 200MWth Pebble-bed type VHTR Core Concepts

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1. Introduction

KAERI has established a plan to construct a very high temperature gas cooled reactor (VHTGR) by the early 2020s to demonstrate a safe and economic production of nuclear hydrogen. The 200MWth power is selected for this Nuclear Hydrogen Development and Demonstration (NHDD) reactor[1].

In this paper, some pebble-bed type core concepts (PBR200) were explored as candidates for the 200MWth NHDD reactor. To investigate the feasibility of each core concept, the static core characteristic parameters and the fuel temperatures during the most severe accidents were evaluated for the equilibrium core conditions.

2. Candidate Core Concepts

Two candidate core designs (PBR200-CD1 and PBR200-CD2) are scaled down from their reference, that is, the 400MWth PBMR core[2]. They are a simple cylindrical concept without an inner reflector. Figure 1 shows a cross-section view at the vessel midplane of the PBR200 cores. The active heights of the two cores are 9.70 m and 9.43 m, respectively. They are surrounded by a 90 cm thick outer graphite reflector.

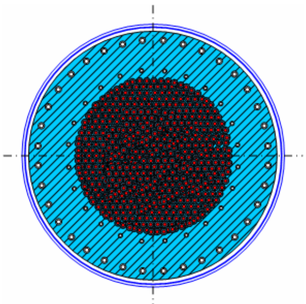

Fig. 1 Cross-section view of the PBR200 cores

The average power density of PBR200-CD1 is very low (i.e., 2.27 w/cc), because it does not have an inner reflector, which limits the maximum fuel temperature during reactor accidents. This may result in an inferiority in a competition with the prismatic type cores which usually have a high power density of circa 6 w/cc. To strengthen its competitiveness by improving its power density, PBR200-CD2 adopts a two-zone refueling scheme in which relatively more burnt fuel pebbles are reloaded into the central refueling zone and less burnt ones into the outer zone, when they are put into the core form the top of the core. Furthermore, control rods are assumed to be inserted at the top of the core at the normal operation to flatten the axial power shape. The PBR reactors use the same sphere fuels as used in the PBMR reactor. Each pebble contains 9g of U, and the fuel enrichment is 9.76w/o for the equilibrium cycle. On average, each fuel pebble is assumed to make six passes through the reactor before finally being discharged to the spent fuel storage tanks.

3. Design Tools

By implementing several methodologies to resolve the technical difficulties raised in the VHTR reactor physics, we are now developing the HELIOS[3]/CAPP[4] code system for the analysis of the pebble-bed type VHTR cores. However, since the development of CAPP is not progressed enough to be applied to an actual design, we used VSOP94[5] in the study.

The safety of the core candidates was investigated for the most limiting event, that is, the low pressure conduction cooldown (LPCC) accident. The multi-dimensional and multi-component mixture analysis code, GAMMA code[6], was used to evaluate the maximum fuel temperatures during the event initiated at the equilibrium core conditions.

4. Design Results

4.1 Neutronic Parameters

The core neutronic characteristic parameters including the power distributions and the temperature coefficients were evaluated for the equilibrium core conditions of the two PBR candidate core designs. In the VSOP94 modeling, the control rods inserted at the top of the PBR200-CD2 were modeled by placing a boron concentration at the control rod region. The negative reactivity due to these control rods was accessed at 981 pcm at the equilibrium core condition. The reactivity penalty of these control rods inserted to improve the power density may inevitably hurt a safe shutdown at an emergency. The evaluation of the shutdown margin is required in the near future. From the results of the temperature coefficients analysis, it is shown that all the temperature coefficients including the isothermal temperature coefficients shown in Figures 2 are negative for all the operating conditions at equilibrium core conditions.

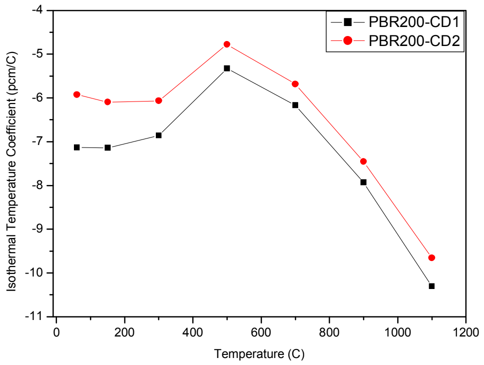

Fig. 2 Isothermal temperature coefficients of PBR200 cores

4.2 Safety Analysis

The safety of the two core candidates was investigated for the low pressure conduction cooldown (LPCC) accident using the GAMMA code. The LPCC accident is initiated by a loss of coolant event caused by a break of a connection pipe. Immediately following the break, the coolant is discharged to the reactor cavity. It is assumed that the reactor scrams immediately and the coolant flow and the system pressure decrease to a zero flow and atmospheric pressure, respectively, in 10 seconds. In the LPCC event, the peak fuel temperature is of greater concern, which depends very much on the decay heat after a shutdown.

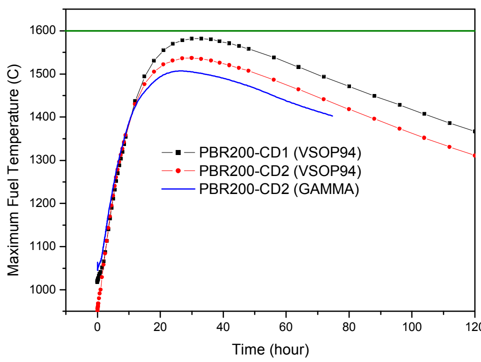

Fig. 3 Maximum fuel temperature distribution at LPCC accident of PBR200 cores

Figure 3 shows the maximum fuel temperatures calculated for the two PBR candidates by VSOP94, among which the temperatures for PBR-CD2 are compared with those calculated by GAMMA. In the VSOP94 modeling of the LPCC, the passive reactor cavity cooling system was not modeled explicitly but replaced by a room temperature boundary condition. This figure shows that this simple VSOP94 modeling can provide relatively consistent results to those of the GAMMA detailed modeling. The maximum fuel temperatures are shown in this figure to be below the fuel failure limit of 1600°C for the two core candidates. Although PBR200-CD2 has a higher power density than PBR200-CD1, it results in lesser maximum fuel temperatures in the LPCC accident. This is due to the radial and axial power shape flattening by adopting the two zone refueling scheme and by inserting control rods at the top of core, respectively. Note that the decay heat distribution is relatively proportional to the power shape at the normal operation.

5. Conclusions

In this paper, two PBR core concepts which are both cylindrical without an inner reflector were investigated for a 200MWth NHDD reactor. PBR200-CD2 among them adopts a two zone refueling scheme to improve the poor power density of PBR200-CD1.

From the results of this study, it can be concluded that PBR200-CD2 has more potential to be selected as a 200MWth NHDD reactor core, since it has a reasonable value for its power density and its safety related parameters such as the temperature coefficients and the maximum fuel temperatures during accidents which meet the limits for these cores.

Acknowledgements

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