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Thermo-Hydraulic design of 12 by 12 FCM fuel assembly on transition core of OPR-1000

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1. Introduction

Fully Ceramic Micro-encapsulated(FCM) fuels with multiple layers are a high resistance fuel of releasing fission product. The fuel concept borrows the tri-isotropic(TRISO) fuel particle design from Very High Temperature Reactor(VHTR) technology to adapt it on the LWR design. The fuel particles would be pressed into compacts using SiC as the matrix material and would be reloaded into fuel pins for use in conventional or next generation LWRs. The design of FCM fuel assembly adopted the 12 by 12 rod array based on the design criteria of 2 mm gap clearance and the nuclear design value[1].

In order to estimate the possibility of transition core of OPR-1000 with FCM fuel assembly, fuel assembly design analysis is performed on the both a thermal and a hydraulic margin. Thermal margin estimated on the Departure Nucleate Boiling Ratio(DNBR) margin should be required with the value more than the DNBR of reference assembly. Hydraulic design margins focused on the axial pressure drop are estimated on the mechanical integrity of hold-down spring and the maximum cross flow between existing assembly and reloaded assembly

Interim design features of 12 by 12 FCM assembly consisted a transition core with the 16 by 16 assembly of OPR-1000. Systematic estimations on the applicability of 12 by 12 FCM assembly to the OPR-1000 core were performed on the maximum cross flow rate, assembly pressure drop, and MDNBR of transition core consisted of 12 by 12 FCM fuel assembly and 16 by 16 reference fuel assembly.

2. Methods and Results

2.1 Design Criteria of 12 by 12 assembly

Design criteria on the transition core is to select the applicable FCM 12 by 12 assembly on the OPR-1000 core as shown in Table 1. On the estimation of thermal margin, DNBR correlation are used to the W-3 correlation[3] and KRB-1 correlation[4]. Reference value of MDNBR is calculated on the reference assembly using same DNBR correlation as the DNBR correlation applied to FCM assembly. According to the DNBR design criteria, acceptable design value on the MDNBR should be always greater than the MDNBR value of reference assembly.

The hydraulic design criteria is strongly related to then the available maximum cross flow and the spring force of hold-down spring to assure the mechanical integrity of the fuel assembly. The criteria is directly dependent on the fuel assembly pressure drop.

Table I: Geometry and Operating Conditions of 12 by 12 FCM fuel assembly

Parameter	**Criteria**	**Note**
Pressure Drop	> Existing FA	Transition Core
DNBR	> Existing FA	Transition Core
FA lift force	< 20% increase in existing FA	Transition Core

2.2 Analysis of FCM Fuel Assembly Design

Scoping analysis on the FCM fuel assembly is performed to estimate the acceptable design value for the design criteria. Independent parameters of scoping analysis are the pitch to rod diameter ratio(P/D ratio) and guide tube diameter. Scoping analysis has been calculated under the same conditions of the total power and inlet mass flow rate. The calculation models of MATRA-S code are identical with the general PWR design model[4]. From the preliminary analysis, high thermal performance (HTP) grid was estimated as the only acceptable design to satisfy the design criteria in Table 1.

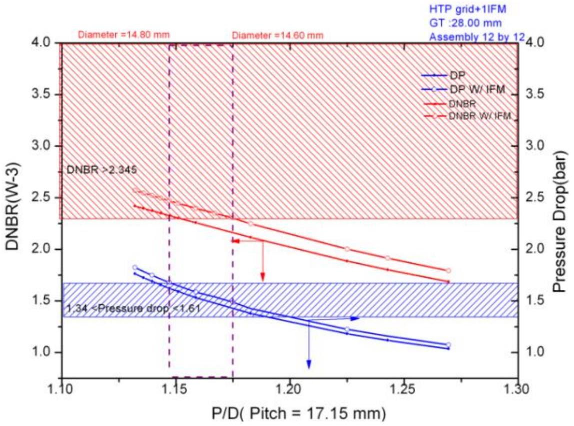

Fig.1. DNBR and pressure drop with the P/D; vertical dash line depicts the acceptable design region.

DNBR calculation shows the tendency that increasing rod diameter decreases the DNBR as shown in Fig.1. The intermediate flow mixing grid (IFM grid) affects the DNBR improvement with 6.2 % but slightly increasing pressure drop. The positive effect of IFM grid expands the acceptable design range from 1.15 to 1.18 on the P/D. The expansion of range makes possible to yield the acceptable design range of 1.15 ~

1.18 where both DNBR(red-line) and pressure drop(blue-line) are satisfied with the design criteria(hatched rectangle with red and blue color).

2.3 Transition Core Analysis of the OPR-1000 with the FCM Assembly

In order to calculate the transition core, two different batch were selected with the typical and the check board array as shown in Fig. 2. MATRA-S calculation model was the 9-lumped channel model which used the assembly size as a lumped channel. A gap between assemblies was calculated as the arithmetic mean on the gaps of two lumped channels.

Transition core analysis is performed to calculate the maximum cross flow between assemblies as shown in Fig. 2.

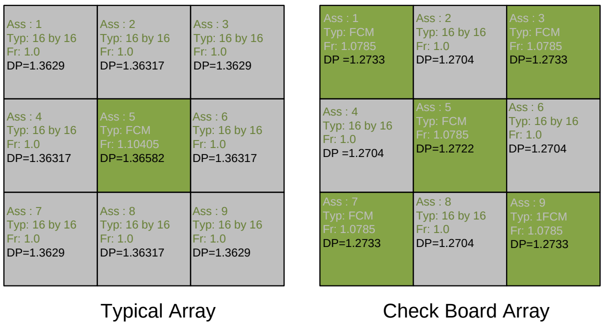

Fig.2. Two different assembly array for core transition analysis

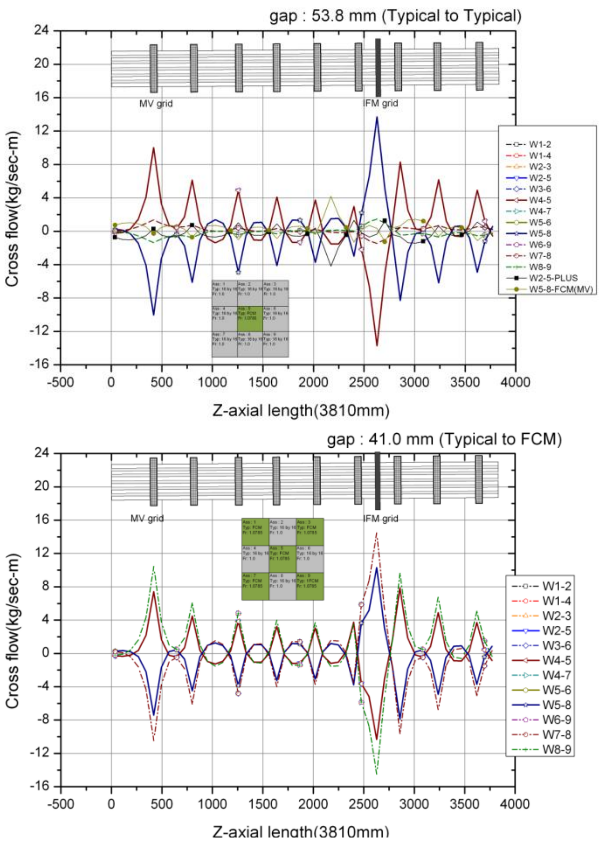

Fig.3. Axial distribution of cross flow with array type

Maximum cross flow due to the radial pressure difference between assemblies can be calculated using Eq. (1).

$$W_{ij} = \sqrt{\frac{(P_i - P_j)}{c_{ij}}} \quad (1)$$

, where P_i : Pressure at subchannel i

c_{ij} : Lateral pressure loss coefficient

W_{ij} : Cross flow between channel i and j

The acceptable maximum cross flow calculated from Eq. (1) is estimated with 32.62 kg/m-sec. The equation is derived with the assumption that lateral pressure drop is only affected to the cross flow. Therefore, allowable cross flow is limited under the estimation.

From the transition core analysis, maximum cross flow occurs at the IFM grid location. The maximum cross flow is 13.72 kg/m-sec on a typical array and 14.48 kg/m-sec on a check board array, respectively. These maximum cross flows were satisfied with the maximum cross flow limit from the calculation of transition core.

3. Conclusions

A feasibility to apply FCM 12 by 12 assembly into the OPR-1000 core as transition core was estimated on the assembly design and core design level consisted of 9-lumped channel.

In order to select a feasible design, assembly design was evaluated to satisfy the MDNBR and pressure drop criteria, firstly. The selected assembly design is consisted of the transition core of OPR-1000 with the reference 16 by 16 assembly. In the transition core analysis, maximum cross flow was investigated. From these analysis, feasible FCM assembly design on the transition core was P/D = 1.480 ~ 1.490, guide tube diameter with 28.00 mm and 12 by 12 array with HTP grid.

Further study was required to improve the turbulent mixing model on the tight lattice bundle and cross flow model on the heterogeneous assembly type.

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