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Fuel Arraying and Rod Dimensioning of FCM replacement fuel for LWRs

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1. Introduction

After Fukushima accident, necessity of developing an accident-tolerant fuel for existing LWRs has been raised. The joint R&D project (US-DOE funded) on the FCM replacement fuel for LWRs has been recently begun at KAERI[1]. FCM refers to the fully ceramic micro-encapsulated fuel which is compacted hundreds of TRISO particles into ceramic conductive matrix pellet. The project aims to show the fuel feasibility and compatibility with existing LWR cores (OPR1000). They require new design to compensate the low fissile inventory of particle-based fuel and comprehensive qualification of neutronic, thermal hydraulics and mechanical aspect. Figure 1 shows the overall concept of the FCM replacement fuel.

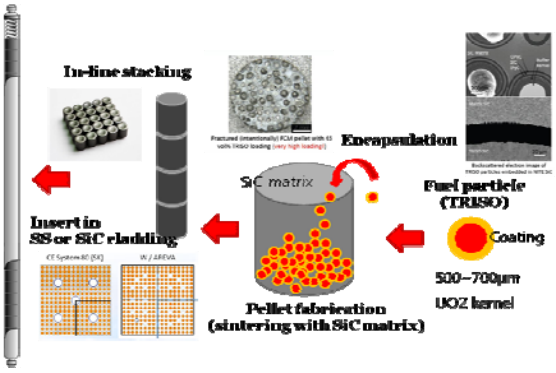

Fig. 1 Overview of FCM replacement fuel for LWRs.

For a particle-based fuel, a thick coated layer surrounding UO_2 kernel retains released fission gas within the fuel particle element and significantly reduce fissile inventory per unit fuel volume. On the consideration of low fissile inventory and high enrichment cost, FCM fuel will be a fat fuel with tight inter-rod spacing. Thus, this paper introduces some technical issues related to fuel arraying (fuel lattice formation) and fuel rod dimensioning (fuel rod diameter) of FCM replacement fuel for LWRs, based on the experience of developing dual-cooled annular fuel for existing LWRs.

2. Candidate Array and Rod Dimensioning

To accommodate control rods of existing power plant (OPR 1000), new fuel lattice must have even square array of fuel rods with uniform diameter. Each fuel assembly has one center guide tube and four corner guide tubes with the same diameter. The number of rod that can be allocated at the corner region bounded by one guide tube and fuel's outer territory determines the number of rod over the fuel lattice. Thus, the features of candidate FCM fuel arrays originated from the location and the size of guide tube. Figure 2 shows three candidate arrays of FCM replacement fuel, compared with the present 16x16 fuel array. The candidate arrays were selected from the experience of developing dual-cooled annular fuel for existing LWRs[2].

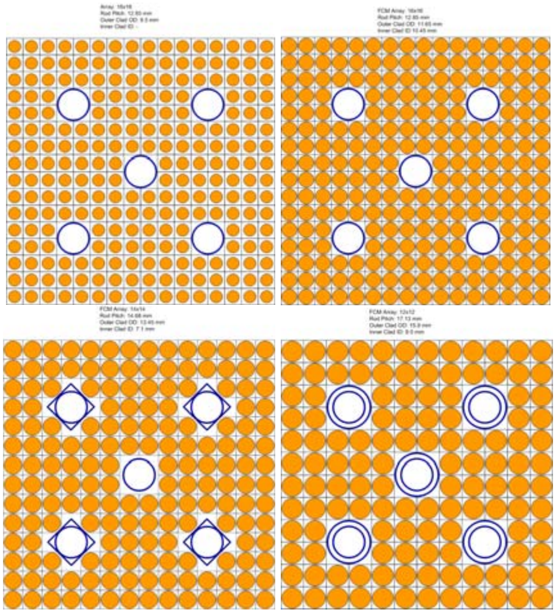

Fig.2 FCM fuel array candidates (16x16 present, 16x16 FCM, 14x14 FCM, 12x12 FCM fuel array, in order)

12x12 fuel array has two fat fuel rods at the corner of the assembly. Adaption of double circular guide tube relieves moderator and flow concentration due to larger spacing around the guide tubes. If three fuel rods allocate at the corner of guide tube in 14x14 fuel lattice, interference at the four sides of the guide tube occurs while allocating fuel rods. Then, two fuel rods at four direct sides and three fuel rods at four diametrical corners of the guide tube were applied. The additional square guide of four corner guide tubes aims for hydraulic balancing. 16x16 fuel lattice has the same array to the existing LWR fuel assembly, but adapt enlarged diameter of rods. This is superior in structural compatibility over the other candidates, but has thermal hydraulic deficiencies. Larger array increases heat transfer area together with pressure loss. Furthermore, average heat flux decrease with the inversely proportional to the heat transfer area.

In principle, fuel rod dimensioning requires comprehensive parametric studies of thermal hydraulics and neutronics for the specific rod dimensions and arrays. Comparison results and safety analysis will support and confirm the design decision. However, in the present stage, any rod dimension for pre-designated fuel array doesn't meet the thermal hydraulic fuel design requirements for current LWRs. Main reason is the reduction and difference of flow area due to the enlarged diameter of FCM fuel rods. Thus, further thermal hydraulic scoping analysis was carried out and resolving measures to overcome technical problems of FCM replacement fuel were currently being considered. Here this paper suggests preliminary FCM fuel rod dimensions with the same fissile inventory to present fuel, according to the packing fraction and enrichment. Table 1 summarizes preliminary FCM rod diameter with equivalent fissile inventory to the current fuel design. The nominal percentage of flow area was compared with those of the FCM candidate dimension and arrays, referenced with that of the current fuel. 12x12 FCM array with 14.24 mm cladding diameter has 12.6 % difference in flow area, which is the lowest difference over the others.

3. Results

In this paper, candidate fuel arrays and associated rod dimensions of FCM replacement fuel for LWRs was proposed based on the experience of dual-cooled annular fuel development. There wasn't much flexibility for choosing new fuel arrays compatible to existing power plant because of the stringent location and the size of control rods. Preliminary fuel rod diameters with the same fissile inventory to present fuel were proposed. 12x12 FCM fuel array with 14.2 mm rod diameter has the minimum difference in flow area against that of present fuel. The cladding thickness will be designed based on the elastic buckling theory. It can be likely to reduce if the pressure difference between rod inside and coolant system is minimized

ACKNOWLEDGEMENT

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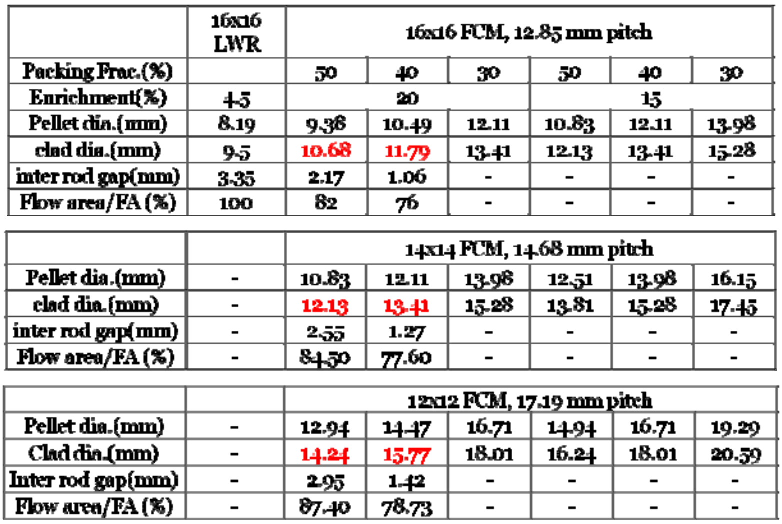
REFERENCES

[1] National R&D Proposal Document for Fully Ceramic Microencapsulated Replacement Fuel for LWRs, US-DOE-KAERI Joint Project (I-NERI Project).

[2] T. H.Chun, et al, Feasibility Study on Dual-Cooled Annular Fuel for OPR-1000 Power Uprate, KAERI/RR-3152/2000

Table 1 Preliminary FCM rod diameter with equivalent fissile inventory



	16x16 LWR	16x16 FCM, 12.85 mm pitch					
Packing Frac.(%)		50	40	30	50	40	30
Enrichment(%)	4.5	20			15		
Pellet dia.(mm)	8.19	9.36	10.49	12.11	10.83	12.11	13.98
clad dia.(mm)	9.5	10.68	11.79	13.41	12.13	13.41	15.28
inter rod gap(mm)	3.35	2.17	1.06	-	-	-	-
Flow area/FA (%)	100	82	76	-	-	-	-

		14x14 FCM, 14.68 mm pitch					
Pellet dia.(mm)	-	10.83	12.11	13.98	12.51	13.98	16.15
clad dia.(mm)	-	12.13	13.41	15.28	13.81	15.28	17.45
inter rod gap(mm)	-	2.55	1.27	-	-	-	-
Flow area/FA (%)	-	84.50	77.60	-	-	-	-

		12x12 FCM, 17.19 mm pitch					
Pellet dia.(mm)	-	12.94	14.47	16.71	14.94	16.71	19.29
Clad dia.(mm)	-	14.24	15.77	18.01	16.24	18.01	20.59
Inter rod gap(mm)	-	2.95	1.42	-	-	-	-
Flow area/FA (%)	-	87.40	78.73	-	-	-	-