Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Thermal-Hydraulic Potential of Dual Cooled Annular Fuel for OPR-1000

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1. Introduction

A drastic change on conventional PWR fuel rod was recently explored to enable more power in a same core size [1]. This reformed rod is shaped annular to provide an additional flow channel where the peak temperature lies in the cylindrical solid rod. Previous study showed the annular fuel can withstand 50% more power for W standard 4-loop plant, provided that the flow rate increases proportionally to the power uprate. However, the fuel array design was configured for the operating reactors to hardly adopt it because of structural incompatibility in current guide tube positions and size. The purpose of this study is to evaluate a potential of a proposed annular fuel array completely compatible with OPR-1000's control rod driving system unlike the previous study.

2. Proposed Annular Fuel Array

The proposed annular fuel array is a 12x12 lattice with 5 guide tubes as shown in Fig. 1 as a substitution of 16x16 conventional solid fuel array [2]. The annular fuel rod dimensions are determined as close as to the present value for a moderator-to-fuel volume ratio (*Vm/Vf*) to minimize the impact of new fuel on the nuclear physics. But total fuel loading actually becomes smaller because of additional claddings in the dual cooled annular fuels. Table 1 describes the OPR-1000 operating condition and the proposed annular fuel data.

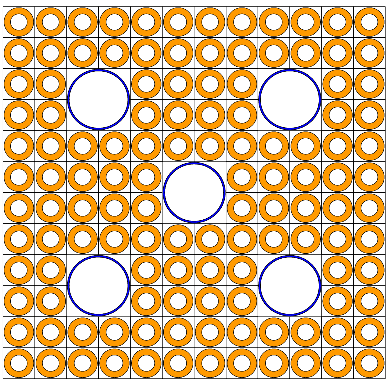
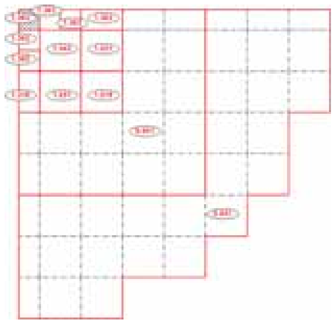


Table 1 OPR-1000 operating condition and major input

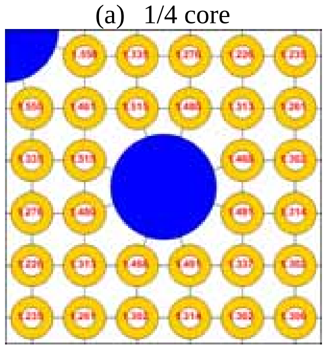
Parameter	Values
Nominal Reactor power [Mwth]	2815
Core outlet temperature [°C]	328
Core flowrate [kg/s]	14841
System pressure [Mpa]	15.5
(*Vm/Vf*)a/ (*Vm/Vf*)s	1.0
(*Vf*)a/ (*Vf*)s	0.82

3. Whole Core Subchannel Analysis

Subchannel code, MATRA-AF was used to analyze the thermal-hydraulic parameters in a whole core. It can predict the heat and mass splits between inner and outer channels in annular fuels. Actual analysis domain is 1/4 core by using geometrical symmetry. Fig. 2 shows the power distribution in the quarter of core and hot assembly, respectively. The hottest radial pin peak is 1.55 relative to the core average.



(a) 1/4 core



(b) 1/4 hot assembly

Fig. 2 Power distributions

For the evaluation of possible power uprate, a conservative approach is implemented in several input values. The core power is given 118% overpower for the nominal condition to cover various condition I and II transients. Core inlet temperature is increased +2°C to consider the insufficient coolant mixing in the lower plenum. Core outlet temperature is kept unchanged regardless the power increase. The gap conductances of annular fuel are assumed 7500 W/m^{2}K for the outer and 3200 W/m^{2}K for the inner at initial burn-up condition. But those are varied along the burn-up. A value of TDC for turbulent mixing between outer channels in the rod bundle is assumed 0.03, which is a little lower than the design value of conventional mixing grid. The CHF is predicted by W-3L for inner channel and W-3R for outer channel. The limit DNBR of the W-3 correlation is 1.30.

4. Results

Several thermal hydraulic parameters like heat split, DNBR, pressure drop were evaluated at 120% power increase. The heat split of the annular fuel is an importance factor affecting the MDNBR and dependant strongly on the inner and outer gap conductances. As a result, the axial heat flux distributions at initial burn-up condition are predicted and shown in Fig. 3. The heat flux ratio of inner to outer channel was estimated 1.03. The DNBRs for the hottest rod are plotted along the axial direction in Fig. 4. MDNBRs for the inner and outer channels are respectively 2.01 and 2.24. The inner MDNBR is slightly lower than that of the outer. However, those are far from the limit DNBR of 1.30, which indicate the annular fuel can accommodate the target power uprate.

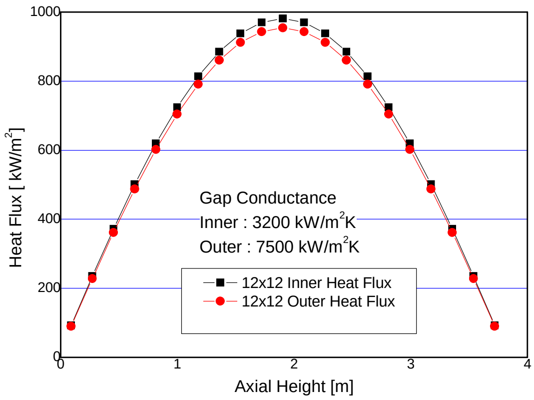


Fig. 3 Axial heat flux variations for inner and outer surfaces of the hottest annular fuel

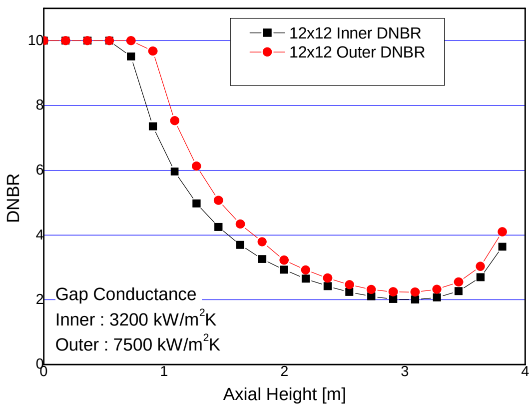


Fig. 4 DNBR variations along the axial direction for inner and outer channels at the hottest annular fuel

As mentioned before, both inner and outer pellet-to-cladding gap clearances change as fuel burn-up due to the thermo-mechanical behavior like densification, swelling and creep. It is expected from the experience that the outer gap will be disappeared early burn-up, but the inner gap are not very much changed and won't be closed until the fuel can be maintained as the hottest pin in the core. So in this study outer gap conductance is ranged between 4,500 W/m^{2}K and 18,400 W/m^{2}K, while the inner one between 2500 W/m^{2}K and 4500 W/m^{2}K.

To account the above effect of gap conductance on MDNBR, some more analyses were additionally performed. Table 2 describes the MDNBR results at 120% power for nine combinations. The dark portion in the Table 2 is a zone where MDNBRs for both inner and outer channels are commonly larger than limit DNBR of 1.3. The remaining are the cases which do not cover the 20% power increase. But fortunately, those combinations are not likely to happen considering the real situation.

Table 2 MDNBR results at inner and outer channels of hottest rod at 120% power

Inner \ Outer	18400	7500	4500
4500	2.15	2.62	3.15
	2.27	0.95	0.09
3200	1.82	2.24	2.70
	3.32	2.01	0.82
2500	1.48	1.92	2.36
	4.07	2.98	1.65

5. Conclusions

A proposed 12x12 annular fuel array for OPR-1000 was examined on its thermal hydraulics performance. The results showed a potential of power uprate to 20%. However, the gap conductance variations assumed in this study has to be validated by the irradiation data with the annular fuel.

REFERENCES

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[2] Y.S. Yang, K.M. Bae, C.H. Shin, T.H. Chun, J.G. Bang, and K.W. Song, "Conceptual Design of OPR-1000 Compatible Fuel Assembly, Proc. ICAPP, paper 7445, Nice, France, 2007.