Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 25-26, 2007

Safety Analysis of an Annular Fuel in a LBLOCA using the MARS code

Hyoung Tae Kim, Kyoo Hwan Bae, Tae Hyun Chun
Korea Atomic Energy Research Institute
150 Dukjin-Dong, Yusong-Gu, Daejon 305-353, Korea
kht@kaeri.re.kr

1. Introduction

Since an annular fuel [1] is both externally and internally cooled, its power density can be increased while maintaining its fuel temperature lower than that of a solid fuel. The large break loss of coolant accident (LBLOCA) analyses are performed using the MARS code [2] for the cases of solid fuel and annular type fuel rods which are loaded in the Ulchin nuclear power plant units 5&6 (UCN 5&6). The steady-state initial conditions under full power operation are calculated both for the solid and the annular fuels. From these steady-state conditions a transient simulation for a double-ended cold leg break is performed and the cladding surface temperatures between the solid and the annular fuels are compared.

2. MARS models for the LBLOCA analysis

2.1 Fuel models for the reference plant

Figure 1 shows the configurations of the solid and the annular fuels. The annular fuel has dual gaps and claddings for the inner and the outer channels and its outside diameter is larger than that of the solid fuel.

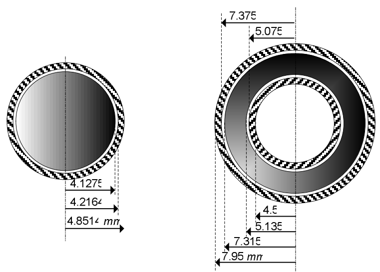


Figure 1. Geometries of the solid and annular fuels

The reference plants, UCN 5&6 are two loop-type PWRs with 177 fuel assemblies (FAs) of the 16×16 solid fuel rod array. However, the conceptual design of annular fuel has a 12×12 fuel rod array in the same fuel assembly. The main thermal-hydraulic parameters for these two fuel models are listed in Table 1. For the conservative analysis, the initial core power was assumed to be 102% of nominal value and ANS-73 decay heat curve was used with a 1.2 multiplication factor. Also, the analysis used the top skewed axial power profile and the minimum gap conductance value specified in the UCN 5&6 final safety analysis report (FSAR) [3].

Table 1. Main thermal-hydraulic parameters

Parameter	**Models**	
	solid	annular
Initial Core Thermal Power	2871.0 MWt (102% of Nom. Power)	
Decay Heat Curve	1.2 x ANS-73	
No. of Axial Nodes	12	
No. of Fuel Channels	Average(176 FA) & Hot (1 FA)	
Fuel Rod Array	16 × 16	12 × 12
Axial Power Peaking Factor	1.58	
Radial Power Peaking Factor	1.57	
Average Linear Power	18.04 kW/m	34.335 kW/m
Gap Conductance	8512 W/m^2-K	*12612 W/m^2-K

* *The gap width of the annular fuel is smaller than that of the solid fuel*

2.2 MARS code modelling

The nodalization diagram of the UCN 5&6 the MARS code is shown in Fig. 2. The present MARS model of the UCN 5&6 was developed from that of Yonggwang units 3&4 [4]. Core nodalization both for the solid and the annular fuels are shown in Fig. 3. The solid fuel model has two fuel channels representing a core average (176 FAs) and a hot (1 FA) channels with cross flow junctions for lateral flow between the channels. However, this core nodalization was modified such that each fuel assembly channel was divided into two flow channels representing the inner and outer flow paths of the annular fuel. Thus the core is modeled by 4 cooling channels (inner and outer, each hot and average), which were used for the annular fuel model in reference [5].

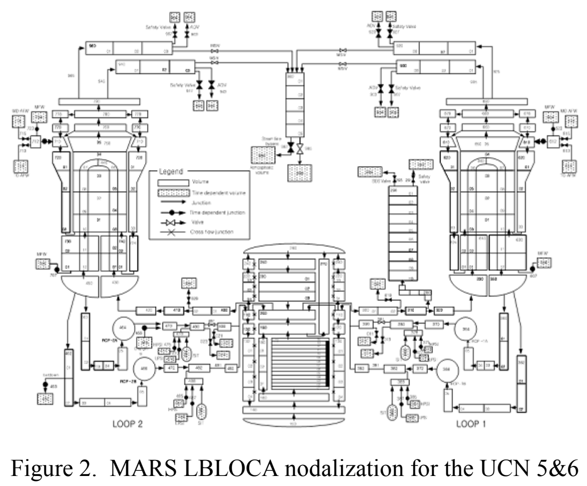
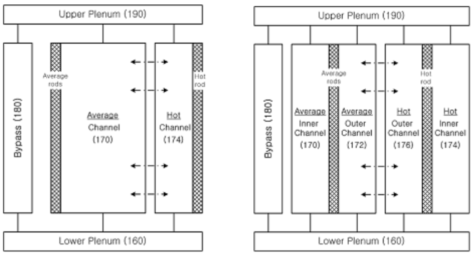


Figure 2. MARS LBLOCA nodalization for the UCN 5&6



(a) solid fuel (b) annular fuel

Figure 3. Nodalization of the core region

3. Simulation results of the LBLOCA

3.1 Steady-state calculations

To simulate a LBLOCA under full power operation, the steady-state condition of UCN 5&6 was calculated. The steady-state calculations for the solid and the annular fuels were done for 300 seconds to obtain the stable conditions as shown in Table 2. Figure 4 shows a comparison of the fuel temperature distribution of the solid fuel with that of the annular fuel at steady-state. It can be shown that the fuel temperature of the annular fuel is substantially lower than that of the solid fuel. This, in turn, will result in a lower cladding temperature during the LBLOCA transient due to the redistribution of the initial stored energy in the fuel.

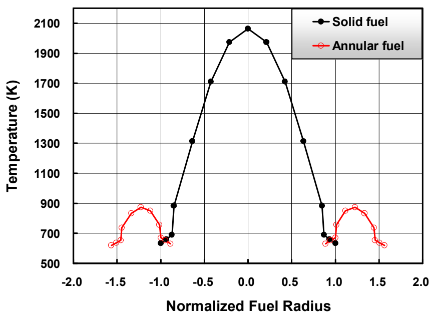


Figure 4. Comparison of fuel temperature at steady-state

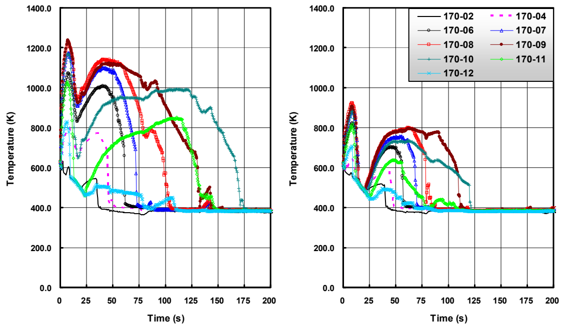
Table 2. Steady-state initialization

Parameters	Desired	Simulated	
		Solid	Annular
Core Power (MWt)	2871.0	2871.0	2871.0
Pressurizer Pressure (MPa)	15.82	15.82	15.82
Core Inlet Temperature (K)	568.95	570.55	570.52
Core Outlet Temperature (K)	600.95	602.00	602.13
Total Loop Flow (kg/s)	15,308	15,400	15,305
Effective Core Flow (kg/s)	14,855	14,936	14,827
Bypass Flow Fraction (%)	3.0	3.0	3.1
SG Secondary Pressure(MPa)	7.56	7.49	7.49

3.2 Transient calculations

The transient was initiated by opening the valves in one of the cold legs, which were simulating a double-ended break.

The hot rod cladding surface temperatures for the reference solid fuel and annular fuel are compared in Fig. 5. It can be seen that the peak cladding temperatures (PCTs) both for the solid and annular fuels are well below the PCT limit (2200 ^{o}F or 1477 K) specified in 10 CFR 50.46. Furthermore, the PCT of the annular fuel is lower than that of the solid fuel about 300 K. This means that the annular fuel can have more safety margin compared with the solid fuel for the reference plant.



(a) solid fuel (b) annular fuel

Figure 5. Comparison of fuel cladding surface temperature during a LBLOCA

4. Conclusion

The safety analysis of a LBLOCA for the annular fuel reveals a higher safety margin than that of the solid fuel with the same plant configuration. If larger power increase is desirable for the currently operating PWR, the core replacement with the annular fuel could be a very promising measure.

REFERENCES

[1] H.T. Kim, P. Hejzlar, H.C. No and M.S. Kazimi, "Performance of Internally and Externally Cooled Annular Fuel in a Loss of Coolant Accident," International Congress on Advanced Nuclear Power Plants (ICAPP), Hollywood, Florida, June 2002.

[2] J.-J, Jeong, et al., "Development of a multi-dimensional thermal-hydraulic system code, MARS 1.3.1," Ann. Nucl. Energy 26 (18), pp.1161–1642, 1999.

[3] KHNP, Ulchin units 5&6 Final Safety Analysis Report, Rev. 1, Korea Hydraulic and Nuclear Power Co., 2007.

[4] J.-J, Jeong, et al., "Development of the MARS Input Model for Yonggwang 3/4 Transient Analyzer," KAERI/TR-2797/2004, Korea Atomic Energy Research Institute, 2004.

[5] D. Feng, P. Morra, W.-J Lee, et al., "Safety Analysis of High Power Density Annular PWR Fuel," Proc. of ICAPP '05, Seoul, Korea, May 15-19, 2005.