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Preliminary Analysis of LOCA for an Irradiation Test of an Annular Fuel Rod

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1. Introduction

An irradiation test of an annular fuel rod is planned in the HANARO Fuel Test Loop. The annular fuel rod has an inner and outer cladding tube, with cooling water flowing on both the inner and outer surfaces. The main advantage of the annular fuel rod with an increased heat transfer surface would be an increased fuel melting margin and DNB margin, and a decreased peak cladding temperature during a LOCA. This paper deals with a preliminary analysis of postulated loss-of-coolant accidents while the irradiation test of the annular fuel rod is being carried out in the HANARO Fuel Test Loop. The HANARO Fuel Test Loop was modeled by the MARS code. The temperature behaviour of the annular fuel rod for the loss of coolant accident was investigated in a given preliminary design and test condition of the annual fuel rod.

2. Analysis Methods

2.1 Modeling of the Annular Fuel Rod

The HANARO Fuel Test Loop consists of the main cooling water system (MCWS), the emergency cooling water system (ECWS), and the letdown, makeup, and purification system (LMPS), etc. The MCWS removes the fusion heat of test fuel and the gamma heat generated from the IPS (in-pile test section) in which a test fuel is installed. The ECWS consisting of two accumulators, safety injection valves, discharge valves, and associate pipes supplies emergency coolant to the test fuel and IPS.

The MCWS and the ECWS including the IPS had been modeled by the MARS code as described in detail in the reference [1, 2]. In this work the annular fuel rod together with the IPS was modeled as shown in Figure 1. Figure 1 shows half of the annular fuel rod and the IPS. The fuel rod with 700mm in length was modeled as 14 axial heat structures. The flow divider and the IPS vessel were also modeled as heat structures to simulate the gamma heat. The inner and outer radiuses of the annular fuel rod are 4.18mm and 7.95mm respectively. The inside diameter of the flow divider is 11.75mm. The inside and outside flow channels were modeled as pipe components of the MARS code indicated 312 and 310 respectively. The each pipe component has 14 sub-volumes. The number of 206 and 210 indicates the annular downward flow channel.

The thermal power of the annular fuel rod investigated in this work is 47.5kW. The maximum and average linear powers are 83.7kW/m and 64.3kW/m respectively. The flow rate, pressure, and temperature of the main cooling water in normal operation are 1.65kg/s, 14.8MPa, and 300^{o}C respectively.

2.2 Conservative Modeling

In this work the Moody model was used for calculating the discharge rates from broken pipes to get conservative results of cladding temperatures for the loss of coolant accidents [3]. Because the realistic correlations of the heat transfer coefficients were implemented originally in the MARS code, multipliers for the correlations of the heat transfer coefficients were also introduced to the MARS code so that cladding temperatures were predicted conservatively.

2.3 Modeling of Pipe Breaks

In analyses of postulated loss-of-coolant accidents, a spectrum of possible pipe breaks shall be considered. In this work, however, it is assumed that the upstream pipe from the IPS in the HANARO pool, the so-called “in-pool cold leg”, only is broken. It is because the break of the in-pool cold leg resulted in the most severe cladding temperature in the previous study similar to this work [4]. The break area investigated is up to the same size to the cross-sectional area of the pipe. Double-ended guillotine breaks are not taken into account and longitudinal splits only are assumed. The pipe break is modeled as the extremely abrupt opening of a valve connected to the in-pool cold leg. The opening time is assumed as 0.01 second. The minimum interval of the break area investigated is 1% of the cross-sectional area of the pipe.

3. Results

The cladding temperatures with the break sizes are shown in Figure 2 and Figure 3. Figure 2 and Figure 3 show the inside and outside cladding temperatures respectively. In general the cladding temperatures increase rapidly right after the pipe-break accidents occur and then decrease as time goes up to around 80 second. The cladding temperatures increase again after about 80 second and then decrease again. The behavior of the second increase and decrease of the cladding temperatures is highly dependent on the break size and is very complicated. After the second decrease of the cladding temperatures, the cladding temperatures do not increase again and thereafter slowly decrease.

The maximum temperatures of the inside and outside claddings reach about 1089K and 1026K respectively at about 2 to 3 second right after the pipe breaks occur.

The maximum temperature of the inside cladding is higher than that of the outside cladding by about 53K. The maximum temperatures of the inside and outside claddings are predicted at the break sizes of 15% and 13% of the cross-sectional area of the pipe respectively. In the loss of coolant accidents it is indicated that the maximum temperatures of the inside and outside claddings are less than the design limit, 1477K, of fuel cladding temperature for PWRs.

4. Conclusion

The irradiation test of an annular fuel rod is planned in the HANARO Fuel Test Loop. Therefore analyses of the postulated loss-of-coolant accidents due to the break of the in-pool cold leg have been carried out. In the preliminary design and test conditions for the annular fuel rod, the maximum cladding temperature is predicted to be about 1089K, which is less than the design limit, 1477K, of fuel cladding temperature for PWRs. Therefore, it is found that there is a sufficient possibility to increase the average and maximum linear heat rate of the test fuel.

References

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[3] S. K. Park, et al., Compliance Report for MARS/FTL_L to the License Review Guide (KINS/GE-N005), KAERI/TR-3445/2007, 2007.

[4] S. K. Park, et al., HANARO Fuel Test Loop Safety Analysis Report, KAERI/TR-3898/2009, 2009.

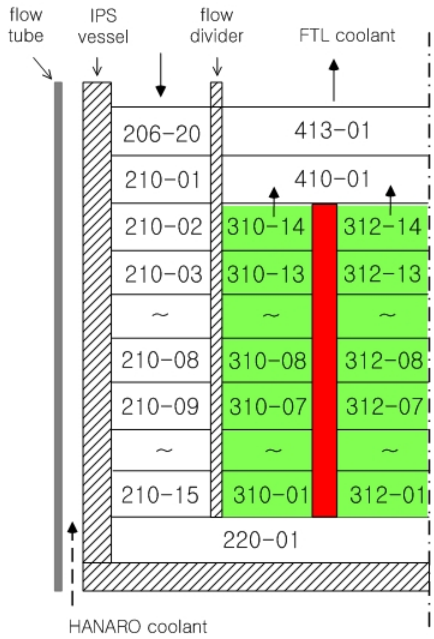

Fig.1. Modeling of the annular fuel rod within the IPS.

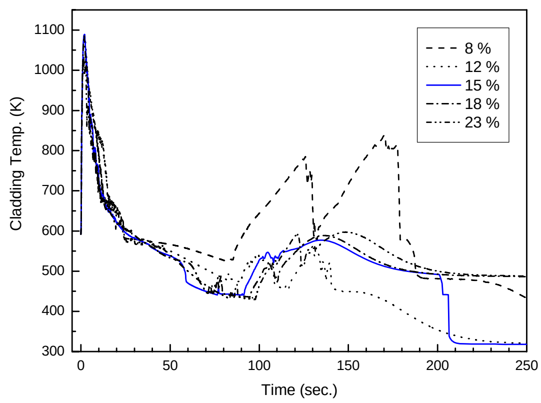

Fig.2. Cladding temperatures of the inside cladding.

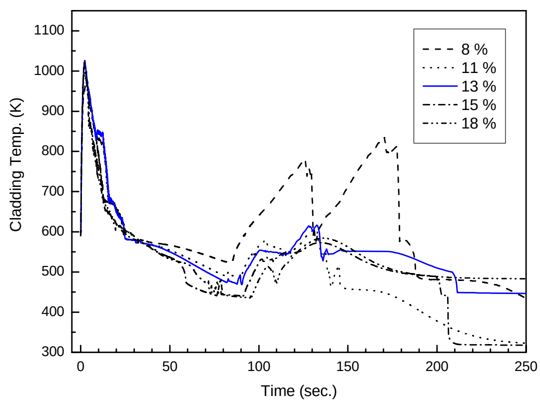

Fig.3. Cladding temperatures of the outside caldding.