Effects of Zr migration on the temperature distribution of U-Zr metallic fuel

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1. Introduction

The temperature distribution of the nuclear fuel affects various factors that determine its performance, such as fission gas release, thermal expansion, fuel and cladding chemical interaction, cladding creep, and even cladding oxidation. Therefore, calculating the temperature of the fuel is essential for evaluating nuclear fuel performance.

Zr migration in U-Zr metallic fuels occurs during irradiation because of the temperature gradient and chemical potentials [1, 2], resulting in a non-uniform distribution of both Zr and the heat source of U. However, current fuel performance evaluation codes ignore the heat generation rate that depends on U distribution. This study calculates the temperature distribution of U-Zr fuel using a case study.

2. Temperature calculation of the U-10Zr metallic fuel

A fuel rod of metallic fuel consists of a U-Zr fuel slug and a ferritic martensitic steel of HT9 cladding. To enhance radial heat transfer, bond sodium is filled in the gap between U-Zr fuel and cladding. Fig.1 shows a schematic cross section of the typical metallic fuel rod.

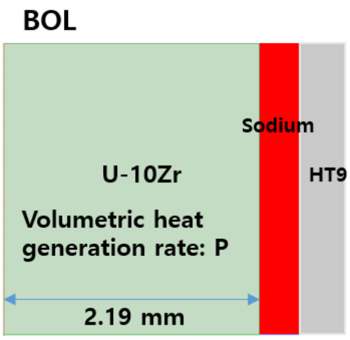

Fig. 1 Schematic cross-section of the metallic fuel

Using COMSOL, this study calculated the temperature distribution of the metallic fuel with a 2D asymmetric heat transfer model.

Table 1. Parameters of fuel rod

Linear power	344.732 W/cm
Coolant temperature	617 ℃
Heat transfer coefficient of Coolant	1.28E5 W/m^2K
Radius of Fuel	2.192 mm
Sodium gap thickness	0.348 mm
Thickness of Cladding	0.348 mm

This study assumed that only radial heat transfer occurs in the fuel rod and that conduction is the mode of heat transfer for bond sodium. Table 1 presents the fuel rod dimensions and the parameters for calculating temperature.

3. Results and discussion

3.1 Temperature distribution of current nuclear fuel performance code

The temperature gradient and the chemical potential of the phase gap causes the redistribution of metallic fuel constituents. The heat generation rate is uniform at Beginning of Life (BOL, uniform Zr distribution in U-10Zr), but Zr redistribution in the metallic fuel occurs during irradiation and results in an uneven heat generation distribution.

Although radial heat generation rate of metallic U-(Pu)-Zr varies with time, the current metallic fuel performance code assumes an even radial heat generation rate and calculates the temperature distribution.

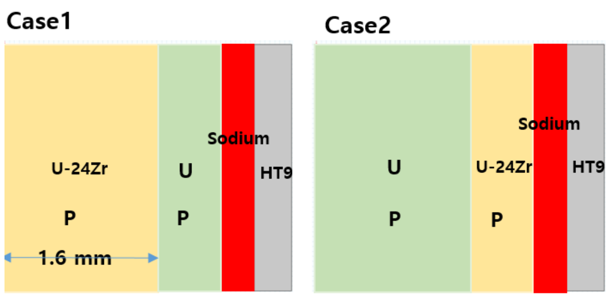

Fig. 2. Schematic cross-section of the metallic fuel: Case1 and Case 2

The redistribution of elements in metallic fuel can be simply classified into two cases: Case 1 is when Zr migrates into the inner region, and Case 2 is when all of Zr in the fuel migrates to the outer area. Region 1 is the half of the fuel volume, and Region 2 is the other half. In Case 1, the chemical composition of Region 1 and Region 2 is U-24Zr and U, respectively, and in Case 2, it is U and U-24Zr.

Fig. 3 shows the temperature distributions of metallic fuel with uniform heat generation of uniform Zr distribution, Case1, and Case2. The temperature differences in Fig. 3 are due to thermal conductivity difference from the radial element's composition of fuel. The centerline temperature of Case 1 is higher than that of uniform Zr distribution and peripheral temperature of

Case1 is lower than that of uniform Zr distribution. The entire temperature of Case2 is slightly hotter than uniform Zr distribution. Thermal conductivity of Zr is lower than that of U, therefore, this indicates that high thermal conductivity at the periphery is good to keep the lower temperature of fuel.

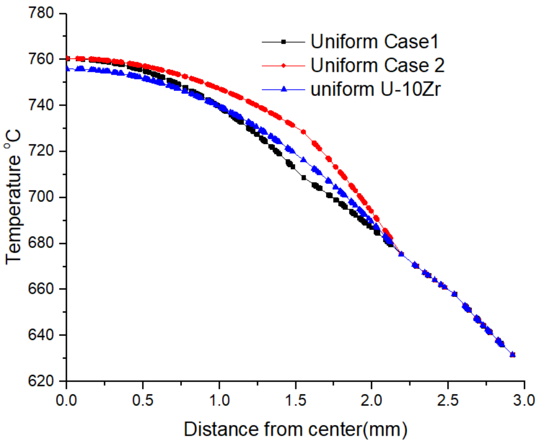

Fig. 3. Temperature profile of metallic fuel with uniform heat generation: Uniform Zr distribution, Case1, Case2.

3.2 Temperature calculation with consideration of radial heat generation rate

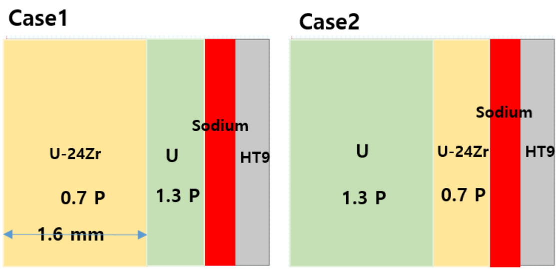

Fig. 4. Schematic cross-section of the metallic fuel: Case1 and Case 2

Fig. 4 shows schematic cross-section of metallic fuel of Case1 and Case2 with different power distribution. Atomic density of U in U-24Zr region is 0.7 times of U-10Zr, and therefore, the radial power of U region is 1.3 times of average heat generation rate of P, and the radial heat generation rate of U-24Zr is 0.7 times of average heat generation rate of P. Fig. 5 shows the temperater distribution of Case 1 and 2 with/without consideration of radial heat generation rate distribution. The center line temperature of uniform power is higher than redisributed power. This indicates that current fuel performance code over-estimates the temperature of metallic fuel during reactor operation. On the other hand, temperater distribution of Case 2 with consideration of radial heat geration rate under-predict the temperature of metallic fuel. In both cases, current fuel performance code under the assumption of uniform radial power distribution cannot recisely predict exact temperature distribution of the fuels.

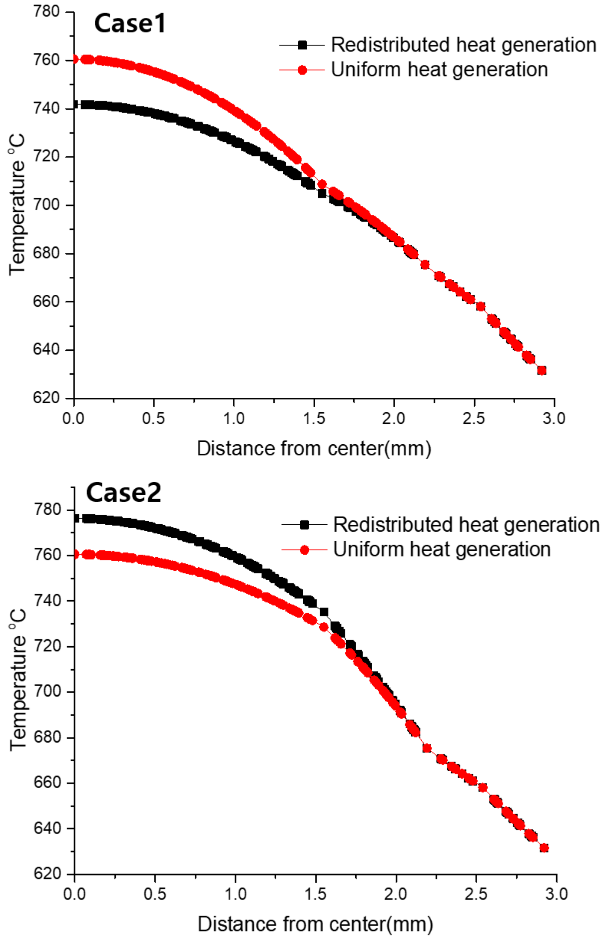

Fig. 5. Temperature distribution of Case 1 and Case2 with consideration of radial heat generation rate distribution.

4. Summary

Temperature distribution of metallic fuel was calculated with consideration of radial heat generation rate distribution Following conclusion can be introduced

- Current fuel performance code under the assumption of uniform radial heat generation rate distribution tends to over- or under-estimate temperature of metallic fuel.

-Radial heat generation rate distribution should be considered in temperature calculation of metallic fuel.

Acknowledgement

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References

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