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Simulation of Halden IFA-790 test with FRAPCON4.0P1

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1. Introduction

KEARI (Korea Atomic Energy Research Institute) has been developing micro-cell UO_2 pellet as accident tolerant fuel (ATF) pellet to enhance the performance and safety of current LWR fuels under normal operation condition as well as during transients/accidents [1-3]. In order to investigate the in-reactor fuel performance and behavior of the developed microcell UO_2 pellets, irradiation test was started in December of 2015, through cooperation with Thor Energy in Norway. However, due to the decision of permanent shutdown of Halden test reactor, IFA-790 test could no longer be performed. Although long-term experiments have not been performed, the results of in-pile test of microcell UO_2 pellet are meaningful in the verification of the effects of microcell.

In this paper, reference UO_2 fuel which has been irradiated at Halden reactor was simulated by using FRAPCON 4.0P1 code [4] to evaluate the in-pile behavior of reference UO_2 pellets. Also, the densification model in FRAPCON4.0P1 was modified to accurately simulate the measured fuel centerline temperature.

2. IFA-790 Experiment

The developed microcell fuels have been irradiated in the IFA-790 test rig in Halden Research Reactor. The data of the KAERI rods have been obtained during the irradiation of IFA-790 in the Halden reactor, entailing about 360 days of operation at power. The peak burn-up achieved during this time period is about 16.2MWd/kgM.

The IFA-790 rig has in total 12 rods, 6 placed in the upper cluster and six in the lower cluster. The KAERI rods and UO_2 fuel rod which can serve as reference are placed in the upper cluster. The main parameters and instrumentation of the KAERI rods and UO_2 fuel rod are given in Table 1. Rod 7 consists of UO_2 pellet and Zircaloy-2 cladding. Rod 11 consists of Metallic microcell UO_2 pellet and Cr-Al coated zircaloy-4 cladding.

The IFA-790 assessment is based on the on-line measurements carried out by means of the fuel rod instrumentation. Centerline temperature of the fuel pellets is measured by a thermocouple inserted into a hole drilled through a few pellets at the top or bottom of the fuel stack.

Tabel.1 Main parameters and instrumentation of the KAERI rods and reference rod.

Rod No.	7	11
Fuel type	UO_2 (Reference)	Metallic Microcell UO_2
Additive	-	Cr
Cladding	Zr-2	Zr-4
Clad coating	None	Cr-Al
Instrument	TF, PF, EC	TF, PF, EC

TF : Fuel Temperature
PF : Rod Pressure
EC : Cladding elongation

3. Simulation of IFA-790

Based on the power history, the fuel centerline temperature was calculated by FRAPCON4.0P1. The calculated fuel temperature at the node where the thermocouple is expected to be located was used to accurately compare measured fuel centerline temperatures. Fig. 1 shows the comparison of the fuel centerline temperature measured by thermocouple with calculated by FRAPCON4.0P1. This result show that calculated temperature are under-estimated. It is necessary to modify the densification model to accurately simulate the fuel centerline temperature.

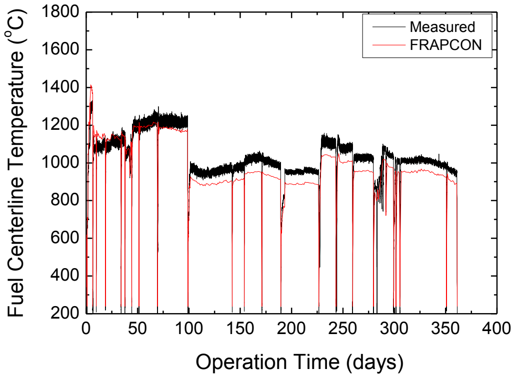

Fig.1 Comparison between measured fuel centerline temperature and calculated fuel centerline temperature.

Fuel densification as a function of burnup is calculated from equation (1).

$$\frac{\Delta L}{L} = \left(\frac{\Delta L}{L}\right)_m + e^{[-3(FBU+B)]} + \left(2.0e^{[-35(FBU+B)]}\right) \quad (1)$$

where,

$(\frac{\Delta L}{L})$ = dimension change (percent)

$(\frac{\Delta L}{L})_m$= maximum possible dimension change of fuel due to irradiation (percent)

FBU = fuel burnup (MWd/kgU)

B = a constant determined by the subcode to fit the boundary condition : $\frac{\Delta L}{L}$ = 0 when FBU = 0

As shown in Figure 1, since the calculated fuel centerline temperature is lower than the measured that, it needs to change fuel dimension change in equation (1) to increase the fuel centerline temperature. The first term in equation (1) is the maximum possible dimension change and this term was changed to increase fuel densification.

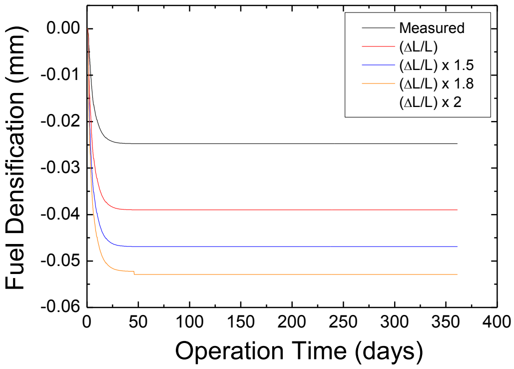

Fig.2 The variation in densification as the first term change in equation (1).

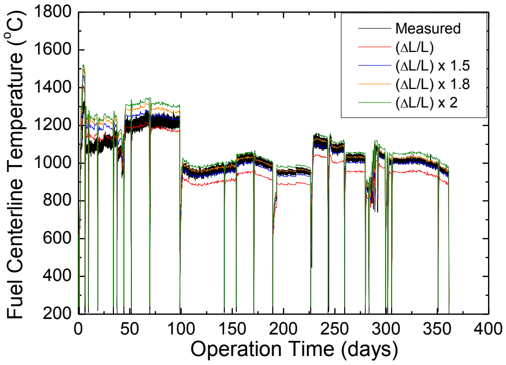

Fig. 3 The variation in the fuel centerline temperature as the first term change in equation (1).

Figure 2 shows the variation of densification as the first term changes. Densification increases as the first term in equation (1) increases. Increased densification leads to widening the gap between pellet and cladding and thereby, the fuel centerline temperature increases.

Figure 3 shows that the fuel centerline temperature increases with increasing densification. In case of 1.8 times the first term in equation (1), the calculated fuel centerline temperature increased and was similarly simulated to the measured that. However, the fuel centerline temperature, calculated in the range between the early days and 100 days, was calculated above the measured that by changing the first term in equation (1). This result is due to densification rate proceeds rapidly. To correct this, the densification model should be modified so that initial densification occurs slowly.

The relation between densification and burnup suggested by Rolstad et al.[5] has been adopted for use in the FRAPTRAN4.0P1. Densification is assumed to consist of a slowly varying component, represented by the second term $e^{[-3(FBU+B)]}$ in equation (1), and a rapidly varying component, represented by the third term $2.0e^{[-35(FBU+B)]}$ in equation (1). Therefore, the second term in equation (1) was changed to decrease the densification rate.

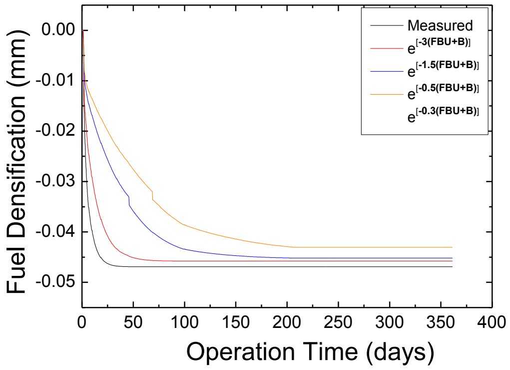

Fig. 4 The variation in densification as the second term change in equation (1).

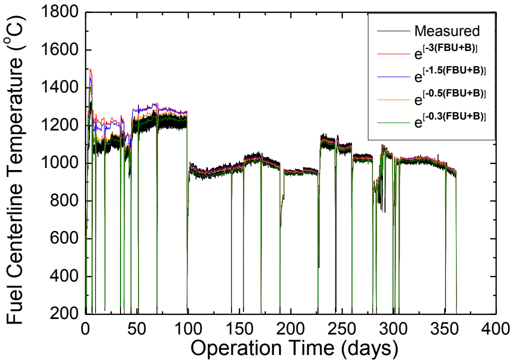

Fig. 5 The variation in the fuel centerline temperature as the second term change in equation (1).

Figure 4 shows the variation of densification as the second term (slowly varying component) in equation (1). In the second term, the densification rate decreased as the constant term decreased. Initial densification rate reduction suppresses fuel centerline temperature increase by densification. Figure 5 shows the change in fuel core temperature with decreasing densification rate.

The decrease in the constant of the second term results in a decrease in temperature in the range between the early days and 100 days. In case of -3 of constant in the second term in equation (1), calculated fuel centerline temperature was similarly simulated to the measured that.

As a result, the fuel centerline temperature over the entire range was accurately simulated to the measured that by modified densification model from equation (1) to equation (2).

$$\frac{\Delta L}{L} = [\left(\frac{\Delta L}{L}\right)_m * 1.8] + e^{[-0.3(FBU+B)]} + \left(2.0e^{[-35(FBU+B)]}\right) \quad (2)$$

4. Conclusions

The fuel centerline temperature of the reference UO_2 rod of IFA-790 was simulated by FRAPCON4.0P1. However, since the calculated fuel centerline temperature was simulated lower than the measured that, the densification model was modified from equation (1) to equation (2). As a result, the calculated fuel temperature was simulated similar to the measured that.

Based on the modified densification model, equation (2), we will simulate the fuel centerline temperature of a metallic microcell UO_2 pellet with Cr as an ATF pellet. To simulate accurate ATF rod, the thermal conductivity of mixture between Cr and UO_2 in metallic microcell UO_2 pellet with Cr should be considered.

Acknowledgement

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