Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Preliminary simulation of the KAERI rods irradiated in IFA-790 using FRAPCON4.0P1

Jang Soo Oh, Hyochan Kim, Dong-Joo Kim, Yongsik Yang, Jae Ho Yang*

Korea Atomic Energy Research Institute,
989-111 Daedeok-daero, Yuseong-gu, Daejeon-si, 34057, Korea
jangsoo@kaeri.re.kr

1. Introduction

A recent development of advanced UO_2 pellets mainly focus on enhancement of the safety of nuclear power reactor. Several accident tolerant fuel (ATF) are being developed around the world to mitigate the consequences of an accident [1-3]. Korea atomic energy research institute (KAERI) is developing a microcell UO_2 pellet to provide chemical traps or a physical barrier against the movement of volatile FPs, or to enhance the thermal conductivity of pellets [4-6]. There are two kinds of microcell UO_2 pellets with distinct features. The first is a metallic microcell UO_2 pellet and the second is a ceramic microcell UO_2 pellet.

The metallic microcell UO_2 pellet is a highly thermal conductivity pellet with a continuously connected metallic wall. It can be increase of the safety margin under LOCA as well as the thermal and operational margin under normal operation condition.

The ceramic microcell UO_2 pellet can reduce the release of fission products to the outside of the pellet by providing ceramic wall which is composed of an oxide phase with chemical affinity to fission product.

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, and Halden irradiation testing is ongoing.

In this paper, reference UO_2 fuel which is being irradiated at Halden reactor was simulated by using FRAPCON 4.0P1 code [7] to evaluate the in-pile behavior of reference UO_2 pellets. Based on the simulation results, the in-pile behavior of reference UO_2 pellets was studied.

2. IFA-790 Experiment

The developed microcell fuels are being 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 190 days of operation at power. The peak burn-up achieved during this time period is about 10.7Mwd/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 of UO_2 fuel rod are given in Table 1. Rod 2 consists of UO_2 pellet and Zircaloy-2 cladding. Rod 8 consists of ceramic microcell UO_2 pellet and FeCrAl coated zircaloy-4 cladding. Rod 11 consists of Metallic microcell UO_2 pellet and Cr-Al coated zircaloy-4 cladding.

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

Rod No.	2	8	11
Fuel type	UO_2	Ceramic microcell UO_2	Metallic Microcell UO_2
Additive	-	Si-Ti-O	Cr
Cladding	Zr-2	Zr-4	Zr-4
Clad coating	None	Fe-Cr-Al	Cr-Al
Instrument.	TF, PF, EC	TF, PF, EC	TF, PF, EC

TF : Fuel temperature
PF : Rod pressure
EC : Cladding elongation

The IFA-790 assessment is based on the on-line measurements carried out by means of the fuel rod instrumentation. A schematic of the test rig and the placement of the instrumentation are shown in Fig.1. Centerline temperature of the fuel pellets is measured by means of a thermocouple inserted into a hole drilled through a few pellets at the top or bottom of the fuel stack.

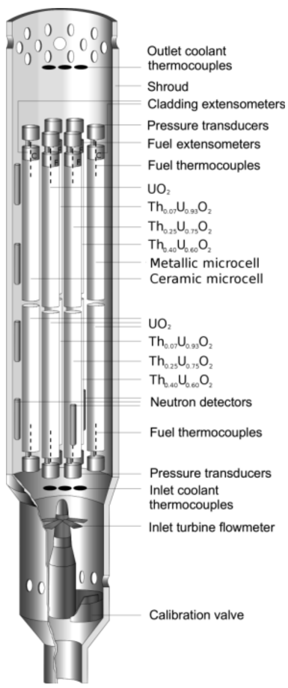

Fig.1 Schematic of the test rig IFA-790 [8]

During the operating period so far, all of rods in IFA-790, including the KAERI rods, have operated normally and without any indication of failure.

3. Simulation of IFA-790

For the simulation, the input parameters to model an experiment in FRAPCON are required to specifics on the rod design and fabrication, in-core operational characteristics. Most input parameter for simulation in FRAPCON was provided from IFA-790 fabrication report, but some input values were unknown. So, some input parameter was calculated and applied as optional value.

Pitch in IFA-790 which means center-to-center distance between rods was calculated by using the following relationship

$$D_e = \frac{4[P_{pit}^2 - \frac{\pi}{4} D_0^2]}{\pi D_0}$$

where,

P_{pit} = rod-to-rod pitch
D_0 = outside cladding diameter

Above relationship is to calculate Coolant channel hydraulic diameter in a square array. However, the fuel rods in the IFA-790 are arranged in a circular array. With this in mind, assuming that the hydraulic diameter is the same in a square array and a circular array, we can see that P^2 and A are the same as shown in the figure 2. Thus, pitch in a circular array can be calculated to root A.

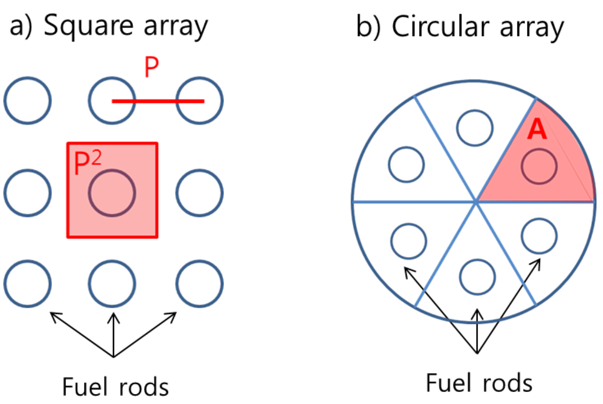

Fig. 2 Two types of rod array

The rod total free volume differed between the calculated value by FRAPCON and the value specified by IFA-790, because information of plenum volume and plenum spring dimension is insufficient. In order to match rod total free volume, Plenum length and plenum spring dimensions were arbitrarily adjusted to match the free volume values specified in IFA-790.

Fig.2 shows Linear Heat Generation Rate (LHGR) history during operation period. The LHGR in FRAPCON was simulated to match measured LHGR well.

Based on the power history, the fuel centerline temperature was calculated by FRAPCON. To accurately compare measured fuel centerline temperatures, the calculated fuel temperature at the node where the thermocouple is expected to be located was used. The fuel centerline temperature variation as a function of operation time is shown in Fig. 3. In early stage of operation time, the calculated fuel centerline temperature is about 100°C higher than measured one. It seems that this result is due to not considering heat loss corresponding to the volume of thermocouple inside the fuel pellet as shown in right side of Fig.3.

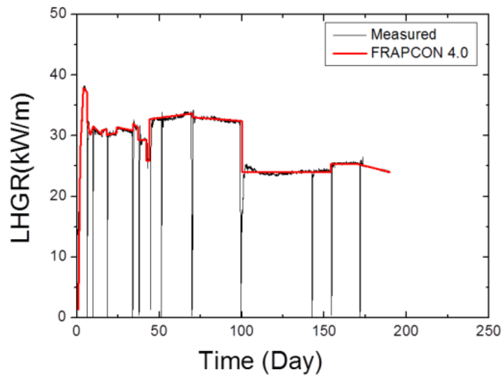

Fig. 2 Linear Heat Generation Rate (LHGR) history versus operation time

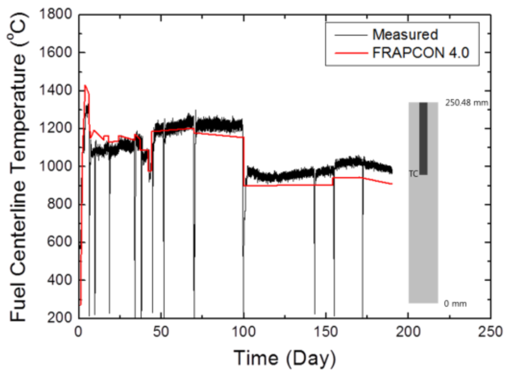

Fig. 3 Comparison between measured fuel centerline temperature and calculated fuel centerline temperature

4. Conclusions

The IFA-790 experiment was simulated by FRAPCON 4.0P1 code. Based on raw data of LHGR, input power was generated and it was similar to given data. However, a comparison of fuel centerline temperature between measured by thermocouple and calculated by FRAPCON showed that the calculated fuel centerline temperature is higher than the measured one in early stage of operation time

In the future, we will adjust the power input value to improve the simulation accuracy of the fuel centerline temperature. When the simulation accuracy of the in-pile behavior of UO_2 pellet increases, it will be evaluation with simulation.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2017M2A8A5015056).

REFERENCES

[1] M. Q. Awan, L. Cao, H. Wu, "Neutronic Design and Evaluation of a PWR Fuel Assembly with Accident Tolerant-Fully Ceramic Micro-Encapsulated (AT-FCM) fuel," *Nuclear Engineering and Design*, **319**, 126 (2017).

[2] K. D. Johnson, A. M. Raftery, D. A. Lopes, J. Wallenius, "Fabrication and Microstructural Analysis of UN-U3Si2 Composites for Accident Tolerant Fuel Applications," Journal of Nuclear Materials, 477, 18 (2016).

[3] C.P. Deck, G.M. Jacobsen, J. Sheeder, O. Gutierrez, J. Zhang, J. Stone, H.E. Khalifa, C.A. Back, "Characterization of SiC-SiC Composites for Accident Tolerant Fuel Cladding," *Journal of Nuclear Materials*, **466**, 667 (2015).

[4] Y. H. Koo, J. H. Yang, J. Y. Park, K. S. Kim, H. G. Kim, D. J. Kim, Y. I. Jung, K. W. Song, "KAERI's Development of LWR Accident-tolerant Fuel," *Journal of Nuclear Technology*, **186**, 295 (2014).

[5] H. G. Kim, J. H. Yang, W. J. Kim, Y. H. Koo, "Development Status of Accident-tolerant Fuel for Light Water Reactors in Korea," *Nuclear Engineering and Technology*, **48**, 1, 1 (2016).

[6] D. J. Kim, Y. W. Rhee, J. H. Kim, K. S. Kim, J. S. Oh, J. H. Yang, Y. H. Koo, K. W. Song, " Fabrication of Micro-cell UO2-Mo Pellet with Enhanced Thermal Conductivity," *Journal of Nuclear Materials*, **462**, 289 (2015).

[7] K,J. Geelhood et al., FRAPCON-4.0: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup, PNNL-19481, Vol.1 Rev2, 2015

[8] K.I. Björk, C.W. Lau, C. Vitanza, H.G. Kim, D.J. KIM, " TEST IRRADIATION OF ENHANCED NUCLEAR FUEL AND CLADDING", *WRFPM* (2017)