Evaluation of the Centerline Temperature for the Irradiated DUPIC Pellet

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1. Introduction

The DUPIC (Direct Use of spent PWR fuels In a CANDU reactor) fuel has a proliferation-resistant property and provides an efficient utilization of a spent fuel through a direct fabrication with the OREOX process[1] in which most of the fission products remain and some volatile elements such as Xe, Kr, Cs, and I are reduced significantly. It is expected that the performance of the DUPIC fuel exhibits different behavior when compared with the fresh uranium oxide fuel. To evaluate the performance of the DUPIC fuel, total five irradiation tests have been performed in the HANARO reactor since May 2000. Recently, the fifth irradiation test of the DUPIC fuel was successfully completed for a total of three cycles from March 2006 to July 2006. The important characteristics of the first irradiation test are a high power test and a validation of a remote assembly of an irradiation rig. The second irradiation test was instrumented with a SPND (self-powered neutron detector) first for a typical CANDU burnup test. The third test was an extensive irradiation test of the second test and the total burnup was estimated as 6,700 MWd/tU. The forth test was a remote-instrumented test of the pellet centerline temperature and the inlet and outlet coolant temperatures. The first remote instrumentation test was achieved with our own technology. The fifth test was a remote-instrumented test of the pellet centerline temperature by extending the technology of the forth irradiation test. In this paper, a DUPIC fuel performance code (KAOS, KAERI Advanced Oxide fuel performance code System)[2,3] was used to compare the main simulation results of the irradiation tests in the HANRO.

2. Methods and Results

For the preliminary analysis of the DUPIC fuel performance, the KAOS code was developed based on the existing computational algorithms. Similar to the uranium oxide fuel, the MATPRO model was chosen for the thermal expansion, creep, swelling, specific heat, grain growth of the pellet. It was also used to evaluate thermal conductivity, thermal expansion, creep, and specific heat of the cladding. The thermal conductivity model of the DUPIC pellet was newly implemented in the KAOS code modified the exiting formula[4]. The mechanical interaction of the pellet and cladding was simplified based on the FRAPCON-3 code[5]. Additionally, a one dimensional finite element method was implemented based on the algorithm of the FEMAXI-V code[6] for a deformation of the pellet and cladding.

TABLE I. Evaluation Results of the HANARO Irradiation Test of the DUPIC Fuel

Test	MLP[a] (kW/m)	Burnup (MWd/tU)	MCT[b] (^{o}C)	MMCT[c] (^{o}C)	MFGRR[d] (%)
1	66.1	1770	2602	N.M.[e]	0.25
2	34.7	3400	1445	N.M.	0.25
3	39.4	3300	1686	N.M.	0.81
4	36.0	2130	1424	1095	0.92
5	43.5	3300	1785	1402	0.94

a) Maximum Linear Power,
b) Maximum Centerline Temperature,
c) Maximum Measured Centerline Temperature,
d) Maximum Fission Gas Release Rate,
e) Not Measured.

The results of the HANARO irradiation tests for the DUPIC fuel are summarized in Table I. The linear power rates obtained from the HANARO reactor analysis range from 34 to 66 kW/m and the maximum centerline temperatures of the DUPIC pellet were range from 1420 to 2600 ^{o}C. Compared to the measured data, the centerline temperatures of the forth and the fifth irradiation tests were overestimated by about 320-380 ^{o}C, respectively. The main reasons for these overestimations are thought to be the lack of an exact modeling of the pellet and cladding for a steep power changes during the reactor start-up and shutdown period and an uncertainty of the estimated linear power rate. The fission gas release rates were also provided and they are somewhat low due to an overall short irradiation period and small burnup. Although the linear power is high in the first irradiation test, it was estimated that the fission gas released was as small as 0.25% due to a low burnup. But in the case of the third, the forth and the fifth irradiation tests, the estimated fission gas release rates were slightly increased due to increased burnup.

In Fig. 1, the centerline temperatures are depicted for the DUPIC irradiation tests and compared with the results of some existing fuel performance codes. To evaluate the DUPIC fuel, only some models including thermal and mechanical models of the FEMAXI and the FRAPCON codes were modified remaining main calculation frame. From the results, it was found that there was a small discrepancy among the fuel performance codes within ~100 °C except for the first irradiation test. The large discrepancy in the first irradiation test was mainly because the estimated linear power rate was higher than the other tests and the thermal and mechanical behaviors in such a high power rate revealed quite different results and their models were not constructed accurately. The existing fuel performance codes are based on developed for the commercial light water reactor condition, which has lower power rate than the research reactor. For the forth and the fifth irradiation tests, the discrepancies between the measured and calculated temperatures increased slightly for the proceeding cycles. This results in the pellet deformation and cracking for abrupt power change[3]. However, the KAOS code provides a reliable result when compared to the existing codes and it is useful to apply it for the preliminary analysis of the DUPIC fuel performance.

3. Conclusion

Total of five irradiation tests for the DUPIC fuel were performed successfully by achieving a remote assembly rig technology, a high power test, a CANDU equivalent burnup test, and remote instrumentation technology. Among them, two measured temperatures were obtained for the forth and the fifth irradiation tests with remote instrumented technology. For the preliminary analysis for the DUPIC fuel irradiation tests, the KAOS code has been developed and some of its computational results were compared with the existing fuel performance code systems results. The estimation results show that the KAOS code exhibits enough good results and provides fundamental data on the irradiated DUPIC fuel behavior. It is expected in the future that more accurate models for a high power and an extended burnup will be developed to evaluate the DUPIC fuel performance properly.

Acknowledgements

This work has been carried out under the Nuclear Research and Development program of the Korea Ministry of Science and Technology.

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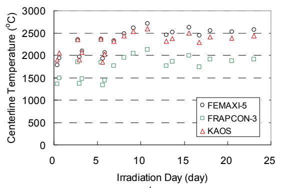
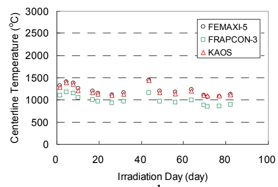
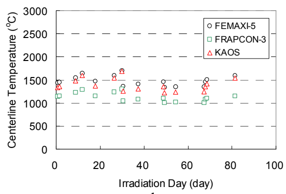


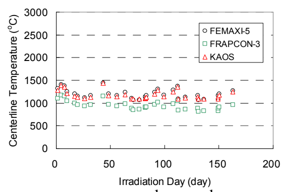
(a) 1st test



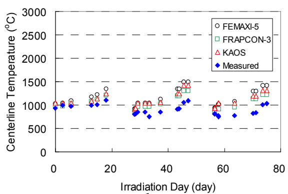
(b) 2nd test



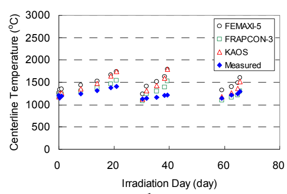
(c) 3rd test



(d) 2nd + 3rd test



(e) 4th test



(f) 5th test

Figure 1. Centerline temperature estimation for the HANARO irradiation tests of the DUPIC fuel.