Transactions of the Korean Nuclear Society Virtual spring Meeting
May 13-14, 2021

FRAPCON Base Irradiation Input for FFRD Analysis

Yong Sik Yang, Jang Soo Oh
Korea Atomic Energy Research Institute, 111 Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon, Korea
yys@kaeri.re.kr

1. Introduction

The Phenomena, so called FFRD(Fuel Fragmentation, Relocation and Dispersion) is the most important issues in reactor safety analysis area. The importance of FFRD phenomena and its progress can be briefly presented below.

During LOCA(Loss Of Coolant Accident), a finely fragmented UO2 pellets may move to empty region which is caused by high temperature ballooning. And then, the increased pellet particles heats and breaks the fuel cladding. Dispersed fuel particles can interfere with coolant flow and affect to long term coolability

According to the results of various studies, it is known that fine pellet fragmentation is greatly influenced by the pellet burnup, more details, the existence of HBS(High Burnup Structure).

In terms of fragmented pellet movement, so called relocation, the distance between fuel pellet and cladding is an important factor in determining the total transfer amount.

Finally, the amount of dispersed pellet particles through the ruptured area of cladding is determined by the pellet fragment particle size and the size of the hole.

Recently, among several studies to reflect the FFRD phenomenon in safety analysis, various research is being conducted to apply the QT model developed in VTT to the safety analysis code.

This paper is a thesis that summarizes the results of development of input deck for FFRD model verification based on the IFA 650.5 test, one of the results of several FFRD tests conducted in Halden Reactor Project, as part of the development process of safety analysis technology that reflects the FFRD model.

Especially, an input deck development for FRAPCON4.0 code, based on manufacturing and base irradiation history of IFA 650.5's mother rod is proposed which is inevitable pre-requisite base of FRAPTRAN code system to perform LOCA and FFRD analysis.

2. FRAPCON and FRAPTRAN code

The main role of FRAPCON code is a NRC's steady-state fuel performance code which can calculate various fuel behavior during in-reactor burnup increase such as a fuel temperature, deformation, fission gas release, cladding's degradation and internal pressure change.

In addition to its original role, an initial condition of FRAPTRAN code can be supplied by FRAPCON code only. Therefore, if we perform LOCA analysis by FRAPTRAN code including burnup dependent characteristics such as a material properties, rod internal pressure and cladding corrosion thickness, pre-calculated FRAPCON output should be served.

In conclusion, both FRAPCON and FRAPTRAN input deck are required for proper LOCA analysis. In this paper a FRAPCON input deck is called "base irradiation input deck" for FRAPTRAN calculation.

3. Manufacturing and Base Irradiation of Mother Rod

The mother rod used in the IFA 650.5 test was produced from the Framatome 15X15 fuel. The test specimen was collected between the No. 5 and No. 6 spaer grid of the fuel assembly operated for six cycles at the PWR commercial reactor, with a burnup of approximately 83.4 MWd/MTU. [1]

Fig. 1 shows the power history during the base irradiation period of the test section fuel. There is no significant difference in axial power distribution over the base irradiation period, as the axial length is a relatively short about 480 mm.

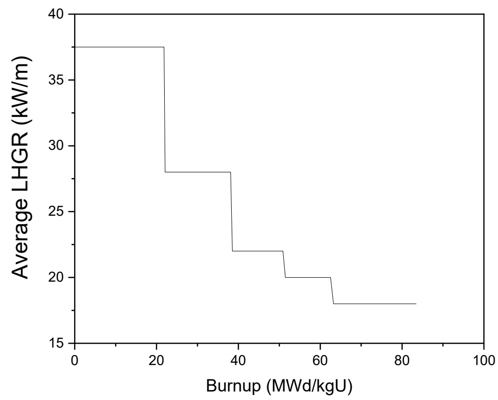

Fig. 1 Base irradiation history of IFA 650.5 test

The detailed dimensions of cladding and pellet required for base irradiation calculations using FRAPCON were mainly determined by comparing three references.[1,2,3]

The IFA-650.5 sample input provided by PNNL via user groups was modified through three steps.

The first modification resulted in some code differences in the process of changing the British unit to SI units, but this was negligible. In general, we use the Massih model for calculating fission gas release in basic sample inputs, but we change it to the FRAPFGR model for LOCA calculation with FRAPTRAN codes.

In the second revision, other design data between references were finally modified based on the values which contained in the data sheet prepared prior to the IFA test[1]. All other values are referenced in Reference 3. In Fig. 2, a final dimension of base irradiation mother rod is summarized.

cladding outside diameter	cm(in.)	1.0735E+00	(4.2264E-01)
cladding inside diameter	cm(in.)	9.2930E-01	(3.6587E-01)
cladding thickness	mm(in.)	7.2100E-01	(2.8386E-02)
clad arithmetic mean roughness	mm(mils)	5.0000E-03	(1.9685E-01)
diametral gap thickness	mm(mils)	1.6100E-01	(6.3386E+00)
fuel pellet diameter	cm(in.)	9.1320E-01	(3.5953E-01)
fuel pellet length	cm(in.)	1.1000E+00	(4.3307E-01)
fuel pellet dish depth	mm(in.)	2.8000E-01	(1.1024E-02)
fuel pellet dish shoulder width	mm(in.)	1.2000E+00	(4.7244E-02)
fuel pellet dish sperical radius	cm(in.)	2.0372E+00	(8.0205E-01)
fuel pellet core radius	mm(in.)	0.0000E+00	(0.0000E+00)
fuel pellet sintering temperature	K(F)	1.8726E+03	(2.9110E+03)
fuel pellet true density	percent	9.4800E+01	
fuel pellet resinter density chng	kg/cu.m	1.0000E+02	
fuel volume	cu.m(cu.in.)	3.1003E-05	(1.8919E+00)
fuel arithmetic mean roughness	mm(mils)	2.0000E-03	(7.8740E-02)
fuel stack height	m(ft.)	4.8000E-01	(1.5748E+00)
Uranium mass per unit length	kgU/m(kgU/ft.)	5.9155E-01	(1.8030E-01)
fuel dish volume fraction		1.3865E-02	
Fuel is UO2			
U-235 enrichment	at% in U	3.5000E+00	
Fuel is doped with	wt% Gd	0.0000E+00	
fuel fission atoms(Xe + Kr)/100 fissions		3.1000E+01	
fuel water concentration	ppm	0.0000E+00	
fuel nitrogen concentration	ppm	0.0000E+00	
plenum length	cm(in.)	2.2000E+01	(8.6614E+00)
plenum spring diameter	cm(in.)	9.1300E-01	(3.5945E-01)
plenum spring wire diameter	mm(in.)	1.0000E+00	(3.9370E-02)
plenum spring volume	cu.m(cu.in.)	4.0120E-07	(2.4483E-02)
plenum volume	cu.m(cu.in.)	1.4521E-05	(8.8611E-01)
plenum spring turns		2.0000E+01	
volume fraction of plenum occupied by spring		2.6887E-02	
rod total void volume	cu.m(cu.in.)	1.6152E-05	(9.8566E-01)
rod internal helium pressure	mpa(psia)	2.2500E+00	(3.2633E+02)
fuel rod pitch	cm(in.)	1.4000E+00	(5.5118E-01)
channel equivalent diameter	cm(in.)	1.2512E+00	(4.9259E-01)

Fig. 2 Detailed dimension of IFA650.5 mother rod

4. Results and Discussion

After the input generation, FRAPCON4.0P1 was used to calculation base irradiation for IFA 650.5 mother rod.

The last change is a modification of the coolant outlet temperature and the coolant flow conditions used in reference [3], based on the cladding oxide thickness and hydrogen content measured before the IFA test.

The coolant mass flux and inlet coolant temperature were adjusted to make the oxide thickness as similar as possible values, which resulted in similar results as the average oxide thickness of 65μ m and up to 80μ m within the test fuel section. (Fig. 3)

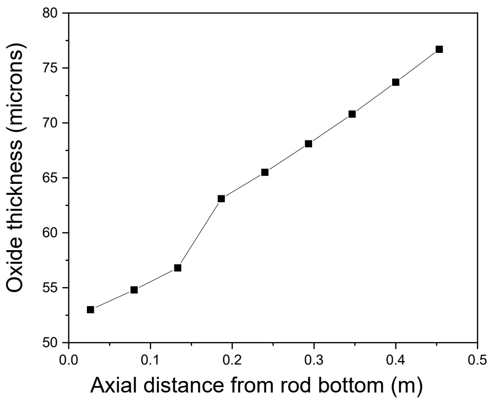

Fig.3 Axial oxide thickness distribution

The hydrogen content of cladding measured by the PIE(Post Irradiation Examination) is known to be around 650 ppm, but the developed input is slightly less expected to be around 550 ppm. However, the development of the input deck was completed considering that the effect of the oxide thickness was greater than the hydrogen content.

Figures 3 and 4 show the axial oxide thickness distribution and hydrogen content prediction results calculated by developed input deck respectively.

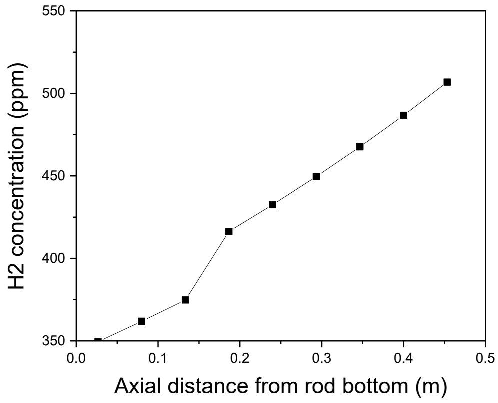

Fig. 4. Axial distribution of hydrogen

The newly developed input deck will be applied to the IFA 650.5 analysis in conjunction with the FRAPTRAN code

Acknowledgement

This work was supported by the Korea Hydro & Nuclear Power (KHNP)(A19LP05, Establishment of optimal evaluation system for safety analysis of OPR1000 and Westinghouse type nuclear power plant(1))

REFERENCES

[1] Laura Kekkoonen, “LOCA testing at Halden, The PWR Experiment IFA 650.5”, HWR-839
[2] R. Manzel et al, “The rold of the pellet rim on fission gas release at extended burnup”, IAEA-TECDOC-1036, 1998
[3] FRAPCON4.0 Sample input, supplied by USER Group.