The Evaluation of the Pressure Tube Creep Effect on the CANDU-6 Equilibrium Core with the Modified 37 Element Fuel

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1. Introduction

The diameter of pressure tube (PT) in the CANDU reactor is increased by the irradiation and thermal effect and is called creep. The creep rate is increased in process of operation time. The amount of coolant is also increased slightly due to increasing PT diameter and the bypass flow path is generated. So, the safety analysis is performed in the condition of the expected longest EFPD (Effective Full Power Day).

Recently the modified fuel (37M) is being developed to improve the heat-transfer properties relative to standard 37 element fuel (37R) designs. The fuel design change is only the reduction of center pin's diameter and the others have the same diameter.

In this study, the creep effect is evaluated in terms of reactor physics. And also the effect of fuel design change is evaluated because the radius reduction increases the flow area around the center pin similar to the creep conditions. The maximum channel and bundle power, and reactivity change according to the temperature are compared between the equilibrium and aged core for each fuel type.

2. Methods and Results

In this section the procedure of modeling aged core and the creep effect on the core properties are described.

2.1 Calculation of Creep Rate

The diameter of pressure tube is increased by the irradiation and thermal effect. The creep rates at the 8000 EFPD for Wolsong-2 unit are considered to evaluate the effect on the lattice properties by the creep of pressure tube. The RC-1980 is the program to predict the creep rate of pressure tube at the each EFPD. Because the creep rate of RC-1980 has the uncertainty the creep rate used in aged core model is determined using both the creep rate of RC-1980 and the measured diameter of some channel's pressure tube.

In the thermal hydraulic model using CATHENA code, the 380 channels are divided into 7 groups as follows as figure 1. So, the 84 fuel types for the aged core model are selected among the 4560 bundles. Table 1 is the maximum creep rate of each bundle in each channel group. These 84 bundles are used to model the aged core.

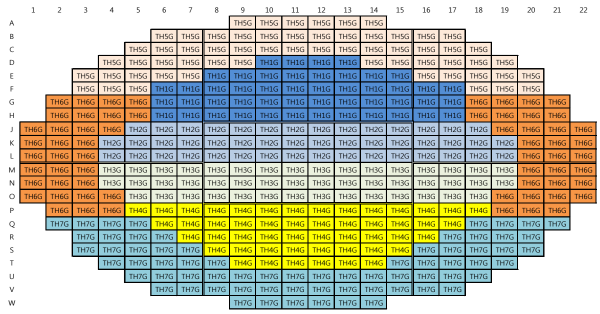

Fig. 1. 7 channel groups of the thermal hydraulic model for the safety analysis

Table 1: Maximum creep rate (%) for each bundle in the channel group

Channel Group	Maximum Creep Rate [%] for each Bundle in the Channel Group					
	1	2	3	4	5	6
1	0.58	1.09	1.60	2.10	2.53	3.16
2	0.58	1.09	1.60	2.07	2.54	3.15
3	0.56	1.05	1.58	2.11	2.60	3.23
4	0.61	1.14	1.68	2.22	2.74	3.38
5	0.47	0.87	1.30	1.78	2.30	2.85
6	0.50	0.93	1.34	1.84	2.44	3.03
7	0.51	0.95	1.40	1.91	2.53	3.15
Channel Group	Creep Rate [%] for each Bundle in the Channel Group					
	7	8	9	10	11	12
1	3.71	4.04	4.37	4.38	3.71	2.28
2	3.71	4.11	4.30	4.36	3.71	2.30
3	3.80	4.23	4.46	4.39	3.76	2.26
4	3.99	4.38	4.71	4.64	3.94	2.42
5	3.34	3.69	3.80	3.55	2.89	1.82
6	3.59	4.01	4.06	3.80	3.10	1.93
7	3.73	4.13	4.15	3.90	3.23	2.06

2.2 Aged Core Modeling

The bundles in the aged core are assumed to have the maximum creep rate. The fuel tables for each crept bundles are needed for the aged core model.

1) Lattice Model

The lattice model provides the cross section of unit lattice for the 3D core model using RFSP code. The lattice model is established using the WIMS-AECL 3.1, a two-dimensional multi-group neutron transport code and ENDF/B-VII.0 library [1, 2]. The two types of fuel tables including the cross section of unit lattice are produced for each fuel with the different creep rate.

One is modeled under the nominal condition. The temperature of fuel, coolant and moderator in nominal condition is 687, 288 and 69 ^{o}C, respectively. The density of coolant and moderator at nominal condition is 0.8080042 g/cm^3 and 1.0851822 g/cm^3, respectively. Another is including the various conditions of temperature and density perturbation. Both cases are calculated in 50 burnup steps.

2) Core Model

While the equilibrium core has the same fuel type for all bundles, the aged core has the various fuel types with each creep rate. The aged core model has the 84 fuel types and is modified the bundle geometry and fuel tables in the equilibrium core model using RFSP code [3,4].

2.3 PT Creep Effect on the Core Property

In the WIMS calculation the k_{inf} for each bundle according to the creep rate 1.14% and 4.71% is compared and is 0.04% and 0.16% lower than the reference fuel type. Figure 2 shows the k_{inf} for the 2nd and 9th bundle in 4th channel group.

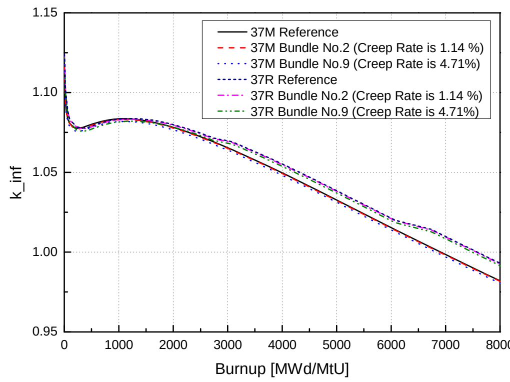

Fig. 2. k_infinity with burnup for each bundle with the different creep rate (WIMS calculation)

Table 2: Comparison of the core properties between the equilibrium and aged core for each fuel type, 37M and 37R

37M Fuel Core	Equilibrium Core	Aged Core
k_{eff}	1.000615	1.000150
Max. Channel Power	6587.74 (O-17)	6593.56 (O-17)
Max. Bundle Power	782.55 (P-17/6)	781.47 (P-06/6)
37R Fuel Core	Equilibrium Core	Aged Core
k_{eff}	1.000621	1.000161
Max. Channel Power	6597.27 (O-17)	6603.91 (O-17)
Max. Bundle Power	783.32 (P-17/6)	781.93 (P-06/6)

The maximum channel power in the aged core with the various creep bundles is about 0.1% bigger than the equilibrium core for both fuel types. The maximum bundle power for 37M and 37R core is 0.14% and 0.17% lower. The comparison of the maximum channel and bundle power is shown in the table 2. The position of bundle with the maximum power is changed to the symmetric position.

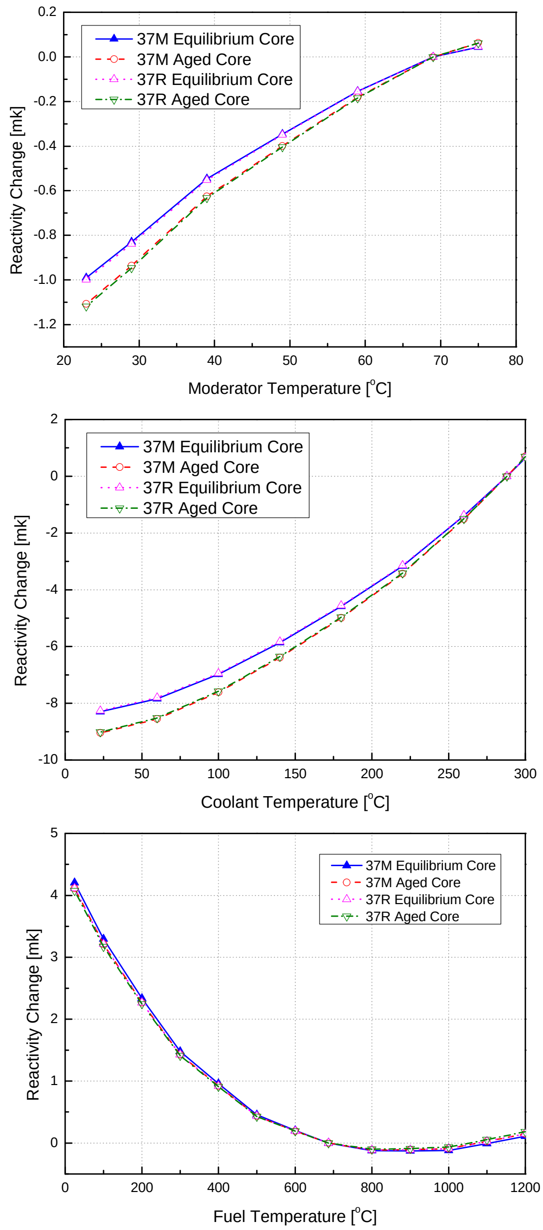

Fig. 3. Reactivity change according to the temperature of moderator, coolant and fuel for the equilibrium and aged core

The reactivity change according to the temperature of moderator, coolant and fuel is shown in the figure 3. The reactivity change of the moderator and coolant for the aged core is more negative in the lower temperature region. There is little effect on the reactivity change of fuel temperature. There is little difference between the 37M and 37R core. The design change of 37M fuel is not effect on the physics characteristics.

3. Conclusions

The creep effect of pressure tube in CANDU reactor is evaluated in terms of reactor physics. The evaluation is performed in conditions of equilibrium and aged core for each fuel types, 37M and 37R fuel. The bundles in the aged core are assumed to have the maximum creep rate which is calculated using the RC-1980 program and the measured creep rate of some channels. The results show that there are no big differences in the lattice and core properties between 37M and 37R fuel core. For the change of the coolant and moderator temperature, the reactivity change in aged core is more negative. But there is no effect for the reactivity change of fuel temperature.

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