Generation of Incremental Cross Sections for Modified 37-element Fuel of CANDU6

Hwan-Soo LEE [a*], Young-Ae KIM [a]
[a] *KHNP Central Research Institute, 70 1312-gil Yuseong-daero Yuseong-gu, Daejeon, Korea*
[*] *Corresponding author: leehwansoo@khnp.co.kr*

1. Introduction

In order to make margin of ROP (Regional Overpower Protection) trip setpoint, new type of fuel, modified 37-element (37M) bundle, has developed for CANDU6 reactor. 37M fuel is modified as reduction of the central element diameter size in comparison with one of standard 37-element (37R) bundle. More central coolant of 37M fuel bundle opens sub-channels up more flow in the middle of the bundle. It makes greater margin to critical heat flux (CHF) in the core. And there are small effects on bundle power and coolant void reactivity.

In this study, incremental cross sections of reactivity control devices for 37M fuel bundle are calculated with the new versions of CANDU reactor physics codes and ENDF/B-VII based library [1].

2. Methods and Results

2.1 Code and Methodology

The incremental cross sections are calculated using the two-dimensional lattice code WIMS3.1[2], the three-dimensional lattice code DRAGON3.06[3] and the T16MAC 1.0 program. T16MAC functions as an interface between WIMS and DRAGON. Because of the data transfer between these two codes, this procedure is called the "side-step" method [4].

The incremental cross sections are calculated for the stainless-steel adjuster rods, the liquid zone control units, the shutoff rods, the mechanical control absorbers and the various structural materials.

2.2 37M Fuel Bundle Model and Supercell Model

37M fuel bundle cell contains a 37-element natural-uranium bundle and pressurized heavy-water coolant in a pressure tube enclosed within a calandria tube

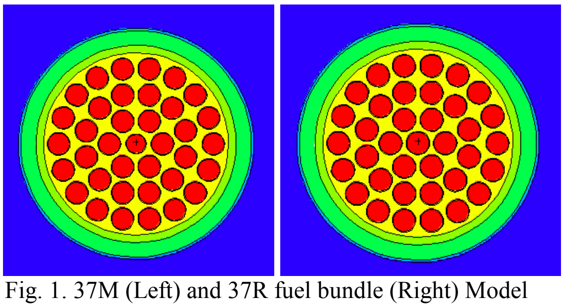

Fig. 1. 37M (Left) and 37R fuel bundle (Right) Model

As mentioned before, center fuel element diameter of 37M fuel bundle is different with other fuel elements, the center pin diameter is 10.66mm and other elements diameter is 11.5 mm. UO_2 weight per fuel bundle is set to 21.615 kg

A 28.575 cm square region of unpressurized heavy water (moderator) at low temperature surrounds this calandria tube. Figure 1 shows 2D lattice models of 37M and 37R fuel bundle by WIMS code.

In the supercell calculation, the reactivity device is located between two fuel bundles in a 2 lattice pitch x 1 lattice pitch x 1 bundle length model (57.15 cm x 28.575 cm x 49.53 cm). Each reactivity devices are modeled and 3D lattice calculations are performed with WIMS/T16MAC/DRAGON codes.

2.3 Adjuster and Liquid Zone Control Model

There are 21 adjuster rods used and their main functions are to establish a flattened power shape and to override the negative xenon reactivity following reactor shutdown or power decrease. All adjuster rods are made of concentric stainless-steel rods and tubes; no approximations were made in the geometric modeling of the adjuster rods with DRAGON.

There are fourteen liquid zone control compartments that play an important role in the control of the 3-D core power distribution. The zone-control system is designed to compensate for the fact that fuelling is not continuous or exactly uniform from day to day. It is also designed to provide spatial control of the power distribution. LZC geometry is more complex and equivalent radii were computed and applied annularization process as follows,

$$r_{eqv} = \sqrt{n_{sc} R^2_{sc} + n_{fe} R^2_{fe}}$$

where, n_{sc} is the number of scavenger tubes, R_{sc} radius of a scavenger tube, and, similarly n_{fe} and R_{fe} refer to the feeder tubes.

2.4 SOR/MCA Model

There are 4 mechanical control absorber rods and 28 shutoff rods, normally residing out of the core. The shutoff rods and mechanical control absorbers are physically the same and are composed of a cadmium tube sandwiched between two stainless steel tubes. These absorber rods were represented with an inner region of heavy-water moderator surrounded by a stainless-steel region, a cadmium region, another stainless-steel region, and another heavy-water moderator region, all surrounded by a Zircaloy-2 guide tube.

2.5 Structure Model

The incremental cross sections for the guide tube for the adjusters and the shutoff rods/mechanical control absorbers were calculated. The incremental cross sections were also separately calculated for liquid zone control assembly.

And incremental cross sections for various structural materials are also calculated such as adjuster supporting bars and cables, brackets and locators, tensioning springs, coupling nuts, moderator inlet nozzle deflectors, etc.

2.6 Results

37M fuel bundle incremental cross sections for the adjuster rods, the empty zone controllers units, full zone controllers units, the structural materials and the shutoff /mechanical control absorbers are calculated and the adjuster and liquid zone controller cases for equilibrium core state are shown in Table 1 and 2.

Table 1. Incremental Cross sections for Adjuster rod

ICX	A-Inner	A-Outer	B	C-Inner	C-Outer	D
$\Delta\Sigma_{tr1}$	5.71E-4	4.93E-4	9.35E-4	8.19E-4	3.14E-4	4.70E-4
$\Delta\Sigma_{tr2}$	1.15E-4	1.01E-4	1.91E-4	1.65E-4	6.10E-5	9.50E-5
$\Delta\Sigma_{A1}$	3.09E-5	2.67E-5	4.94E-5	4.37E-5	1.74E-5	2.56E-5
$\Delta\Sigma_{A2}$	6.00E-4	5.18E-4	8.90E-4	8.12E-4	3.58E-4	5.02E-4
$\Delta\Sigma_{F1}$	-5.05E-6	-4.37E-6	-7.55E-6	-6.86E-6	-3.00E-6	-4.23E-6
$\Delta\Sigma_{F2}$	9.18E-5	7.98E-5	1.38E-4	1.25E-4	5.42E-5	7.70E-5
$\Delta\Sigma_{S12}$	5.56E-5	4.81E-5	7.48E-5	7.09E-5	3.55E-5	4.73E-5
$\Delta\Sigma_{S21}$	4.95E-6	4.27E-6	7.50E-6	6.79E-6	2.91E-6	4.13E-6
H1	-2.47E-4	-2.14E-4	-3.69E-4	-3.35E-4	-1.47E-4	-2.07E-4
H2	4.63E-0	4.02E-3	6.96E-3	6.30E-3	2.73E-3	3.88E-3
F	3.41E-3	2.99E-3	5.05E-3	4.57E-3	2.03E-3	2.88E-3

Table 2. Incremental Cross sections for Liquid Zone Controller

ICX	Empty Zone			Full – Empty Zone		
	LZC 32	LZC 21	LZC 10	LZC 32	LZC 21	LZC 10
$\Delta\Sigma_{tr1}$	-4.9.E-3	-5.7.E-3	-6.6.E-3	4.8.E-3	5.8.E-3	6.8.E-3
$\Delta\Sigma_{tr2}$	-4.0.E-3	-8.5.E-3	-1.3.E-2	5.4.E-2	6.1.E-2	6.8.E-2
$\Delta\Sigma_{A1}$	4.3.E-6	-7.7.E-6	-2.1.E-5	8.1.E-5	9.5.E-5	1.1.E-4
$\Delta\Sigma_{A2}$	2.4.E-4	1.7.E-4	9.1.E-5	9.6.E-4	1.1.E-3	1.2.E-3
$\Delta\Sigma_{F1}$	-7.9.E-6	-1.8.E-5	-2.9.E-5	6.2.E-5	7.4.E-5	8.6.E-5
$\Delta\Sigma_{F2}$	4.2.E-5	5.0.E-5	5.9.E-5	2.8.E-5	2.5.E-05	2.1.E-5
$\Delta\Sigma_{S12}$	-1.0.E-4	-3.7.E-4	-6.6.E-4	1.8.E-3	2.1.E-3	2.4.E-3
$\Delta\Sigma_{S21}$	-8.4.E-7	-2.5.E-7	3.9.E-7	-1.8.E-6	-2.4.E-6	-3.0.E-6
H1	-3.9.E-4	-8.9.E-4	-1.4.E-3	3.0.E-3	3.6.E-3	4.2.E-3
H2	2.1.E-3	2.5.E-3	3.0.E-3	1.4.E-3	1.2.E-3	1.0.E-3
F	1.5.E-3	2.0.E-3	2.6.E-3	-3.3.E-4	-6.6.E-4	-1.0.E-3

3. Control Device Reactivity

In order to verify and compare with incremental cross section of 37R fuel bundle, liquid zone control reactivity corresponding to water level is calculated and shown in Table 3. Reactivity of control devices is calculated by RFSP3.53 [5]. There are a little change (< 0.2mk) between 37R and 37M fuel bundle. However, as shown in Table 4, shutoff rods worth is resulted as little bigger difference about 2mk between 37R and 37M fuel bundle.

Table 3. Zone Control Water Level Versus Reactivity Worth for 37R and 37M fuel bundle

Average Zone Controller level (%)	37R fuel bundle Reactivity Worth (mk)	37M fuel bundle Reactivity Worth (mk)	Difference of Reactivity Worth (mk)
0	0.000	0.000	0.000
25	1.777	1.813	0.036
50	3.519	3.600	0.081
75	5.048	5.190	0.142
100	6.229	6.424	0.195

Table 4. Static Reactivity Worth of Shutoff Rods at Equilibrium Fueling Condition

Case	37R fuel bundle Reactivity Worth (mk	37M fuel bundle Reactivity Worth (mk)	Difference of Reactivity Worth (mk)
28 Shutoff rods inserted	-85.05	-83.91	1.14
26 Shutoff rods inserted	-51.85	-49.77	2.08

4. Conclusions

The incremental cross sections for reactivity devices of new 37M fuel bundle, adjuster rods, the liquid zone controllers, the shutoff rods, the mechanical control absorbers and various structural materials have been generated and these values will be used for full-core reactor simulations of modified 37-element fuel bundle by using RFSP.

REFERENCES

[1] D. Altiparmakov, "E70LIB1: 89-Group WIMS-AECL Library Based on ENDF/B-VII", COG Report, 153-119190-COG-014 / ISTO-08-5073 / FFC-RRP-949, 2008 November.

[2] D. Altiparmakov, "WIMS-AECL 3.1 Theory Manual", AECL Report 153-119190-STM-001, Revision 0, 2006 December

[3] G. Marleau, A. Hébert, and R. Roy, "A User Guide for DRAGON 3.06," Report IGE-174R7, École Polytechnique de Montréal (2009).

[4] W. Shen, C. Ngo-Trong and R.S. Davis, "Validation of DRAGON Side-Step Method for Bruce-A Restart Phase-B Physics Tests" in Proceedings of 25th Annual CNS Conference, 2004 June 6-9, Toronto.

[5] P. Schwanke, "Software Design & Development and User Application Documentation for RFSP 3.5.3", COG Report, SQAD-11-5023 / NL-117360-COG-001, 2013 January