Assessment of Cobalt Adjuster Effect on CANDU reactors

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1. Introduction

A CANDU reactor has 21 stainless steel adjuster rods of four types in three rows of seven. The adjuster rods are used to provide positive reactivity by withdrawing them from the core. They are used primarily to compensate transient increases in xenon concentration, or to compensate for reactivity decrease due to fuel burnup during periods when fuelling machines are not available. Also, they play a role of the spatial control of power. The design basis for reactivity worth of the system is to balance the reactivity decrease due to the increase in xenon during 30 minutes following a shut-down from full power.

The stainless steel adjuster rods have been replaced with cobalt adjuster assemblies in a CANDU reactor, such as Gentilly‐2 and Embalse. The assemblies have to be neutronically equivalent to stainless steel adjuster rods and have a minimum effect on the safety and operating of reactors. The neutronic equivalence means that an identical reactivity worth and the effect on the power and flux distribution of the core are same for both stainless steel and a cobalt adjusters.

In this study, we calculate the incremental cross section of cobalt adjuster rods with irradiation and evaluate the reactivity worth of cobalt adjuster rods using RFSP code.

2. Methods

A. Adjuster: The cobalt bundles contain one to four cobalt pencils arranged on a 5.08cm pitch circle as in Gentilly‐2 model. When one cobalt pencil is used, a solid zirconium dummy pencil is placed symmetrically opposite for structure support. A cobalt pencil is composed of eight cobalt slugs, each of 0.6223cm in diameter and 2.527cm in length and so the cobalt bundle is of length of 21.04cm, encapsulated with zirconium. Two structural supports are used to bind cobalt bundles.

B. Dragon model: The supercell geometries of DRAGON were used to calculate the incremental cross sections of cobalt bundles. The geometry is the model of two fuel channels with reactivity device located in a perpendicular position between the two fuel channels. The dimensions of the supercell are two lattice pitches in width, one lattice pitch in height and one bundle length in the axial direction as in a Figure 1. The reflective boundary conditions were used along the X, Y and Z axes. The reference configuration consisted of a guide tube located between two fuel channels and the guide tube is filled with heavy water. The perturbed configuration is consisted of a cobalt bundle between two fuel channels. The incremental cross sections were calculated at the mid‐burnup condition using WIMS‐AECL with library ENDF/B‐VI. Also, ORIGEN‐S code was used for the properties of irradiated cobalt adjuster

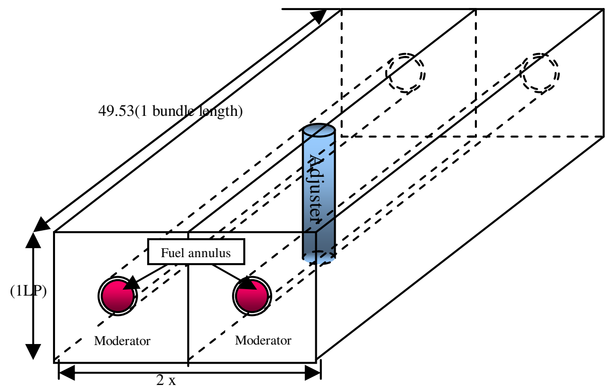

Figure 1 Dragon model

C. RFSP Model: The CANDU reactor are supplied with 21 stainless steel adjuster rods of four type of A, B, C and D. Adjusters A and C is divided into two types of segment: A‐outer, A‐inner, C‐outer, C‐inner. They are replaced into 16 cobalt bundles for A, B, C types and 6 bundles for D type. In order to model the cobalt adjuster in RFSP, the mesh was changed from 44x36x24 into 44x54x24. The pencil number and location of bundles were determined to match the reactivity worth of stainless steel adjuster, respectively.

3. Results

The design target for the worth of the stainless steel adjusters is ‐15 mk and the reactivity worth reaches to about ‐15.0mk in the realistic RFSP simulation of equilibrium core when we consider the irradiation of adjuster.

First, the composition of cobalt adjuster is changed with the irradiation and the results are shown in the Table 1 and the mass of Co59 and Co60 is changed with the irradiation of adjuster as in Figure 2. With this composition, the two-group incremental cross section was calculated by WIMS-AECL/DRSGON/RFSP using side-step method for each 0.5, 1, 1.5, 2 year and for one to four cobalt bundles. Table 2 shows the incremental cross section for fresh cobalt adjuster rods and Figure 3 shows the 2 group cross-section for one to four pins and the irradiated periods. The total reactivity worth was calculated using these incremental cross-sections and the value is about 16.7mk for Time-averaged model of RFSP in case of fresh adjuster.

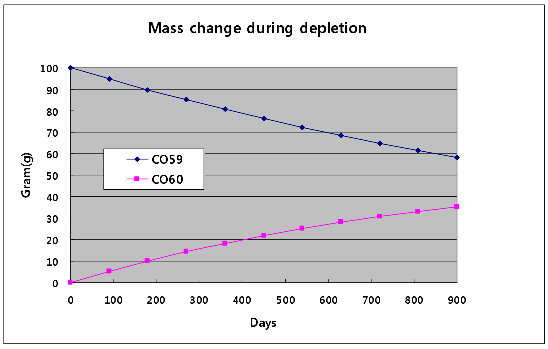

Figure 2 Total mass changes of Co59 and Co60 with depletion using ORIGEN‐S

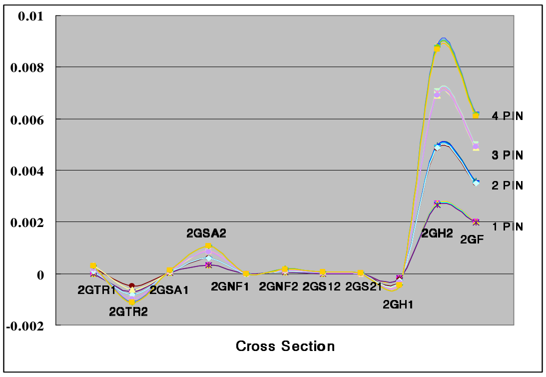

Figure 3 Incremental cross-sections of cobalt adjuster rods

Table 1 Isotope composition changes with depletion using ORIGEN‐S

	0.5year	1 year	1.5 year	2 year
H1	8.374E‐06	1.594E‐05	2.282E‐05	2.913E‐05
Fe56	2.573E‐05	4.866E‐05	6.906E‐05	8.720E‐05
Fe57	4.413E‐07	2.109E‐06	5.850E‐06	1.234E‐05
Fe58	9.874E‐06	2.776E‐05	6.053E‐05	1.149E‐04
Co58	3.080E‐06	2.765E‐06	2.482E‐06	2.228E‐06
Co60	1.002E+01	1.832E+01	2.513E+01	3.064E+01
Co60m	3.101E‐04	2.784E‐04	2.499E‐04	2.244E‐04
Co61	3.669E‐05	6.706E‐05	9.197E‐05	1.122E‐04
Ni60	3.471E‐01	1.280E+00	2.692E+00	4.488E+00
Ni61	3.517E‐02	1.356E‐01	2.943E‐01	5.049E‐01
Ni62	8.213E‐05	6.324E‐04	2.057E‐03	4.700E‐03
Ni64	9.521E‐09	2.934E‐07	2.149E‐06	8.738E‐06

Table 2 Incremental cross section at fresh adjuster

	1 PIN	2 PIN	3 PIN	4 PIN
2GTR1	-1.901E-05	2.244E-04	1.975E-04	2.995E-04
2GTR2	-7.228E-04	-4.894E-04	-9.863E-04	-1.106E-03
2GSA1	3.567E-05	6.786E-05	1.009E-04	1.321E-04
2GSA2	3.302E-04	5.992E-04	8.623E-04	1.081E-03
2GNF1	-3.958E-06	-5.087E-06	-7.881E-06	-9.501E-06
2GNF2	5.422E-05	9.640E-05	1.406E-04	1.763E-04
2GS12	-4.050E-07	3.827E-05	3.664E-05	4.542E-05
2GS21	2.153E-06	3.614E-06	5.231E-06	6.509E-06
2GH1	-1.865E-04	-2.370E-04	-3.684E-04	-4.436E-04
2GH2	2.730E-03	4.856E-03	7.084E-03	8.882E-03
2GF	2.007E-03	3.480E-03	5.003E-03	6.216E-03

4. Conclusion

In this paper, the incremental cross section of cobalt adjuster rods with irradiation and the reactivity worth calculated and compared with stainless steel adjuster rods. The result shows the equivalence between cobalt and stainless steel adjuster rods in case of fresh condition. In the future, the comparison will be made for the irradiated cobalt adjuster rods.

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