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Feasibility Study for Cobalt Bundle Loading to CANDU Reactor Core

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1. Introduction

The cobalt-60 sources are widely used to sterilize medical products including; surgical kits, gloves, gowns, drapes, and cotton swabs. Other applications include sanitization of cosmetics, microbial reduction of pharmaceutical raw materials, and food irradiation. Cobalt-60 tele-therapy machine is used for cancer treatment. Low radioactivity sources are used in level gauges and brachytherapy. All of cobalt-60 sources are imported to Korea. CANDU units are generally used to produce cobalt-60 at Bruce and Point Lepreau in Canada and Embalse in Argentina. China has started production of cobalt-60 using its CANDU 6 Qinshan Phase III nuclear power plant in 2009. For cobalt-60 production, the reactor's full complement of stainless steel adjusters is replaced with neutronically equivalent cobalt-59 adjusters, which are essentially invisible to reactor operation. With its very high neutron flux and optimized fuel burn-up, the CANDU has a very high cobalt-60 production rate in a relatively short time. This makes CANDU an excellent vehicle for bulk cobalt-60 production [1]. Several studies have been performed to produce cobalt-60 using adjuster rod at Wolsong nuclear power plant. This study proposed new concept for producing cobalt-60 and performed the feasibility study.

2. Concepts and Results

In this section new concept used to produce the cobalt-60 source are introduced and investigated the feasibility to load cobalt-59 and productivity of cobalt-60 without any limitation such as design change and safety system.

2.1 Cobalt bundle concept

In CANDU reactor most of cobalt-60 sources have been produced using cobalt-59 adjuster rod in the core. Stringing a number of cobalt bundles onto a tie rod makes up the cobalt adjuster element of the CANDU reactor. The bundles consist of cobalt pencils arranged circumferentially around a central rod, and held between two end plates; these are counter bored to receive the cobalt pencils. The rod and the plates are made of Zircalloy. Twenty-one cobalt adjuster elements are placed in the reactor [2]. This concept has an advantage to load the cobalt-59 adjuster and remove the cobalt-60 adjusters without any impact to the core power distribution. But this work to replace high activated cobalt-60 adjusters to new cobalt-59 adjusters is very high risk to worker, and cobalt-60 production is only limited during the outage period.

Therefore the cobalt-penciled bundle concept was proposed in Fig. 1. The size of cobalt bundle such as bundle length, fuel rod radius, and other appendages is exactly same with the conventional uranium fuel bundle. Only uranium fuel pellets will be replaced with cobalt-59 pencils, and these bundles can be loaded and removed using fueling machine.

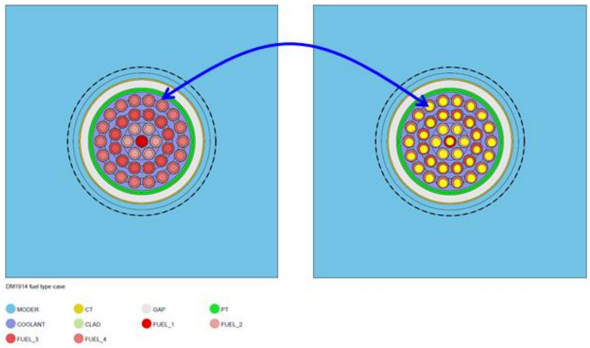


Fig. 1. New concept of cobalt bundle

2.2 Cobalt Bundle Loading Strategy

The most important key point to load the cobalt bundles in the core is how core power distribution can be maintained as designed without design change. To evaluate the impact to core power distribution by loading the cobalt bundle, several possible fuel channels were candidate with limitation to load. The requirements to choose the cobalt bundle loading channels are as follows.

- Outside of CPPF Region
- No Adjacent Channel at ROP detectors
- No Flow Measurement Channel
- Axially Symmetry Bundle Position

Based on the above requirements, 3 candidate loading channels (F04, E03, and B06 in the second quadrant) were chosen as shown in Fig. 2. Those channels should have symmetry channels by top-to-bottom and side-to-side. 2 or 4 cobalt bundles can be loaded in the channel due to high negative reactivity. To maintain axial power shape symmetrically, the bundle 02, 03, 10, and 11 positions by 8 bundle shift fueling scheme are chosen as shown in Fig. 3(a). If fueling scheme can be changed to 12 bundles, then bundle position 02 and 11 are available in Fig. 3(b).

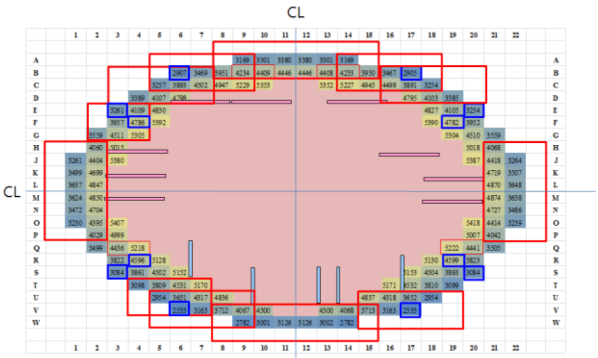


Fig. 2. Candidate for Cobalt Bundle Loading Channel

(a) 8 Bundles Shift Fueling Scheme

(b) 12 Bundles Fueling Scheme

Fig. 3. Cobalt Bundle Positions by Fueling Scheme

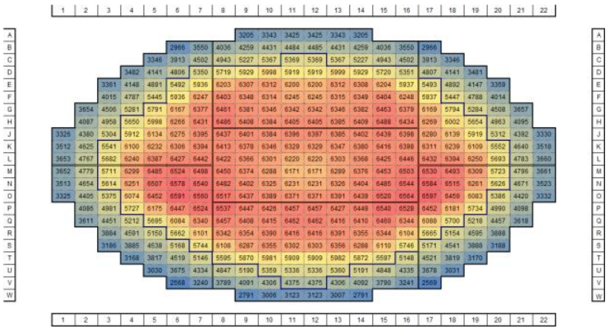
2.2 Results for Case Study

Based on 3 candidate loading channels (F04, E03, and B06 in the second quadrant), case studies were done to evaluate core power distribution and burnup impact. 6 evaluation cases were shown in Table I. The physics calculating tool was used by WIMS/RFSP code[3][4].

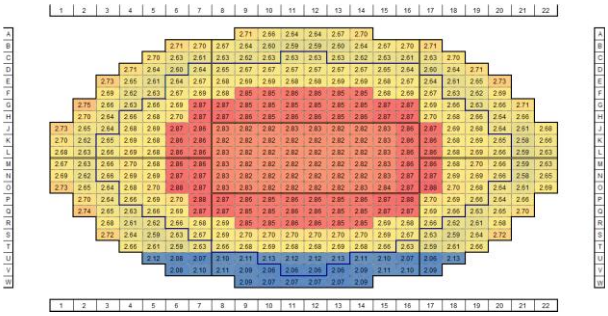
Table I: Case Study for Cobalt Bundle Loading

	Channel Position to load	Bundle Position to load
CASE 01	F04/F19/R04/R19	02,03,10,11
CASE 02	E03/E20/S03/S20	02,03,10,11
CASE 03	B06/B17/V06/V17	02,03,10,11
CASE 04	F04/F19/R04/R19	02,11
CASE 05	E03/E20/S03/S20	02,11
CASE 06	B06/B17/V06/V17	02,11

Fig. 4 shows channel power and burnup(Irradiation) distribution in generic CANDU6. Cobalt bundle loaded core has been simulated and compared for each case. Fig. 5 and 6 show channel power and burnup (Irradiation) distribution for CASE01 and CASE05, respectively. Table II shows the results for the production of cobalt-60 source for each case. As expected, more cobalt bundles and higher flux produce more cobalt-60 sources. However, inside of loading channel makes tort the channel power distribution and impact to the fuel burnup as CASE01. CASE05 are not much impact to channel power distribution and burnup. But the production of CASE05 is about one quarter than that of CASE01.

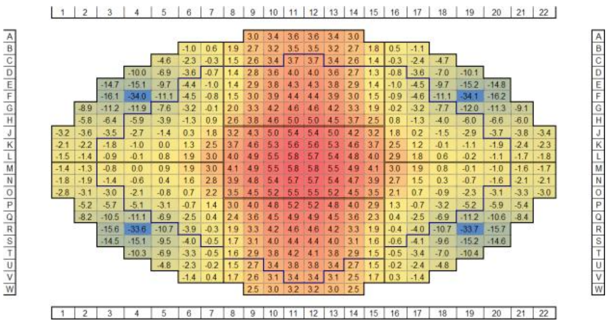


(a) Channel Power Distribution

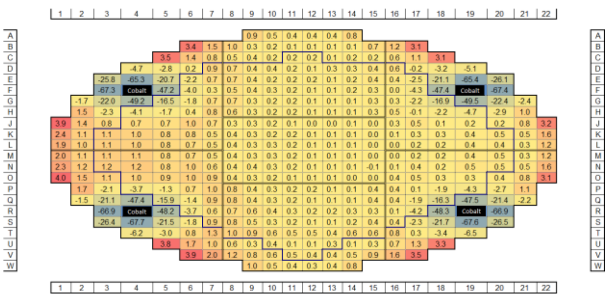


(b) Burnup Distribution

Fig. 4. Generic CANDU6 Power and Burnup Distribution

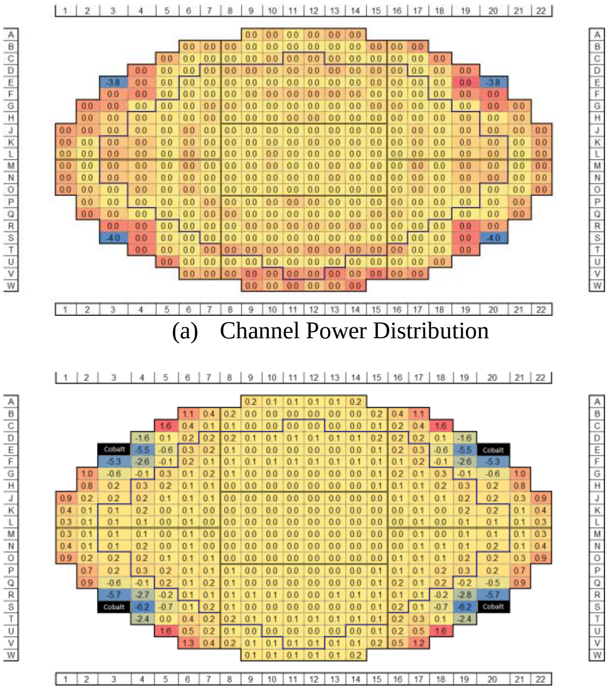


(a) Channel Power Distribution



(b) Burnup Distribution

Fig. 5. Channel Power and Burnup Distribution for CASE01
[Error(%) = (Ref.-CASE)/CASE*100(%)]



(a) Channel Power Distribution

(b) Burunp Distribution

Fig. 5. Channel Power and Burunp Distribution for CASE05
[Error(%) = (Ref.-CASE)/CASE*100(%)]

Table II: Case Study Results

	Avg. Thermal Flux	Activity (Ci/g)	Bundle Activity (Curies)	Estimated Total Activity (MCi)
CASE01	6.99E+13	60	299,354	4.8
CASE02	4.58E+13	39	196,483	3.1
CASE03	4.05E+13	35	173,861	2.8
CASE04	6.08E+13	52	260,479	2.1
CASE05	3.61E+13	31	155,317	1.2
CASE06	3.04E+13	26	130,797	1.0

3. Conclusions

Bundle typed cobalt loading concept is proposed and evaluated the feasibility to fuel management without physics and system design change. The requirement to load cobalt bundle to the core was considered and several channels are nominated.

The production of cobalt-60 source is very depend on the flux level and burnup directly. But the neutron absorption characteristic of cobalt bundle is too high, so optimizing design study is needed in the future.

REFERENCES

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