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Study on the Use of Slightly Enriched Uranium Fuel Cycle in an Existing CANDU 6 Reactor

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Abstract

To test the viability of CANFLEX-SEU bundles in an existing CANDU 6 reactor, core follow-up simulation has been carried out using the reactor fueling simulation program of the CANDU 6, RFSP computer code, and a lattice physics code, WIMS-AECL. During the core follow-up, bundle and channel powers and zone levels have been checked against their operating limits at each simulation. It is observed from the simulation results that an equilibrium core loaded with 0.9 w/o CANFLEX-SEU bundles could be refueled and maintained for 550 FPD without any significant violations in the channel and bundle power limits and the permissible operating range of the liquid zone controllers.

I. Introduction

Many studies have been done for the fuel cycle alternatives of the CANDU reactors using Slightly Enriched Uranium (SEU), Reprocessed Uranium (RU), Mixed Oxide Fuel (MOX) or DUPIC (Direct Use of PWR fuel In CANDU) fuel. A fuel cycle using CANFLEX (CANdu FLEXible) bundle [1][2] loading SEU has been also studied to provide additional flexibility for the design and operation of CANDU reactor. It is shown that the use of the CANFLEX bundles can provide the extended burnup capability and enhanced operating margins in the existing CANDU reactors.

The objective of this study is to examine the usability of CANFLEX-SEU bundles in an existing CANDU 6 reactor by carrying out core follow-up simulations using the RFSP computer code [3]-[5] together with the WIMS-AECL code [6][7].

In the simulation, a bi-directional, 2-bundle-shift fuelling scheme [8] is employed, and the bundle and channel powers and the zone controller levels are checked at each time step such that the increase in peak bundle powers and some power boosting at relatively high burnup regions as a result of refueling should not be severe. The bundle enrichment is chosen as 0.9 w/0 of U-235 and thus, this upgraded enrichment effect in the fuel management is forced to satisfy the operating limits used in an existing CANDU 6 reactor. The bundles refueled are chosen manually until 100 Full Power Day (FPD), and automatically and manually in some cases from the 100 FPD to equilibrium core loaded with CANFLEX-SEU bundles.

2. Methodology

2.1 Procedure

A time-dependent simulation for the transition period in which all the natural fuel bundles in the operating CANDU 6 reactor are replaced by CANFLEX-SEU bundles is carried out. The sequential procedure for the transition period is as follows:

(1) The first step is to generate the lattice parameters of natural uranium lattice, reflector lattice and CANFLEX-SEU lattice, and the incremental cross sections for control devices and structural materials.

(2) The second step is to construct the time-averaged cores loaded with the natural uranium bundles and CANFLEX-SEU bundles, respectively. The latter is carried out for the comparison with the results from core follow-up simulations

(3) The third step is to execute major core follow-up simulation at each time step until the exit burnup is converged.

(4) The last step is to analyze the viability of CANFLEX-SEU bundles in the existing CANDU 6 reactor.

2.2 Conditions and Criteria

During the transition period, the simulation is forced to keep the channel and bundle powers within acceptable criteria and to use the fuelling machines without any disturbance. The channels to be refueled with CANFLEX-SEU bundles are chosen as following manners:

(1) The maximum channel power should be below 7.1MW_{th} under full power operation.

(2) The maximum bundle power should be below 930kW_{th} under full power operation.

(3) The averaged zone controller level should be in the range of 0.2 to 0.7, and individual zone level should be in the range of 0.05 to 0.9.

The core follow-up simulations are done at the interval of 4 FPD up to 100 FPD, whereas, after 100 FPD, 2 FPD interval is used due to possible flux distortion which makes it difficult difficult to simulate within the operating ranges. The average fuelling rate of approximately 5 channels or 10 bundles per FPD is employed.

The reactor operations assume the most significant conditions as follows:

(1) Reactor power is 100 % full power.

(2) Spatial and bulk controls by only liquid zone controllers are carried out.

(3) All adjuster rods are kept on at the positions fully inserted during the transition.

3. Results

From the simulations, it is shown that an equilibrium core fully loaded with the CANFLEX-SEU bundles can be attained at 550 FPD with the condition satisfying the existing operating limits assigned for channel and bundle powers, and individual and average liquid zone levels.

Average liquid zone levels during the transition have been mostly kept between 0.2 and 0.7, and individual liquid zone levels between 0.05 and 0.9. However, average zone levels have sometimes reached the minimum limit. It means that the eight bundle refueling of CANFLEX-SEU during 1 FPD is not sufficient to compensate for the reactivity loss due to the burnup. Therefore, more than eight bundles during 1 FPD have been sometimes refueled to compensate for the reactivity loss. Fig. 1 shows the behaviors of average liquid zone level during the transition.

The maximum channel powers for all the simulations were below 7.1 MW_{th}. Especially, the maximum channel powers after 100 FPD were almost in the range of 7 to 7.1 MW_{th}. It says that the power distributions are seldom distorted due to a few CANFLEX-SEU bundles before 100 FPD. Fig. 2 shows maximum channel power distribution over the 550 FPD transition period. The maximum bundle powers calculated from the simulations did not violate 930 kW_{th} limit in all the simulations. In Fig. 3, it is observed that the bundle powers go to higher as the transition period is advanced

The results from the time averaged calculation fully loaded with the CANFLEX-SEU bundles and from the core following simulations are compared in Table 1. It should be mentioned that the average exit burnup did not reach its maximum value completely in the core follow-up simulations. Extended simulations for further FPD should be executed until an average exit burnup would be converged completely.

4. Conclusion

The results show that the CANFLEX-SEU bundle fuel cycle is acceptable in an existing CANDU 6 core without exceeding the operating limits. In the present work, 2 bundle shift scheme and 0.9 w/o CANFLEX-SEU have been used. To obtain more realistic and accurate results, simulations with the transition period should be extended until an average exit buruup is converged completely. It may also be required for safety verification to analyze fuel performance by power boost envelope with the stress corrosion cracking threshold and maximum linear powers which are related to the fuel failure.

References

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	Time-Average Results	Core-Follow Results
Exit Burnup (MWhr/kg)	324.432	307.296
Feed Rate (Channels/FPD)	4.275	4.549
Max. Channel Power (MWth)	6.812	7.096
Max. Bundle Power (kWth)	769	879

Table 1. Comparison of Time Average Values and Core Follow Values at 550FPD

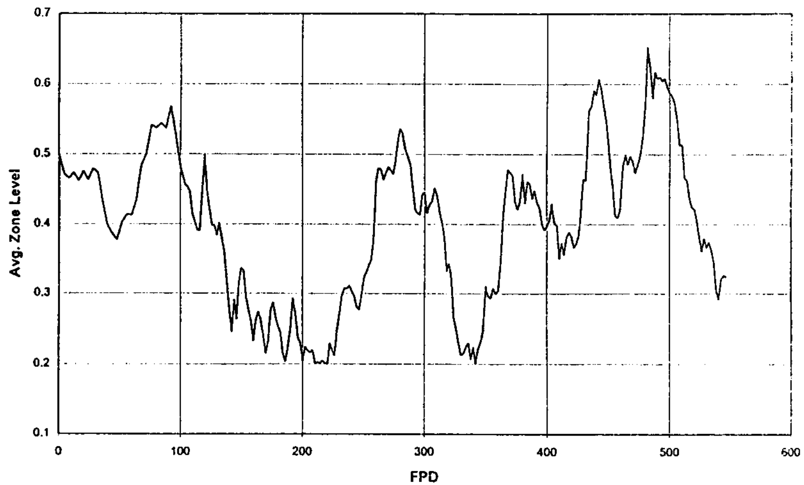

Figure 1. Average Zone Levels over the 550 Core Follow

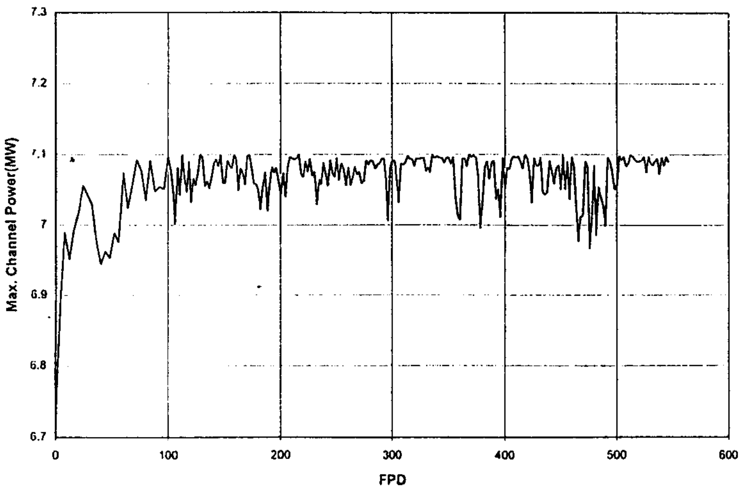

Figure 2. Maximum Channel Powers over the 550 Core Follow

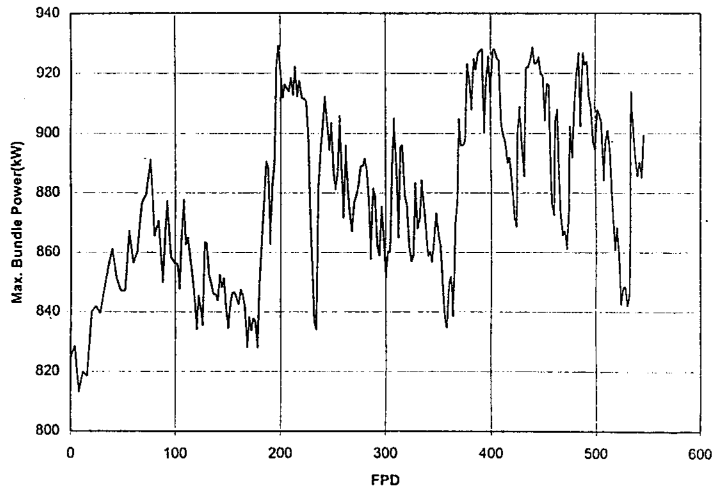

Figure 3. Maximum Bundle Powers over the 550 Core Follow