Fuel Management Study for a CANDU reactor Using New Physics Codes Suite

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1. Introduction

A CANDU reactor is a heavy-water-moderated, natural uranium fuelled reactor with a pressure tube. The reactor contains a horizontal cylindrical vessel (calandria) and each pressure tube is isolated from the heavy-water moderator in a calandria. This allows the moderator system to be operated of a high-pressure and of a high-temperature coolant in pressure tube. The primary reactivity control in a CANDU reactor is the on-power refueling on a daily basis and an additional reactivity control is provided through an individual reactivity device movement, which includes 21 adjusters, 6 liquid zone controllers, 4 mechanical control absorbers and 2 shutdown systems.

The refueling in CANDU is carried out on power and this makes the in-core fuel management different from that in a reactor refueled during shutdowns. The objective of a fuel management is to determine a fuel loading and fuel replacement procedure which will result in a minimum total unit energy cost in a safe and reliable operation. In this article, the in-core fuel management for the CANDU reactor was studied by using the new physics code suite of WIMS-IST/DRAGON-IST/RFSP-IST with the model of Wolsong-1 NPP.

2. Initial Fuel Loading and Refueling

The operation life in a CANDU reactor can be separated into 3 three periods. The first period is from the start until the onset of a refueling, about 117 FPD (Full Power Days). The reactor is initially loaded with all fresh fuel and there is a considerably excess reactivity, which is compensated for by adding boron poison to the moderator. When the excess reactivity becomes to a small value, the fueling is started to maintain the reactor critical. This is a pre-equilibrium period and the reactor approaches to the equilibrium state gradually. The equilibrium is reached after about 400~500 FPD and it is characterized by a relatively unchanging core condition, in which the power and burnup distributions do not vary significantly with time.

At equilibrium, the power distribution is flattened by differential burnup and insertion or remove of reactivity device from the core. However, when starting with all fresh fuel in the initial core, the central region power is unacceptably high and so a power flattening is accomplished by the loading of two depleted fuel bundles in 80 channels in the central region of core. The depleted fuel means a fuel having a lower U^{235} content than natural fuel. (0.711 atom percent U^{235} for natural fuel and 0.51 atom percent U^{235} for depleted fuel) Figure 1 shows the excess reactivity variation with a burnup for the natural fuel and depleted fuel.

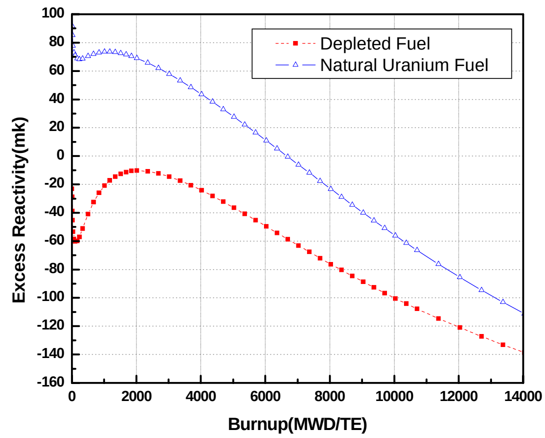

Figure 1 Excess reactivity versus burnup of natural and depleted fuel

When the inner region of the reactor has the highest burnup and the lowest power relative to equilibrium power distribution, the refueling begins and the rate of the refueling rapidly approaches its equilibrium value (about 1.9 bundles per FPD). After about 450FPD, an equilibrium burnup distribution is attained.

3. Fuel Management Calculation

The fuel management calculations for CANDU reactor were performed by RFSP-IST code, with the fuel and reflector cross-sections generated by WIMS-IST and the incremental cross-section generated by DRAGON-IST.

For fresh core, the incremental cross-section is calculated with macroscopic cross-section library of 2.0 ppm boron in moderator and the LZC level is fixed with 50%. The simulation of the fresh core is deterministic in the sense that the excess reactivity is controlled only by the insertion of boron. The boron concentration varies from 2.65 ppm at the fresh state to about 0 ppm at 117 FPD, at which a refueling begins and the incremental cross-section is replaced with that generated by using a macroscopic cross-section library of 0 ppm boron at 100 FPD.

For the pre-equilibrium core, the refueling begins. First, the swing-8 refueling scheme is used until the first 380 channels are visited and 8x380 bundles are discharged, and then a normal 8 fueling scheme is used.

When the core reaches to an equilibrium state, the bundle power and channel power do not vary significantly with time.

While the maximum bundle power is 798 kW in the time-averaged calculation, the highest maximum bundle power is 850 kW. (Figure 2)

While the maximum channel power is 6601 kW in the time-averaged calculation, the maximum channel power averaged over the all time is 6824 kW and the highest maximum channel power is 7063kW, less than 7070kW of the operating limit. (Figure 3)

From the Figure 4, the fueling machine visit rate is about 1.9 channels per FPD on average and 3.4 channels per FPD at the beginning.

4. Conclusion

The in-core fuel management for the CANDU reactor was studied by using the new physics code suite of WIMS-IST/DRAGON-IST/RFSP-IST with the model of Wolsong-1 NPP. With a fixed 50% LZC level, the number of channels refueled is 1.9 channels per FPD and the maximum bundle and channel powers are kept below 7.07 MW and 850 kW.

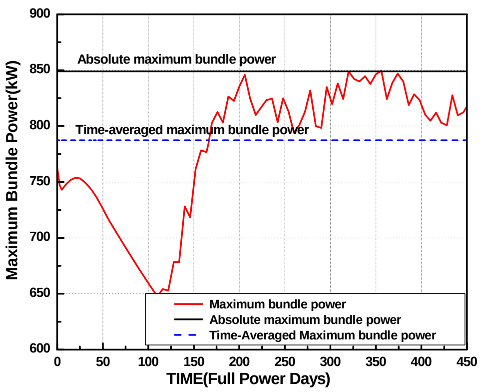

Figure 2 Maximum Bundle Power

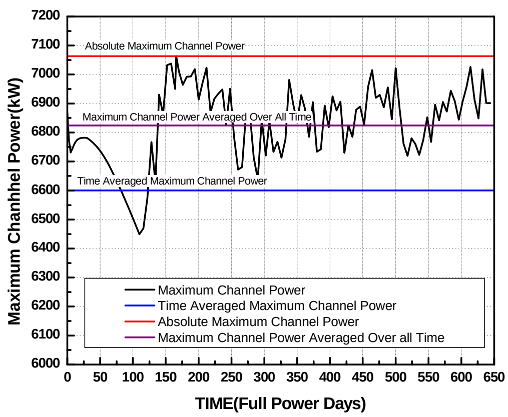

Figure 3 Maximum Channel Power

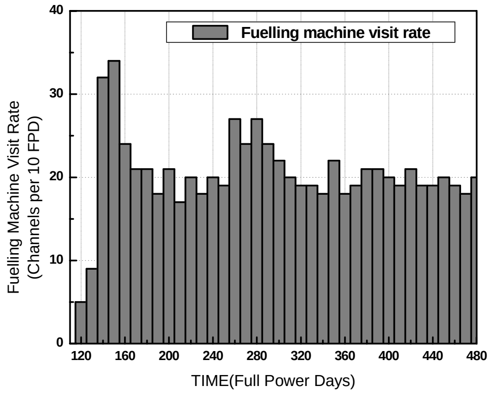

Figure 4 Fueling machine visit rate

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