Assessment of the Neutronic Characteristics of a CANDU Lattice

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1. Introduction

The purpose of this study is to investigate the neutronic behavior of CANDU lattices using the codes WIMS-IST/DRAGON-IST/RFSP-IST. In order to assess the neutronic properties of a CANDU lattice, a model was developed for a uniform lattice containing fresh natural uranium with 37-elements of a CANDU fuel for Wolsong unit 1 and then the physics parameters were calculated and compared. The comparison studies of the reactor physics parameters such as the moderator/coolant temperature, coolant density and moderator purity reactivity change were conducted with a change of the internal isotope composition due to the fuel burning-up and with perturbations of the temperature, density and purity.

2. Physics Codes Suites

The reactor physics simulation of a CANDU reactor contains three codes;

- WIMS-IST : 2D lattice code
- DRAGON-IST: 2D-3D lattice code(device code)
- RFSP-IST: 3D full core simulation

Since POWDERPUFS-V is a lattice code designed especially for CANDU reactors and validated within the range of experimental results on a fresh fuel, WIMS-IST was developed to conduct the lattice calculation for the irradiated CANDU fuel, as a replacement of POWDERPUFS-V. In the reactor simulation, WIMS-IST is used for the generation of a WIMS cross-section table for use in RFSP-IST and for the generation of a homogenized macroscopic cross-section for use in DRAGON-IST with nuclear data library ENDF/B-VI. As a device code, DRAGON-IST carries a 3D supercell calculation for an incremental cross-section using the macroscopic cross-section generated by a 2D lattice calculation. Then with the cross-section tables generated previously, the core simulation is performed by RFSP-IST. In order to investigate the temperature/density reactivity effects, the perturbation option in RFSP-IST is employed.

3. Results

Since the reactivity effects on a given perturbation depend on the composition of the fuel, the following three irradiation options are considered.

- Fresh clean fuel: this refers to fuel which is not irradiated and does not contain any fission products. A few ppm of boron is used to suppress the excess reactivity
- Fresh fuel: this refers to fuel which has been irradiated for brief periods such that the saturating fission products(SFP) have attained close to asymptotic concentration.
- Equilibrium Fuel : this refers the average of all fuel in a core which is under equilibrium fueling condition. The fuel properties are obtained from the Time-averaged calculation.

A. Moderator temperature reactivity effects: Figure 1 shows the reactivity change on changing the moderator temperature, for a fresh clean fuel, fresh fuel with 9 ppm boron and an equilibrium fuel. The reactivity coefficient (slope of the curve) is negative for the fresh fuel but is positive when the moderator is poisoned with boron. It is also positive for the equilibrium fuel where there is a significant amount of plutonium isotopes.

B. Coolant temperature reactivity effects: A change in the coolant temperature affects the coolant density (assumed saturated) and the neutron spectrum. As the coolant temperature increases, the coolant density drops, which makes a decrease in the resonance absorption in the fuel. The reactivity coefficient due to the density effects alone is positive but the coefficient due to the spectrum effects is negative for the fresh fuel and positive for the equilibrium fuel. For the fresh fuel, the coefficient changes its sign at around 180^{o}C and this is due to the density effect and spectrum effect acting in an opposite sense. (Figure 2)

C. Coolant density reactivity effects: In the event of a break in the coolant circuit, the coolant in the channel may partially void and thereby give rise to a reactivity transient. In order to analyze the reactivity increase due to a partial or complete voiding, we assume the uniform boiling inside all the channels and the boiling is represented by a reduction of the coolant density. Figure 3 shows the reactivity increase on the voiding for the coolants of a different density and for different fuel conditions. It can be seen that the void reactivity increase is the highest for an initial core containing 9 ppm of boron in the moderator.

D. Moderator purity reactivity effects: The nominal moderator purity is 99.833 atom percent with the remaining 0.167 atom percent H_2O. A decrease in the moderator purity implies an increase in the H_2O concentration. Due to the large absorption cross-section of H_2O, even a small increase in the H_2O concentration leads to a significantly loss in reactivity. Figure 4 shows the reactivity change according to the moderator temperature purity. Over the range of 98.0 to 100 atom percent, the purity coefficients of reactivity are 35.1 mk/atom percent and 32.4 mk/atom percent for the fresh and equilibrium fuel, respectively.

4. Conclusion

In order to investigate the neutronic behavior of a CANDU fuel, the reactor physics parameters such as moderator/coolant temperature, coolant density and moderator purity reactivity change were calculated and compared with a change of the internal isotope composition due to the fuel burning-up and with perturbations of the temperature, density and purity. When the results are compared with the POWDERPUFS-V point model calculation, the tendency is similar to POWDERPUFS-V although an absolute value of a reactivity change is more or less.

References

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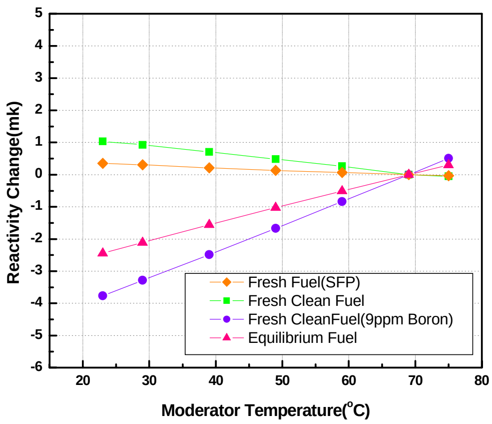

Figure 1 Reactivity change due to moderator temperature change

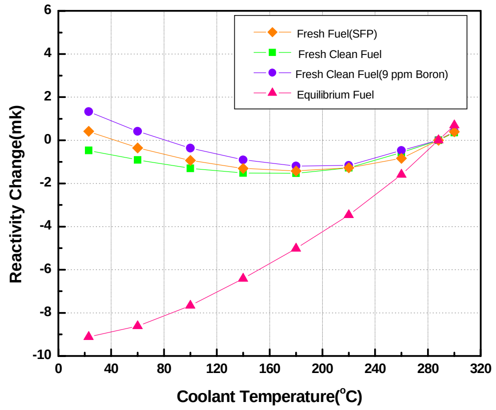

Figure 2 Reactivity change due to coolant temperature change

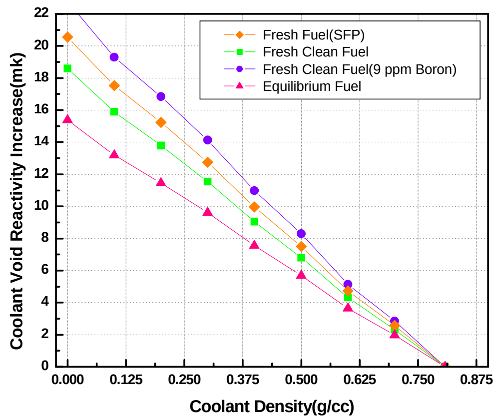

Figure 3 Reactivity increase due to coolant density change

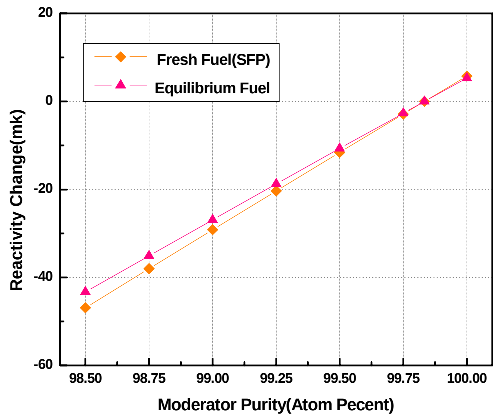

Figure 4 Reactivity change due to the moderator purity change