Assessment of Loss-of-Coolant Effect on Pressurized Heavy Water Reactors

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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. This causes the pressurized liquid coolant in the channel to void and therefore give rise to a reactivity transient in the event of a break or fault in the coolant circuit. In particular, all CANDU reactors are well known to have a positive void reactivity coefficient and thus this phenomenon may lead to a positive feedback, which can cause a large power pulse. We assess the loss-of-coolant effect by coolant void reactivity versus fuel burnup, four factor parameters for fresh fuel and equilibrium fuel, reactivity change due to the change of coolant density and reactivity change in the case of half- and full-core coolant.

2. Methods

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-AECL was developed to conduct the lattice calculation for the irradiated CANDU fuel, as a replacement of POWDERPUFS-V. In the lattice model, the buckling is used for the leakage calculation and calculated by WIMS-AECL. In the reactor core simulation, WIMS-AECL is used for the generation of a WIMS cross-section table for use in RFSP and then with the cross-section tables generated previously, the core simulation is performed by RFSP. In order to investigate the density reactivity effects, the perturbation option in RFSP is employed.

3. Results

A. Coolant void reactivity versus fuel burnup: As fuel burns up, plutonium isotopes build up and decrease the change on the thermal production per neutron absorbed upon coolant voiding until it become negative. Figure 1 shows the variation of coolant void reactivity with fuel burnup and as fuel burns up, the void reactivity increment decreases. At fresh fuel, the coolant void reactivity is about 18mk and at mid-burnup about 16mk.

B. Reactivity change due to a loss of coolant for fresh and equilibrium fuel: The coolant void reactivity change is given in terms of change in the four-factor parameters. In the case of fresh fuel, the four-factor parameters are changed positively and so give a positive change in void reactivity. For equilibrium fuel, the parameters are changed positively except thermal production per neutron absorbed η.

(a) Thermal production per neutron absorbed η: When coolant is removed from channel, the fuel has a softer spectrum and so this causes an increase in thermal production for fresh fuel but a decrease for equilibrium fuel which has a significant amount of plutonium.

(b) Fast fission probability ε: The fast neutrons are removed from their fission spectrum to lower energies by scattering with coolant. When this is removed, the fast fission probability is enhanced and the fast fission factor is increased.

(c) Resonance escapes probability p: The CANDU reactor is well moderated and the contribution to the slowing down power of the cell from the coolant is small. Thus the loss of coolant results in a small decrease in the cell slowing down power and hence in a resonance absorption in the fuel. This is overcompensated by the much larger decrease in the resonance integral and the result is a reduction in the resonance absorption and hence an increase in p.

(d) Thermal utilization f: Since the absorption is significant when compared to the total absorption of the cell, the removal of coolant will result in an increase in the thermal utilization.

Table 1 shows the reactivity change due to a complete loss of coolant at full power for fresh and equilibrium fuels (at 3690MWd/tU), which are calculated by WIMS-AECL(2-5d).

C. Void reactivity versus degree of voiding: 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 2 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. Core simulations of coolant void: In CANDU 6, the left and right halves of the core have separate coolant circuits, which lead to half core voiding. Table 2 shows the reactivity change in case of half-core voiding and full-core voiding for fresh core and equilibrium core. The reactivity increase is turned out to be 9.7mk for half-core coolant for equilibrium core.

4. Conclusion

We showed the loss-of-coolant effect by coolant void reactivity versus fuel burnup, four factor parameters for fresh fuel and equilibrium fuel, reactivity change due to the change of coolant density and reactivity change in the case of half- and full-core coolant.

References

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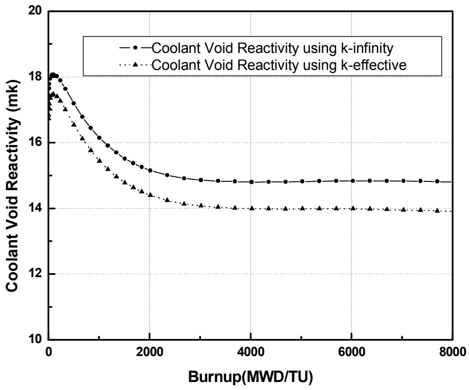

Figure 1 Coolant void reactivity change versus fuel burnup

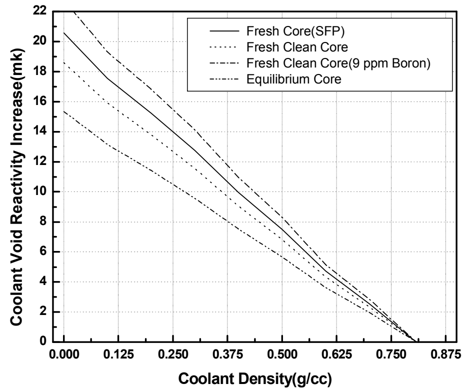

Figure 2 Reactivity increase due to coolant density change

Table 1 Change of four-factor parameters due to a total loss of coolant at full power

	Fresh Fuel	Equilibrium Fuel
$\Delta\rho$	16.56	14.01
$\Delta\eta/\langle\eta\rangle^{*}$	1.18	-3.34
$\Delta\varepsilon/\langle\varepsilon\rangle$	6.70	7.39
$\Delta p/\langle p\rangle$	5.89	6.68
$\Delta f/\langle f\rangle$	4.37	3.61

* < > denotes average value of reference and perturbed cases

Table 2 Reactivity change for half- and full-core voiding

	Half-voiding	Full-voiding
Fresh core	13.9 mk	20.2 mk
Equilibrium core	9.7 mk	15.4 mk