FUEL MANAGEMENT SIMULATION OF CANDU 3 AT EQUILIBRIUM CONDITION

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SUMMARY

This paper presents the results of the detailed fuel management study performed for the CANDU 3 reactor at equilibrium fuelling condition, that is when each channel is fuelled at a constant rate and the average power distribution remains constant. First, the characteristics of the time–average equilibrium core were calculated, using the fuel management code FMDP. The time–average power distribution is indicative of what would be seen "on average" in the core. Therefore, it serves as a reference distribution and should be used as a target during day–to–day reactor operation. In reality, there would be perturbations about the time–average burnup and power distributions, due to refuelling operations and control actions.

In order to estimate parameters such as instantaneous peak powers and refuelling ripples, a time–dependent fuelling simulation was performed for 100 full power days (FPD) of reactor operation (including channel refuelling) in steps of 5 FPD. The fuel management code RFSP was used to simulate the reactor core (232 fuel channels) and reflector including 12 adjuster rods and 4 pairs of mechanical zone control rods as well as device structural materials. Both bulk and spatial control actions were credited at the end of each simulation step. Xenon distribution was also included explicitly in the simulation model. The time–dependent calculation was started from an instantaneous "snapshot" power and burnup distributions which represent the core at an arbitrary point in time.

In CANDU 3, the flux and power distributions are flattened in both axial and radial directions in order to operate the reactor at full power without exceeding the limits in bundle and channel powers. Radial flattening is achieved by adjuster rods and by using different fuelling rates in various parts of the core. Axial flattening is achieved by adjuster rods as well as by the use of an appropriate fuel management scheme.

The CANDU 3 reactor is designed for single–ended fuelling and utilizes one fuelling machine, operating at the outlet end of the reactor. This permits a wide variety of refuelling schemes, in which fresh fuel bundles are added in any position in the channel, while some irradiated bundles are discharged and some are shuffled from one position to another in the channel. The fuelling scheme assumed in the present simulation is a combination of axial shuffling schemes in the central channels, and a once-through bi–directional scheme in the outer channels. The bi–directional fuelling is mimicked with a single fuelling machine by placing fresh bundles at alternate ends of alternate channels. The shuffling schemes tend to flatten the axial power distribution and therefore reduce the peak bundle power. Power flattening leads to an increased neutron leakage and therefore to burnup loss. The bi–directional scheme was used in outer channels (where the channel and bundle powers are relatively low) in order to reduce the burnup loss.

The channel selection for refuelling was based on general guidelines recommended to avoid clustering of highly reactive channels and to minimize power peaking and flux tilt.

By the end of the 100 FPD simulation period, a total of 1200 fuel bundles had been discharged from the core, corresponding to refuelling 300 channels. The average fuelling rate during this period was 12 bundles/FPD which is about equal to the value predicted by the time–average calculation.

In addition to the 100 FPD simulation, 21 FPD of reactor operation (between 61 FPD and 81 FPD) were re–simulated assuming a less "idealistic" fuel channel selection (in steps of 1 FPD), that is, assuming that the reactor operator deviated from the guidelines generally recommended for channel selection. The reason for the improper channel selection may be a bad judgement of the operator or some operating restrictions that forced him to make that selection. Moreover, a refuelling schedule similar to that followed at one of the CANDU 6 stations was assumed in which refuelling operations were performed only during three days over a week period, usually the first, second and fourth days of the week.

In the first week, (between 61 FPD and 67 FPD) the central core region was deliberately over–fuelled (about 40% more channels fuelled than the time–average fuelling rate). This is a real challenge to the spatial control system due to the lack of zone controllers in that region of the core. In the following two weeks, the operator tried to correct for the inappropriate channel selection by over-fuelling the outer region of the core and therefore bringing the power distribution closer to its nominal shape.

In the case of improper channel selection, the average fuelling rate over the three–week simulation period was 13.3 bundles/FPD. In the second week (between 68 and 74 FPD), the average rate of refuelling was 16.0 bundles/FPD. This was the period when the operator selected more channels in the outer core region for refuelling.

Tables 1 and 2 summarize the results of the simulation and show the maximum channel and bundle powers and channel power peaking factors (CPPF) encountered during the simulation period. The CPPF is a measure of the refuelling ripple, and is defined here as the largest value of the ratio of instantaneous channel power to time–average channel power, taken over channels having an instantaneous power of at least 90% of the peak channel power at that point in time.

Over the 100 FPD of normal fuelling simulation, the maximum channel and bundle powers were always less than 7.70 MW and 800 kW, whereas the maximum CPPF value was 1.06. These are below the respective target values. However, with the less "idealistic" fuelling simulation, the maximum channel and bundle powers exceeded 7.95 MW and 825 kW and the CPPF had values as high as 1.09. By the end of the three–week simulation, the maximum channel and bundle powers were brought down to 7.76 MW and 795 kW and CPPF was reduced to 1.061.

In summary, the present study has shown that if the recommended channel selection guidelines are followed, the reactor can be operated without exceeding the target bundle and channel power limits. If these guidelines are violated, the peak powers increase by 3–4% which means that power derating of this magnitude would be necessary. Corrective actions should be taken by the operator to bring the peak powers back to their normal levels. This will be at the expense of increased fuelling rates.

TABLE 1

MAXIMUM POWERS AND CHANNEL POWER PEAKING FACTOR

(Normal Channel Selection)

TIME (FPD)	MAXIMUM CHANNEL POWER, MW (LOCATION)	MAXIMUM BUNDLES POWER, kW (LOCATION)	CPPF, % (LOCATION)
0	7.62 (J08)	736 (H04–09)	–
5	7.48 (J10)	776 (J11–07)	3.2 (L08)
10	7.47 (H06)	774 (H06–07)	3.0 (N08)
15	7.55 (J07)	775 (J11–07)	3.6 (E07)
20	7.65 (J09)	788 (J09–07)	4.7 (J09)
25	7.67 (J09)	791 (J09–07)	5.5 (G08)
30	7.61 (J09)	787 (J09–07)	4.5 (K11)
35	7.60 (K08)	778 (H11–07)	5.0 (E08)
40	7.59 (J12)	784 (J12–07)	4.2 (E08)
45	7.53 (J12)	773 (J12–07)	4.5 (L09)
50	7.56 (H10)	769 (H08–07)	4.7 (L07)
55	7.53 (K06)	770 (K06–07)	3.9 (K06)
60	7.53 (K09)	770 (J11–07)	4.3 (M08)
65	7.54 (H09)	775 (J06–07)	4.8 (M08)
70	7.57 (J08)	779 (J06–07)	4.4 (F07)
75	7.62 (J10)	789 (H09–07)	5.2 (F09)
80	7.58 (G10)	789 (J06–07)	5.0 (G10)
85	7.72 (J09)	794 (J09–07)	5.6 (J09)
90	7.70 (J09)	795 (J09–07)	5.7 (M09)
95	7.66 (J09)	796 (H11–07)	5.2 (L10)
100	7.65 (H08)	801 (H11–07)	4.9 (F11)

TABLE 2

MAXIMUM POWERS AND CHANNEL POWER PEAKING FACTOR

(Less Idealistic Channel Selection)

TIME (FPD)	MAXIMUM CHANNEL POWER, MW (LOCATION)	MAXIMUM BUNDLES POWER, kW (LOCATION)	CPPF, % (LOCATION)
61	7.73 (J10)	788 (J11–07)	7.9 (L08)
62	7.82 (H09)	808 (H09–07)	7.6 (L08)
63	7.80 (H09)	804 (H09–07)	7.3 (L08)
64	7.97 (J08)	826 (J08–07)	9.0 (J08)
65	7.95 (J08)	822 (J08–07)	8.7 (J08)
66	7.93 (J08)	818 (J08–07)	8.5 (J08)
67	7.90 (J08)	813 (J08–07)	8.1 (J08)
68	7.83 (J08)	807 (J08–07)	7.2 (J08)
69	7.77 (J08)	803 (J08–07)	6.6 (L08)
70	7.70 (J08)	798 (J08–07)	6.1 (L08)
71	7.74 (J08)	806 (J08–07)	6.4 (L08)
72	7.72 (J08)	802 (J08–07)	6.1 (L08)
73	7.69 (J08)	797 (J08–07)	5.7 (L08)
74	7.68 (H06)	792 (H06–07)	5.4 (L08)
75	7.67 (H06)	799 (H06–07)	5.3 (L08)
76	7.83 (J09)	805 (J09–07)	7.1 (J09)
77	7.81 (J09)	802 (J09–07)	6.9 (J09)
78	7.82 (J09)	808 (H09–07)	7.3 (F09)
79	7.81 (J09)	804 (J09–07)	6.8 (J09)
80	7.79 (J09)	800 (J09–07)	6.5 (J09)
81	7.76 (J09)	795 (J09–07)	6.1 (J09)