FUEL MANAGEMENT STUDY OF REFUELLING OF ONE QUARTER AND ONE HALF OF THE CORE AT POINT LEPREAU

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ABSTRACT

In 1995 September after a prolonged outage, an incident occurred during the restart of the Point Lepreau reactor, that led to entry of foreign materials into the Heat-Transport System (HTS). To rehabilitate the HTS and to ensure that flow impairment or blockage did not exist, it was proposed that channels in certain coolant-passes could be defuelled and flushed. Such an operation would imply defuelling all 95 channels in a pass in Loop 1, or possibly 190 channels in both Loop 1 and Loop 2. Such refuelling would create certain highly asymmetric fuel burnup configurations, not previously analyzed in the design or operation of the CANDU® 6 reactors. Three defuelling options are discussed. The core characteristics in terms of system reactivity, flux tilts, power distribution, controllability, response to subsequent refuelling, fuel burnup redistribution, zone-fill variations needed to be analyzed. Fuel-management studies were conducted to investigate these issues, in particular the optimal initial-fuel-loading configuration and subsequent flux shape controllability, with routine refuelling at full-power operation for an extended period of time until the nominal equilibrium fuel burnup distribution is re-established. In general, the "operability" of the core according to design intent was investigated and re-confirmed.

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1. INTRODUCTION

In 1995 September after a prolonged outage, an incident occurred during the restart of the Point Lepreau reactor, that led to entry of foreign materials into the Heat-Transport System (HTS). To rehabilitate the HTS and to ensure that flow impairment or blockage did not exist, it was proposed that channels in certain coolant-passes could be defuelled and flushed. Such an operation would imply defuelling all 95 channels in a pass in Loop 1, or possibly 190 channels in both Loop 1 and Loop 2 (depending on where the debris was suspected to reside) followed by reloading with all new fuel or reshuffled fuel from other passes. Depleted-uranium fuel was also available for flux-shaping purposes. Such refuelling would create certain highly asymmetric fuel burnup configurations, not previously analyzed in the design or operation of the CANDU 6 reactors. The core characteristics in terms of system reactivity, flux tilts, power distribution, controllability, response to subsequent refuelling, fuel burnup redistribution, zone-fill variations needed to be re-analyzed and, in general, the "operability" of the core according to design intent had to be re-confirmed. Fuel-management studies were conducted to investigate these issues, in particular, the optimal initial-fuel loading configuration and subsequent flux shape controllability with routine refuelling at full-power operation for an extended period of time until the nominal equilibrium fuel burnup distribution could be re-established.

2. DEFUELLING OPTIONS

The HTS configuration and fuelling (and coolant flow) directions are shown schematically in Figures 1 and 2. Debris was suspected to be in channels in Pass 2, fed by Reactor Inlet Header (RIH) #2, and in Pass 4 fed by RIH#6. Possibly all 95 channels in Pass 2, or all 190 channels in Pass 2 and Pass 4 would have had to be defuelled. The fuel reloading options analyzed were

A. If debris was found only in Pass 2 channels, defuel 95 channels in Pass 2 and reload with new fuel bundles (natural and depleted uranium) in these channels.

B. If the asymmetric fuel burnup distribution in option A proved to be untenable, defuel 95 channels in Pass 2 and reload half (48) of these channels with new fuel, and refuel the other 47 channels with irradiated fuel bundles reshuffled from Pass-3 channels. New fuel would also be loaded in the 47 Pass-3 channels.

C. If debris was found in both Pass-2 and Pass-4 channels, defuel all 95 channels in both Passes. Reload all 190 channels with new fuel.

In options A and C, the studies involved designing a loading arrangement for the natural and depleted-uranium fuel, and verifying the reactor "operability" at full power by simulating the reactor operation for an extended period of time. In option B, pairing of the channels in Pass 2 and Pass 3 for fuel reshuffling had to be investigated, as well as the loading configuration of the new fuel bundles.

3. OPERATIONAL REQUIREMENTS

The starting fuel-burnup distribution corresponded to the core prior to reactor shutdown on 1995 April 13 at Full-Power Day (FPD) 4215. The arrangement of the natural-uranium and depleted-uranium fuel bundles in new fuel channels and the reshuflling pattern in option B were based on the following considerations:

a. Match the pre-outage reactivity.

b. Minimize the distortion in the radial, azimuthal and axial power distribution relative to the pre-shutdown power shape.

c. Ensure that the zone level distribution after reactor startup and during normal refuelling does not lead to the impairment of spatial control performance.

d. Keep the number of depleted-uranium bundles to a minimum.

e. Ensure that the maximum bundle power and the maximum channel power do not exceed 900 kW and 7.0 MW respectively.

f. Keep the maximum channel power peaking factor (CPPF) low.

Because of the ready availability of the 0.52 wt % U-235 depleted-uranium bundles, only this level of depletion was considered. Once a satisfactory initial loading configuration was selected, subsequent simulations of reactor operation for an extended period of time, say up to 150 FPDs, needed to be performed to show that

a. the large number of fresh bundles going through a plutonium peak did not cause uncontrolled flux tilts;

b. the reduced number of mature channels available for refuelling selection, and the overall low core-average fuel irradiation, did not lead to uncontrollable hot spots;

c. the average zone fill and individual zone fills remained within the acceptable range and were not constantly strained to compensate for flux tilts;

d. the channel power ripples did not lead to operational constraint or penalty; and

e. derating from full power could be avoided.

4. METHODOLOGY

The RFSP code[1] was used to study the viability of the three defuelling options, with respect to the operational requirements. All simulations were done with version 2-11HP on the operating system HP9000. The reference core state corresponded to the core burnup distribution prior to the reactor shutdown on 1995 April 13 at 22:59, which was at FPD 4215. The phi-noms were computed from the flux distribution of this reference core state, using the as-measured individual zone fills. The phi-noms are the nominal average zone fluxes, which are used by the Reactor Regulating System (RRS) to regulate the zone powers. These phi-noms were later used in the subsequent simulations with spatial control. The number and positioning of depleted-uranium bundles were judiciously selected to satisfy simultaneously all the operational requirements stated in Section 3. To satisfy these requirements, the core was divided into four broad radial regions, namely Zone 4/11, the Inner Core, the CPPF region and the NON-CPPF region in which different deployment (number and position) of depleted-uranium bundles was allowed. Refer to Figure 3 for details regarding option A. After the reactor startup, 150 FPD of RFSP simulations were performed using a typical burnup step of 5 to 7 FPD. These simulations were done with the history-based local-parameter methodology using steady-state fission products at 100% full power. The refuelling simulations were done with spatial control modelled.

The selection of the channels for refuelling and fuelling sequence were different for options A, B and C. The primary objective was to avoid the creation of hot spots and impairment of spatial control. Moderator boron was required to suppress excess reactivity. During these simulations, the boron concentration in the moderator system was gradually varied to keep the zone fills between 10% and 80%. The average zone fill was kept between 40% and 50%.

5. RESULTS AND DISCUSSION

The results for various defuelling options are given below;

5.1 Results for Option A

With option A, the best loading configuration was determined by trial and error. The final selected loading configuration had a total of 192 depleted-uranium bundles. The channels in radial region, Zone 4/11 and the CPPF region housed 2 depleted-uranium fuel bundles in positions 9 and 10. The Inner-Core had 4 depleted-uranium fuel bundles in positions 4,5,9 and 10, whereas the NON-CPPF region had only 1 depleted-uranium fuel bundle in position 7. Refer to Figure 3 for details on fuel loading. To compensate for the plutonium-peak transient, the boron concentration was gradually increased from 0.1 to 0.5 mg/kg (at FPD 4317), then gradually reduced after 50 FPDs to 0.1 mg/kg at FPD 4366. The results are summarized in Table 1. With spatial control, the selected loading configuration gave a satisfactory power distribution initially. As the core burned through the plutonium peak of the fresh fuel and beyond, the peak channel and bundle powers, the zone power distribution and the channel power ripple in the CPPF region were all contained within the desired limits. The maximum channel power and maximum bundle power reached 6.989 MW in channel K-09 (at FPD 4359) and 846 kW in P17/6 (at 4233 FPD) respectively. The maximum channel power ripple was 1.11 (in channel D16 at 4247 FPD). The side-to-side power tilt varied from +1.4% to -5.0%.

Initially the maximum axial zone power tilt varied from +1.5% to -6.4% and, in most cases, it occurred in zone pairs 6/13 and 7/14. However, an axial zone-fill tilt of about 70% developed in zone pair 7/14 and persisted up to 150 FPD. Such a large zone level tilt results in uncorrected flux tilt. A smaller zone-fill tilt also persisted in zone pair 6/13. Refer to Figure 4 for details. These zone level tilts were attributed to the imbalance in the instantaneous zone-average fuel burnup and could possibly be corrected by adjusting the nominal phi-noms. In this option, all the channels in a particular fuelling direction in one half of the core were fuelled with fresh fuel (and some depleted bundles). Hence the bundles at the downstream end of these channels will have fresh fuel, rather than fuel approaching discharge burnup that would normally be situated there. This imbalance was alleviated only to some extent by the use of depleted-uranium bundles. This would create an axial flux tilt, which would result in an axial zone-fill tilt. In the absence of any corrective action the fuelling engineer is likely to face difficulty in the selection of channels when developing a fuelling list. This axial zone level tilt can be minimized by adjusting the phi-noms in the offending zone levels. A 1% reduction in the value of phi-nom in one zone and an increase by the same amount in the axial counterpart can correct the zone level tilt in a zone pair by approximately 10%. Based on this calculation, the derived zone level tilt correction factor is approximately 5% change in zone level per 1% change in phi-nom in the zone. This coefficient can be assumed to be linear and is applicable only for small changes i.e., under 1% change in the value of phi-nom. Another possible approach to minimize the axial tilt is to create an initial zone level tilt by a suitable deployment of the depleted-uranium fuel bundles in various radial irradiation regions. This strategy was used in option C.

5.2 Results For Option B

With option B, the primary consideration was the selection and pairing of Pass-3 channels and Pass-2 channels for the reshuffling process. The selection of channels for refuelling also had to be tailored to avoid clustering of new fuel channels and relatively low-irradiation channels. The ground-rules for this defuelling strategy were

- Of the 95 channels in Pass 2, 48 channels were selected and refuelled with a 12-bundle shift scheme. Twelve new bundles were placed in each of these channels and the 12 irradiated bundles were discharged to the pool. Depleted-uranium bundles were placed at some positions along the channel for flux- and power-shaping purposes.

- The remaining 47 channels in Pass 2 receiveed irradiated bundles transferred from the 47 selected channels from Pass 3.

- Of the 95 channels in Pass 3, 47 channels were selected. Each of these channels was refuelled with a 12-bundle shift scheme. Fuelling machine #2 (side-A) was loaded with 12 new bundles. It would visit one of the 47 channels (channel X, for example), push the new bundles into the channel, then push the 12 irradiated bundles into fuelling machine #1. One of the 47 channels in Pass 2 (channel Y, for example) was paired with channel X to receive the irradiated fuel bundles. The fuelling machines then would move over to channel Y. Fuelling machine #1 would push the irradiated fuel bundles into channel Y in any desired order of bundle pairs. Fuelling machine #2 would receive the irradiated fuel bundles from channel Y and discharge them to the pool. This shuffling scheme corresponded to the "12-bundle shuffle" option.

For the current study, the shuffled fuel bundles were rearranged in Channel Y as follows:

From Pass 3 , Channel X:

East (side A) West (side C)
<—— Fuelling Direction

1	2	3	4	5	6	7	8	9	10	11	12

To Pass 2 , Channel Y:

East (side A) West (side C)
Fuelling Direction ——>

11	12	9	10	7	8	5	6	3	4	1	2

After 95 refuelling operations (the first 48 operations involved straight 12-bundle shift, the last 47 operations involved 12-bundle shift and re-shuffle), the core burn-up distribution was balanced side to side. In the axial direction, the uniform (zero) burnup distribution in the 95 new fuel channels was compensated for by using depleted fuel bundles. It was found that only one depleted-uranium bundle, located at position 8 from the upstream side, was needed in each of the 95 new fuel channels. The selected shuffling scheme is given in Table 2. The criteria used in the pairing of the channels is to minimize the deviation of the average irradiation in a channel from the time-average irradiation distribution. With the more uniform burnup distribution, the simulation results up to 50 FPD (in steps of 5 to 7 FPD) showed that all operational requirements could be met, with no zone-fill tilts, as observed with option A. The maximum channel power in the first 50 days of fuelling is displayed in Figure 5. The variation of zone levels in Zones 6/13 is shown in Figure 6. The variation in channel ripple in the CPPF region is shown in Figure 7.

5.3 Results For Option C

With option C, there were 95 new-fuel channels in each loop, giving an advantage of side-to-side symmetry. Also the depleted-uranium fuel bundle deployment was designed to minimize the anticipated axial zone-flux tilt experienced in option A. Therefore, an initial zone-flux tilt was allowed that was expected to be reduced with core burnup. Various combinations of the number and position of depleted-uranium fuel bundles were studied, based on experience with option A, to determine the optimum configuration. The most promising configuration housed two depleted bundles in positions 8 and 9 in the CPPF and the NON-CPPF regions. The Inner-Core had three depleted bundles in positions 5, 8 and 9. The Zone 4/11 had 3 depleted bundles in positions 8, 9 and 10. In this configuration, a total of 442 depleted-uranium fuel bundles were required. In this configuration an initial (i.e., post-startup) east-to-west axial zone level tilt of approximately 45% was deliberately created. This axial zone level tilt would reduce as the freshly fuelled channels approached their plutonium peak. Simulations up to the plutonium peak confirmed that the operational requirements were satisfied without excessive zone-fill tilts observed with option A.

The simulation results from 4215 FPD to 4247 FPD are given in Table 3. As the newly fuelled channels approach the plutonium peak, the direction of the zone level tilt reversed, and it helped soften the zone level peaks. The zone level distribution was also more favorable, and the spatial control was not impaired. A healthy spatial control keeps a check on maximum channel power, maximum bundle power and the channel power ripple.

6. CONCLUSIONS

This study shows that when a large segment of the core has to be defuelled and replaced with fresh fuel, the following refuelling strategy helps to minimize the maximum channel power, maximum bundle power, maximum channel power ripple, axial zone level tilt and to achieve healthy spatial control:

- To minimize the severity of the irradiation-dependent zone level tilt, introduce an initial (i.e., post-startup) zone level tilt in the opposite direction by using depleted-uranium bundles at appropriate axial positions. As the fresh bundles pass through the plutonium-peak, the axial zone level tilt gradually increases because of the imbalance in the zone-average irradiation. The number of depleted-uranium bundles and their position depends on the problem at hand.
- To minimize the creation of hot spots, ensure that the difference in the average irradiation in the axial direction and in the mirror-image zones is minimized in the post-startup period for at least 150 FPD.

REFERENCES

1. B. Rouben, "Overview of Current RFSP-Code Capabilities for CANDU Core Analysis", AECL–11407, 1996 January.

Table 1

Results of Various Cases for PLGS Defuelling Study, Option A

Case No	Description of Simulation	Boron (mg/kg)	Rho (mk)	Power Distribution: Max CP (MW)	Max BP (Kw)	Max Ripple	Power Tilt: Radial (Z4/11)	S/S (N/S) (%)	Axial (E/W) (%)	Zone Max (%)	Comments
Ref	Pre-Shutdown S.S. 100 % FP	0.0	2.89	6.751 (P15)	821 (S13/6)	1.084 (D16)	99.6	-3.0	-1.3 (Z3/10)	102.3 Z13	AZL = 58.2%
	Long S/D, ZPC 35 C, .0001 % FP	3.65	2.88	7.124 (P15)	894 (S13/6)	1.107 (K11)	103.8	-3.0	-1.6 (Z3/10)	104.4 Z-13	Critical AZL = 58.2%
fpd4215 (S.S)	S.S. 100 % FP Z4/11 = 9,10 Inner = 4,5,9,10 CPPF = 8,9, NON-CPPF = 7	0.0	3.49	7.044 (N17)	874 (P17/6)	1.110 (P19)	99.1	-3.0	-2.5 (Z4/11)	107.7 Z-14	AZL = 50.0%
fpd4215 (S.C)	S.C. 100 % FP,HB Z4/11 = 9,10 Inner = 4,5,9,10 CPPF = 8,9, NON-CPPF = 7	0.1	2.89	6.806 (N06)	846 (P17/6)	1.104 (D16)	99.7	-0.5	1.3 (Z6/13)	101.8 Z-14	AZL = 46.3% Max ZL = 81%(Z14) Min ZL = 27%(Z03)
fpd4217	S.C. 100 % FP Burn Step = 2 days 9 chan fuelled on North side	0.1	2.89	6.818 (Q09)	832 (Q06/6)	1.093 (S07)	99.7	1.5	1.4 (Z2/9)	102.0 Z-02	AZL = 52.2% Max ZL = 81%(Z02) Min ZL = 13%(Z13)
fpd4219	S.C. 100 % FP Burn Step = 2 days 4 chan fuelled on South side	0.1	2.89	6.784 (P07)	820 (S11/6)	1.077 (S07)	99.5	0.5	1.4 (Z6/13)	101.3 Z-07	AZL = 44.7% Max ZL = 71%(Z01) Min ZL = 23%(Z04)
fpd4226	S.C. 100 % FP Burn Step = 7 days 3 chan fuelled	0.1	2.89	6.759 (P07)	826 (P17/6)	1.083 (D16)	101.1	-0.5	-1.2 (Z3/10)	101.7 Z-13	AZL = 40.2% Max ZL = 82%(Z13) Min ZL = 17%(Z03)

continued ...

Table 1 (continued)

Case No	Description of Simulation	Boron (mg/kg)	Rho (mk)	Power Distribution Max CP (MW)	Power Distribution Max BP (Kw)	Power Distribution Max Ripple	Power Tilt Radial (Z4/11)	Power Tilt S/S (N/S) (%)	Power Tilt Axial (E/W) (%)	Power Tilt Zone Max (%)	Comments
fpd4233	S.C. 100 % FP Burn Step = 7 days 4 chan fuelled	0.1	2.89	6.902 (P15)	842 (P17/6)	1.099 (D16)	99.2	-5.0	-4.6 (Z7/14)	106.7 Z-14	AZL = 42.2% Max ZL = 76%(Z14) Min ZL = 10%(Z09)
fpd4240	S.C. 100 % FP Burn Step = 7 days 5 chan fuelled	0.25	2.88	6.952 (P15)	837 (S13/6)	1.103 (D16)	98.8	-4.	-4.0 (Z3/10)	104.6 Z-14	AZL = 21.0% Max ZL = 84%(Z14) Min ZL = 5%(Z01)
fpd4247	S.C. 100 % FP Burn Step = 7 days 15 chan fuelled	0.30	2.88	6.787 (P15)	815 (S13/6)	1.110 (D16)	99.1	-2.0	-2.1 (Z3/10)	103.4 Z-14	AZL = 31.1% Max ZL = 80%(Z14) Min ZL = 8%(Z01)
fpd4254	S.C. 100 % FP Burn Step = 7 days 11 chan fuelled	0.25	2.89	6.741 (P15)	802 (S13/6)	1.100 (D16)	99.4	-3.0	-4.6 (Z3/10)	105.4 Z-14	AZL = 43.2% Max ZL = 85%(Z14) Min ZL = 9%(Z09)
fpd4261	S.C. 100 % FP Burn Step = 7 days 13 chan fuelled	0.30	2.89	6.784 (L13)	805 (S13/6)	1.087 (D16)	100.0	-2.0	-3.3 (Z7/14)	103.4 Z-14	AZL = 46.8% Min ZL = 13%(Z05)
fpd4268	S.C. 100 % FP Burn Step = 7 days 15 chan fuelled	0.45	2.88	6.735 (L13)	798 (S12/6)	1.087 (K20)	99.4	-4.0	-3.2 (Z6/13)	104.7 Z-13	AZL = 42.74% Max ZL = 82%(Z13) Min ZL = 9%(Z08)

continued ...

Table 1 (continued)

Case No	Description of Simulation	Boron (mg/kg)	Rho (mk)	Power Distribution: Max CP (MW)	Power Distribution: Max BP (Kw)	Power Distribution: Max Ripple	Power Tilt: Radial (Z4/11)	Power Tilt: S/S (N/S) (%)	Power Tilt: Axial (E/W) (%)	Power Tilt: Zone Max (%)	Comments
fpd4275	S.C. 100 % FP Burn Step = 7 days 10 chan fuelled	0.40	2.89	6.707 (L13)	801 (M04/6)	1.069 (L12)	99.6	-2.0	-2.4 (Z7/14)	102.6 Z-13	AZL = 45.14% Max ZL = 80% (Z14) Min ZL = 9% (Z07)
fpd4282	S.C. 100 % FP Burn Step = 7 days 13 chan fuelled	0.50	2.89	6.787 (L13)	800 (O06/6)	1.080 (L13)	99.8	-1.5	-2.2 (Z4/11)	103.1 Z-13	AZL = 36.2% Max ZL = 80%(Z14) Min ZL = 12% (Z07)
fpd4289	S.C. 100 % FP Burn Step = 7 days 14 chan fuelled	0.50	2.89	6.796 (L13)	812 (O06/6)	1.082 (L13)	99.8	-2.0	-3.2 (Z7/17)	103.5 Z-14	AZL = 42.2% Max ZL = 82% (Z14) Min ZL = 13% (Z05)
fpd4296	S.C. 100 % FP Burn Step = 7 days 14 chan fuelled	0.50	2.89	6.733 (O07)	826 (O06/6)	1.067 (L13)	99.5	-0.5	-3.5 (Z6/13)	102.5 Z-13	AZL = 43.5% Max ZL = 79% (Z14) Min ZL = 8% (Z06)
fpd4303	S.C. 100 % FP Burn Step = 7 days 14 chan fuelled	0.50	2.89	6.749 (O07)	833 (O06/6)	1.072 (C11)	99.5	1.0	-6.1 (Z6/13)	103.5 Z-10	AZL = 42.6% Max ZL = 79%(Z10) Min ZL = 9% (Z04)
fpd4310	S.C. 100 % FP Burn Step = 7 days 16 chan fuelled	0.50	2.89	6.734 (L07)	814 (O06/6)	1.071 (V11)	99.0	-0.5	-2.6 (Z6/13)	103.6 Z-10	AZL = 52.5% Max ZL = 82% (Z10) Min ZL = 9% (Z06)

continued ...

Table 1 (continued)

Case No	Description of Simulation	Boron (mg/kg)	Rho (mk)	Power Distribution: Max CP (MW)	Power Distribution: Max BP (Kw)	Power Distribution: Max Ripple	Power Tilt: Radial (Z4/11)	Power Tilt: S/S (N/S) (%)	Power Tilt: Axial (E/W) (%)	Power Tilt: Zone Max (%)	Comments
fpd4317	S.C. 100 % FP Burn Step = 7 day 12 chan fuelled	0.50	2.89	6.611 (M14)	811 (O05/6)	1.064 (V11)	99.8	-0.5	-2.2 (Z6/13)	102.4 Z-13	AZL = 50.0% Max ZL = 80% (Z10) Min ZL = 9% (Z06)
fpd4324	S.C. 100 % FP Burn Step = 7 days 7 chan fuelled	0.40	2.89	6.747 (P08)	820 (O05/6)	1.077 (V11)	99.8	-0.5	-3.7 (Z6/13)	102.5 Z-13	AZL = 47.0% Max ZL = 78% (Z14) Min ZL = 8% (Z06)
fpd4331	S.C. 100 % FP Burn Step = 7 days 10 chan fuelled	0.30	2.89	6.726 (P08)	808 (O05/6)	1.091 (V11)	99.7	-0.0	-6.4 (Z6/13)	102.4 Z-13	AZL = 49.0% Max ZL = 79% (Z10) Min ZL = 5% (Z06)
fpd4338	S.C. 100 % FP Burn Step = 7 days 6 chan fuelled	0.20	2.89	6.704 (L17)	788 (O05/6)	1.080 (V11)	99.3	-2.0	-3.4 (Z7/14)	103.8 Z-14	AZL = 42.3% Max ZL = 80%(Z14) Min ZL = 9% (Z06)
fpd4345	S.C. 100 % FP Burn Step = 7 days 13 chan fuelled	0.15	2.89	6.667 (P08)	791 (O05/6)	1.097 (V11)	99.6	-1.5	-3.7 (Z6/13)	103.0 Z-13	AZL = 39.3% Max ZL = 80% (Z14) Min ZL = 8% (Z06)
fpd4352	S.C. 100 %FP Burn Step = 7 days 23 chan fuelled	0.15	2.89	6.754 (G10)	791 (S11/6)	1.102 (V11)	99.3	-2.0	-4.0 (Z3/10)	102.5 Z-10	AZL = 45.1% Max ZL = 80% (Z10) Min ZL = 9% (Z06)

continued ...

Table 1 (continued)

Case No	Description of Simulation	Boron (mg/kg)	Rho (mk)	Power Distribution			Power Tilt				Comments
				Max CP (MW)	Max BP (Kw)	Max Ripple	Radial (Z4/11)	S/S (N/S) (%)	Axial (E/W) (%)	Zone Max (%)	
fpd4359	S.C. 100 % FP Burn Step = 7 days 17 chan fuelled	0.10	2.89	6.989 (K09)	797 (D10/6)	1.103 (V11)	100.4	-0.0	-4.3 (Z6/13)	102.5 Z-11	AZL= 49.7% Max ZL= 80%(Z11) Min ZL= 8%(Z07)
fpd4366	S.C. 100 % FP Burn Step = 7 days 15 chan fuelled	0.10	2.89	6.941 (K09)	791 (H06/7)	1.118 (V11)	100.2	-1.0	-4.0 (Z4/11)	102.1 Z-11	AZL = 49.7% Max ZL = 81% (Z11) Min ZL = 9% (Z07)

Note 1: Target k-effective for spatial control simulations is 1.0029.

Table 2

Refuelling and Re-Shuffling Scheme, Option B

Pass-2 Channels Fuelled with 12 New Bundles	Shuffling of Pass-3 Channels to Pass-2 Channels (Channel Pairing)
A14	A09 – K19
B13	B06 – G12
B15	B08 – T14
B17	B10 – L18
C12	C05 – D13
C14	C07 – Q19
C16	C09 – G16
C18	D04 – H19
E12	F06 – O15
E14	F08 – A12
E20	F10 – O17
F13	G03 – R14
F15	H02 – H13
F17	J03 – E16
F19	J05 – L14
G20	J07 – U15
H21	J09 – K15
J14	J11 – K13
J16	K02 – Q13
J18	L01 – H17
J20	M02 – D17
K21	M04 – D19
L12	M06 – R16
L22	M08 – N14
M13	M10 – L20

continued ...

Table 2 (continued)

Pass-2 Channels Fuelled with 12 New Bundles	Shuffling of Pass-3 Channels to Pass-2 Channels (Channel Pairing)
M15	N01 – N20
M19	O02 – H15
M21	D08 – N16
N12	P03 – E18
N22	P05 – L16
O13	P07 – V12
O21	P09 – P20
P14	P11 – P18
P16	Q02 – M17
Q21	R03 – J22
R12	R05 – P12
R18	S04 – O19
R20	S06 – G14
S13	S08 – T16
S15	S10 – K17
S17	T05 – Q15
T12	T07 – D15
T18	T09 – S19
U13	U06 – G18
U17	V07 – N18
V14	V09 – Q17
V16	W10 –J12
W13	

Table 3

Results of RFSP Simulations for Refuelling Study of 190 Channels for Various Burnup Steps In Reloading Option, C

FPD	Radial Power Distribution (% Time-Average)			Axial Power Tilt [(E-W)/E x 100] (%)			Zone Level Distribution (E / W) (%)			Zone Level Tilt (E - W) (%)			Boron / AZL / C.P. B.P. / Ripple
Before		99.6			-1.3			53/54			-1		Boron = 0.000 ppm
Startup	99.0		102.1	-1.0		-0.5	73/70		59/63	3		-4	AZL = 58.22%
		99.6			-1.1			39/43			-4		C.P. max = 6.751 MW (P15)
4215	99.0		100.8	0.1		0.2	69/64		56/56	5		0	B.P. max = 822 kW (S13/6)
		100.0			-0.3			56/58			-2		Ripple = 1.084 (D16)
After		98.1			3.1			40/8			32		Boron = 0.100 ppm
Startup	99.4		100.4	3.8		6.9	80/16		62/9	64		51	AZL = 44%
		99.6			3.0			50/40			10		C.P. max = 7.028 MW (P15)
4215	99.7		103.5	5.4		7.3	81/18		79/40	63		39	B.P. max = 853 kW (P17/6)
		99.9			2.9			64/22			42		Ripple = 1.074 (Q16)
		98.5			1.7			52/15			37		Boron = 0.100 ppm
	100.7		102.0	5.3		4.3	83/49		81/30	34		51	AZL = 55%
4226		99.5			1.5			58/68			-10		C.P. max = 6.894 MW (P15
	98.6		101.8	4.2		5.3	78/24		82/43	54		39	B.P. max = 827 kW (P17/6)
		99.6			2.6			75/36			39		Ripple = 1.068 (K20)
		98.5			1.1			37/13			24		Boron = 0.280 ppm
	100.2		101.9	3.5		3.1	81/50		70/31	31		39	AZL = 51%
4233		99.9			0.7			46/77			-31		C.P. max = 6.911 MW (P15)
	98.8		101.3	3.6		3.4	65/26		76/43	39		33	B.P. max = 818 kW (P17/6)
		99.8			1.8			58/41			17		Ripple = 1.112 (K20)
		98.6			0.6			6/25			10		Boron = 0.407 ppm
	99.7		102.0	2.0		2.6	47/39		31/16	26		27	AZL = 44%
4240		100.1			0.0			5/90			-45		C.P. max = 6.911 MW (P15)
	98.8		101.3	3.0		2.8	48/40		58/64	26		20	B.P. max = 806 kW (P17/10)
		99.9			1.1			8/60			3		Ripple = 1.062 (K20)
		98.9			.2			33/30			3		Boron = 0.400 ppm
	99.6		101.9	1.4		2.0	79/65		54/38	14		17	AZL = 52%
4247		99.5			-.9			24/80			-54		C.P. max = 6.852 MW (P15)
	99.1		100.9	2.7		2.2	65/46		52/44	19		8	B.P. max = 824 kW (S11/6)
		100.4			.8			57/62			-5		Ripple = 1.067 (D16)

Note 1: The pressurizer is located on side-C which is west side at Point Lepreau.
Note 2: 1 ppm = 1 mg/kg

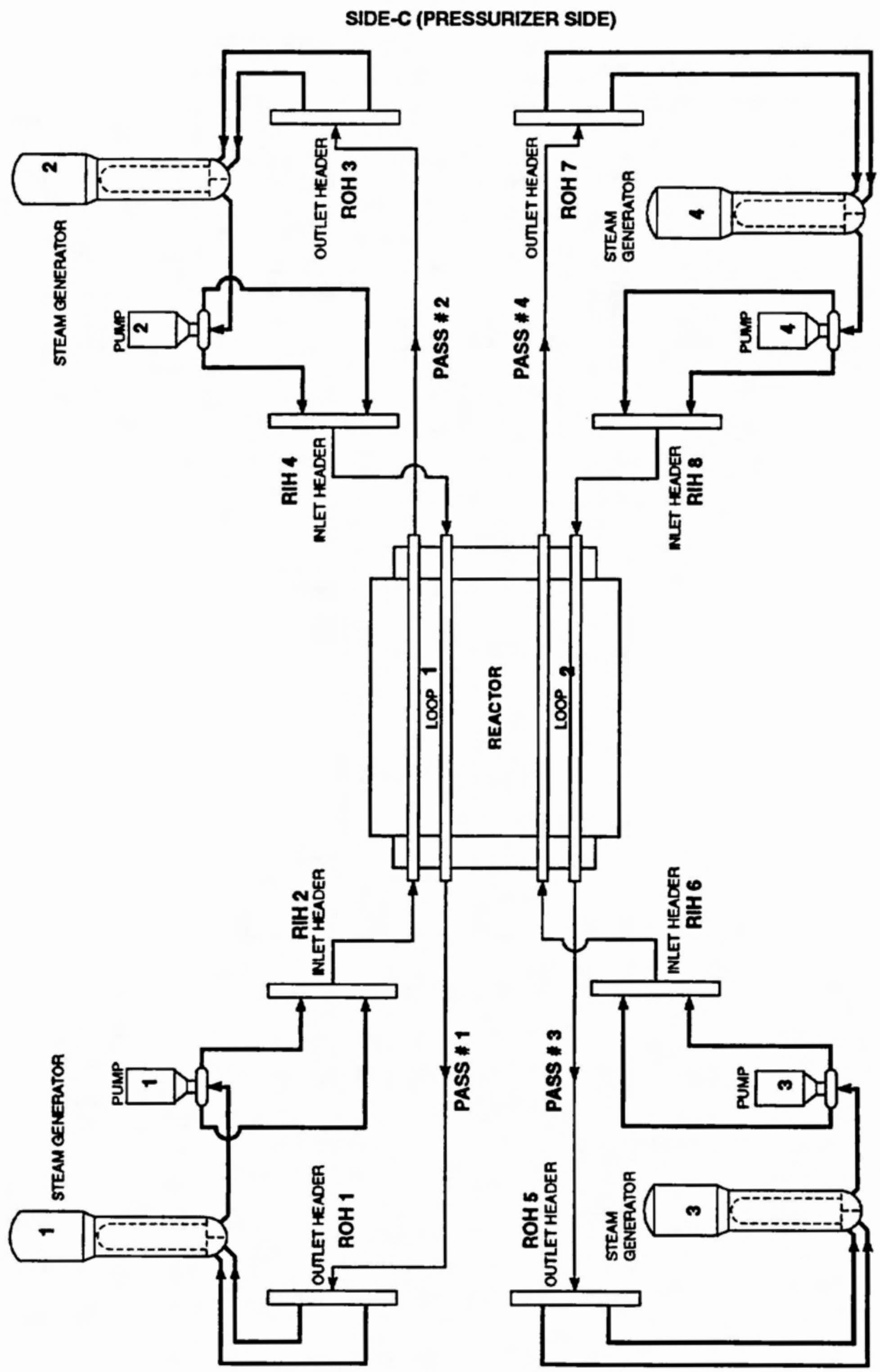
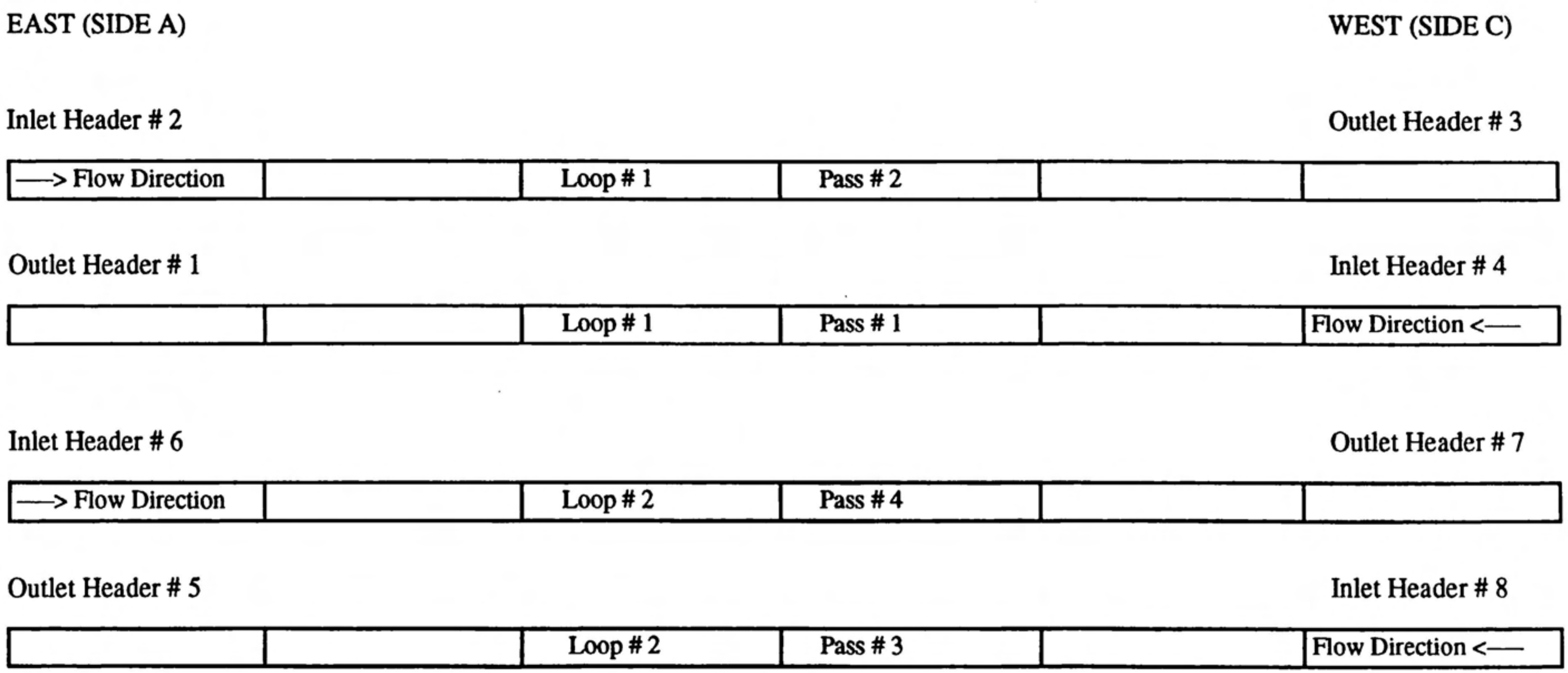


Figure 1: Heat Transport System

Figure 2

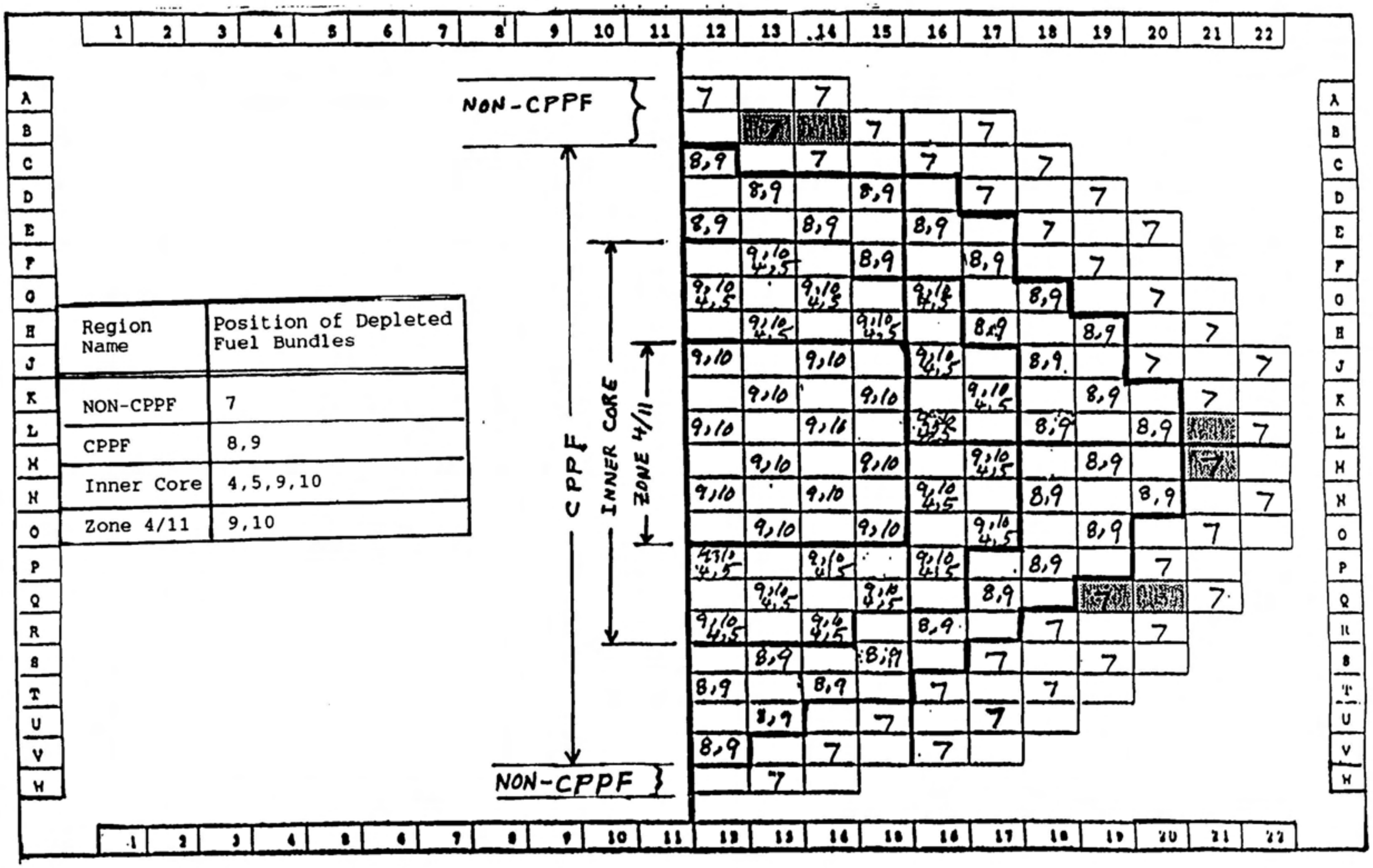
Schematic of HT Layout at Point Lepreau



Note: The fuelling direction in CANDU 6 is the same as the direction of coolant flow.

Figure 3

Position Of Depleted–Uranium Fuel Bundles In Pass-2 Of Loop-1



Region Name	Position of Depleted Fuel Bundles
NON-CPPF	7
CPPF	8,9
Inner Core	4,5,9,10
Zone 4/11	9,10

Figure 4

Evolution Of Average Zone Burnup Distribution And Zone Level In Zones 6 and 7

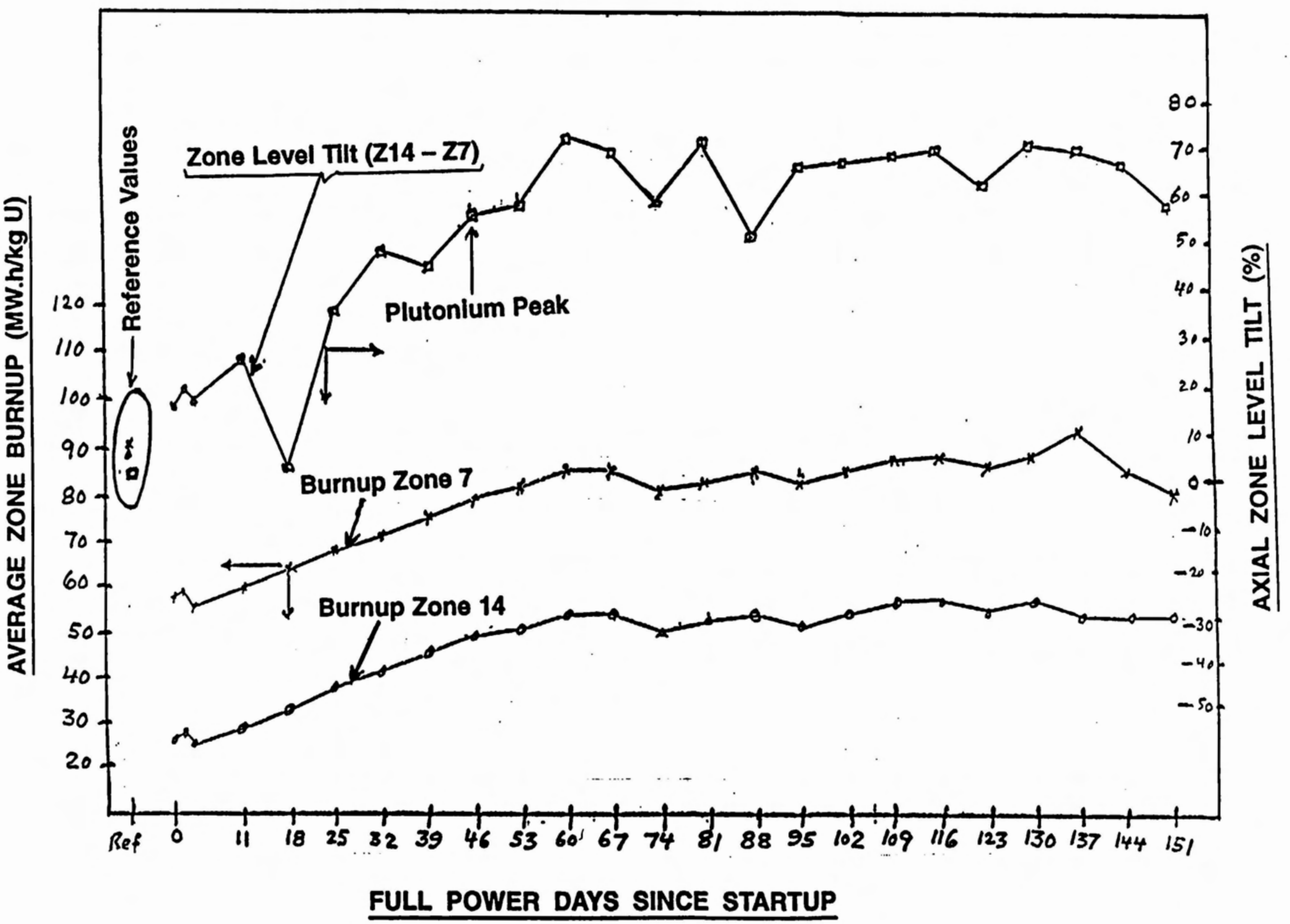


Figure 5 Maximum Channel Power Versus FPD For Option B

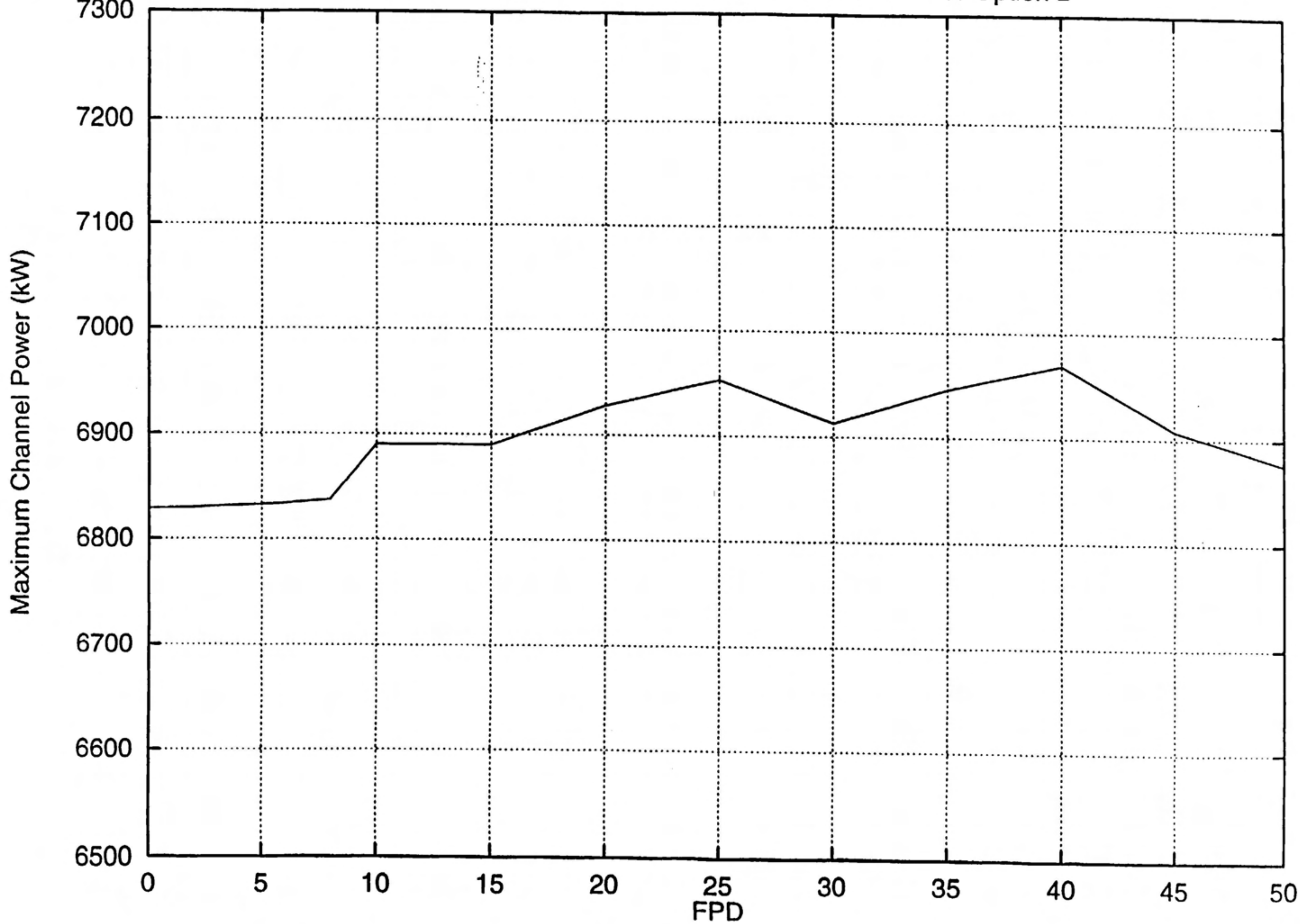


Figure 6 Zone 6 and Zone 13 Fills Versus FPD For Option B

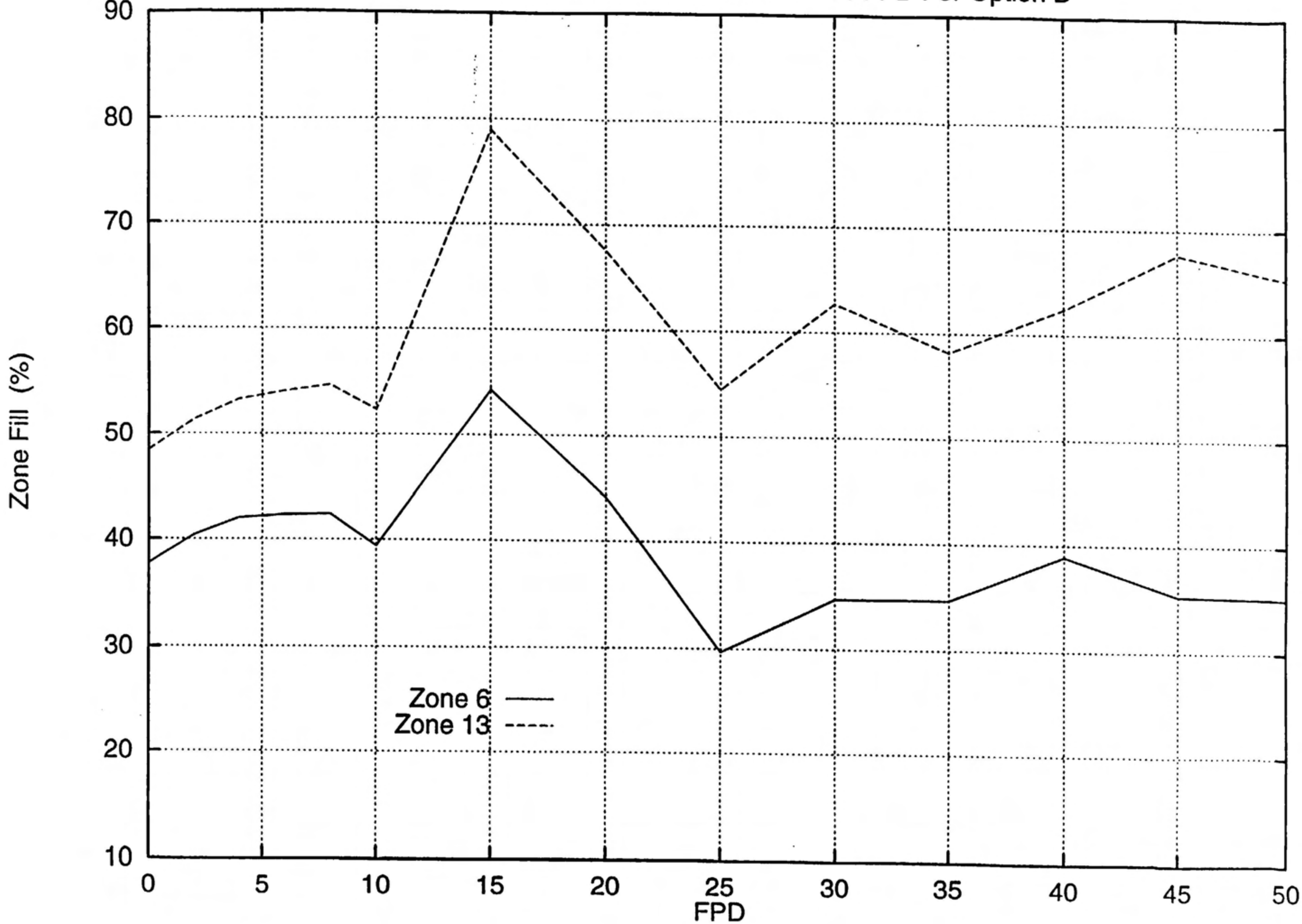


Figure 7 Maximum Ripple In CPPF Region Versus FPD For Option B