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Analysis of Wolsong-1 Reactor Power Pulses with Boron in Moderator at Plutonium Peak

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1. Introduction

The restart of the Wolsong-1 CANDU 6 reactor (W-1) after the major refurbishment project including replacement of the pressure tube is scheduled for spring 2011. After the refurbishment, the reactor is due to be operated based upon the Improved Technical Specifications (ITS) (Refs. 1-2) that are in the finalization phase for the regulatory approval.

During the course of preparing ITS, it is felt that the operation of the W-1 reactor during the time period with boron and/or gadolinium in the moderator system should be supported with the detailed analysis results of power pulses so that the Limiting Condition of Operation (LCO) selection base, which corresponds to Criterion 2 (Design Basis Accident/Transient Safety Analysis – Initial Conditions) of Article 2008-10, as applied to the design of ITS is satisfactorily met. Thus, a study is conducted in the present paper as a preliminary step to the accomplishment of the comprehensive compilation of power pulse analyses for various scenarios related to the situations with boron in the moderator system that are expected to be encountered during reactor operations. In consideration of LCO selections for ITS, this paper specifically deals with a case when the boron concentration in the moderator system would reach the maximum value at plutonium peak of initial core as it will be the case for the W-1 reactor.

In the following, the technical background of consequences resulting from the presence of boron in the moderator system in the context of safety aspects is briefly described with respect to the power pulse during a transient accompanied by the insertion of positive reactivity worth into the core. Then, the model used for simulations is described followed by the discussion of results and some conclusions.

2. Background of Safety Aspects

The coolant voiding, typically, in the case of Loss-Of-Coolant-Accident, is much of concern for CANDU reactors due to the increase of core system reactivity which leads to the power pulse. For the typical LOCA, such as, Reactor Inlet/Outlet Header (RIH/ROH) breaks, the coolant voiding in the pressure tubes (fuel channels) connected to the broken thermalhydraulic loop contributes to the insertion of positive reactivity worth into the core. Beside these main phenomena of LOCA, the case of a single channel in-core break can be postulated which results also in the insertion of positive reactivity worth into the core.

For the later case, the reactivity increase due to the coolant voiding in a single channel would not be as significant as in the case of multiple channel coolant voiding resulting from the RIH/ROH breaks. However, there could be situations during reactor operations when the core system reactivity is balanced with the poison in the moderator system. In this case, the intrusion of pressurized hot coolant into the moderator volume causes the dilution of the poison concentration and the increase of moderator temperature which are equivalent to the insertion of positive reactivity worth into the core. The moderator temperature reactivity coefficients are positive for fresh fuel with boron in the moderator and equilibrium fuel. Based upon these considerations, the power pulse analyses are conducted in the present study for the W-1 reactor at plutonium peak.

3. Models, Simulation Results and Discussions

The RFSP-IST (Ref. 3) core model has 48x36x34 mesh spacings in x-, y- and z-direction, respectively. All 28 shutoff rods (SOR) are initially hung in the reactivity mechanism deck outside the core. The insertion of positive reactivity worth is postulated with the uniform decrease of coolant densities in time at 12 bundle positions of 380 channels so that the core system reactivity increase would approximately correspond to ~1.7 mk/s. The initial condition is set up at about ~40 Full Power Days (FPD) of reactor operation after the restart with loading of 4560 fresh fuel bundles. At this stage the excessive core system reactivity due to the plutonium buildup would take the peak value and the core system reactivity is balanced with about ~4.303 ppm boron in the moderator system. The initial power level is assumed to be 103% FP with 100% FP = 2016.4 MW (th) and the uniform distribution of zone levels of 50% average zone level (AVZL) are applied to 14 zone controller compartments.

In order to simulate the power transient the reactor trip actuation time when SORs start being dropped into the core is firstly examined. In Table 1 the results for Case A, B and C are summarized.

Table 1: Trip actuation times (milli-s)

		Case A Plutonium Peak Core	Case B Fresh Fuel Core	Case C Equilibrium Fuel Core	Case (B-A)	Case (C-A)
	Boron (ppm)	4.303	2.747	---		
SDS1	ROP	628	620	544	-8	-84
	LOG	520	512	464	-8	-56
SDS2	ROP	628	621	544	-7	-84
	LOG	690	681	593	-9	-97
				Average	-8	-80

Note that the trip actuation occurs on average about ~80 ms earlier for the equilibrium core compared to the initial state core with boron in the moderator. The ROP trips occur almost at the same time for SDS1 and SDS2 for Case A and B. The differences in trip actuation times between Case A and B is on average -8 ms and this time difference could be practically overlooked because it would correspond to the range of uncertainty. In other words, for the cases presented in Table 1 the amount of boron concentration in the moderator system would bear no consequences in the outcome of trip actuation time.

In Table 2 the similar comparisons are displayed again for three cases of the core state at plutonium peak with the different amount of boron concentrations. The change in boron concentrations from Case A to Case B and C is equivalent to the zone level change from 50% to 20% and 80%, respectively, which are determined based upon the RFSP-IST simulations in such a way that the reactor sustains criticality. The average zone level change of 30% would approximately equivalent to the core system reactivity change due to refueling for a period of about ~ 4 FPD.

As can be seen the difference in boron concentration would not bear any significant consequences in the outcome of trip actuation times and this phenomenon is to attribute to the uniformity of boron dispersion in the moderator system. Thus, it can be argued that the outcome of trip actuation time would be mainly subject to the any perturbation that might cause localized peak and/or distortion of flux shapes.

Table 2: Trip actuation times at plutonium peak (ms)

		Case A (50%AVZL)	Case B (20% AVZL)	Case C (80% AVZL)	Case (B-A)	Case (C-A)
	Boron (ppm)	4.303	4.596	4.053		
SDS1	ROP	628	625	627	-3	-1
	LOG	520	517	519	-3	-1
SDS2	ROP	628	625	628	-3	0
	LOG	690	687	690	-3	0
				Average	-3	-1

In order to simulate the transient the most effective two shutoff rods, namely, SOR #4 and #8 are assumed to be unavailable.

Table 3: Power transient (Initial power level = 103% FP)

	Case A	Case B	Case C		
	4.303 ppm Boron	4.596 ppm Boron	4.053 ppm Boron	Case (B-A)/A*100	Case (C-A)/A*100
Time (s)	Rel. Power	Rel. Power	Rel. Power	Rel. Diff. (%)	Rel. Diff. (%)
0.00	1.000	1.000	1.000	0.00	0.00
0.12	1.011	1.011	1.011	-0.03	-0.02
0.20	1.026	1.025	1.025	-0.05	-0.04
0.32	1.053	1.053	1.053	-0.05	- 0.04
0.40	1.075	1.074	1.074	-0.06	- 0.05
0.51	1.111	1.110	1.110	-0.05	-0.06
0.63	1.151	1.151	1.151	-0.05	-0.06
0.71	1.181	1.180	1.180	-0.06	-0.08
0.82	1.230	1.229	1.229	-0.06	-0.09
0.94	1.285	1.284	1.283	-0.06	-0.10
1.02	1.324	1.324	1.323	-0.06	-0.11
1.11	1.371	1.370	1.370	-0.05	-0.11
1.17	1.393	1.395	1.393	0.11	-0.04
1.30	1.355	1.359	1.356	0.26	0.07
1.41	1.202	1.209	1.207	0.55	0.43
1.51	1.001	1.010	1.011	0.84	0.97
1.56	0.902	0.911	0.914	0.93	1.24

The power transient for the cases shown in Table 2 is given in Table 3 for the time period between t=0-1.56 s. During this transient period the power peaks to nearly ~1.4 times to the initial power level at t=~1.17 s and the relative power level drops below 1 at t=1.56 s, at which time the long shutoff rods are travelled 10 L.P. deep into the core.

The last two columns to the right in Table 3 show the relative differences in relative powers between Case A and Case B and C, respectively. As can be seen the differences are practically negligible independent of the boron concentrations for the ppm range studied here. This is due to the uniform dispersion of boron in the moderator system that keeps the core flux shapes globally same independent of the boron concentrations.

In Figure 1 the transient of dynamic reactivity is graphically shown for the case with 4.303 ppm boron in the moderator system. The maximum reactivity is +1.85 mk at t=~1.11 s and it turns to negative value from t=~1.41 s. At t=~2.22 s when 26 SORs are fully inserted into the core the dynamic reactivity becomes about ~-63.8 mk.

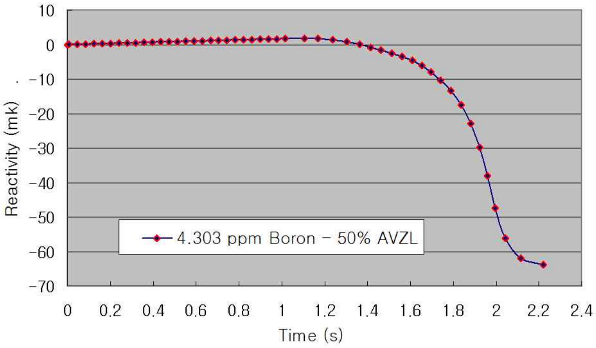

Fig. 1. Dynamic reactivity transient

4. Conclusions

In the present study the effect of the presence of boron in the moderator system studied at the core state of plutonium peak and the amount of boron concentrations do not bear any practically significant consequences to the outcome of trip delay times, power pulses and dynamic reactivity transient for the same amount of reactivity perturbations that cause reactor power excursions.

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