Effect of Initial Conditions on Power Pulses of Wolsong-1 Reactor at Plutonium Peak

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1. Introduction

The effect of initial conditions such as the poison in the moderator system and the initial power level on the power pulse of the Wolsong-1 CANDU 6 reactor (W-1) is presented here. The W-1 reactor will be restarted in spring of the next year after the major refurbishment project including replacement of the pressure tube. Thus, the power pulse simulations are carried out at plutonium peak. This approach offers opportunity to gain an insight into the power pulse behavior resulting from the inclusion of substantial amount of poison in the moderator system as initial condition.

For the purpose of suppressing the excessive core system reactivity boron and gadolinium are in practice used as poison in the moderator system so that the reactor can be operated without localized distortion of flux shapes in the core. Although boron and gadolinium are equally effective as poison it is well known that their neutronic behavior in terms of energy spectrum dependent absorptions is quite different. Furthermore, the trip actuation time depends on the initial power level before the transient starts so that the final outcome of power pulse is also dependent on this initial condition.

A brief review of the technical background of consequences resulting from the presence of poison in the moderator system is presented in the context of safety aspects. For this purpose the study is conducted for the core state at plutonium peak when the amount of poison in the moderator system would represent the maximum value during reactor operations with nominal core configurations. The model used for simulations is then presented followed by the discussion of simulation results and some conclusions.

2. Background of Safety Aspects

The Loss-Of-Coolant-Accident (LOCA) results in the increase of core system reactivity which leads to power excursion. For the typical LOCA the coolant voiding takes place in multiple fuel channels (pressure tubes) that are connected to the broken thermalhydraulic loop of Reactor Inlet/Outlet Header (RIH/ROH). The insertion of positive reactivity worth into the core with poison in the moderator system can also happen, beside these main phenomena of LOCA, in the case of a single channel in-core break based upon the twofold effects, namely, the dilution of poison concentration and the moderator temperature increase, due to the intrusion of hot pressurized coolant into the moderator volume.

For the single channel in-core break the core system reactivity increase would not be as significant as in the case of coolant voiding resulting from the RIH/ROH breaks. However, the effect of the presence of poison in the moderator system should be more clearly understood by analyzing the power pulses in details, which is the topic of the present paper.

Since the moderator temperature reactivity coefficients are positive for fresh fuel with boron in the moderator system and equilibrium fuel, the power pulse analyses are carried out in the present study for the core state of the W-1 reactor at plutonium peak so that the effects of poison in the moderator system on power pulses can be clearly pronounced. Furthermore, the study conducted and results obtained here could be considered as the preliminary steps that would be extended to further detailed and categorized approach to the systematic investigations of postulated scenarios related to the accidental situations arising with poison in the moderator system. Such investigations are deemed to be applicable to the safe and economic operation of the W-1 reactor as designed in Improved Technical Specifications (ITS) (Ref. 1).

3. Models, Simulation Results and Discussions

The simulations are performed by using the CERBERUS module of the RFSP-IST code (Ref. 2). The core model is set up with 48x36x34 mesh spacings in x-, y- and z-direction, respectively. The power pulse is initiated by the insertion of positive reactivity worth into the core that is postulated with the uniform decrease of coolant densities in time at 12 bundle positions of 380 channels. The initial condition corresponds to the core state at about ~40 Full Power Days (FPD) of reactor operation after the restart with loading of 4560 fresh fuel bundles. Due to the plutonium buildup the excessive core system reactivity takes the peak value which is suppressed by the inclusion of poison in the moderator system.

The initial power level is assumed to be 103% and 50% FP with 100% FP = 2016.4 MW (th). The uniform distribution of 14 zone controller levels is applied with 50% average zone level (AVZL). Boron and gadolinium are used as poison in the moderator system. Furthermore, the core system reactivity increase rate is approximately found to be about ~1.7 and 1.85 mk/s. for 103% and 50% initial FP, respectively, for the same decrease rate of coolant densities in time.

For the transient simulations all 28 shutoff rods (SOR) are initially hung in the reactivity mechanism deck outside the core and the most effective two SORs, namely, SOR #4 and #8 are assumed to be unavailable when the trip is actuated.

Table 1: Trip actuation times at plutonium peak (milli-s)

		Case A	Case B	
	103% FP	Boron 4.303 ppm	Gadolinium 1.255 ppm	Case (B-A)
SDS1	ROP	628	625	-3
	LOG	520	517	-3
SDS 2	ROP	628	625	-3
	LOG	690	687	-3

The reactor trip actuation times for the case of using boron and gadolinium as poison in the moderator system are given Table 1 for the initial power level of 103% FP. Note that the trip actuation occurs for the case of boron and gadolinium in the moderator system with -3 ms time differences which would be practically negligible. In other words, using either boron or gadolinium does not make any significant differences as far as the trip actuation times are concerned.

In Table 2 the trip actuation times are given for 103% and 50% initial FP. The SDS1/2 ROP trip actuation times for Case B are considerably longer compared to Case A. This is obvious due to the fact that for the same reactivity insertion rate the lower initial power level transient takes longer to have the flux distribution to reach the trip set point. For the LOG trip actuation times the differences are -13 and -26 ms for SDS1 and SDS2, respectively.

Table 2: Trip actuation times for the different power levels at plutonium peak (s)

		Case A 103% FP ~1.75 mk/s	Case B 50% FP ~1.85 mk/s	
		Boron 4.303 ppm	Boron 4.345 ppm	Case (B-A)
SDS1	ROP	628	2013	1385
	LOG	520	507	-13
SDS 2	ROP	628	2014	1386
	LOG	690	664	-26

In Table 3 the power transients with boron and gadolinium as poison in the moderator system are given for 103% initial FP until the relative power runs down below 1.

Table 3: Power transient with boron and gadolinium as poison at plutonium peak

	Case A		Case B
103% FP	Boron 4.303 ppm		Gadolinium 1.255 ppm
Time (s)	Rel. Power	Time (s)	Rel. Power
0.00	1.000	0.00	1.000
0.28	1.043	0.28	1.043
0.43	1.086	0.43	1.086
0.51	1.111	0.51	1.110
0.74	1.197	0.74	1.196
0.86	1.248	0.86	1.247
0.94	1.285	0.94	1.284
1.02	1.324	1.01	1.324
1.11	1.371	1.10	1.371
1.17	1.395	1.17	1.395
1.30	1.355	1.30	1.355
1.36	1.286	1.36	1.286
1.41	1.202	1.41	1.203
1.51	1.001	1.51	1.002
1.56	0.902	1.56	0.903

As can be seen the difference in power transients between Case A and B virtually reveals no significances and the same behavior is also found for the dynamic reactivity transients.

The power transients with the SDS1 trip actuations are graphically shown in Figure 1 for Case A – 103% initial FP – and Case B – 50% initial FP. Note that the relative power for Case B is normalized by 103% FP. As expected the transient for Case B lasts longer by about ~1.52 s to have the power pulse run down below 1. The power pulse reaches the peak value of ~1.395 at t=~1.17 s and ~2.070 at t=~2.69 s for Case A and B, respectively. The time interval to reach the peak power after the trip actuation is found to be 542 and 674 ms for Case A and B, respectively and during these time periods the power increased by 25% and 91% FP. It is here to add that in reality the SDS1 trip actuation will occur based upon rather LOG than ROP trip.

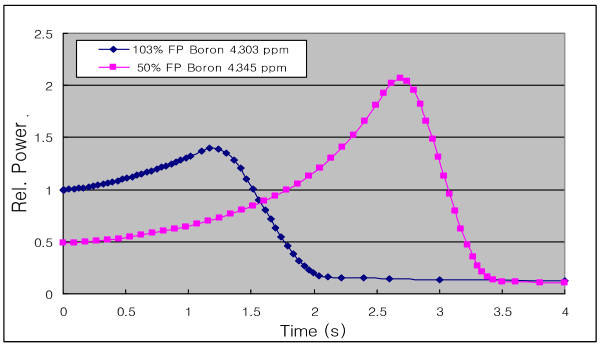

Fig. 1. Power transient for 103% and 50% initial FP

In Table 4 the dynamic reactivity behavior after the full insertion of SORs into the core is shown for Case A and B. The average value for the given time period is -62.91 and -58.77 mk for Case A and B, respectively. Note that Case A predicts the dynamic reactivity on average about ~-4.14 mk more compared to Case B due to the different rate of positive reactivity worth insertion into the core.

Table 4: Dynamic reactivity after full insertion of SORs into the core at plutonium peak

	Case A 103% FP ~1.75 mk/		Case B 50% FP ~1.85 mk/s
Time (s)	Dynamic Reactivity (mk)	Time (s)	Dynamic Reactivity (mk)
2.221	-63.80	3.606	-59.62
2.400	-63.29	3.800	-59.15
2.600	-62.75	4.000	-58.65
3.000	-61.81	4.400	-57.66

4. Conclusions

Base upon the results obtained in the present study it can be concluded that the power transient using either boron or gadolinium as poison in the moderator system reveals practically similar behaviors and the power pulse for the 50% initial FP case is more pronounced in the peak power value and the transient period compared to the 103% initial FP case at plutonium peak.

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