Transactions of the Korean Nuclear Society Spring Meeting
Pyeongchang, Korea, May 27-28, 2010

Analysis of Wolsong-1 SDS1 Effectiveness with Stuck-In Shutoff Rod Core Configurations

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1. Introduction

The Wolsong-1 CANDU 6 reactor (W-1) is currently undergoing the major refurbishment project including replacement of the pressure tube after nearly 25 years of service. In parallel to the refurbishment, the reactor is planned to be operated with Improved Technical Specifications (ITS) that are being prepared as an integrated part of the new project to conduct the overall Improved Standard Technical Specifications (ISTS) layout for PHWR (Ref. 1).

The ISTS project is dually purported, namely, firstly, to improve and update the existing Current Technical Specifications (CTS) with the specific emphasis of rooting the conceptual and practical applications that are derived out of the PWR oriented TS so that PHWR could be operated in more closely surveillant practices with PWR domestically, and secondly, the finished ISTS product could also be exposed overseas for global marketing purposes.

During the course of reviewing the draft version of the W-1 ITS it is felt that ITS Items related to the unavailability of Shutdown System No. 1 (SDS1) should be supported with some detailed analysis performed by using the safety analysis codes as a precautionary measure. The present paper deals with the cases of SDS1 shutoff rod (SOR) stuck into the core so that the stuck rod will not be available when SDS1 is actuated to drop rods into the core. In the following, the models used for the simulations are briefly described and the corresponding results are presented with some conclusions.

2. Background of Safety Aspects

The increase of system reactivity with coolant voiding, typically, in the case of Loss-Of-Coolant-Accident, is much of concern for CANDU reactors since its inception as power reactor. In order to cope with the system reactivity increase in accidental situations, two independently designed and geometrically separated Shutdown Systems #1 and #2 (SDS1/2) of the W-1 reactor, which consist of 28 SORs and 6 poison (gadolinium) tanks, respectively, function with the complete independence. The conservatism of the safety analysis results for SDS1 is emphasized by assuming as initial condition that, e.g., two most effective SORs, say, #4 and #8, would be unavailable out of 28 rods. In the same way, the W-1 Limiting Condition of Operation (LCO) prescribed in ITS dictates that 26 SORs out of 28 rods shall be available to be dropped into the core.

In view of the above-mentioned aspects, a question would arise whether or not a condition that all 28 SDS1 SORs shall be hung outside the core all the times must be included in LCO. In other words, from the core physics view point the quantitative understanding of the SDS1 reactivity worth is required if the condition is violated by any situation, e.g., that SOR is stuck into the core while the reactor is on power. The purpose of the present study addresses itself to the comparison of the SDS1 reactivity worth between the normal state and the other cases where the core configuration is characterized by stuck SOR into the core.

3. Models, Simulation Results and Discussions

Two cases are considered, namely, SOR #4 and #8 stuck into the core. These two SORs are selected as the most effective ones, as earlier mentioned in Section 2, so that the conservatism of safety analysis is preserved.

3.1 Reference Case – Nominal Configuration

The core model including the SOR drop curve are the same ones as they were used for the W-1 LOCA analyses. The initial condition with 100% Full Power (FP) operation corresponds to the equilibrium core state at 7968 FP Days (FPD), and the distributed liquid zone controller (LZC) levels are used with the average level of 49.52%. The RFSP-IST (Ref. 2) core model has 48x36x34 mesh spacings in x-, y- and z-direction, respectively. The simulations are performed by using the space-time dependent Improved Quasi-Static (IQS) method based kinetics code, the CERBERUS module of RFSP-IST. The reactivity worth of SDS1 is assessed by performing the transient simulations without any insertion of positive reactivity, i.e., power rundown as a result of SOR insertions into the core. The transient lasted for 1.593 seconds until SORs are fully inserted into the core.

In this nominal core configuration with all 28 SORs initially hung outside the core in their normal positions, SDS1 is actuated with SORs #4 and #8 are missing to be dropped. The coordinates of SORs #4 and #8 are x_1=511.438, x_2=540.013 y_1=-531.550, y_2=-17.200, z_1=100.465 and z_2=150.465, and x_1=597.162, x_2=625.737, y_1=-560.125, y_2=-74.350, z_1=146.125 and z_2=196.360 centimeters, respectively.

3.2 Case A – SOR #4 Stuck-In and Adjuster Bank #1 Withdrawn

The reactor is operated with the adjuster bank #1, rod #s 1, 7, 11, 15 and 21, withdrawn out of the core so that the system reactivity could be sustained to Reference Case. The reactor power is derated to 93% FP and the spatial and bulk control are activated in order to redetermine the core power distribution based upon the reference zonal power distribution that is obtained from the time-average model design calculations. The LZC levels are also redistributed with 54.41% average level.

3.3 Case B – SOR #8 Stuck-In

The reactor is operated without adjuster removal at 100% FP and the system reactivity is sustained to Reference Case by activating the spatial and bulk control so that the core power distribution could be redetermined based upon the reference zonal power distribution. The LZC levels are also redistributed with 32.09% average level.

In Table 1 the results of steady-state simulations are summarized for all three cases to show the effect of core configuration changes. The spatial and bulk control keep the RFSP-IST calculated excess system reactivity within ~0.1 mk difference which is acceptable value for usual core physics simulation practices.

Table 1 Power Redistribution due to Core Configuration Change

Case (% FP)	Ref. (100)	A (93)	B (100)
1.0-1/k_{eff} (mk)	-0.504	-0.508	-0.423
Max. BP (kW)	798.2 H06/6	846.9 M05/6	830.1 H06/6
Max. CP (MW)	6.636 H08	6.909 L06	6.904 H08
Max. Ripple	1.028 C11	1.067 L11	1.075 C11

The maximum bundle and channel powers of Case A and B are increased by about ~4% with an exception that MBP experiences about ~6% increase for Case A. In other words, the local flux peak is clearly pronounced due to adjuster removal beside the overall flux tilt in the core caused by SOR stuck-in. The maximum ripple change behaves similarly compared to MCP changes. As can be seen, the MBP and MCP of Case A and B are below the licensing limits of 935 kW and 7.3 MW, respectively.

The dynamic behavior out of the SDS1 power rundown simulations are compared in Table 2 as the transient results are obtained by using the CERBERUS module of RFSP-IST.

Table 2 Transient Behavior of Relative Power and Dynamic Reactivity

	Reference Case		Case A		Case B	
Time (s)	Rel. Power	Dynamic Reactivity (mk)	Rel. Power Diff.*	Reactivity Diff.+ (mk)	Rel. Power Diff.*	Reactivity Diff.+ (mk)
0.000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.100	1.0000	0.0100	0.0000	-0.0100	0.0000	0.0000
0.200	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.300	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.388	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.477	0.9982	-0.0600	0.0751	0.0000	0.0000	0.0000
0.542	0.9857	-0.3900	0.0741	0.0000	-0.0005	-0.0200
0.608	0.9533	-0.8700	0.0719	0.0100	-0.0015	-0.0400
0.674	0.9015	-1.5300	0.0684	0.0200	-0.0031	-0.0600
0.734	0.8390	-2.3300	0.0643	0.0300	-0.0048	-0.0900
0.785	0.7752	-3.2500	0.0600	0.0500	-0.0062	-0.1100
0.834	0.7075	-4.2300	0.0554	0.0500	-0.0071	-0.1300
0.885	0.6375	-5.2300	0.0502	0.0500	-0.0075	-0.1400
0.934	0.5733	-6.4500	0.0449	0.0300	-0.0072	-0.1500
0.981	0.5135	-7.9200	0.0393	-0.0100	-0.0066	-0.1500
1.026	0.4573	-9.7200	0.0337	-0.1000	-0.0057	-0.1700
1.069	0.4050	-11.9000	0.0281	-0.2200	-0.0048	-0.1800
1.113	0.3541	-14.6900	0.0225	-0.3900	-0.0040	-0.2000
1.160	0.3050	-18.2500	0.0177	-0.5900	-0.0033	-0.2400
1.208	0.2615	-22.9100	0.0142	-0.8500	-0.0028	-0.3300
1.255	0.2247	-28.9600	0.0116	-1.2000	-0.0026	-0.5100
1.296	0.1962	-36.3000	0.0099	-1.6600	-0.0025	-0.8000
1.332	0.1735	-45.0900	0.0086	-2.2500	-0.0025	-1.2800
1.369	0.1544	-55.1000	0.0077	-3.0200	-0.0025	-1.9700
1.415	0.1397	-65.0700	0.0070	-3.8400	-0.0024	-2.8000
1.486	0.1305	-72.2800	0.0067	-4.4800	-0.0023	-3.4700
1.593	0.1258	-75.1700	0.0065	-4.8100	-0.0022	-3.7500

* Diff. = (Case A/B-Reference Case)
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The relative power for Case A increases by 7.33%, (0.9982+0.0751)/0.93=1.0733, at t=0.477 s compared to the initial power, in contrast to Reference Case. However, this increase corresponds to the net increase of 0.0733*93=6.82% FP. Thus, the actual reactor power level is 99.82% FP, so that the consequences of power increase of Case A are practically negligible. The relative power transient for Case B is effectively same as in Reference Case and the differences between two cases are less than 1% throughout the transient.

As mentioned earlier in Section 2, the dynamic behavior of Case A/B is much of concern to confirm whether or not the SDS1 effectiveness would be deteriorated due to stuck-in SOR into the core.

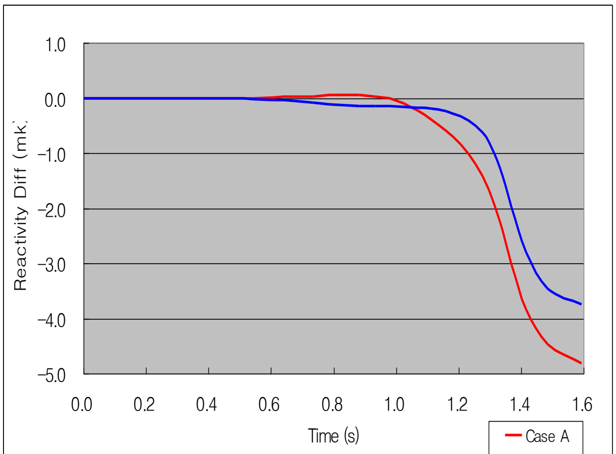

Figure 1 Dynamic Reactivity Difference

The simulation results of the reactivity transient are given in Table 2 and also graphically displayed in Figure 2. Similar to the power transient, the dynamic reactivity for Case A increases initially compared to Reference Case and reaches its maximum value of 0.05 mk between t=0.785~0.885 s. This increase of 0.05 mk dynamic reactivity is again practically negligible and conveys no consequential meaning to the effectiveness of SDS1. For Case B one can observe that the dynamic reactivity transient behaves again similarly to the power transient and the reactivity decreases monotonically in contrast to Case A.

Note that the reactivity value of Case A drops below the value of Case B at t=1.069 s, turning point, and from that time point the Case A reactivity runs down much faster than in the Case B reactivity rundown, and in the end of the transient the reactivity reaches the lowest value of -4.810 and -3.750 mk for Case A and B, respectively, with a difference of -1.06 mk. It is interesting to observe that the effectiveness of SDS1 for the core configurations with stuck-in SOR is actually enhanced. This phenomenon can be attributed to the fact that the neutron importance is relatively more concentrated in the central high flux region resulting from the distorted flux shape caused by the given core configurations.

4. Conclusions

The present study has shown that the effectiveness of the W-1 SDS1 increases slightly with the stuck-in SOR core configurations.

5. Acknowledgements

The authors wish to express their appreciations to D.H. Chung, ACT, for the CERBERUS simulations.

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