Wolsong-1 Reactor Power Pulse Simulations with Stuck-In Shutoff Rod at Plutonium Peak

Young-Suk Jung[a*], Hyung-Jin Kim[a], Seong-Soo Choi[a] and Sung-Min Kim[b]
[a]*Atomic Creative Technology Co., Ltd.*
[b]*Korea Hydro and Nuclear Power Co., Ltd.*
[*]*Corresponding author: youngsuky@actbest.com*

1. Introduction

The power pulse of the Wolsong-1 CANDU 6 reactor (W-1) is studied here for the case with a shutoff rod (SOR) stuck into the core (Ref. 1). Since the reactor will be restarted in spring 2011 after the major refurbishment project including replacement of the pressure tube, the study is conducted with boron in the moderator system at plutonium peak in order to gain an insight into the power pulse behavior resulting from the abnormality of initial conditions.

The reactor can be in operation even with a stuck-in SOR into the core. Nevertheless, it is felt that such an abnormal situation should be analyzed further in details to cope with an accidental case, e.g., corresponding to the insertion of positive reactivity worth into the core that leads to power excursion.

In the present paper the technical background of consequences resulting from the presence of boron in the moderator system at plutonium peak is briefly reviewed in the context of safety aspects for the situation of stuck-in SOR. After that the model used for the simulations is described and the simulation results are discussed and some conclusions are drawn.

2. Background of Safety Aspects

The safety analysis of the W-1 reactor is conducted for the case of Loss-Of-Coolant-Accident (LOCA) using the space-time dependent kinetics code CERBERUS, which is a module of RFSP-IST (Ref. 2), in order to follow the power excursion and dynamic reactivity transient.

Although the shutdown system of the W-1 reactor consists of two independently designed and geometrically separated Shutdown System #1 and #2 (SDS1/2), the simulation of LOCA power pulse is usually carried out using SDS1 based upon the consideration that SDS2, which consists of 6 poison (gadolinium) tanks, exerts larger negative reactivity worth into the core so that the LOCA simulation results obtained with the actuation of SDS1 can be accepted as more conservative results.

For the SDS1 LOCA analysis further conservatism is emphasized adopting the initial condition that, e.g., two most effective SORs, say, #4 and #8, are not available out of 28 SORs so that only the remaining 26 SORs are actuated for being dropped into the core. This situation is postulated in the W-1 reactor Limiting Condition of Operation (LCO) for the Improved Technical Specifications (ITS) by dictating that 26 out of 28 SORs shall be available for being dropped into the core.

During the course of LCO layout, a question arose whether or not the condition that all 28 SDS1 SORs should be available all the times for being dropped into the core must be included as LCO in ITS. The concern is derived from the consideration that the negative reactivity depth being exerted into the core could still be sufficient enough to shut down the reactor safely for a situation that, e.g., a SOR is stuck into the core while the reactor is on power. In such case the differences in the SDS1 dynamic reactivity worth behavior between the cases that the normal state and the other state where the core configuration being characterized by stuck-in SOR into the core are used as initial conditions should be analyzed in details.

Although the LOCA analyses are mainly conducted for the cases of typical Reactor Inlet/Outlet Header (RIH/ROH) breaks that result in multiple channel coolant voiding, the case of a single channel in-core break also results in the insertion of positive reactivity worth into the core when the core system reactivity is balanced with the inclusion of poison in the moderator system before the in-core break. In this case, the reactivity increase due to the coolant voiding in a single channel that is caused by the dilution of poison concentration due to the intrusion of hot coolant into the moderator volume and moderator temperature increase would not be as significant as in the case of multiple channel coolant voiding resulting from the RIH/ROH breaks. However, the single channel in-core break case could be more clearly understood by studying the power pulse behaviors with boron in the moderator system, which is the topic of the present paper.

The moderator temperature reactivity coefficients are positive for fresh fuel with boron in the moderator system and equilibrium fuel. Based upon these considerations, the power pulse analyses are conducted here for the W-1 reactor at plutonium peak when the boron concentration in the moderator system would have the maximum value during reactor operations.

3. Models, Simulation Results and Discussions

The RFSP-IST/CERBERUS core model used for the transient simulations consists of 48x36x34 mesh spacings in x-, y- and z-direction, respectively. The SOR #8 is assumed to be stuck into the core while the reactor is on power and the remaining 27 shutoff rods (SOR) are initially hung in the reactivity mechanism deck outside the core. The SOR #4 is assumed to be unavailable and only 26 SORs are actuated for being dropped into the core on trip to shut down the reactor.

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 so that the excessive core system reactivity due to the plutonium buildup would take the peak value and the core system reactivity is balanced with about ~4.150 ppm boron in the moderator system with SOR #8 stuck into the core. The initial power level is assumed to be 103% FP with 100% FP = 2016.4 MW (th) and the spatial and bulk control generated the distributed zone levels for 14 zone controller compartments with 49% average fill.

The uniform decrease of coolant densities in time at 12 bundle positions of 380 channels is postulated in order to simulate the positive reactivity worth insertion into the core so that the core system reactivity increase would approximately correspond to ~1.7 mk/s. For the comparison purposes the transient simulation is also performed for the case with the same initial condition as the above-described one but the SOR #8 being parked outside the core. In the later core state the boron concentration is turned out to be about ~4.303 ppm to balance the core system reactivity with the average 50% fill of 14 uniform zone levels.

In order to compare the transient behavior of the cases for two different initial conditions with and without stuck-in SOR, the reactor trip actuation times and the power transient simulation results are given Table 1 and 2, respectively.

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

		Case A	Case B	
		SOR #8 Stuck-In #4 Missing	SOR #8 Missing #4 Missing	Case (B-A)
	Boron (ppm)	4.150	4.303	
SDS1	ROP	426	628	202
	LOG	518	520	2
SDS 2	ROP	442	628	186
	LOG	689	690	1

Table 2: Power transient with and without stuck-in SOR at plutonium peak

	Case A		Case B
	SOR #8 Stuck-In #4 Missing		SOR #8 Missing #4 Missing
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	1.084	0.43	1.086
0.62	1.148	0.63	1.151
0.66	1.163	0.67	1.166
0.81	1.226	0.82	1.230
0.97	1.283	0.94	1.285
1.03	1.278	1.11	1.371
1.10	1.240	1.17	1.395
1.16	1.175	1.30	1.355
1.21	1.097	1.36	1.286
1.26	1.008	1.41	1.202
1.31	0.913	1.46	1.106
1.36	0.824	1.51	1.001
1.41	0.740	1.56	0.902

Note that the actuation of SDS1/2 of Case A occurs 202 and 186 ms earlier compared to Case B for ROP trips due to the localized peaks of flux shapes in the core caused by the stuck-in SOR and distributed zone levels. For LOG trips the results practically show no differences between Case A and B.

As expected the power pulse of Case A turns over earlier than Case B due to the earlier trip actuation as given in Table 1. The maximum relative peak power for Case A is 1.283 at t=0.97 s whereas it is 1.395 at t=1.17 s for Case B. The peak power of Case A is about ~8% less compared to Case B peak power. The relative power becomes lower than 1 at t=1.31 s for Case A, which is about ~250 ms earlier compared to Case B.

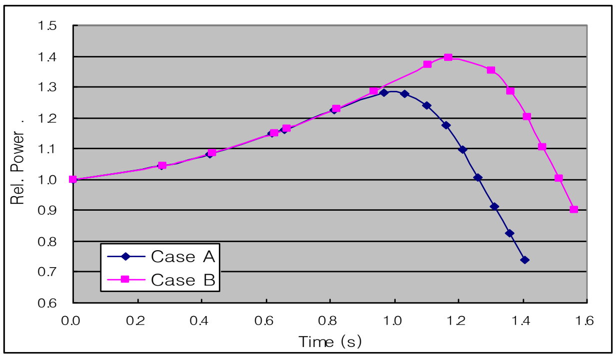

Fig. 1. Power transient with and without stuck-in SOR at plutonium peak

The power transients are graphically displayed in Figure 1. Note that the power pulse drop curves run down nearly in parallel after the peak due to the overwhelming exertion of negative reactivity worth by the insertion of SORs into the core.

The dynamic reactivity behavior after the full insertion of SORs into the core is given in Table 3 until t=3.0 s for Case A and B. The average value for the given time period is -68.34 and -62.91 mk for Case A and B, respectively. It is interesting to note that Case A predicts on average about ~-5.47 mk more compared to Case B due to the delayed neutron holdback effects. The initial flux shape of Case A exerts more neutron importance during the transients studied here.

Table 3: Dynamic reactivity after full insertion of SORs into the core at plutonium peak

	Case A		Case B
Time (s)	Dynamic Reactivity (mk)	Time (s)	Dynamic Reactivity (mk)
2.019	-69.63	2.221	-63.80
2.300	-68.78	2.400	-63.29
2.600	-68.00	2.600	-62.75
3.000	-67.10	3.000	-61.81

4. Conclusions

Based upon the results obtained in the present study by the CERBERUS power pulse transient simulations for the case of reactor operations of the W-1 reactor with a SOR stuck into the core at plutonium peak, it could be concluded that the given situation would not add any concerns to the power pulse related safety issues.

5. Acknowledgements

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

REFERENCES

[1] "Analysis of Wolsong-1 SDS1 Effectiveness with Stuck-In Shutoff Rod Core Configurations", H.J. Kim, Y.S. Jung, S.S Choi and S.M. Kim, Proceedings of Spring Meeting, KNS, Pyeong-Chang, Korea, May 27-28, 2010.

[2] B. Rouben, "RFSP-IST, The Industry Standard Tool Computer Program for CANDU Reactor Core Design and Analysis", Proceedings of the 13th Pacific Basin Nuclear Conference, Shenzhen, China, Oct. 21-25, 2002.