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The Impact of Fuel Temperature Reactivity Coefficient on Loss of Reactivity Control Accident

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1. Introduction

Nuclear reactors experience small power fluctuations or anticipated operational transients during even normal power operation. During normal operation, the reactivity is mainly controlled by liquid zone controllers, adjuster rods, mechanical control absorbers, and moderator poison. Even when the reactor power is increased abruptly and largely from an accident and when reactor control systems cannot be actuated quickly due to a fast transient, the reactor should be controlled and stabilized by its inherent safety parameter, such as a negative PCR (Power Coefficient of Reactivity) feedback.

A PWR (Pressurized Water Reactor), it is well designed for the reactor to have a negative PCR so that the reactor can be safely shut down or stabilized whenever an abrupt reactivity insertion into the reactor core occurs or the reactor power is abruptly increased. However, it is known that a CANDU reactor has a small amount of PCR, as either negative or positive, because of the different design basis and safety concepts from a PWR [1]. CNSC's regulatory and safety regime has stated that; "The PCR of CANDU reactors does not pose a significant risk. Consistent with Canadian nuclear safety requirements, nuclear power plants must have an appropriate combination of inherent and engineered safety features incorporated into the design of the reactor safety and control systems. A reactor design that has a PCR is quite acceptable provided that the reactor is stable against power fluctuations, and that the probability and consequences of any potential accidents that would be aggravated by a positive reactivity feedback are maintained within CNSC-prescribed limits." [2]

Recently, it was issued licensing the refurbished Wolsong unit 1 in Korea to be operated continuously after its design lifetime in which the calculated PCR was shown to have a small positive value by applying the recent physics code systems, which are composed of WIMS-IST, DRAGON-IST, and RFSP-IST. These code systems were transferred from AECL (Atomic Energy Canada Limited) to KHNP (Korea Hydro and Nuclear Power) for a full scope safety analysis of the refurbished Wolsong unit 1. Even though the recent physics code systems are well developed, uncertainties of the calculated physics or safety parameters still exist. To see how much PCR uncertainty exists in the calculation, the PCR at the full power condition has been indirectly measured in the Wolsong units and its measurement and analysis uncertainties were evaluated [3]. It was shown that the maximum values of the PCR during normal operation were estimated to be about four-times the calculated PCR of the refurbished Wolsong unit 1.

This study presents a sensitivity assessment of LORC (Loss of Reactivity Control) accident events to investigate the impact of a higher PCR (based on the measured positive maximum value) than the reference value (based on the calculated value) on a safety analysis.

2. Calculation Model

The analysis has used the thermal-hydraulic code CATHENA, and the LORC event was selected as a bounding case for reactivity insertion accidents of the Wolsong unit 1. It showed that the major contribution to the PCR is the coefficients related to changes in the reactivity coefficients of the fuel, coolant, and moderator. Because the PCR is not an independent input parameter into the reactor models, the effect of variation in the overall PCR can be evaluated by increasing the reactivity coefficients of the fuel, coolant, and moderator. On the other hand, if the FTC (Fuel Temperature Reactivity Coefficient) has a positive value, during normal operation, which is different from the previous results, and the reactivity insertion accident is initiated, the positive FTC can help increase the reactor power most abruptly in terms of a very fast reactivity feedback compared to the other reactivity parameters such as the reactivity coefficients of the coolant and moderator temperature. Hence, the assumption to be the higher FTC than the reference value (calculated value) could result in most severe or conservative in terms of the fast reactivity feedback.

Recently, the measured PCRs were estimated by investigating not only the results of an 'On-Load Valve (OLV) Test', which has been performed regularly at each quarter year at the Wolsong units, but also the results of new power maneuvering tests for the power to be perturbed small as 2% because the OLV test process turns out to have too large a power fluctuation due to the rather big power reduction of about 5%. The indirect measurement of the PCR showed a range of -6.81pcm/%p to +8.02pcm/%p, including the measurement and analysis uncertainties [3]. However, the reference value, which has been calculated for the safety analysis of the refurbished Wolsong unit 1, was 1.7pcm/%p [4]. With a comparison of the measured and reference values, it was shown that the maximum positive PCR is over four-times the reference value (ref. PCR).

To assess the maximum impact of the PCR on LORC, it was assumed that the FTC is four-times the ref. FTC based on a comparison of the measurement and reference PCRs. The typical data of the assumed FTC shown in Fig. 1, was compared to the ref. FTC. Also, it was assumed that the curve of the assumed FTC is the same as the reference value below the reference fuel temperature of 687℃, and is four-times the ref. FTC of over 687℃ for more conservatism.

In the LORC event of a CANDU-6, it is known that the maximum physical reactivity insertion rate is 0.35mk/s assuming that all reactivity control mechanisms malfunction simultaneously in the same direction at their maximum speeds. Hence, in the present study, five cases of reactivity insertion accidents, 0.0001mk/s, 0.01mk/s, 0.1mk/s, 0.25mk/s, and 0.5mk/s, were considered at 103% full power.

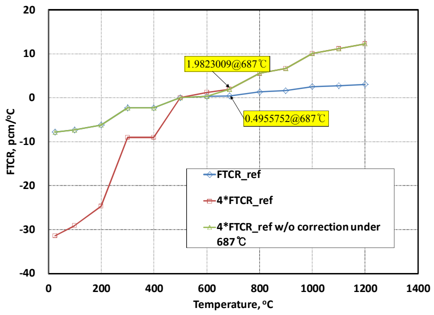


Fig. 1 Assumed hypothetical FTC for a typical zone of core

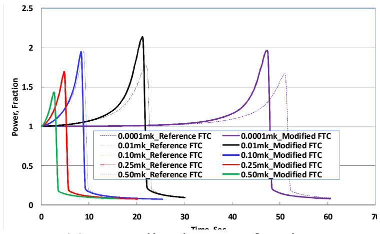
3. Results and Discussion

The FTC among the physics parameters affecting the PCR was selected, and multiplied the ref. FTC by four to assess the effect of the maximum measured PCRs on LORC accidents. The results of LORC accidents for the 4*ref. FTC were compared with those of the ref. FTC, and show in Fig. 2 and their trip types and times are summarized in Table 1. The analysis results show a similar system response for the above five simulated cases. For the ref. FTC at 103% full power with 0.0001mk/s and 0.01mk/s reactivity insertions, the HNP (High Neutron Power) trip is the primary trip signal followed by the HP (High Heat Transport System Pressure) trip, while the HNP trip is the primary trip signal and followed by the RAT (Rate of Neutron Power Increase) trip for the 0.1mk/s and 0.25mk/s reactivity insertions, and the RAT trip is the primary trip signal followed by the HNP trip for a 0.5mk/s reactivity insertion. For the 4*ref. FTC with five reactivity insertions, on the other hand, the trip types are very similar to the reference case of the FTC, except the RAT trip as the second trip signal at 0.01mk/s. The trip times of the 4*ref. FTC for all cases were a litter earlier than those of the ref. FTC as expected.

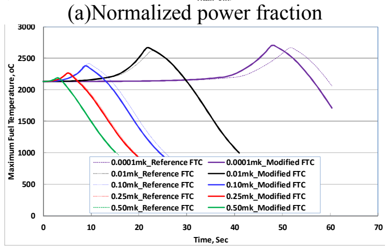
The normalized power fractions and peak fuel temperatures for 4*ref. FTC were compared to those for the ref. FTC in Figs. 2 (a) and 2(b), respectively. As shown in Fig. 2, the normalized peak power fraction of 4*ref. FTC with 0.0001mk/s is 1.9609 and 1.6589 for the ref. FTC. For 0.01mk/s reactivity insertions, the peak power fraction is 2.1359 for the 4*ref. FTC and 1.7771 for the ref. FTC. But, the normalized peak power for the 4*ref. FTC with 0.1mk/s, 0.25mk/s, and 0.5mk/s reactivity insertions were very similar to those of the ref. FTC.

On the other hand, the peak fuel temperatures for 4*ref. FTC were almost the same as for the ref. FTC. It may be explained that the stored energy for 4*ref. FTC is quite similar to that for the ref. FTC, even when the normalized power fractions for both cases are a little different. The small difference in trip times, the peak reactor powers, and the peak fuel temperatures support the idea that the effect of the higher FTC due to the fast and large reactivity feedback on safety, which reflects the PCR being higher, is insignificant.

From the present impact assessment of the higher FTC on the LORC events with several reactivity insertions, it was noted that the reactor can be shutdown properly with the safety shutdown systems of SDS1 and SDS2 even when considering the higher PCR attributed to a high FTC multiplied by four.



(a)Normalized power fraction



(b)Peak temperature of fuel centerline

Fig. 2 Transient behavior after accident initiation for 103% FP

Table 1: Comparison of trip types and times of 4*ref. FTC and ref. FTC

Reactivity Insertion Rate	103% Full Power				
	Reference FTC		4*Reference FTC		Ratio (Fraction)
	Trip Type	Trip Time (s)	Trip Type	Trip Time (s)	
0.0001mk/s	SDS1HNP	42.6765	SDS1HNP	38.9765	
	SDS1HP	48.619	SDS1HP	44.2185	
	SDS2HNP	42.6765	SDS2HNP	38.9765	
	SDS2HP	**50.6874**	**SDS2HP**	**46.8303**	
NormalPeak Power	1.6569		1.9609		**1.183**
0.01mk/s	SDS1HNP	13.9765	SDS1HNP	13.1765	
	SDS1HP	19.0177	SDS1HP	17.8175	
	SDS2HNP	13.9765	SDS2HNP	13.1765	
	SDS2HP	**21.6272**	**SDS2RAT**	**20.6644**	
Normalized Peak Power	1.7771		2.1359		**1.202**
0.1mk/s	SDS1HNP	4.0765	SDS1HNP	3.9765	
	SDS1RAT	7.0594	SDS1RAT	6.5589	
	SDS2HNP	4.0765	SDS2HNP	3.9765	
	SDS2RAT	**8.3594**	**SDS2RAT**	**7.7589**	
Normalized Peak Power	1.9516		1.9468		**0.998**
0.25mk/s	SDS1HNP	2.3128	SDS1HNP	2.3126	
	SDS1RAT	2.9128	SDS1RAT	2.8626	
	SDS2HNP	2.3128	SDS2HNP	2.3126	
	SDS2RAT	**4.3817**	**SDS2RAT**	**4.2126**	
Normalized Peak Power	1.7011		1.6944		**0.996**
0.5mk/s	SDS1RAT	1.2265	SDS1RAT	1.2265	
	SDS1HNP	1.5265	SDS1HNP	1.5265	
	SDS2HNP	1.5265	SDS2HNP	1.5265	
	SDS2RAT	**2.1297**	**SDS2RAT**	**2.0962**	
Normalized Peak Power	1.4385		1.4317		**0.995**

4. Conclusion

The impact of the 4*ref. FTC on the LORC accidents was assessed. Even if the best estimated values of FTC or PCR are assumed to be higher than the reference values in considering the uncertainties in the reference values of FTC or PCR, which were calculated during a safety analysis of the refurbished Wolsong unit 1, we can conclude that the impact of the higher FTC or higher PCR on the LORC accidents is insignificant if the trips of the SDS1 and SDS2 can be initiated and actuated as designed. Moreover, the reactor can also be properly shutdown for any kind of hypothetical reactivity insertion accident, as it does not exceed to safety limitation.

REFERENCES

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[3] Y.H. Kim, Power coefficient assessment of a CANDU using measurement data, KAERI/CM-1547/2011, April, 2012.
[4] Revised Physics Design Manual (Draft) of Wolsong Unit 1, KHNP, in publishing, 2012.