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LBLOCA Analysis and Its Sensitivity Study Using Coupling (CATHENA and RFSP) Method for Wolsong NPP Unit 1

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1. Introduction

For refurbished Wolsong NPP Unit 1, the Power Pulse used in the LBLOCA safety analysis was calculated by coupling method with CATHENA and RFSP codes. In this analysis for the aged core of 11 EFPY (Effective Full Power Year), ROPT (Regional Overpower Protection Trip) setpoint of 115.5% instead of 122% suitable to fresh core was used, which would result in reduction of LOE (Limit of the Operating Envelop). Therefore, it is necessary to quantitatively assess the possibility that the ROPT setpoint of 122% can be acceptable for even the aged core.

In order to do so, a rigorous sensitivity study for LBLOCA crucial to ROP trip setpoint limiting LOE was performed for several parameters such as ROP setpoint, core horizontal side-to-side power tilt and initial ROH quality. Finally, representative results of this analysis and its related sensitivity study are presented.

2. Methods and Results

Power increase mechanism in LBLOCA is attributed to increase of CVR (Coolant Void Reactivity) resulted from quick pressure drop and void increase. Generally in order to analyze the comprehensive phenomena like LBLOCA in detail, it is required to couple neutron physics and thermal-hydraulic code as shown in Fig.1 for the calculation of local CVR and core TH conditions, respectively [1,2]. In this section, therefore, a coupling method, some constraints related to initialization, safety criteria and sensitivity parameters are explained briefly.

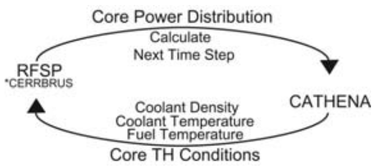

Fig.1. Simple diagram of coupling

2.1 Coupling Method

Whereas the local coolant density (and temperature) and fuel temperature are calculated in CATHENA, power distribution in the core is calculated in RFSP using IQS(Improved Quasi Static) method [3,4]. And then each code input was generated from its own template files whose appropriate parts could be replaced with alternatively calculated results. For instance, core power distribution provided from RFSP is inserted into CATHNEA template file for next time step. After the execution of CATHENA, core TH conditions are inserted into RFSP template file for an update of power distribution resulted from CVR. The above procedure is repeatedly continued until the transient time is completely elapsed.

All procedures related to coupled calculation was performed automatically utilizing rfspcb.pl as a script file based on perl script domain [5]. Power pulse calculation would be terminated within a few seconds and might be extended to 200 s for other purpose.

2.2 Initialization

On initialization, first step is TH steady-state calculation with CATHENA during about 2000 s and then update power distribution with RFSP under the TH conditions at the last time step. With updated power distributions, TH calculation is redone like the first step until relative difference in local power distribution would be decreased below a predefined range, say, 1%.

In doing so, the initial core horizontal power tilt, which is normally controlled by LZC (Liquid Zone Controller) level, is required to be set as high as possible in order to postulate severe accident cases. Furthermore, the so-called density-scaling factor is calculated based upon the best (WIMS-1.6 mk) or biased (WIMS+2.1 mk) estimate of CVR deviation [2].

2.3 Safety Criteria and Sensitivity Parameters

Three potential measures of shutdown-system effectiveness are maximum fuel centerline temperature, margin to fuel break-up and margin to prompt criticality. Additionally ROP margin to trip at every detector must be greater than 8% to accommodate power ripple.

In the present paper, the sensitivity study was carried out for ROP trip setpoints (115.5, 122, 124%), core power tilts (4%, 6%) and initial ROH qualities (0.84, 1.12, 1.57, 2.24%), respectively.

2.4 Analysis Models and Cases

35% break at RIH and 55% break at PSH were determined as the most limiting cases and labeled as RIH-35% and PSH-55%, respectively. In this paper, these two cases are used as the models for analysis. And for each case, BE(Best Estimate) as well as Biased case are employed to see the effect of CVR uncertainty. Analysis models and cases are summarized in Table I.

Table I: Model and analysis cases

Model	RIH-35%	PSH-55%
Initial power level	94%FP, same as the base case	
ROPT setpoint	115.5%, 122%, 124%	
Tilt	4%, 6%	
ROH quality	0.84%, 1.12%, 1.57%, 2.24%	
Uncertainty in CVR	BE, Biased Case	

2.5 Results

Fig.2 shows the power pulses with the different ROP trip setpoints, which are all the same. Because the RLOG (High Rate Log Neutron Power) trip triggered secondly after ROP trip was regarded as an effective trip parameter for conservatism. The sensitivity results for power tilt are in Fig.3 to 5. The maximum power difference between 4% and 6% tilt was less than 10%. Trip time for 6% tilt was slightly faster and peak fuel temperatures were stayed far below its criterion, 2840℃. And margin to ROP trip (>8%), prompt criticality (>ε) and fuel break-up were satisfied sufficiently as shown in Fig.4, Fig.5 (right) and given in Table II, respectively.

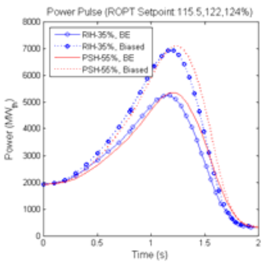

Fig.2. Power pulse vs. ROP setpoint

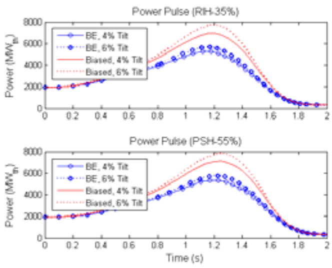

Fig.3. Power pulse vs. horizontal core power tilt

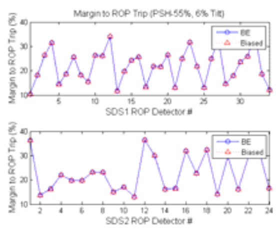

Fig.4. Margin to trip indicated at detector

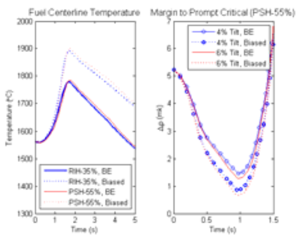

Fig.5. Fuel temperature(L) & margin to criticality(R)

Table II: Related margins to horizontal power tilt, 6%

Model	Uncertainty	Margin to	
		Prompt criticality	Fuel break-up
RIH-35%	BE	1.34 mk	23.2 %
	Biased	0.71 mk	15.5 %
PSH-55%	BE	1.28 mk	22.5 %
	Biased	0.67 mk	14.5 %

The results of sensitivity studies for ROH quality are displayed in Fig.6 and 7. Fig.6 (left) shows the initialized ROH qualities determined by tuning of the correction factor which can control the heat transfer rate to secondary loop. Fig. 6 (right) indicates the density-scale (void weighting factor) appropriate to uncertainty applications, BE or Biased. The factor, density-scale, is likely to be proportional to ROH quality. Fig. 7 (left) shows the power pulses of LBLOCA initiated from different ROH quality from 0.84 to 2.24%. As ROH quality is higher, power pulse has a little bit higher peak and trip time becomes faster shown in Fig. 7 (right).

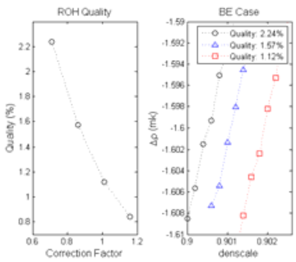

Fig. 6. ROH quality vs. correction factor(L) & Δρ vs. density-scale (R)

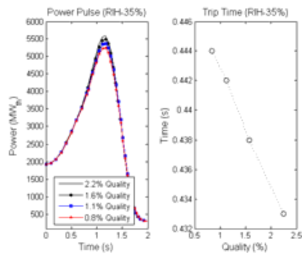

Fig. 7. Power pulse(L) & trip time vs. ROH quality(R)

3. Conclusions

LBLOCA analysis for two representative models, RIH-35% and PSH-55%, and its related sensitivity study for ROP trip setpoint, horizontal core power tilt and ROH quality have been rigorously performed.

According to the results, trip time and power pulse would not be affected in spite of increase in the ROP trip setpoint. Because the effective trip parameter would be still RLOG trip which occurs later than ROP trip.

From the results related to core power tilt change into 6%, RLOG trip time is a little bit faster than 4% of tilt. The peak in power pulse for BE and Biased with 6% of tilt is 10 % and 15% higher than those with 4% of tilt, respectively. Nevertheless, safety criteria such as margin to trip, prompt criticality, and fuel break-up described in 2.3 were satisfied. Additionally it was found that power pulse was affected by the initial ROH quality, however, not so much, and major safety parameters were remained within all criteria related to safety.

As a result, ROPT setpoint of 122% used for the fresh core of refurbished WS-1 can also be applied for 11 EFPY aged core.

REFERENCES

[1] R.D. McArthur, W.E. Ross, Simulation of CANDU 6 LLOCA Power Transients Terminated by SDS1 with a Full 2-Energy-Group Coupled RFSP-IST/CATHENA Approach, CNS Sixth International Conference on Simulation Methods in NE, Montreal, Quebec, Canada, Oct. 2004

[2] D. Morris, Part A: Large Loss of Coolant in the Primary Circuit with Safety System Available, 59REF-03500-AR-029-Vol. 1, Rev. 3, Feb. 2010

[3] P. Schwanke, RFSP-IST Version REL_3-04: Users' Manual, 153-117360-UM-002, Dec. 2006

[4] T.G. Beuthe, CATHENA MOD-3.5d/Rev 2 Input Reference, 153-112020-UM-001, Rev. 0, Aug. 2005

[5] McArthur Randall, RFSPCB Ver. 2.0.0 Application Manual: Users' Manual, CW-117370-UM-001, Oct. 2007, AECL