Establishment of Safety Basis for Power Maneuvering in CANDU NPP

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1. Introduction

A safety basis for nominal operating condition is well established in CANDU6. But at off nominal condition like shim operation and startup after shutdown, safety basis for adjuster movement and power limit is not well developed. In this paper safety basis for operation at off nominal condition is established in CANDU6 NPP.

2. Power limit considering adjuster configuration

2.1. Introduction to ROP

Unique feature of CANDU6 is the concept of time-average power shape which is target power distribution operator is trying to maintain whenever he does on-line fuel reloading and movement of control devices. Uncontrolled local power increase in core is prevented by regional over power (ROP) trip. Design basis for ROP trip is a slow loss of reactivity control (LORC) transients from any of a large number of potential precursor flux-shapes or device configuration. To ensure coverage of all such flux-shapes, a comprehensive set of flux-shapes are simulated using RFSP code.

2.2. Modeling of adjuster configuration

The movement of adjuster makes local increase of core flux and deviation from time-average power shape. So adjuster movement induced scenarios from ROP flux shape set are reviewed and core power limit for each scenario is developed. Three kind of adjuster configuration is considered in this paper: start-up after short shutdown, startup after poison-out and shim operation. When operator trys to go back full power within 30 minutes after shutdown, he has enough control device to overcome negative reactivity from xenon. The increase of xenon from shutdown makes the level of liquid zone controller (LZC) drop to 20% low limit and all adjuster withdrawn from core. To go back from zero power to full power, positive reactivity induced from xenon depletion is compensated by adjuster insertion. 21 adjusters are grouped into 7 banks and inserted in sequential order from bank 7 to bank 1. Flux distribution for adjuster bank 7 inserted is shown in Figure 1 and it represents relative distribution from time-average power shape at ROP detector position. Startup after poison out is same as startup after short shutdown except for xenon equilibrium. Shim operation is also considered for simulating fuel handling machine failure without shutdown. In this case adjuster is withdrawn to compensate reactivity loss from fuel loading failure.

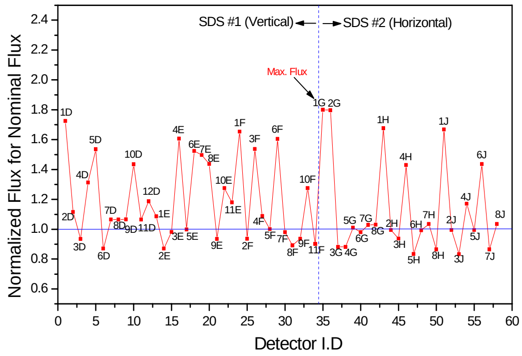

Figure 1. Flux response of ROP detectors (with adjuster bank7 inserted)

2.3. Power limit

The flux distribution for the three kind of adjuster configuration considered above are analyzed. To bound the local flux within time average power shape, core power is limited as eq.(1) and the results are shown in Table 1.

$$\%FP_{LIM} = \frac{\%FP_{Reactor}}{[\Phi_{case} / \Phi_{nom}]_{\max}} \qquad (1)$$

Table 1. Power limit vs adjuster configuration

Withdrawn Bank	Startup after Short shut-down(%FP)	Startup after poison out(%FP)	Shim operation (%FP)
1	85.7	93.3	92.9
2	78.4	89.3	89.1
3	72.9	85.7	85.7
4	67.0	79.6	78.9
5	63.7	76.8	77.1
6	62.9	74.9	75.3
7	55.6	63.6	63.9

3. Channel power limit

Safety analysis for CANDU6 type plant is performed on the conservative assumption that maximum channel power is 7.3MW. And at power less than 100%, linear relationship between core power and permissible maximum channel power is assumed. For example, limiting channel power is 5.84MW, 80% of 7.3MW when core is operating at 80%FP. But there is no specific safety basis for the linear relationship. Operator has difficulty in having confidence for his operation. In this paper, channel power limit at low power is established.

3.1. Regulatory constraint

Consultative documents,C-144[1], describes the criteria for the acceptability of the trip parameters to prevent fuel failures and consequential failures of the pressure tubes. If the maximum fuel sheath temperature is less than 800^{O}C and duration of post-dryout operation is less than 60 seconds, it is believed that the fuel deformation will be small, and thus fuel elements will not contact and cause failure of the pressure tube. So the secondary trip parameter on each shutdown system shall prevent :

- fuel sheath temperature from exceeding 800^{O}C
- the duration of post-dryout operation from exceeding 60 second.

3.2. Thermal-hydraulic behavior

For the loss of forced flow accident(LOFA), the effective trip parameters for SDS1 are coolant low flow trip and coolant high pressure trip, and for SDS2 coolant low differential pressure trip and coolant high pressure trip. Trip time for Coolant low flow of SDS1 and coolant low differential pressure of SDS2 does not change much as power decreases, but coolant high pressure of SDS1 and SDS2 is sensitive to core power. Delayed trip time for coolant high pressure at low core power can affects fuel integrity. To assure fuel integrity, limiting channel power for the loss of forced flow accident is analysed at low core power.

The Trip time for the loss of forced flow accident is shown in Table 2. Dryout time, maximum fuel sheath temperature and the time maximum temperature reached for different channel powers at 73%FP are shown in Table 3. As channel power increases, dryout starts earlier and maximum fuel sheath temperature increases. Upto channel power of 7.0MW, fuel sheath temperature is below 800^{O}C. So channel power 7.0MW is set for limiting channel power for 73%FP including some uncertainty.

Table 2. Effettive trips and trip time for LOFA

Core power	Trip parameter	Trip time (sec)
73%FP	SDS1 coolant low flow	5.58
	SDS2 low differential press.	6.08
	SDS1 coolant high press.	6.28
	SDS2 low differential press.	7.83

Table 3. Fuel channel behavior vs channel power

Channel Power (MW)	Dry out time (sec)	Max. fuel sheath Temp (C)	Time of max. temp. (sec)
5.83	7.72	339	8.91
6.50	5.85	646	7.65
7.00	3.70	755	7.66

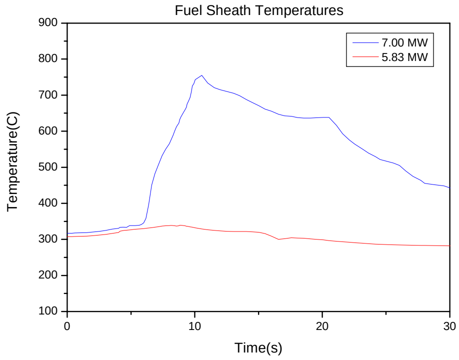

Figure 4. Fuel sheath temperature behavior

3.3. Channel power limit

Four additional low power thermal-hydraulic model is developed and trip time is analyzed. Channel power limit is determined at four powers levels below 100%FP as shown in Figure 3. It is shown that in the view of operation, more flexible maneuvering space is achieved through safety analysis .

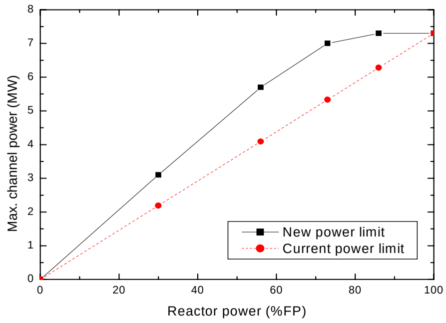

Figure 3. Channel power limit vs core power

6. Conclusion

The safety basis of core power limit for startup after short shutdown, startup after poison-out and shim operation at different adjuster configuration is defined. And channel power limit for less than 100%FP is determined through analysis of loss of force flow accident. From this study, current channel power limit has enough safe margin and more flexible operation can be possible by utilizing the margin in CANDU6 core.

REFERENCES

[1] C-144(E), Proposed Regulatory Guide ‘Trip Parameter Acceptance Criteria For the Safety Analysis of CANDU Nuclear Power Plants’, AECB,1997.

[2] C-6, Requirements for the Safety Analysis of CANDU NPPs, 1980.

[3] R-8, Requirements for Shutdown Systems for CANDU NPPs, 1991.

[4] 86-03310-DM-000 rev1, CANDU6 Generating Station Physics Design Manual, AECL, 1995