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Development of Steady-state Thermal-hydraulic Model for Wolsong-3

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1. Introduction

CANDU6, Pressurized Heavy Water Reactor (PHWR) has Regional Overpower Protection (ROP) system composed of 58 self-powered in-core flux detectors grouped into 3 channels of two independent Shut-Down Systems. The failure of an in-core flux detector can trip the reactor if it is not repaired within 1 week. But it is possible to operate the reactor with appropriate penalty for the failed detector without reactor trip. Full scope of ROP analysis was done to quantify the detector failure penalty for Wolsong-3. The condition of primary heat transport system (PHTS) is important to calculate Critical Channel Power (CCP). To assess the current condition of primary heat transport system, a steady-state thermal-hydraulic model is developed.

2. CANDU6 PHTS description

The core of CANDU6 is subdivided into two symmetrically located figure of eight loops. Each loop consists of two core passes of 95 channels each. Each pass contains a pump which feeds an inlet header which is connected to 95 inlet feeders which connect to the channels as described above. The 95 outlet feeders connect to an outlet header. Two riser pipes connect the outlet header to the hot leg side of a steam generator. Coolant flows through the vertical steam generator U-tubes to the steam generator outlet where it flows to the pump suction line of the pump in the other core pass in the loop. Because it is a figure of eight loop, flow in channels in one core pass is in the opposite direction to the other. The two Heat Transport System (HTS) loops are connected at each end of the reactor through the pressurizer interconnect line and the purification and feed interconnect lines. The pressurizer is connected to the discharge pipes of outlet headers 3 and 7. The purification feed flow is associated with inlet headers 2 and 6, while the purification return flow enters the HTS at the suction of pumps 1 and 3. The HTS also contains stability pipes which connect outlet headers 1 and 3 in loop 1, and outlet headers 5 and 7 in loop 2(See Figure 1).

3. ROP System description

ROP trip is one of the reactor trip parameter. The purpose of ROP system is to prevent the intermittent dryout at fuel clad due to over-power brought by slow loss of reactivity control or daily refueling. Vertically installed 34 detectors give signal to Shut-Down System No. 1 and horizontally installed 24 detectors give signal to SDS No.2. These two SDS are physically independent. Detectors in each system are arranged into 3 channels. If two channels of them are detecting overpower, ROP system will initiate SDS (See Figure 2).

4. Aging phenomena

Increasing of pressure tube diameter due to irradiation creep reduces the hydraulic resistance in the channel, hence increases flows, but causes the coolant to preferentially bypass the interior subchannels of the bundle, reducing CCP. Because there is more creep in the higher power channels, there is a flow redistribution effect whereby some of the flow from the outer low power channels is redirected to inner channels. This mitigates the effect of pressure tube diametral creep on CCP for the central, ROP most limiting channels.

Hydraulic resistance is increased due to redistribution of magnetite in the HTS. Dissolution of iron and flow accelerated corrosion (FAC) is occurring in the outlet feeders. Iron is being removed from the outlet feeders and being re-deposited in the cold part of the circuit, including the cold leg of the steam generators, the inlet feeders, and possibly the first section of the channel. The magnetite layers cause both a fouling of the inside of the steam generator tubes, leading to reduced heat transfer, and also an increase in hydraulic resistance in the steam generator tubes and inlet feeders. This has a negative effect on core flow, on inlet header tempera-ture and, consequently, on CCP [1].

5. Thermal-hydraulic model

NUCIRC is a steady-state thermal-hydraulic code used by designers and analysts to examine the behavior of the HTS of a CANDU nuclear reactor over a wide range of single-phase and two-phase operating conditions. NUCIRC employs a forward marching iterative method to solve the conservation of mass and energy equations for steady, incompressible flow of Newtonian fluids[2].

Plant operating data at around 80%FP are logged to develop single phase thermal-hydraulic model and data at 100%FP are gathered to confirm the ability of model to simulate single or two phase operating condition. The single phase data can be acquired during stat-up after outage. Single phase operating data acquired on Feb. 24, 2006(2597EFPD) and two phase operating data on Mar. 2(2602EFPD) are used for modeling of Wolsong-3 PHTS.

Geometry data of HTS come from CANDU-6 generic design data. To consider pressure tube diametral expansion, creep rate on the position of each bundle of all channels should be prepared. Wolsong-1's creep prediction and measurement data was used due to Wolsong-3's few measurement data.

NUCIRC, modularized computer code, can consider each sub-system independently and integrally. Modeling starts from below header model, purification system model and steam generator model and merge them into one integrated model. The integrated model includes fuel channel, feeder, header, steam generator, pump and interconnecting pipes. Information from sub-system model is used to make integrated full circuit model and fine tuning is needed.

6. Simulation results and Conclusion

The most representative parameters of HTS condition are temperature of reactor inlet header(T_{RIH}), pressure of reactor outlet header(P_{ROH}) and differential pressure between inlet and outlet header($\Delta P_{Header\text{-}to\text{-}Header}$). Thus, those parameters are the measure of assessing the practicability of the model. Table 1 shows the simulation results of single-phase and Table 2 shows those of two-phase. This thermal-hydraulic model for Wolsong-3 simulates the current operating condition of data acquisition point accurately and can be used as CCP analysis model to calculate the detector failure penalty calculation for ROP system of Wolsong-3 reflecting the aging effects such as pressure tube diametral creep.

References

[1] W.J. Hartmann and M. Cormier, "Plant Aging Adjustments to Maintain Reactor Power at The Point Lepreau Generating Station", The 5th International Conference on CANDU Maintenance, 2000 Nov.

[2] D.J. Wallace, "NUCIRC Program Abstract and Theory Manual", TTR-765 Rev. 2, AECL, 2003 June.

Table 1 Simulation results of single-phase

Parameter	Site Data	NUCIRC Data	Error(%)
PROH(MPa(a))			
Pass23	9.958	9.962	0.04%
Pass41	9.970	9.939	-0.31%
Pass67	9.970	9.977	0.06%
Pass85	9.980	9.961	-0.20%
Δ P H-H(kPa)			
Pass23	1274.04	1274.05	0.00%
Pass41	1236.19	1236.83	0.05%
Pass67	1259.49	1259.52	0.00%
Pass85	1257.93	1257.11	-0.07%
TRIH(℃)			
Pass23	261.86	262.10	0.09%
Pass41	263.65	263.35	-0.11%
Pass67	261.85	262.04	0.07%
Pass85	263.62	263.39	-0.09%

Table 2 Simulation results of two-phase

Parameter	Site Data	NUCIRC Data	Error(%)
PROH(MPa(a))			
Pass23	9.959	9.965	0.06%
Pass41	9.971	9.946	-0.25%
Pass67	9.971	9.973	0.02%
Pass85	9.980	9.957	-0.23%
Δ P H-H(kPa)			
Pass23	1290.22	1299.42	0.71%
Pass41	1259.74	1272.70	1.03%
Pass67	1274.00	1275.61	0.13%
Pass85	1272.59	1278.30	0.45%
TRIH(℃)			
Pass23	262.45	263.45	0.38%
Pass41	264.40	264.76	0.13%
Pass67	262.52	263.01	0.19%
Pass85	264.32	264.77	0.17%

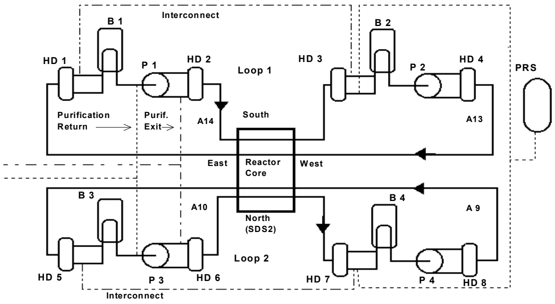

Figure 1 Primary Heat Transport System

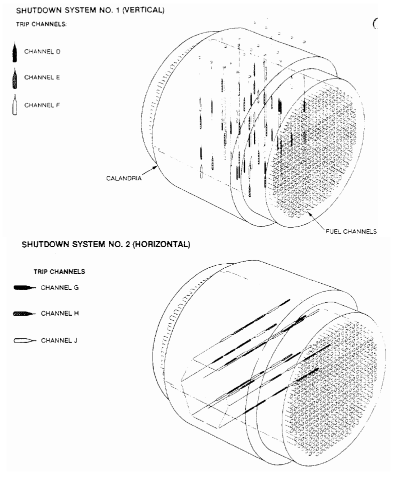

Figure 2 Detector Layout of ROP System