MODTURC_CLAS Analysis for Minimum Subcooling of Moderator in CANDU6

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1. Introduction

This paper presents the results of moderator circulation simulations for the CANDU6 reactor after a large reactor inlet header (RIH) break. The analysis was performed to facilitate the assessment of fuel channel integrity following pressure tube (PT) and calandria tube (CT) contact by estimating the subcooling available for the inlet header break scenario. The simulation was performed with the 3D code MODTURC_CLAS V2.9-IST [1,2] developed by Ontario Power Generation.

2. MODTURC_CLAS Analysis

2.1 Code Description

MODTURC_CLAS (MODerator TURbulent Circulation Co-Located Advanced Solutions) V2.9-IST is a 3D computational fluid dynamics code. The major part of the code is written by AEA Technology Engineering Software Ltd. (AEAT) in Waterloo, Canada. The basic governing equations are those of continuity, momentum and energy. Other equations describing a wide range of physical phenomena are also built into the code, e.g., turbulence models, buoyancy forces, etc. The flow equations are strongly coupled and highly non-linear.

2.2 Analysis Scope

A steady state analysis under normal operating conditions is first performed to determine the initial condition for the subsequent transient analysis for a 40% RIH break. The analysis is undertaken for a loss of Class IV power (LOCL4) during the LOCA without emergency core cooling (ECC) and steam generator crash cooling (SGCC).

2.3 Main Assumptions

Two assumptions are used for the LOCA/LOCL4 scenario as follows: 1) crediting the pony motor flow for the duration of the transient after pony motor flow is initiated, and then 2) crediting the operator to start the main moderator pump at 990 seconds after the start of the accident.

- Class IV power is assumed to be unavailable at 15 seconds after the break.
- The main moderator pump is assumed to rundown to zero rpm linearly over a period of 60 seconds.
- 15 seconds after termination of main moderator pony motor pump flow to the moderator is 255 kg/s, equally distributed to the 8 inlet nozzles.
- 195 seconds after the loss of Class IV power service water flow is restored to the heat exchangers.
- At 1000 seconds main moderator pump flow is re-established. Main moderator flow is assumed to increase from 0 to 940 l/s over the period 990 to 1000 seconds.
- The MODTURC_CLAS moderator temperature controller (MTC) model calculates the moderator inlet temperature considering the changes of moderator flow and capability of heat exchangers.

The computational grid has a butterfly-shaped grid structure in the core region. There are 13 x 4 cells in the circumferential direction and 38 cells in the axial direction (Fig. 1).

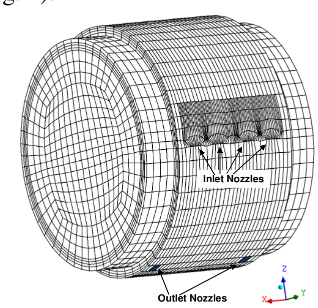

Fig. 1. 3D View of Grid for Moderator Tank.

3. Steady State Calculations

The main thermal-hydraulic parameters in the moderator tank were converged to the design values through 4,086 iterations as shown in Fig. 2. With the moderator heat load of 100 MW, a total inlet flow of 940 *l*/s and outlet temperature of 69℃ as design values, the calculated inlet temperature is 45.7℃. The maximum temperature of the moderator fluid is 82℃, which gives a minimum subcooling of 27℃.

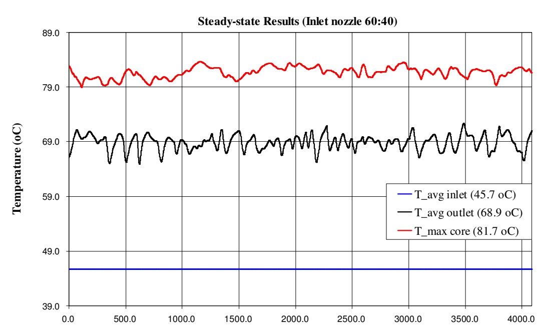

Fig. 2. Steady-state results.

4. Transient Calculations

The transient simulation was done for 1580 seconds showing the calculation results on the Y-Z plane perpendicular to x-axis (x = 1.5, 3.0, and 4.5) and on the plane along the x-axis (y = 0.0).

At 60 seconds buoyancy effects become dominant and thermal stratification starts to develop as the moderator inlet flow is decreased. It creates a counter clockwise flow of the moderator inside the calandria shell (Y-Z plane). This circular flow generates a hotspot, which is pushed towards the upper side of the core.

From 75 to 90 seconds (for 10 seconds), when there is no flow through the inlet nozzles, the dominant forced flow is replaced by the buoyancy flow until the moderator pony motors with 25% of the main pump flow start. The buoyancy effect enhances the thermal stratification and the natural circulation of moderator inside the calandria shell.

From 100 to 195 seconds, 25% of the main pump flow is maintained by the pony motors. However, the inlet temperature is about 70℃ since the moderator heat exchanger is not available yet. The jets from the inlet nozzles are very weak to penetrate the hotspot (they rather help to keep the hotspot at its final position near the top of the core). The cold jets just after entering the calandria flows directly towards the outlet nozzles at bottom.

Since the moderator heat exchanger is available after 195 seconds, the inlet temperature decreases to about 40℃, and this cold injection flow is downward along the calandria shell wall and it lowers the temperature of moderator at bottom side. The cold injection flow is continuously increasing the temperature gradient of moderator.

As time progresses the temperature of the upper zone of the moderator increases continuously due to continuous addition of heat by the PT/CT contact (Fig. 3).

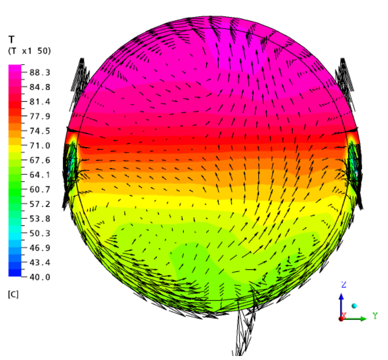

Fig. 3. Distribution of Moderator Temperature and Velocity (x=1.5 m, t = 900.0 sec).

When the main pump is restarted at 1000 seconds, the moderator flow is increased up to 100% of the main pump flow. At this time the moderator heat exchanger cannot lower the inlet temperature. The jets from the inlet nozzles become strong to penetrate the hotspot. These jets, both from left and right sides of nozzles, meet in the mid-plane of the core. The flow is then downward in the middle of the core, flowing through outlet nozzles or recirculating by buoyancy force.

The lowest subcooling is found after restarting the main pump. The lowest subcooling available is 17℃ (Fig. 4).

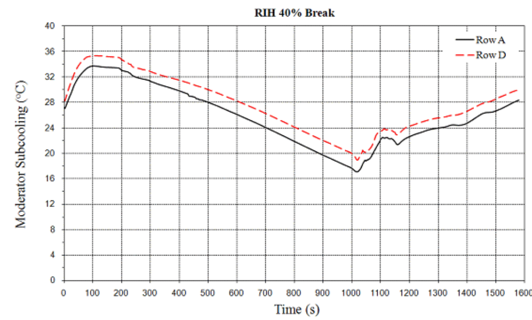

Fig. 4. Prediction of moderator subcooling.

The analysis is performed only up to 1580 seconds, when the moderator heat load is decreasing and there is no PT/CT contact any more.

5. Conclusions

A 3D simulation of CANDU6 moderator circulation behaviour after a large reactor inlet header break with loss of Class IV power was performed.

When Class IV power was lost, the pony motors with 25% flow of the main motors can not deliver sufficient flow to remove the heat input from PT/CT contact. As a result the temperature of the top portion of the moderator inside the calandria vessel increases continuously during the post-blowdown phase. Due to increase of local moderator temperature the minimum subcooling is decreases until the main moderator pump flow is restarted at 1000 seconds. The lowest subcooling found at this time is 17℃, which is higher than the prediction (13℃) by PHOENICS code for Wolsong 2 [3].

REFERENCES

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[3] P. Soedijono, W.M. Collins, and T. De, “Moderator Analysis for In-Core and Out-of-Core Loss of Coolant Accident (LOCA)”, 86-03500-AR-052, Appendix C.I: Details of PHOENICS2 Steady State and Large LOCA Transient Analysis, 1995.