Moderator Circulation Simulation for 35% Reactor Inlet Header Break in the Wolsong Nuclear Power Plant

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1. Introduction

The objective of this study is present the results of moderator circulation simulations by the CFD code MODTURC_CLAS V2.9-IST [1,2] for the refurbished Wolsong unit 1. The present simulations were performed for a loss of Class IV power during a Large Break Loss Of Coolant Accident (35% inlet header break) without ECC injection and steam generator crash cool-down (LOCA/LOECC/LOCC). 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.

2. MODTURC_CLAS Analysis

2.1 Channel Integrity

The assessment of channel integrity requires the evaluation of moderator temperature surrounding the calandria tubes at the time of PT/CT contact to ensure the subcooling requirement is met. Channels downstream of critical-sized breaks can result in PT ballooning early in the transient, while the primary circuit pressure is high, even prior to ECC signal initiation. For LOECC, the late fuel and pressure tubes' heat-up will result in pressure tube sagging (for pressure tubes that do not balloon into contact). The number of contacted pressure tubes, their timing and locations of contact will impact the resultant heat load to the moderator and available subcooling.

2.2 Subcooling Requirement

Figure 1 presents the subcooling requirement curve [3] for early heat-up due to PT/CT ballooning contact that was obtained using experimental results from full-scale tests plotted in terms of subcooling versus pressure tube temperatures at the time of pressure tube/calandria tube contact.

The subcooling requirement curve passes through points of (790°C, 23°C) and (840°C, 26°C) for pressure-tube contact temperature and moderator subcooling, respectively.

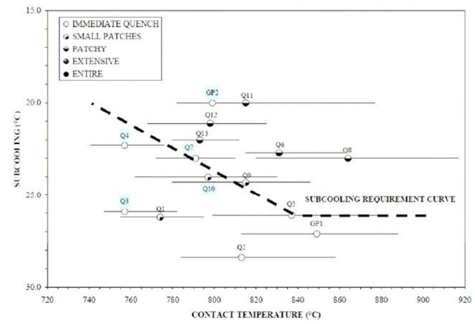


Fig. 1. Subcooling requirement curve.

3. Calculation Results

3.1 Steady-state Results

A steady-state solution is first obtained for reactor normal operation prior to the postulated accident. This solution is subsequently used as the initial condition for the transient analysis. During steady-state calculation of the moderator thermal behaviour, all the maximum core temperature and average core temperature fluctuate proportionally to each other (Fig. 2). Since a reasonable presentation of the steady-state model is best presented by the average value of these fluctuations, the last step of this steady-state solution reflects a maximum core temperature of the calculated average value over the last 5700 iterations. With the moderator heat load of 100 MW, a total inlet flow of 940 *l*/s and outlet temperature of 69°C as design values, the steady-state simulation shows an average value of the maximum temperature in moderator core region of 84°C while the bulk average temperature is 74.3°C.

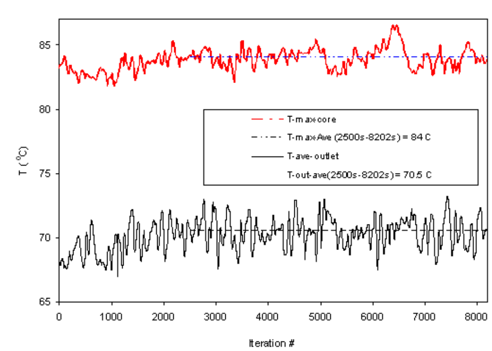


Fig. 2. Temperature variation during steady-state calculation.

3.2 Transient Results

The available subcooling calculated by MODTURC_CLAS analysis with loss of Class IV power is shown in Fig. 3. Before the start of the main pump rundown at 15 seconds, the available subcooling increases mainly due to a substantial decrease of nuclear fission power. At time 15 seconds, when the main pump rundown starts, service water flow to the external heat exchangers stops. Since no heat is taken out of the moderator system before the service water flow to heat exchangers is restored (at 195 seconds), the inlet D_2O temperature rises to the higher outlet temperature. The failure of the heat exchanger means continuation of the moderator inlet flow, but with small moderator heat load, reducing the temperature difference between inlet and outlet temperature. When the service water flow is recovered after 195 seconds, the moderator inlet temperature is decreased to initial value due to heat removal by the moderator heat exchanger. However the inlet temperature is increased again when the inlet flow rate is increased by restarting of the main moderator pump after 1000 seconds.

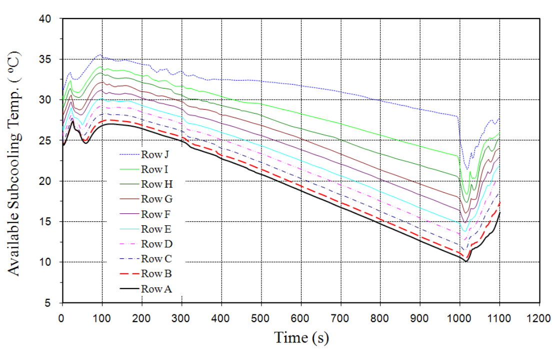
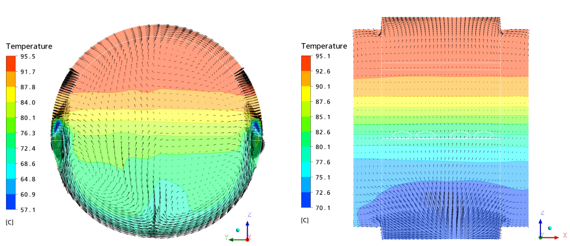


Fig. 4. Available subcooling at rows A to K following a 35% RIH break with LOCA/LOECC/LOCC.

The distributions of moderator temperature and velocity vector [4] are shown in Fig. 5 during the transient state. The transient simulation was done for 1100 seconds showing the calculation results on the Y-Z plane perpendicular to x-axis (x = 3.0) and on the plane along the X-axis (y = 0.0).



x = 3.0 m y = 0.0 m

Fig. 5. Distribution of moderator temperature and velocity at 900 seconds

After 1000 seconds, the moderator flow is fully recovered by main moderator pump and the inlet moderator temperature is increased, more than 60°C. 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 available is 10.1°C at 1015 seconds and the minimum subcooling at the location of PT/CT sagging contact is 13°C at 884 seconds.

4. Conclusions

The moderator subcooling analysis is undertaken for a loss of Class IV power during the 35% inlet header break without ECC and steam generator crash cooling.

When Class IV power is 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 decreased until the main moderator pump flow is restarted at 1000 seconds. In the present study the minimum subcooling at the location of PT/CT sagging contact is shown to be 13°C.

REFERENCES

[1] MacIntosh, S., "User Manual for MODTURC_CLAS V2.9-IST Ontario Power Generation Modules", File No. N-08131.02P, Ontario Power Generation, 2002 August.

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[3] H.Z. Fan, et al., "Enhancement of the Moderator Subcooling Margin Using Glass-peened Calandria Tubes in CANDU Reactors", 30th Annual Conference of Canadian Nuclear Society, Calgary Canada, 2009 June.

[4] H.T. Kim, H.S. Lim, "Moderator Analysis for In-Core and Out-of-Core Loss of Coolant Accident (LOCA)", 59RF-03500-AR-052, Appendix C.I: Details of MODTURC_CLAS Steady State and Large LOCA Transient Analysis, Revision 0, 2009.