COMPARISON OF THE CATHENA MODEL OF GENTILLY-2 END SHIELD COOLING SYSTEM PREDICTIONS TO STATION DATA

G. Zagré[1], G. Sabourin[1] and S. Chapados[2]
[1] Candu Energy Inc., Montréal, Québec, Canada
[2]Hydro-Québec, Montréal, Québec, Canada

Abstract

As part of the Gentilly-2 Refurbishment Project, Hydro-Québec has elected to perform the End Shield Cooling Safety Analysis. A CATHENA model of Gentilly-2 End Shield Cooling System was developed for this purpose. This model includes new elements compared to other CANDU6 End Shield Cooling models such as a detailed heat exchanger and control logic model.

In order to test the model robustness and accuracy, the model predictions were compared with plant measurements.This paper summarizes this comparison between the model predictions and the station measurements. It is shown that the CATHENA model is flexible and accurate enough to predict station measurements for critical parameters, and the detailed heat exchanger model allows reproducing station transients.

1. Introduction

The CATHENA model of the Gentilly-2 End Shield Cooling System was developed based on system design data and a previous CANDU6 model [1]. The exercise of comparing model predictions to station measurements requires the model to be adjusted to realisticparameter values. This is done with plant measurements from a 96% full power (FP) steady state. The model is then tested against steady states measurements at different power levels and power transient measurements.

This paper is organised as follows: Section 2 briefly presents Gentilly-2 End Shield Cooling System; Section 3 presents the CATHENA model; Section 4 discusses the comparison between the model predictions and plant measurements for steady state at different power levels (96%FP, 45% FP and 25% FP); Section 5 and 6 present comparison of the model predictions to station measurements for power rundown and run-up transients.

2. End Shield Cooling System

In CANDU reactors, the shield cooling system removes the heat accumulated in the calandria vault and end shields due to nuclear heating from the reactor core and heat transfer from the fuel channels, heat transport system feeders, and moderator. The other main function of this system is to maintain the calandria vault and end shields full of water sothat they provide biological shielding against radiation during normal operation and shutdown conditions.

The heat from these sources is removed by circulating demineralised water separately through each end shield, each end shield ring and the shield tank, thereby transferring the heat to the recirculating service water system via two heat exchangers. The system diagram is shown in Figure 1.

Inlet temperatures to the shield tanks and end shield rings are controlled by modulating recirculating cooling water flow through the heat exchangers to achieve a constant 49°C process water discharge from the heat exchangers. The end shields inlet temperature is maintained at 60°C by a temperature control valve, which blends a controlled rate of water at 49°C from the heat exchangers with the system return water at approximately 61°C. At full reactor power, the design heat load on the system is evaluated at 6.7 MW(th).

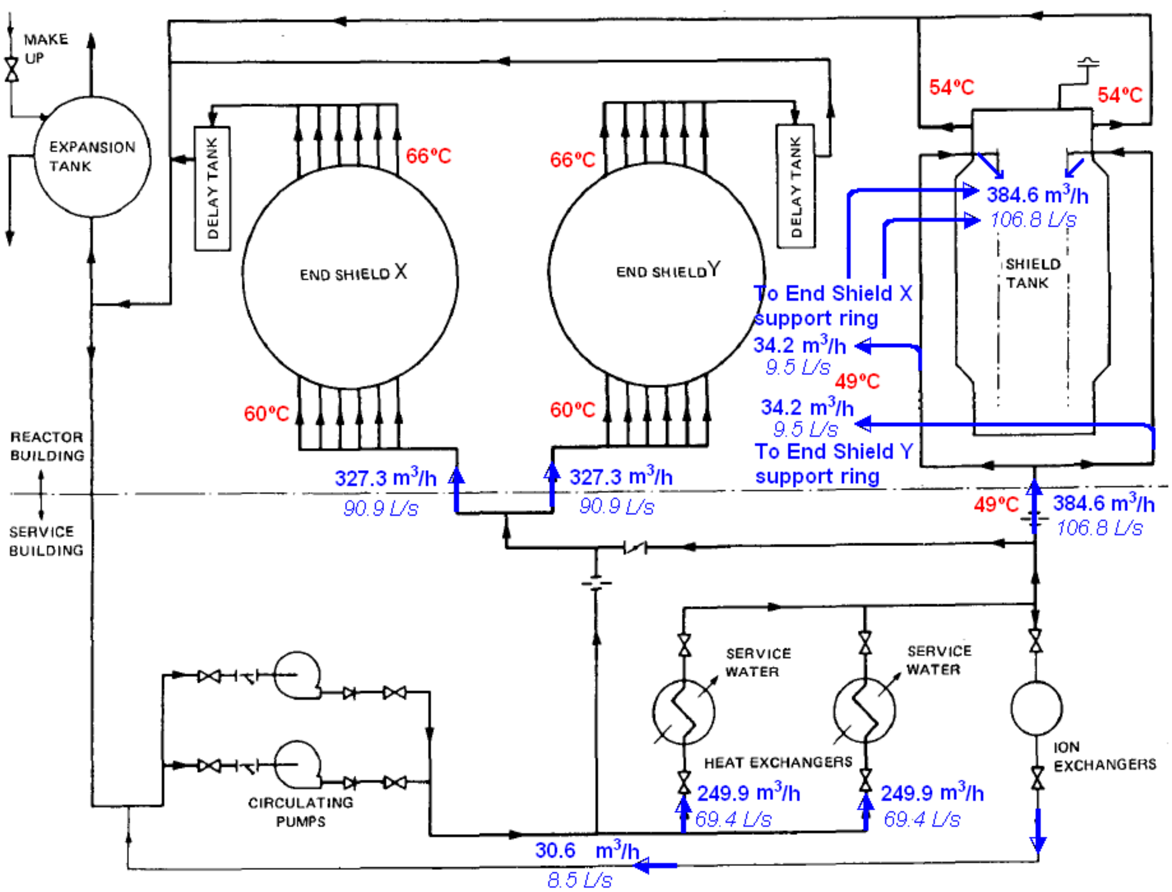

Figure 1 Simplified Diagram of Gentilly-2 End Shield Cooling System with Design Values

3. CATHENA Model of Gentilly-2 End Shield Cooling System

3.1 CATHENA Code

CATHENA is a computer code developed by AECL for analysis of flow transients in reactors and piping networks [2]. It was developed primarily for thermal hydraulic analysis of postulated accident scenarios in CANDU reactors. The CATHENA code includes component models such as pumps, valves, pipes, generalized tank models and point kinetics models, and has extensive control modelling capability. It also contains a GENeralized Heat Transfer Package (GENHTP), which allows heat generation within solid components such as pipes and fuel elements and heat transfer between these components and the surrounding fluid. The version used with this model is CATHENA MOD-3.5d/Revision 2.

3.2 Model description

The CATHENA model of the Gentilly-2 End Shield Cooling System was developed to simulate the response of the end shield cooling system following a loss of heat sink, loss of forced circulation and loss of end shield coolant inventory. The main parameters of interest are those that are related to the assessment of the temperature gradient between the inner (moderator) tubesheet and the outer (fuelling machine) tubesheet.

Figure 2 presents the nodalization diagram of the CATHENA model of Gentilly-2 End Shield Cooling System.

The model includes the end shield cooling system circuit as well as the air pipes and calandria vault cover gas system and represents all the major components of the end shield cooling system including a detailed heat exchanger model with the control logic. The end shield tubesheets, carbon steel balls and lattice tubes are modelled using GENHTP heat structures with the internal heat sources where applicable. The heat sources model the direct neutronic and gamma heating as the reactor operates at full power.

The value of the total heat load to the ESCS is adjusted for the comparison with station data.

3.3 Model Total Heat Load Adjustment for Comparison with Station Measurements

In order to have a realistic model for comparison with Gentilly-2 measurements the CATHENA model parameters are adjusted based on station measurements taken during a 96% FP steady state (see section 4):

- The total heat load to the end shield cooling system is adjusted to 4.9 MW at 100% FP which is representative of the real system heat load at 100% FP. This estimation is based on the system temperature measurement during a 96% FP steady state.

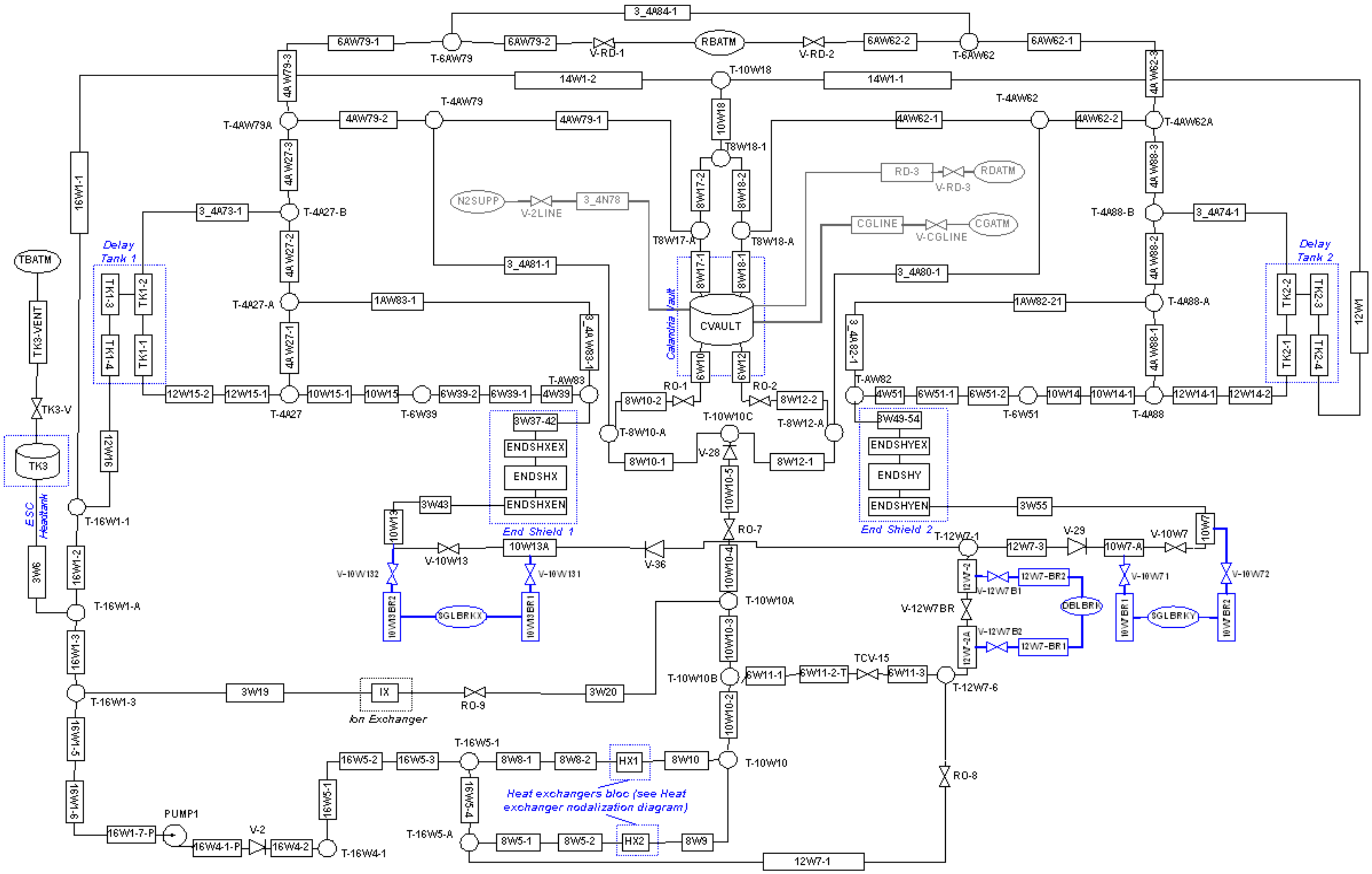

Figure 2 End Shield Cooling System CATHENA Nodalization Diagram

4. Comparison of Steady State Predictions

4.1 Objective of the simulation

The objective of the steady state simulations is to show that the CATHENA model can accurately predict the system thermalhydraulics parameters for different system operating states. The comparison also permits assessment of the accuracy of the assumptions on the system heat load distribution and the detailed heat exchanger model.

4.2 Station data

The station data provided by Hydro-Québec and used for this comparison are steady state measurements of various system parameters at different reactor power levels (96% FP, 45% FP and 25% FP). The 96% FP steady state measurement is used to calibrate the model. For each series of station data, the measurements for the following parameters are available:

- Reactor Power (used as model input parameter),
- Moderator temperature at Calandria Outlet (used as model input parameter),
- Inlet and Outlet headers temperatures (used as model input parameter),
- Calandria Vault and end shields inlet and outlet temperatures (Comparison parameter),
- Level in the Calandria Vault (Comparison parameter),
- Cover Gas pressure (Comparison parameter).

4.3 CATHENA Predictions and Comparison with Plant Measurements

Table 1 presents the results of the 96% FP steady state simulation. The model was adjusted based on the station measurements of this scenario (total heat load to the system and calandria vault inlet temperature). For all the other parameters, the CATHENA results are close to the plant measurements.

Table 1
Comparison between CATHENA Model Predictions and Gentilly-2 End Shield Cooling System Measurements for a 96% FP Steady State

	Station Measurement	CATHENA Prediction
Calandria Vault Inlet Temperature (ºC)	49.6	49.6
Calandria Vault Outlet Temperature (ºC)	53.8	54.0
End Shield Inlet Temperature (ºC)	59.1	58.6
End Shield X Outlet Temperature (ºC)	61.8	62.0
End Shield Y Outlet Temperature (ºC)	61.6	62.0
Calandria Vault Level (mm)	677.7	680.0
Cover Gas Pressure (kPa(g))	10.4	10.4
Pressure Drop Across End Shield X (kPa(d))	174.2	166.2
Pressure Drop Across End Shield Y (kPa(d))	173.4	170.4

Table 2 presents the CATHENA model predictions for the 45% FP steady state. The same adjusted model is used (no further adjustment is done to the model). The moderator temperature and the average headers temperature are used as input parameters. For this case also, the CATHENA predictions are close to the station measurements.

Table 2
Comparison between CATHENA Model Predictions and Gentilly-2 End Shield Cooling System Measurements for a 45% FP Steady State

	Station Measurement	CATHENA Prediction
Calandria Vault Inlet Temperature (ºC)	49.5	49.6
Calandria Vault Outlet Temperature (ºC)	52.5	52.3
End Shield Inlet Temperature (ºC)	56.4	55.9
End Shield X Outlet Temperature (ºC)	58.3	58.5
End Shield Y Outlet Temperature (ºC)	58.0	58.5
Calandria Vault Level (mm)	667.8	662.0
Cover Gas Pressure (kPa(g))	10.4	10.4
Pressure Drop Across End Shield X (kPa(d))	175.6	166.5
Pressure Drop Across End Shield Y (kPa(d))	174.8	170.7

Table 3 presents the CATHENA model predictions for the 25% FP steady state. For this case also, the CATHENA predictions are close to the station measurements.

Table 3
Comparison between CATHENA Model Predictions and Gentilly-2 End Shield Cooling System Measurements for a 25% FP Steady State

	Station Measurement	CATHENA Prediction
Calandria Vault Inlet Temperature (ºC)	49.2	49.6
Calandria Vault Outlet Temperature (ºC)	51.8	51.7
End Shield Inlet Temperature (ºC)	55.3	54.9
End Shield X Outlet Temperature (ºC)	56.6	57.1
End Shield Y Outlet Temperature (ºC)	56.8	57.1
Calandria Vault Level (mm)	664.3	655.0
Cover Gas Pressure (kPa(g))	10.2	10.4
Pressure Drop Across End Shield X (kPa(d))	174.9	166.6
Pressure Drop Across End Shield Y (kPa(d))	174.1	170.8

5. Power Rundown Transient

5.1 Objective of the simulation

The objective of this simulation is to show that the CATHENA model can adequately predict the system behaviour in a case of power rundown transient. This comparison also assesses the heat exchanger control model accuracy and the model assumptions on the different system parameters.

5.2 Station data

Station data provided by Hydro-Quebec for this comparison are plant measurements of Gentilly-2 End Shield Cooling System during a power rundown transient from 87% FP to 0% FP. The same parameters described in section 4.2 are available.

5.3 CATHENA Predictions and Comparison with Plant Measurements

For this scenario, the model adjusted in section 4 with the 96% FP steady state measurements is used (no further modifications are done to the model). The power fraction, the moderator outlet temperature and the headers average temperature are used as input parameters.

Figure 3 shows the CATHENA predictions of Calandria Vault inlet and outlet temperatures, and the comparison of those predictions with plant measurement. During the power decrease, the detailed heat exchanger model and control logic permits the model to keep the calandria vault inlet temperature at 49.5ºC as measured at Gentilly-2. The calandria vault outlet temperature is also close to the plant measurement (the maximum difference is 0.5ºC).

Figure 4 shows the CATHENA prediction of the end shields inlet and outlet temperatures. Once again the CATHENA model predictions are close to the plant measurements. The CATHENA predicted transient is similar to the station transient.

Figure 5 presents the CATHENA prediction of the water level in the Calandria Vault. The predicted transient is similar to the station transient. The maximum difference between both values is less than 10 mm.

Other parameters such as the cover gas pressure and the differential pressure across the end shields are not sensitively affected by the current transient (the measurement of these parameters remains constant), which is also consistent with the model predictions (for instance, the cover gas pressure predicted by CATHENA remains constant at 10.4 kPa(g) as observed in the plant measurement).

It can be concluded that the CATHENA model predictions are similar to the plant behaviour for reactor power rundowns. These results also suggest that the conservative parameters that are used in the safety analysis model would result in pessimistic predictions of the system behavior in case of accident.

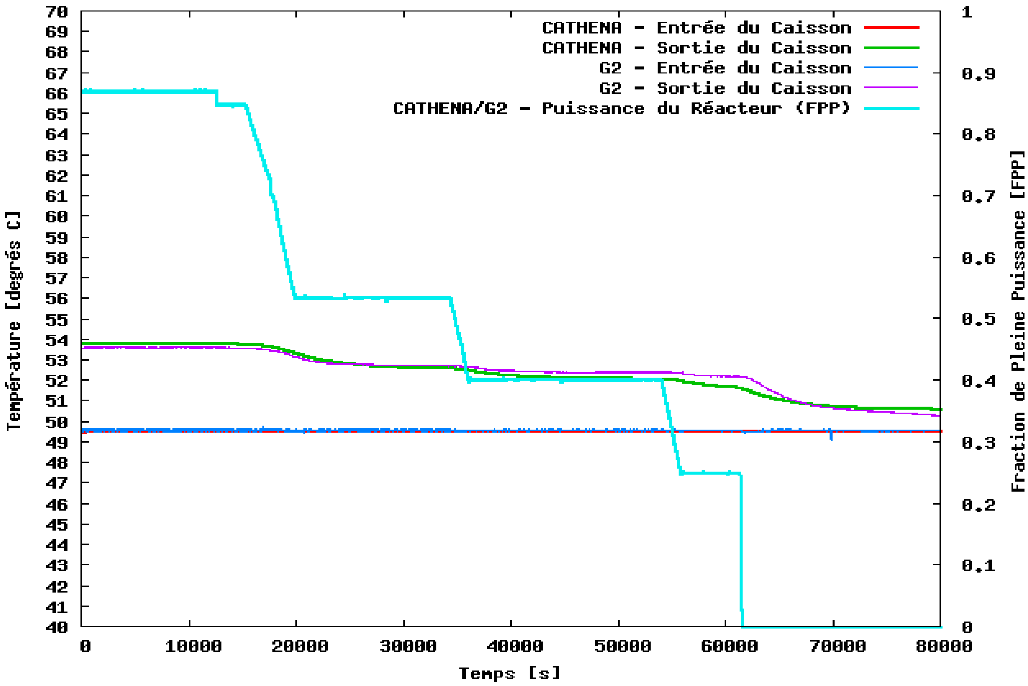

Figure 3CATHENA predictions of Calandria Vault Inlet and Outlet Temperatures and Gentilly-2 Corresponding Measurements[1]

[1]Legend of few French terms: Fraction de pleine puissance = Full Power Fraction
Entrée / Sortie = Inlet / Outlet
Caisson = Calandria Vault
Bouclier = End Shield
Seuil d'alarme haut / bas niveau = High / Low Level Alarm Setpoint

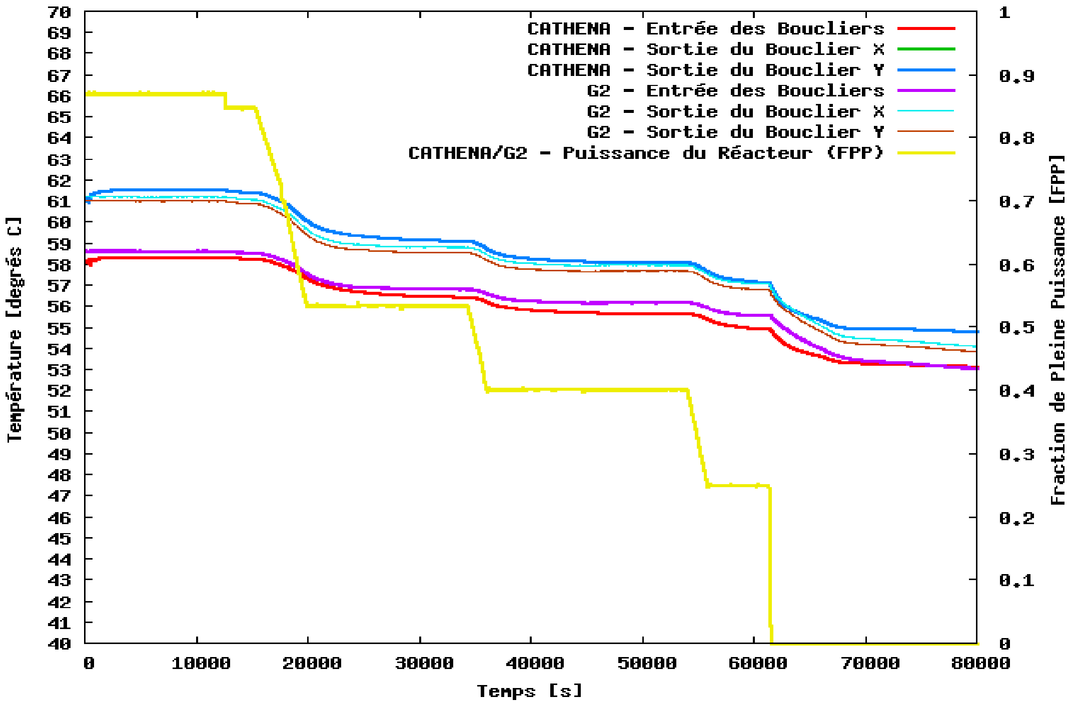

Figure 4CATHENA predictions of End Shields Inlet and Outlet Temperatures and Gentilly-2 Corresponding Measurements

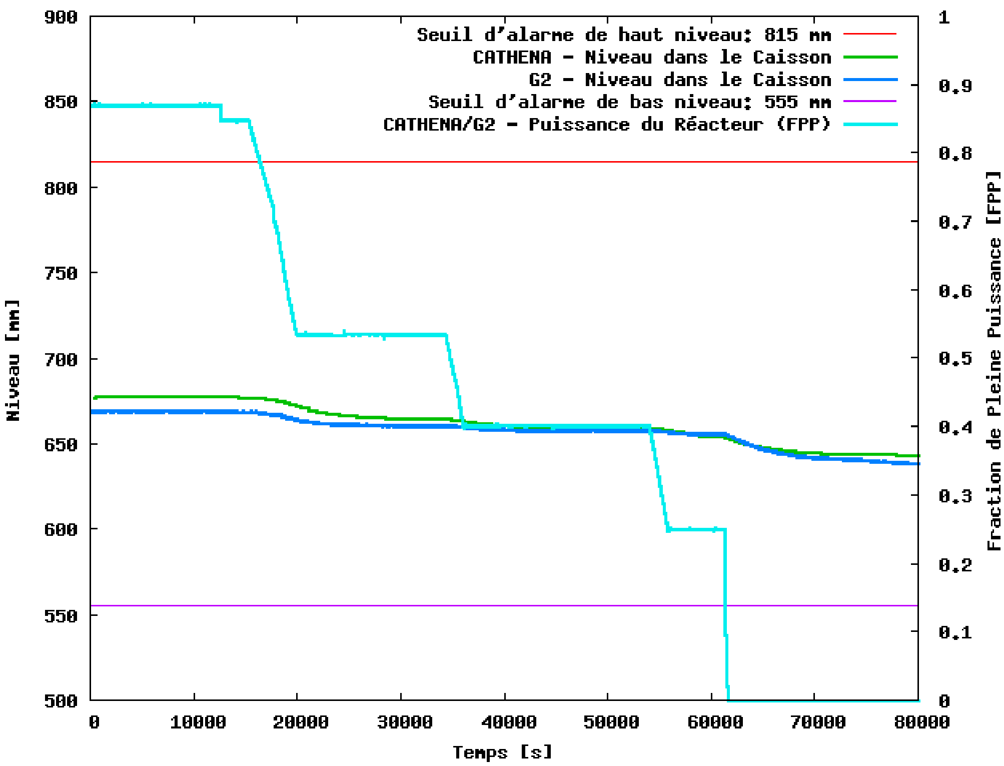

Figure 5CATHENA predictions of Calandria Vault level and Gentilly-2 Corresponding Measurements

6. Power Run-up Transient

6.1 Objective of the Simulation

The objective of this simulation is to show that the CATHENA model can adequately predict the system behaviour in the case of power run-up transient. This comparison also assesses the heat exchanger control model accuracy and the model assumptions on the different system parameters.

6.2 Station Data

Station data provided by Hydro-Québec for this comparison are plant measurements of Gentilly-2 End Shield Cooling System during a power run-up transient from 2% FP to 65% FP. The same parameters described in section 4.2 are available.

6.3 CATHENA Predictions and Comparison with Plant Measurements

Figure 6 shows the CATHENA prediction of end shields inlet and outlet temperatures. The CATHENA model predictions are close to the plant measurements and the temperature transients are similar.

Figure 7 presents the CATHENA prediction of calandria vault inlet and outlet temperature for this scenario. The calandria vault inlet temperature is controlled at 49.5ºC in the CATHENA model (as per initial adjustment with the 96% steady state values). The measured calandria vault inlet temperature is approximately 48.8ºC during the entire transient (resulting in a constant difference of 0.7ºC between the measurement and the model prediction). For consistency with other cases this controlled value was not re-adjusted in the model. The calandria vault outlet temperature prediction transient is similar to the plant measurement. The small difference between both values (maximum of approximately 0.6ºC) is directly related to the difference in the calandria vault inlet temperature resulting from the model adjustment.

Figure 8 shows the CATHENA prediction of the water level in the calandria vault. The CATHENA prediction is close to the station measurement. The maximum difference between both values of approximately 11 mm is also mostly related to the initial difference in the calandria vault inlet temperature due to the model adjustment.

For this transient also, the other parameters such as the cover gas pressure and differential pressure across the end shields are not sensitively affected by the current transient, which is also consistent with the model predictions.

It can be concluded that the CATHENA model predictions are similar to the plant behaviour for reactor power run-ups.

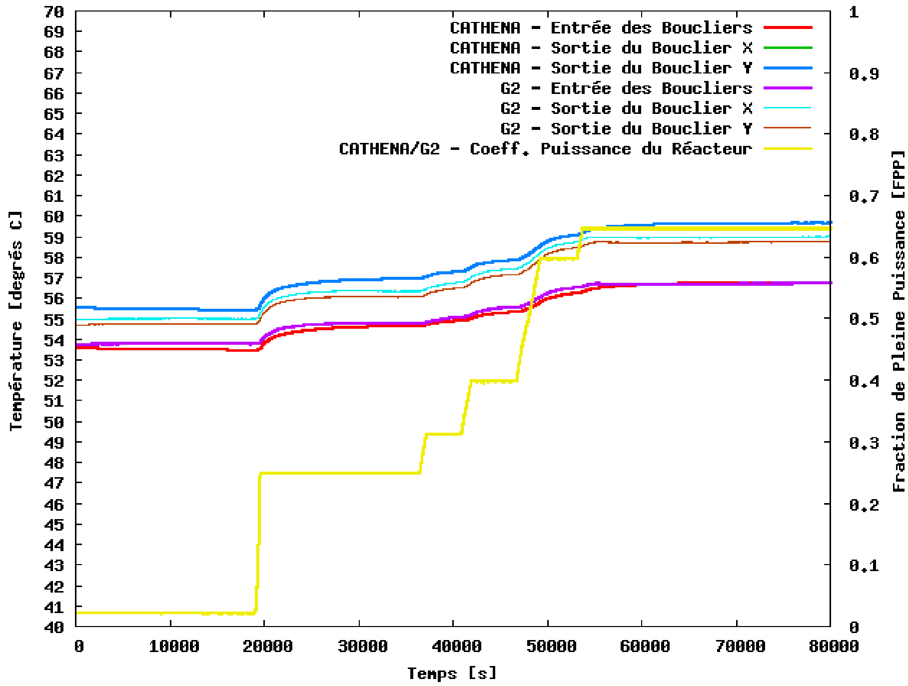

Figure 6CATHENA predictions of End Shields Inlet and Outlet Temperatures and Gentilly-2 Corresponding Measurements

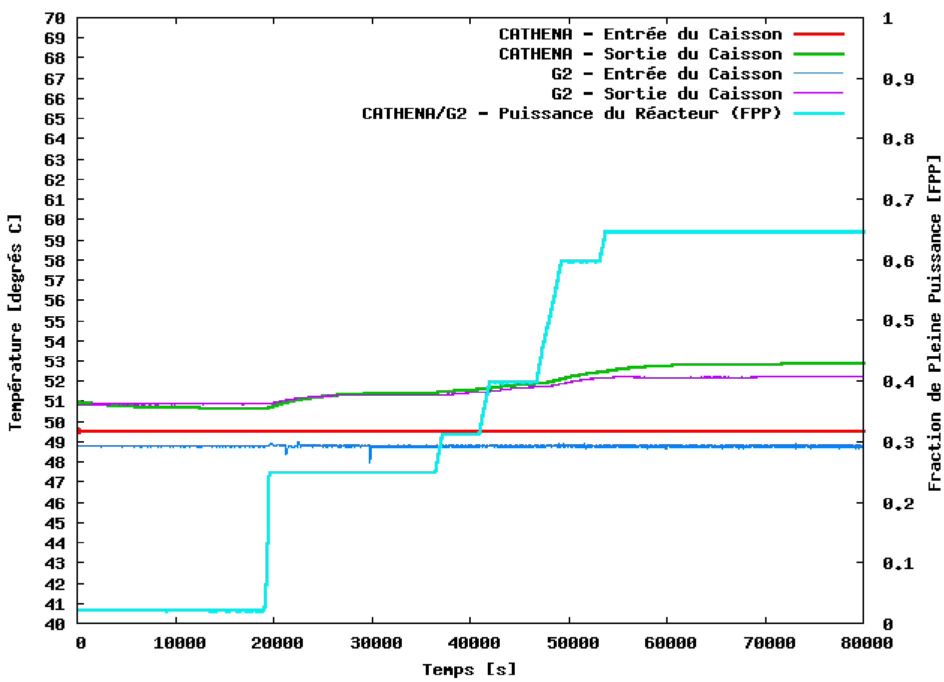

Figure 7CATHENA predictions of Calandria Vault Inlet and Outlet Temperatures and Gentilly-2 Corresponding Measurements

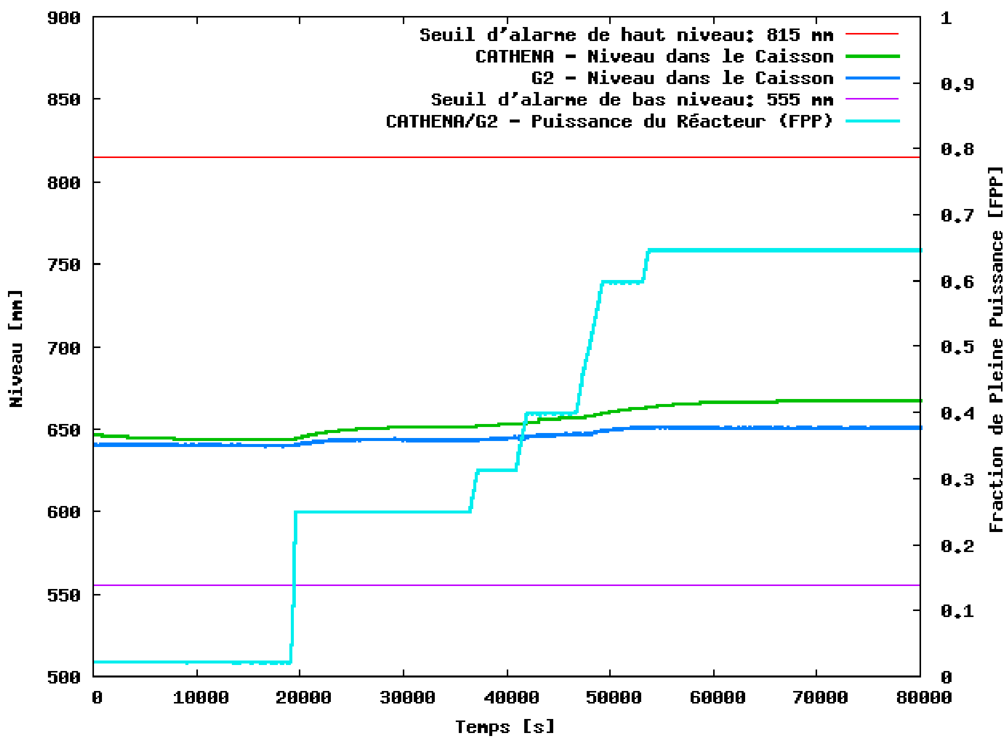

Figure 8CATHENA predictions of Calandria Vault level and Gentilly-2 Corresponding Measurements

7. Conclusion

The CATHENA model is shown to be capable of accurately predicting the plant critical parameter measurements at different power levels, and for various power transients (the maximum temperature difference encountered in these comparisons is 0.7ºC). Comparison with plant measurements requires the model to be adjusted to realistic values. For this comparison analysis, the total heat load to the End Shield Cooling System was reduced from the analysis value of 7.5 MW to 4.9 MW which is representative of the plant at 100% FP.

The current analysis also confirmed that the detailed heat exchanger and control logic model was successfully implemented, and thus permits reproduction of a plant transient by adequately controlling the calandria vault and end shield inlet temperatures during power manoeuvres. The non-adjusted safety analysis model is conservative and leads to pessimistic predictions. Therefore, this safety model is used with confidence to simulate the system behaviour in accident conditions with conservative assumptions.

8. References

[1] F. Caracas, M. Maltchevski, V. Lau, L. Sun, "CATHENA Model of the End Shield Cooling System for Point Lepreau Generating Station", Canadian Nuclear Society, Proceedings of the 23rd Nuclear Simulation Symposium, Ottawa, 2008.

[2] B. Hanna, “CATHENA: A thermalhydraulic code for CANDU analysis”, Nuclear Engineering and Design, Volume 180, Issue 2, March 1998, pages 113-131.