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VERIFICATION OF A CATHENA INTEGRATED POINT LEPREAU PLANT MODEL FOR SAFETY ANALYSIS

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SUMMARY

This paper presents an assessment of a CATHENA integrated plant model, which was created by linking together several existing stand-alone and very detailed CATHENA representations of different Point Lepreau systems. The CATHENA code was coupled with LEPCON, a FORTRAN 77 emulation of the Overall Plant Controller, Reactor Regulating System and a large number of analogue controllers.

The stand-alone idealizations represent the most relevant Point Lepreau systems such as the Primary Heat Transport, the Pressure and Inventory Control, the Emergency Core Cooling, and the Steam and Feedwater systems. The tests performed to validate the model include steady state calculations at different power levels and several transient simulations.

The model was also compared with results from a CATHENA simpler model with a single average channel per pass and the NUCIRC code at 85% power and 102% full power.

Although several transient cases were simulated with the integrated model, this paper presents the results from two of those: 1) a failed open LRV, and 2) a power maneuver which comprised a power reduction from 103% to 60% F.P., followed by a power increase to 103% F.P.

The comparison of the steady state results at 85% full power that are predicted with the model with plant data, the other CATHENA model and the NUCIRC code shows excellent agreement.

The comparison of the results at 102% full power with the NUCIRC code shows some disagreement in the PHTS pressures. The outlet header pressure values obtained with CATHENA are closer to the PHTS pressure set point at full power. The discrepancy is due to the higher flow resistance for two-phase flow used in the NUCIRC plant model. The comparison with the results with the CATHENA single average channel model showed very good agreement.

The conclusion from the transient simulations is that the model produced correct results. This conclusion can be extended to the current emulation of the Overall Plant Controller and the analogue controllers included in LEPCON to emulate the PIC system, BPC and BLC, and also the ECC system and its associated logic. The overall conclusion indicates that the coupling between the CATHENA representation and LEPCON lead to simulation results that are consistent with the expected behaviour.

1.0 Introduction

CATHENA is a one-dimensional, two-fluid thermalhydraulic computer code designed for the analysis of two-phase flow and heat transfer in piping networks [1]. This paper presents the results of simulations performed to validate a CATHENA integrated plant model of the Point Lepreau reactor. The simulations to validate the plant model were performed using the code reference version Mod.3.5c rev. 0 and also the versions Mod. 3.5c, R1-Beta 2 and Mod. 3.5c, R1-Beta 3. The CATHENA code was coupled with LEPCON, a FORTRAN 77 emulation of the Overall Plant Controller, Reactor Regulating System and a large number of analogue controllers [2].

The tests included steady state calculations at different power levels and several transient simulations. The paper presents the results of steady state calculations at different power levels and also the results from two of the transient simulations:

1) a failed open Liquid Relief Valve (LRV), and

2) a power maneuver which comprised a power reduction from 103% to 60% F.P., followed by a power increase to 103% F.P.

2.0 Creation of the Base Model

The base integrated model has been generated by connecting together different CATHENA stand alone idealizations of the more important systems of the Point Lepreau reactor, which have already been documented elsewhere. Those idealizations include:

- The Primary Heat Transport System (PHTS) with a multiple channel representation that comprises seven channel groups for each core pass [3].
- The Steam and Feedwater Systems [4].
- The Pressure and Inventory Control System (P&IC) [5].
- The Emergency Core Cooling System (ECC)[6].
- The portion of the Shutdown Cooling System pipes between the SDCS isolation valves and the connection to the PHTS [7].

The resulting integrated plant representation also incorporates the boundary conditions that existed and were documented in the stand-alone models. Once the different systems listed above were assembled, the resulting CATHENA model contained 3766 nodes and 3897 links, 1274 wall models, 1454 System Control Models, 1733 System Models, 93 Boundary Conditions and 10 Tank Models. Once the model was produced, some minor changes were made to create the base model used in the simulations [8].

3.0 Steady State Simulations Results

The base model was run to obtain a steady state at 85% full power, 102 % full power and 103% full power.

The results at 85% full power are presented in Table 1 together with the results predicted by the CATHENA HT_PL_1 version of the PHTS [9] and plant data at that power level. The CATHENA model of the PHTS, HT_PL_1, has a single average channel representation for each core pass and in the exercise reported there, the boilers secondary side and the P&IC system were represented by boundary conditions, while the ECC system was not included.

The comparison with the PLGS data is excellent. For most of the parameters, the differences are less than 1%. The only exceptions are for the flows in the secondary side and the flow from inlet header 8. However, the data for the inlet header 8 flow (2220.2 kg/s), based on the RTD measurements, also shows some differences with the pump 4 measured flow (2178.3 kg/s). The inlet header 8 is downstream of pump 4, and the flows in both points should not be too different. This is confirmed by the inferred flow in the equivalent inlet header in the other loop, header 4, which does not indicate a significant difference with the measured pump 2 flow. This would suggest that the inferred inlet header 8 flow was not very accurate. The comparison between the integrated multiple channel model and the simpler CATHENA representation is also very good.

The results predicted by the integrated model and the NUCIRC code at 85% are presented in Table 2 . The comparison indicates that the differences between the CATHENA and the NUCIRC predictions are minimal.

The comparison between the CATHENA simulation and NUCIRC at 102% full power is presented in Table 3. The comparison indicates that there are some significant differences between the CATHENA and the NUCIRC predictions. This is particularly true for the header pressures and temperatures. The outlet header pressure values obtained with CATHENA are closer to the PHTS pressure set point at full power. The pressure drop across the core predicted by NUCIRC is higher than the values obtained with CATHENA. As the NUCIRC flows are lower, this suggests that the flow resistance for two-phase flow predicted by NUCIRC is larger than in CATHENA.

4.0 Transient Simulation Results

After these runs were completed, the steady state results were utilized to generate a new input file where several modifications were introduced [8]. These are modifications linked to the feed heating system in the secondary side and were introduced to speed up the solution for turbine powers below 75% F.P. The user has the option to turn those models off. The updated representation constitutes the plant integrated model labeled INT_PL_1M.

4.1.1 LRV Failure Simulation

The simulation assumed that the Liquid Relief Valve 3332-PV3 fails open. This LRV branches off the line that connects the pressurizer to the reactor outlet header 3. No trip, setback nor step back was credited. The automatic control of the P&IC system is assumed to work as designed. No operator action is credited.

The results are presented in Figures 4.1.1-1 to 4.1.1-5. Figure 4.1.1-1 shows the flow through the failed LRV, the D_2O feed flow through 3332-MV22 and the flow from the D_2O storage tank. The initial flow through the LRV to the degasser condenser tank is between 60-80 kg/s. After 200 seconds it drops to very low values and after 700 seconds it rises to about 12 kg/s and remains there until the end of the simulation. This fluctuation in the flow is related to the evolution of the pressure in the degasser condenser tank, which initially is around 1 MPa(a) but starts increasing as a consequence of the relatively hot and high pressure coolant arriving from the PHTS. The increase in the degasser condenser pressure reduces the pressure difference between the PHTS and the tank and hence the LRV flow. The increase in the LRV flow after 700 seconds is related to the opening of the degasser relief valves.

The inventory lost from the PHTS through the failed valve is made up by the P&IC system, which responds to the decreased pressurizer level by increasing the flow through the D_2O feed valves. This is indicated in Figure 4.1.1-1 by the increased flow through 3331-MV22 and the negative flow from the D_2O storage tank. The negative value in this case implies that inventory is leaving the D_2O storage tank. The figure shows that the flow from the tank is twice as large as the flow through MV22. This is because the rest of the D_2O tank flow goes through the valve 3331-MV13, connected to the other PHTS loop. The initial increase to positive values in the tank flow observed in the figure is due to the inflow from the degasser condenser tank as a consequence of the 63332-LCV8 and -LCV15 opening to control the increase in the degasser condenser tank level.

The evolution of the pressurizer tank, the degasser condenser tank and the D_2O storage tank liquid levels is displayed in Figure 4.1.1-2. The pressurizer level initially drops below its normal HTC set-point value of ≈ 8.7 m (PHTS conditions at the beginning of plant life), as a consequence of the inventory lost through the LRV. The result shows that the reactor would have tripped on low pressurizer level because the level dropped below the set point for this trip (7.26 m). Once the flow through the open LRV is reduced below the D_2O feed flow, the pressurizer level begins to increase. By the end of the simulation, the pressurizer level is still below the HTC set-point value.

Figure 4.1.1-2 indicates that the degasser condenser tank level steadily rises from an initial value of 1.46 m to almost 6 m by to 200 seconds and stays at that value for the rest of the simulation. The degasser condenser level is controlled by the valves 63332-LCV8 and -LCV15. However these valves close, thus preventing outflow, because they are overridden and proportionately closed over the cooler outlet temperature range of 57ºC - 77ºC. The initial degasser condenser level of 1.46 m is not correct; as in normal operation the set-point value is 1.0 m. The discrepancy occurs because in the current version of LEPCON, the opening of those valves is controlled only with a proportional term. In the plant, the valves are controlled with proportional and integral terms. The liquid level from the D_2O storage tank is shown to decrease constantly almost from the beginning of the transient as a result of the water make up from the PIC to the PHT system.

Figure 4.1.1-3 presents the pressure in the PHTS, the degasser condenser and the pressurizer and the stem position for one of the steam bleed valves. The PHTS and the pressurizer pressure follow the same behaviour. Initially both decrease as a result of the large discharge through the LRV. Once this flow is reduced below the feed inflow, the pressure starts to increase due to pressurizer steam space compression caused by the D_2O feed make-up. At the end of the simulation, the pressure in the PHTS is at 10.22 MPa(a), well above the HTC normal set-point value of 9.99 MPa(a). The steam bleed valves (PCV5,6) open at around 640 seconds to reduce the PHTS pressure.

However, after 200 seconds, the degasser condenser pressure and the pressurizer pressures are in equilibrium. Therefore, no flow through these valves occurs.

The momentary reduction in the degasser tank pressure shortly before 100 seconds is due to the opening of the degasser spray valves. The valves 63332-PCV24 and -PCV25 are controlled to open when the pressure in the degasser reaches respectively 1.15 and 5.15 MPa(a). Both valves are overridden closed whenever the degasser pressure reaches 9.41 MP(a). Because the degasser spray flow is much smaller than the LRV flow (see Figures 4.1.1-1 and 4.1.1-4) the pressure in the degasser tank cannot be effectively reduced when they open. Both valves are closed by 200 seconds because the pressure in the degasser reaches 9.41 MPa(a). After this time, the pressure in the degasser tank increases at a much lower rate because the LRV flow is reduced, as the pressure in the degasser and the pressurizer become similar.

By 650 seconds the pressure in the degasser reaches the opening set point (approximately 10.0 MPa(a)) of the degasser relief valves. The valve 3332-RV11 opens first and by 700 seconds, valve 3332-RV21 is open.. Figure 4.1.1-5 shows that most of the relief flow occurs through 3332-RV11. The reason is that the other valve is only partially open. This difference in the opening of the valves reflects the behaviour observed in tests done by the manufacturer. This is related to the way the valves are calibrated to open.

The overall result demonstrates that the P&IC system, which is the portion of the model that plays the more important role in the transient, has behaved as expected for this type of event.

4.1.2 Power Maneuver Simulation

The test consists of reducing the power to 60% from 103% full power and then raising power back to 103%. The power reduction to 60% F.P. would be a typical situation when the reactor is in “poison prevent mode” due to a turbine trip.

Figure 4.1.2-1 shows the imposed power transient to the coolant and also the power from the coolant to the secondary side of boiler 1. The power to the coolant is reduced at a rate of 0.01%/s and by 400 seconds the power is at 60% of full power. It is maintained at that level until 1500 seconds and then it is raised again to 100% at a rate of 0.01%/s. The value includes a 3% uncertainty, which accounts for a 2% uncertainty in power measurement, and also for the fact that the power can increase to 101% before the plant operates in alternate mode. In the model this uncertainty is removed for the power level passed to LEPCON. As the figure indicates, the power to the secondary side of one of the boilers follows the power maneuver very closely.

Figure 4.1.2-2 displays the PHTS pressure set-point, the temperature in one reactor inlet header and the maximum reactor outlet header pressure, which is used by LEPCON to control the PHTS pressure. The inlet header temperature drops from the initial value at 263^{o}C to 261^{o}C at 1000 seconds. It remains at that value until approximately 1500 seconds, when the reactor power starts to increase again. At that time the temperature begins to increase until it reaches 263^{o}C again and remains at that value for the rest of the simulation.

Initially, the PHTS pressure decreases due to the reduction in the power to the coolant. By 1000 seconds HTC has increased pressure close to the set-point value (9991.3 kPa(a)). When the power to the coolant starts to rise, the HTS pressure begins to rise and exceeds the HTC set-point value. The pressure is reduced by the opening of the steam bleed valves, which is not shown here.

Figure 4.1.2-3 displays the pressurizer level and the level set point, and also the pressurizer heaters' power to the coolant. The power from the pressurizer heaters initially increases due to the reduction of the PHTS pressure below the HTC pressure set-point value. As it is indicated in Figure 4.1.2-2, by 1000 seconds the pressure is close to the HTC set-point value and the power from the heaters is reduced. By 1500 seconds the power to the coolant begins to rise and the PHTS pressure rises above the HTC set-point value. Because of this, HTC turns the heaters off until 2000 seconds. The opening of the steam bleed valves brings the PHTS pressure below its set-point value and the heaters are turned back on. By the end of the simulation the PHTS pressure is at the HTC set-point value and the heaters are on to compensate for the heat losses from the pressurizer to the environment.

The changes in the level set point are related to the changes in the coolant density as a consequence of the power maneuver. When the power is reduced, the average coolant density increases and the algorithm included in HTC to compute the set point anticipates this effect and reduces the level set point. The reduction in the rector inlet header temperature also results in a lower level set point. Conversely, when the power increases the inlet header temperature increases and the coolant average density decreases and thus the level set point becomes higher.

The figure indicates that the evolution of the level set point is followed closely by the pressurizer level. This indicates that the emulation of the controllers in the P&IC system, built in LEPCON, are working as expected. At the beginning of the simulation the decrease in the level is faster than the reduction in the level set point. By 180 seconds both values are the same. After the power begins to increase, there is a short period of time during which the level is slightly higher than its set-point value. However, the action of the controllers quickly reduces the difference and by the end of the simulation both values are very close.

Figure 4.1.2-4 shows the evolution of the boiler feedwater temperature with the turbine power computed in CATHENA, and also the turbine power computed by LEPCON, labeled as LEPTURP. The algorithm used in LEPCON is based on the turbine chest pressure, which is also calculated by LEPCON. In the CATHENA model, the turbine power is computed based on the steam flow to the turbine and the enthalpy (Ref. 4). The two computed turbine powers are very close and show a very similar behaviour.

The feedwater temperature closely follows the changes in the turbine power computed by the CATHENA model. By the end of the simulation, with the power to the coolant back to its initial level, the feedwater temperature is also back to its initial value. The result is consistent with the expected behaviour, as the extraction steam flow rate that is used to heat the feedwater temperature is a function of the turbine load.

Figure 4.1.2-5 displays the secondary side pressure, the pressure set-point value and the ASDV, CSDV and governor valve stem positions. The BPC set-point remains constant at 4694 kPa(a) during the entire simulation, while the boiler pressure initially drops due to the decrease in the power to the secondary side (see Figure 4.1.2-1). However the closing of the governor valve increases the secondary side pressure to a value close to the BPC set-point value. When the power to the coolant begins to increase, the secondary side pressure rises above the BPC set-point value, but the opening of the governor valve causes the secondary pressure to reduce. By the end of the simulation, the pressure is fluctuating around the set point and the difference between the two values is decreasing with time. This figure also indicates that, as expected, neither the CSDVs nor the ASDVs are opened to control the secondary side pressure at its set-point value.

The steam flow from the boilers, presented in Figure 4.1.2-6, is related to the behaviour of the governor valve, described in the previous paragraph, and is based on the control of the secondary side pressure. The behaviour of the feedwater flow to the boilers follows the steam flow from the boilers.

Figure 4.1.2-7 shows the change of the boiler level set point and the boiler level during the power maneuver. The figure indicates that the boiler level set point follows the behaviour dictated by BLC [[11]]. During the first 100 seconds, it remains at 1.08 meters and then begins to decrease. The figure also indicates that the boiler level tries to follow the changes in the level set point. When the reactor power remains at 60% full power, between 400 and 1500 seconds, the level in the boilers is converging with time to the set-point (0.65 m). Once the reactor power begins to increase, the set point increases and the level also increases trying to match the BLC set-point value. By the end of the simulation the figure shows that the level is converging again to the BLC set-point value. This behaviour is reflected in the feedwater flow to the boilers, shown in Figure 4.1.2-6.

The results from this test indicate that the model behaves as expected during a power maneuver like the one simulated.

5.0 Conclusions

A CATHENA integrated plant model has been created by linking together several existing stand-alone representations. The integrated plant model has been tested against steady state calculations and two plant transients.

A comparison of the steady-state results predicted with the model at 85% full power with plant data and the NUCIRC code showed excellent agreement. The comparison of the results at 102% full power with the NUCIRC code showed some disagreement in the PHTS pressures. The outlet header pressure values obtained with CATHENA are closer to the PHTS pressure set point at full power. The discrepancy is due to the higher flow resistance for two-phase flow used in the NUCIRC plant model. The comparison with the results with the CATHENA single average channel model showed very good agreement at both power levels

The conclusion from the transient simulations is that the model produced correct results. This conclusion can be extended to the current emulation of the Overall Plant Controller and the analogue controllers included in LEPCON to emulate the PIC system, BPC and BLC, and also the ECC system and its associated logic. The overall conclusion indicates that the coupling between the CATHENA representation and LEPCON lead to simulation results that are consistent with the expected behaviour.

6.0 References

1. B.N. Hanna et al.: "CATHENA MOD-3.5/Rev 0 Theoretical Manual", Atomic Energy of Canada Limited Report, COG-93-140, RC-982-3, Vol. 3.
2. R. Girard: "LEPCON Program Description", IR-03500-51, V. 3. November 1995.
3. W. E. Ross: "CATHENA Representation of the Point Lepreau Main Heat Transport System, Version HT_PL_1M - Revision 0", TTR-681. October 1999.
4. L. Coltatu, E. Yetman and A.V. Galia: "CATHENA Detailed Model of the Steam Water System", IR-03551-1, Vol. 1, Rev. 0. March 2000.
5. R. Girard and A. V. Galia: "CATHENA Representation of the Point Lepreau Pressure and Inventory Control System - Version PIC_PL_1", IR-03551-10, Vol. 1, Rev. 0. November 1998.
6. W. E. Ross and G. E. Sabourin: "CATHENA Representation of the Point Lepreau Emergency Core Cooling System - Version ECC_PL_1", TTR-469, Vol. 1, Rev. 0. July 1999.
7. V. I. Costiuc: "CATHENA Representation of the Point Lepreau Shutdown Cooling System - Version SDC_PL_1", IR-03551-07. To be issued.
8. A. V. Galia: "CATHENA Integrated Plant Model For Safety Analysis at the Beginning of Plant Life. Verification Tests", IR-03551-014. To be issued.
9. W. E. Ross: "CATHENA Representation of the Point Lepreau Main Heat Transport System, Version HT_PL_1, Revision 0", TTR-611, Vol. 1. November 1998.
10. W. E. Ross and P. White: "Verification of the Version HT_PL_1 Representation of the Pint Lepreau Main Heat Transport System", TTR-611, Vol. 2, Rev. 0. May 1999.
11. BLC Program Logic Operational Flowsheet (Part 5), 0087-66556-2001-005-CD-F, Rev. 0.

Table 1 - COMPARISON OF CATHENA INTEGRATED MULTI-CHANNEL MODEL SIMULATION WITH CATHENA SINGLE CHANNEL MODEL([1]) RESULTS AND PLANT COMISSIONING DATA AT 85% FULL POWER (January 16, 1983)

	TEMPERATURE (^{O}C)			PRESSURE (MPa(a))			FLOW (kg/s)			DELTA P (MPa)		
	DATA	CATHENA		DATA([2])	CATHENA		DATA	CATHENA		DATA	CATHENA	
		INT. M.	S. CH.		INT. M.	S. CH.		INT. M.	S. CH.		INT. M.	S. CH.
IH2	262.1	262.3	262.1	11.231	11.266	11.232	2145.9 ([3])	2150.2	2156.0			
IH4	261.3	262.7	262.4	11.271	11.271	11.232	2146.8	2153.5	2156.0			
IH6	261.7	261.7	261.7	11.231	11.267	11.229	2174.6	2154.4	2160.2			
IH8	262.1	262.5	262.1	11.241	11.283	11.242	2220.2	2158.9	2163.3			
OH1	302.2	302.8	302.5	9.98	9.991	9.953						
OH3	302.5	302.6	302.4	9.929	9.989	9.952						
OH5	301.3	302.7	302.3	9.963	9.995	9.954						
OH7	301.7	302.0	301.9	9.972	9.989	9.952						
PUMP 1				9.592	9.669		2153.2 ([4])	2160.8	2156.0	1.697	1.668	
PUMP 2				9.504	9.670		2145.2	2153.5	2156.0	1.704	1.671	
PUMP 3				9.608	9.666		2188.6	2165.8	2160.2	1.691	1.671	
PUMP 4				9.599	9.666		2178.3	2158.9	2163.3	1.696	1.688	
BO1 FW	180.5	179.6					201.1	199.5				
BO2 FW	179.8	179.6					199.2	198.3				
BO3 FW	179.7	179.6					199.8	201.6				
BO4 FW	174.4	179.6					201.2	196.4				
BO1 STEAM				4.693	4.7		203.5	220.4				
BO2 STEAM				4.673	4.68		228.5	219.2				
BO3 STEAM				4.699	4.695		216.6	222.5				
BO4 STEAM				4.703	4.684		218.1	217.3				

(1) As reported in Table 2-2 of TTR-611, Vol. 2.
(2) The data is derived by adding to the outlet header pressure the header-to-header pressure difference.
(3) Flow based on outlet feeders RTDs.
(4) Flow based on pump differential pressure.

Table 2 - COMPARISON OF CATHENA INTEGRATED MULTI-CHANNEL MODEL SIMULATION WITH NUCIRC RESULTS AT 85% FULL POWER (January 16, 1983)

	NUCIRC	CATHENA	NUCIRC	CATHENA	NUCIRC	CATHENA	NUCIRC	CATHENA
IH2	262.1	262.3	11.229	11.266	2159.3	2150.2	1.278	1.277[1]
IH4	262.1	262.7	11.235	11.271	2156.0	2153.5	1.292	1.279
IH6	261.7	261.7	11.227	11.267	2166.4	2154.4	1.285	1.278
IH8	261.9	262.5	11.243	11.283	2161.3	2158.9	1.289	1.288
OH1	302.0	302.8	9.957	9.991				
OH3	302.2	302.6	9.949	9.989				
OH5	301.8	302.7	9.977	9.995				
OH7	301.7	302.0	9.952	9.989				
PUMP 1					2165.1	2160.9	1.693	1.668
PUMP 2					2159.7	2153.6	1.707	1.671
PUMP 3					2176.5	2165.9	1.706	1.671
PUMP 4					2166.8	2159.0	1.717	1.688

(1) The DELTA P for the headers indicates for each core pass the inlet header – outlet header pressure. For instance, H2 – H3 pressure

Table 3 - COMPARISON OF CATHENA MULTI-CHANNEL INTEGRATED MODEL SIMULATION WITH NUCIRC RESULTS AT 102% FULL POWER

	TEMPERATURE (^{O}C)		PRESSURE (MPa(a))		FLOW (kg/s)		DELTA P (MP(a)	
	NUCIRC	CATHENA	NUCIRC	CATHENA.	NUCIRC	CATHENA.	NUCIRC	CATHENA
IH2	262.6	263.2	11.159	11.267	2137.1	2141.3	1.299	1.279[1]
IH4	262.9	263.5	11.165	11.272	2140.3	2142.5	1.317	1.279
IH6	262.0	262.5	11.151	11.267	2146.2	2146.2	1.301	1.280
IH8	262.9	263.4	11.168	11.284	2148.2	2148.5	1.313	1.288
OH1	308.9	310.3	9.862	9.996				
OH3	308.9	310.2	9.857	9.991				
OH5	308.9	310.3	9.878	9.997				
OH7	308.9	309.9	9.857	9.990				
PUMP 1					2146.5	2152.1	1.706	1.668
PUMP 2					2140.3	2142.5	1.721	1.674
PUMP 3					2161.3	2157.4	1.717	1.673
PUMP 4					2148.7	2148.5	1.730	1.690

(1) The DELTA P for the headers indicates for each core pass the inlet header – outlet header pressure. For instance, H2 – H3 pressure.

Table 4 - COMPARISON OF CATHENA BASE MODEL AND MODEL INTM_PL_1M STEADY STATE CALCULATIONS AT 103 % FULL POWER

PRIMARY SIDE								
	TEMP. (^{O}C)		PRESSURE MPa(a))		FLOW (kg/s)		DELTA P (MPa(a))	
	BASE	INT_PL1_M	BASE	INT_PL1_M	BASE	INT_PL1_M	BASE	INT_PL1_M
IH2	263.2	263.1	11.270	11.264	2140.8	2141.4	1.279	1.279 [1]
IH4	263.5	263.5	11.275	11.268	2141.8	2141.9	1.278	1.278
IH6	262.5	262.5	11.270	11.264	2146.4	2147.1	1.281	1.281
IH8	263.3	263.3	11.286	11.280	2147.0	2146.7	1.287	1.286
OH1	310.3	310.3	9.996	9.990				
OH3	310.3	310.2	9.991	9.984				
OH5	310.3	310.3	9.999	9.993				
OH7	310.2	310.1	9.989	9.983				
PUMP 1					2151.6	2152.0	1.669	1.669
PUMP 2					2141.8	2141.9	1.675	1.675
PUMP 3					2157.7	2158.5	1.673	1.672
PUMP 4					2147.0	2146.7	1.691	1.691
SECONDARY SIDE								
	TEMP. (^{O}C)		PRESSURE (MPa(a))		FLOW (kg/s)		LEVEL(m)	
	BASE	INT_PL1_M	BASE	INT_PL1_M	BASE	INT_PL1_M	BASE	INT_PL1_M
BO1 FW	187.9	187.9			248.30	249.01	1.09	1.07
BO2 FW	187.9	187.9			247.30	247.97	1.09	1.07
BO3 FW	187.9	187.9			250.90	251.86	1.09	1.07
BO4 FW	187.9	187.9			244.60	245.31	1.09	1.07
BO1 STEAM			4.705	4.702	270.78	270.84		
BO2 STEAM			4.675	4.672	269.98	269.88		
BO3 STEAM			4.696	4.693	273.51	273.69		
BO4 STEAM			4.680	4.676	267.29	267.22		

([1]) The DELTA P for the headers indicates for each core pass the inlet header – outlet header pressure. For instance, H2 – H3 pressure.

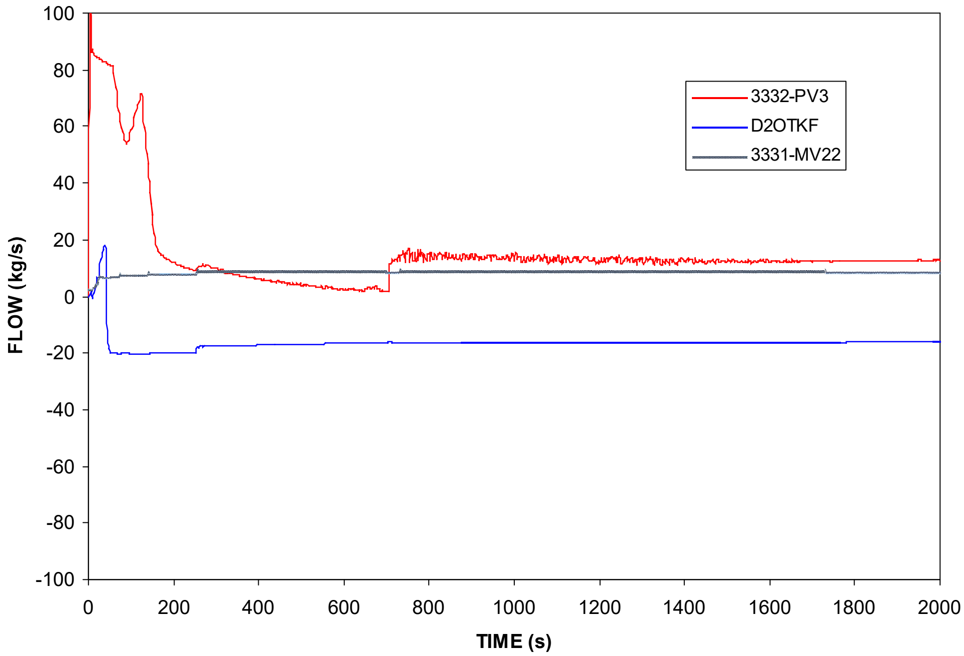

FIG 4.1.1-1 - FLOW THROUGH LRV VALVE 3332-PV3 , D_2O FEED FLOW THROUGH 3331-MV22 AND D_2O STORAGE TANK FLOW- LRV FAILURE - CATHENA INTEGRATED MODEL

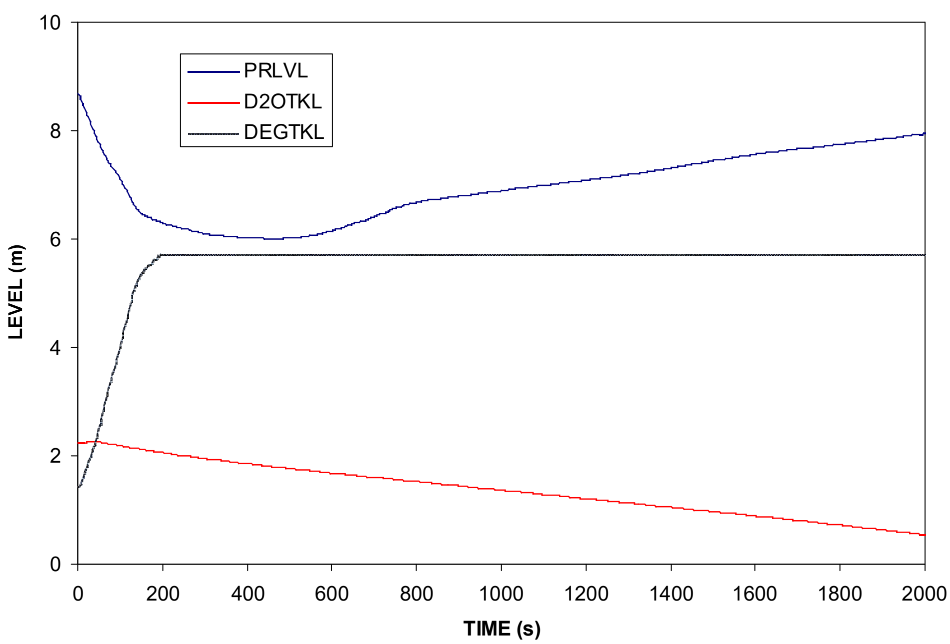

FIG 4.1.1-2 - PRESSURIZER, D_2O STORAGE AND DEGASSER CONDENSER TANK LIQUID LEVEL- LRV FAILURE - CATHENA INTEGRATED MODEL

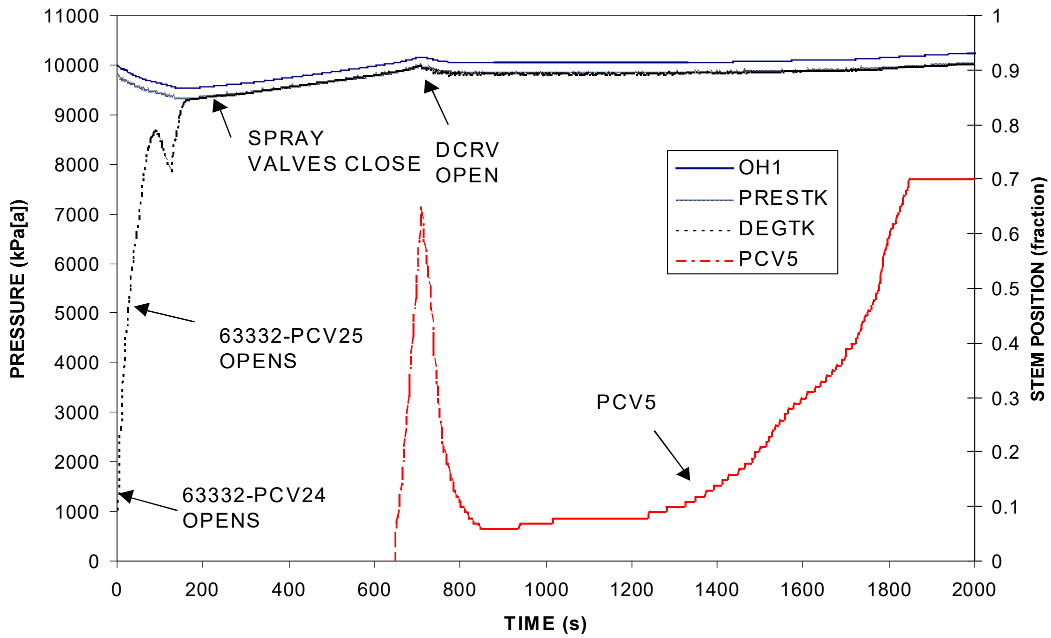

FIG 4.1.1-3 - STEAM BLEED VALVE OPENING AND OUTLET HEADER, PRESSURIZER AND DEGASSER TANK PRESSURES - LRV FAILURE - CATHENA INTEGRATED MODEL

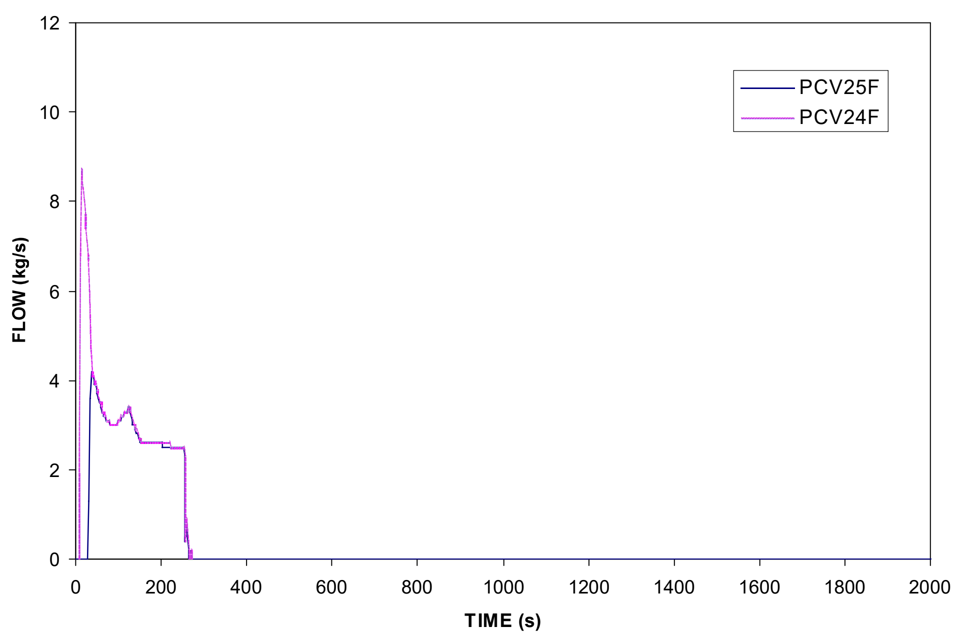

FIG 4.1.1-4 - FLOW THROUGH DEGASSER SPRAY VALVES - LRV FAILURE - CATHENA INTEGRATED MODEL

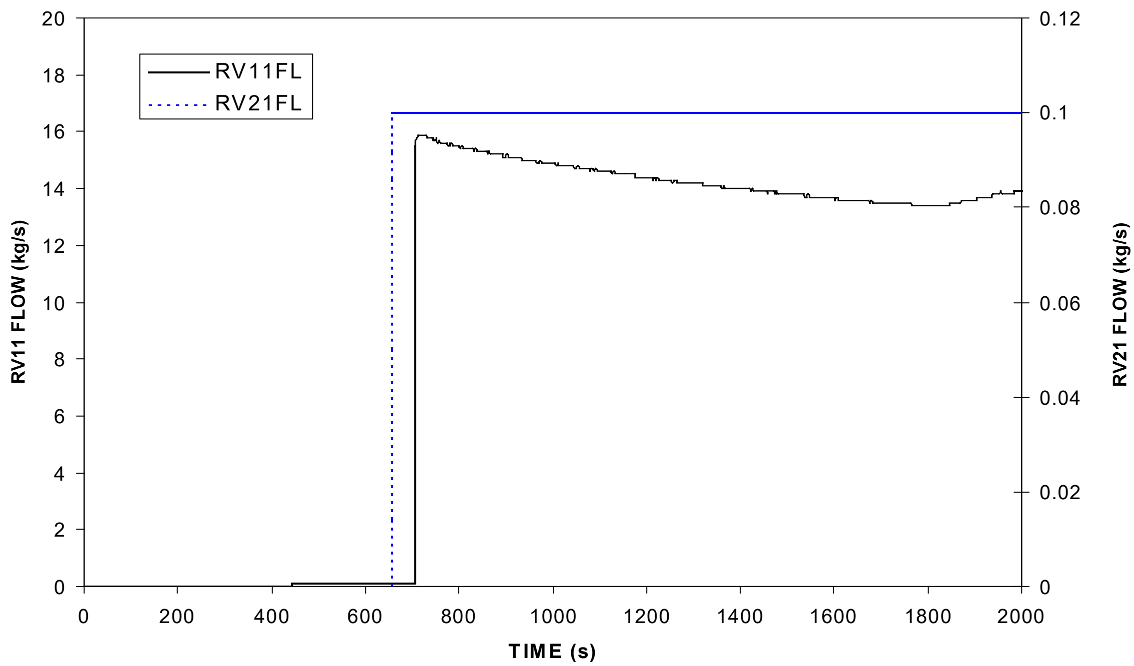

FIG 4.1.1-5 - FLOW THROUGH DEGASSER RELIEF VALVES - LRV FAILURE - CATHENA INTEGRATED MODEL

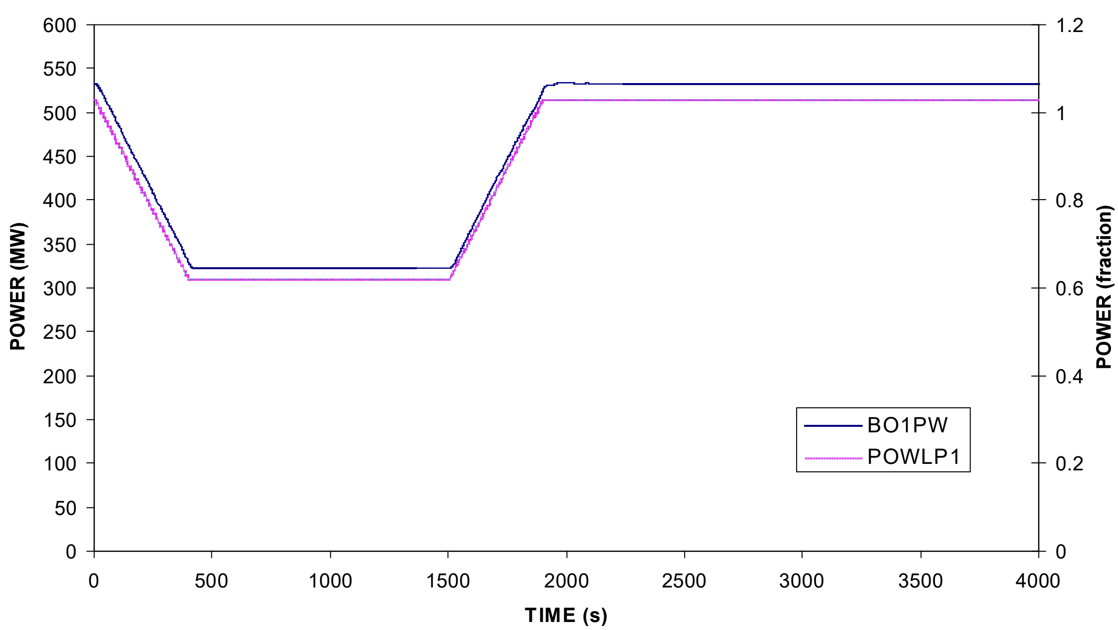

FIGURE 4.1.2-1 - POWER TO COOLANT AND SECONDARY SIDE - POWER MANEUVER - CATHENA INTEGRATED MODEL

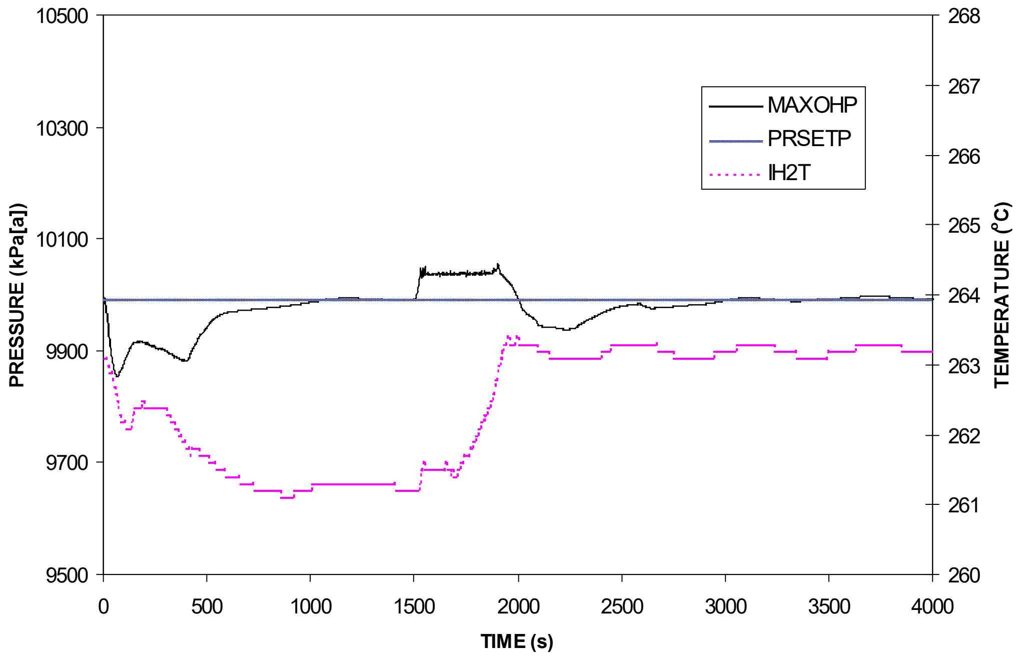

FIGURE 4.1.2-2 - PHTS TEMPERATURE, PRESSURE AND PRESSURE SET POINT - POWER MANEUVER - CATHENA INTEGRATED MODEL

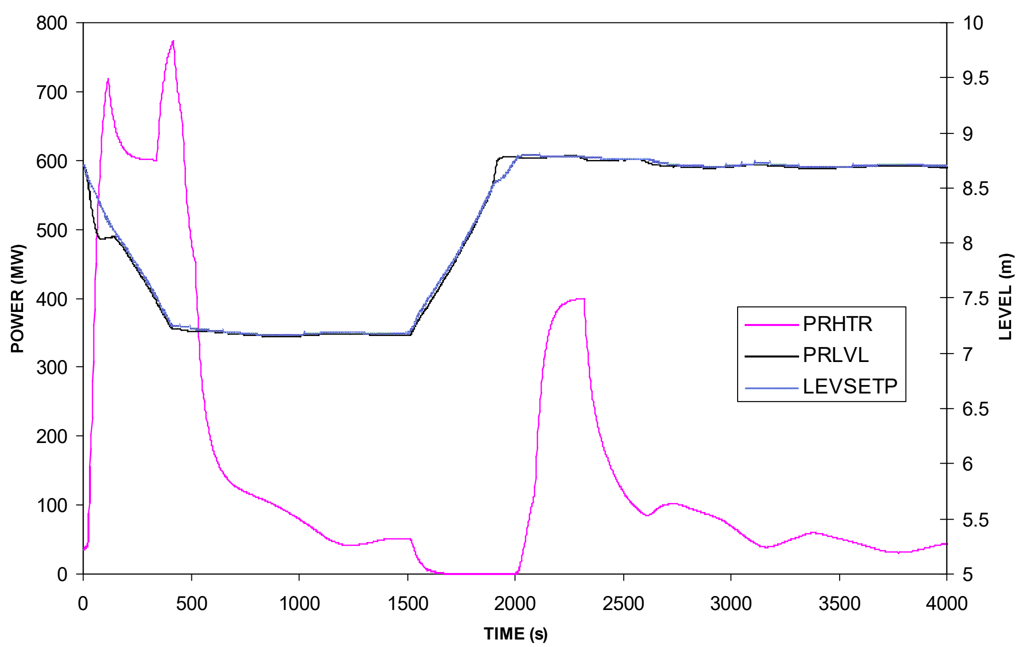

FIGURE 4.1.2-3 - PRESSURIZER HEATER POWER AND PRESSURIZER LIQUID LEVEL AND LEVEL SET POINT - POWER MANEUVER - CATHENA INTEGRATED MODEL

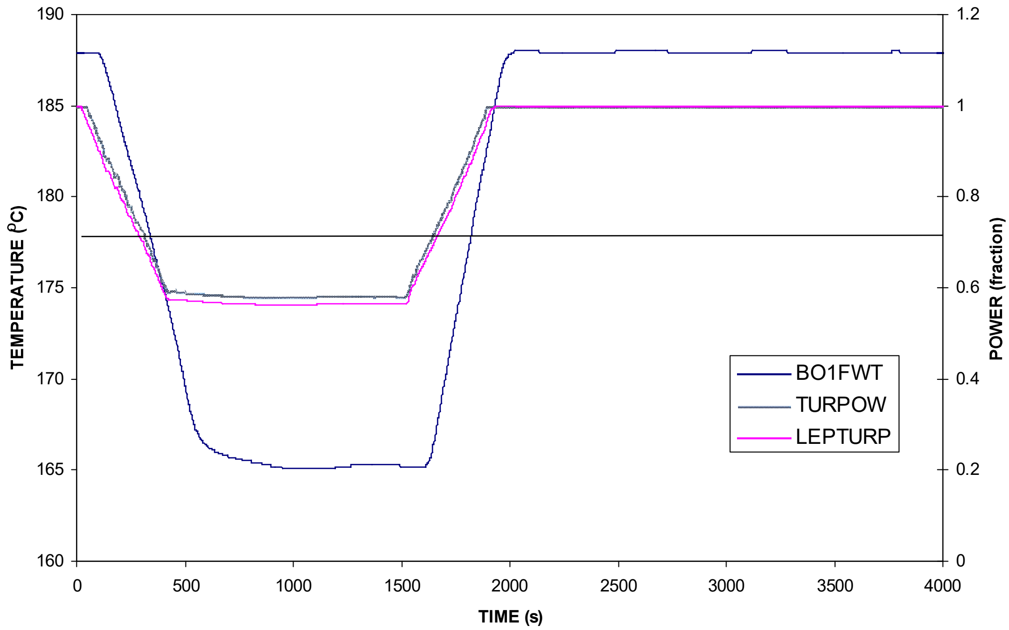

FIGURE 4.1.2-4 - **BOILER FEEDWATER TEMPERATURE AND TURBINE POWER - POWER MANEUVER - CATHENA INTEGRATED MODEL**

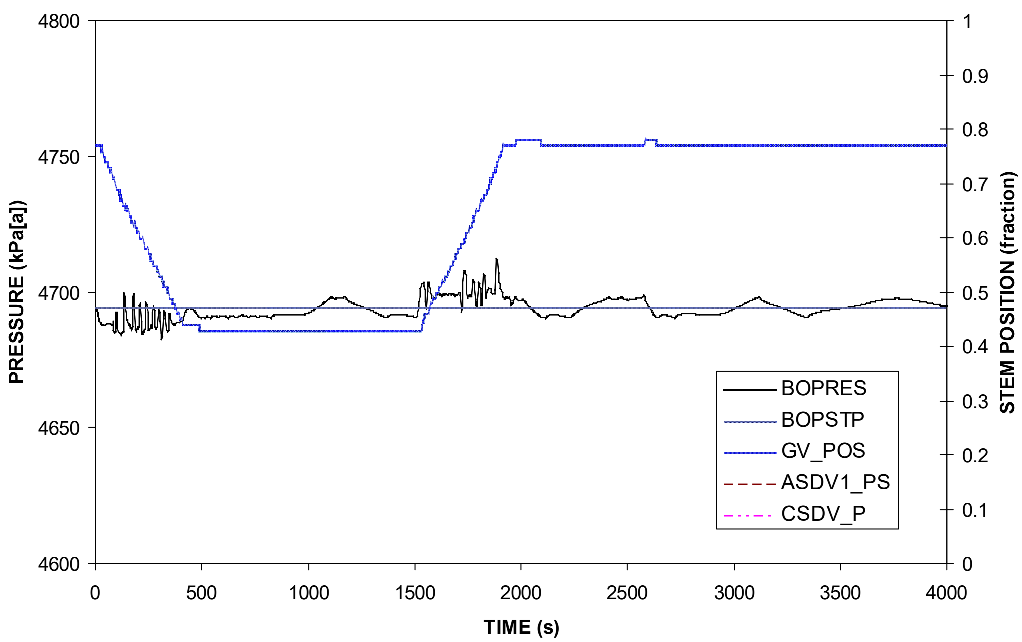

FIGURE 4.1.2-5 - **BOILER SECONDARY SIDE PRESSURE AND PRESSURE SET POINT AND ASDV, CSDV, AND GOVERNOR VALVE STEM POSITION - POWER MANEUVER - CATHENA INTEGRATED MODEL**

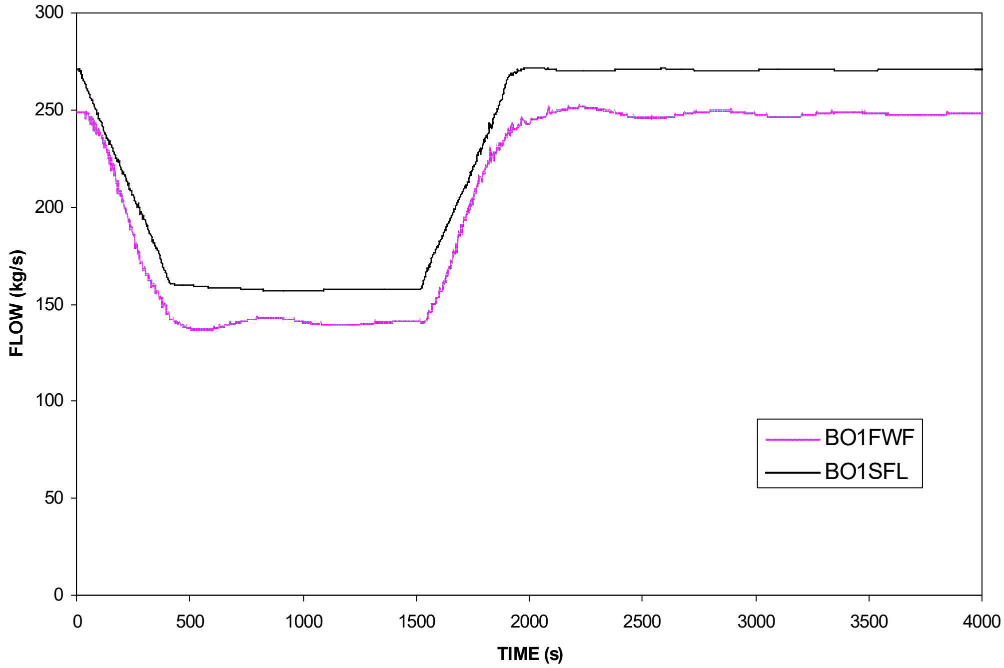

FIGURE 4.1.2-6 - BOILER FEEDWATER AND STEAM FLOWS - POWER MANEUVER - CATHENA INTEGRATED MODEL

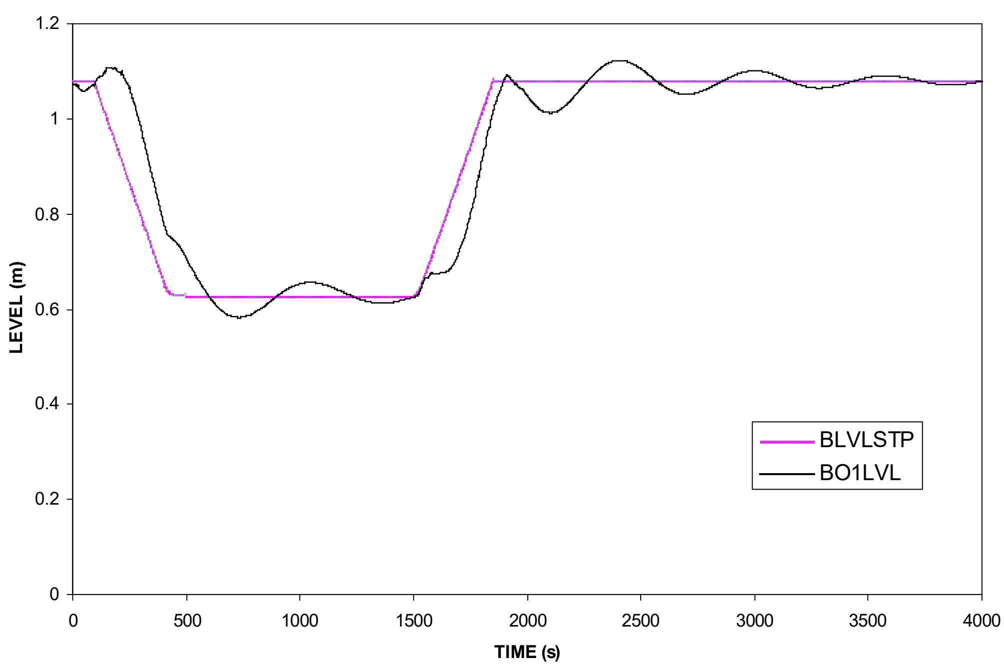

FIGURE 4.1.2-7 - BOILER LIQUID LEVEL AND LEVEL SET POINT - POWER MANEUVER - CATHENA INTEGRATED MODEL