MODELING AND ANALYSIS OF THERMAL HYDRAULIC PHENOMENA FOR VVER-1000 REACTOR WHEN TRIP OUT OF ONE OR TWO MAIN COOLANT PUMPS BY RELAP/SCDAPSIM CODE

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ABSTRACT: RELAP5 - a thermal hydraulic system code - in recent years is used by many reseachers in Vietnam for the reactor thermal-hydraulic analysis. In the other hand, VVER-1000 reactor is selected to be the nuclear reactor technology for the first nuclear power plant in Vietnam. So the studying on VVER-1000 reactor is very important. The project's purpose is modeling the thermal-hydraulic systems of VVER-1000 reactor. The project also targets enhancement of experiences in using RELAP5/SCDAPSIM code and modeling for components of VVER-1000 reactor in steady state and transient, including: steady state at 100% power, transient with switch off 1 or 2 main coolant pumps. The thermal hydraulic parameters were analysised versus time. The thermal hydraulic parameters, such as: outlet pressure, coolant temperature, maximum fuel temperature, water level of pressurizer and steam generator, etc. were compared, analysed and assessed. In steady state, the errors are less 10 per cent.

1. STRUCTURES AND PRINCIPLES OF VVER-1000 THERMAL HYDRAULIC SYSTEMS

In this part, studied about the structures, principles of VVER-1000 thermal hydraulic systems, including: reactor core, main coolant pump, steam generator, pressurizer.

Figure 1 illustrates the main components of VVER-1000 reactor.

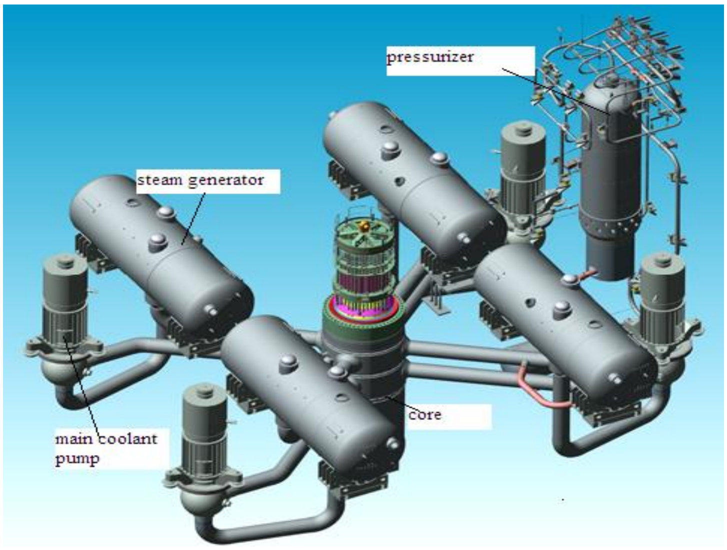


Figure 1: Main components of VVER-1000 reactor.

2. THERMAL HYDRAULIC AND GEOMETRY DATA OF THE MAIN COMPONENTS OF VVER-1000 REACTOR

In this part, collected thermal hydraulic and geometry data of VVER-1000/V392 design. Table 1 shows the main thermal hydraulic parameters of VVER-1000/V392. Table 2 shows the main geometry parameters of fuel assembly.

Table 1: The main thermal hydraulic parameters of VVER-1000/V392.

Parameters	Value
1. Number of loops	4
2. Thermal power, MW	3000
3. Outlet pressure, MPa	15.7
4. Iutlet temperature, ^oC	291
5. Outlet temperature, ^oC	321
6. Core mass flow, m^3/h	86000
7. Mass flow per a cold leg, m^3/h	21500
8. Core mass flow when trip out of one main coolant pump, m^3/h	63700
9. Core mass flow when trip out of two opposite main coolant pumps, m^3/h	40000
10. Core mass flow when trip out of two adjacent main coolant pumps, m^3/h	40800
11. Maximum linear power rate, W/cm	448
12. Steam pressure at head of steam generator, MPa	6.27
13. Steam temperature, ^oC	278.5
14. Steam mass flow rate/ SG, t/h	1470
15. Humidity not execced, %	0.2
16. Average burn up of fuel assembly, MWday/kgU	54.6
17. Maximum burn up of fuel assembly, MW ngày/kgU	56.9
18. By bass mass flow rate, %	3
19. Feedwater temperature at nominal power, ^oC	220
20. Feedwater temperature at disconnect HPH and zero power, ^oC	164
21. Feedwater temperature at disconnect HPH and nominal power, ^oC	186
22. Core pressure drop, MPa	0.387
23. Design parameters of primary system - Pressure, MPa - Temperature, ^oC	 17.64 350
24. Design parameters of second system - Pressure, MPa - Temperature, ^oC	 7.84 300

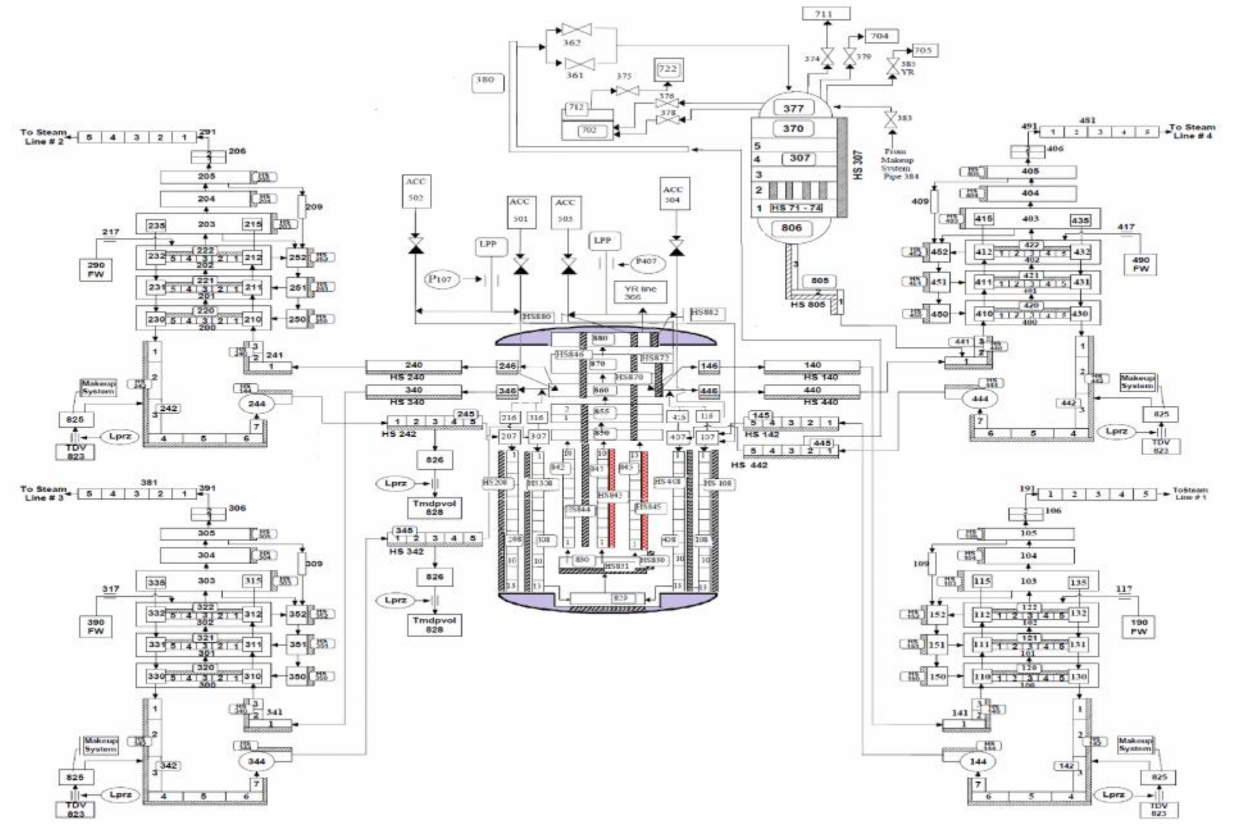
Table 2: The main geometry parameters of fuel assembly.

Parameter	Value
1. Hight fuel assembly, mm	4570
2. Hight cold fuel assembly, mm: - Bottom part of fuel - Active fuel part - Top part of fuel	 281 3530 759
3. Number of fuel rod in a fuel assembly	312
4. Pitch distance, mm	12.75
5. Material of fuel	UO_2 and UO_2+Gd_2O_3
6. Fuel mass of a fuel assembly, kg	505.4
7. Fuel density, kg/m^3	(10.4 to 10.7) x 10^3
8. Material of cladding	Alloy110
9. Outside diameter of fuel pin, mm	7.6
10. Inside diameter of fuel pin, mm	1.2
11.Outside cladding diameter, mm	9.1
12. Inside cladding diameter, mm	7.73
13. Guide tube: - Number - Material - Total hight, mm	 18 Alloy635 4222
14. Number of grid spacer	15

3. MODELING AND INPUT FILE BY RELAP/SCDAPSIM

Figure 2 is the nodalization of VVER-1000 reactor in RELAP/SCDAPSIM. The components are modeled, such as: Core, 4 main coolant pumps, 4 steam generators, pressurizer, main pipes, feed waters …

Input file included: hydrodynamics components, heat structers, trip and logic, reactor kenitics.



4. CALCULATION AND RESULTS ANALYSIS

4.1. Steady state

The calculation results show in table 3. This results are compared with the design data in the steady state. The errors are less than 10 per cent. So this calculation results is good.

Table 3: Calculation at 100% power.

Parameter	Calculation value	Design value	Error (%)
Thermal power	3000 MW	3000	0 %
Outlet pressure	15.7 MPa	15.7 ± 0.3 MPa	0%
Inlet temperature	289.30 ºC	291 ºC	0.58 %
Outlet temperature	319.24 ºC	321 ºC	0.55 %
Core mass flux	83464 m^3/h	86000 m^3/h	2.95 %
Core pressure drop	0.3856 MPa	0.387 MPa	0.36 %
Feedwater temperature	220 ºC	220 ºC	0 %
Steam generator water level	2.51 m	2.7 m	7 %
Steam temperature	278 ºC	278.5 ºC	0.18 %
Pressurizer water level	8.194 m	8.17 m	0.29 %
Top pressurizer pressure	6.266 MPa	6.27 MPa	0.06 %

4.2. Transient

The senarior is trip out of one main coolant pumps when the reactor was operating at 100% power. The events is showed in table 4.

Table 4: The events of trip out of one main coolant pumps [1].

Time, s	Event	Setpoint for actuation
0.0	Trip out of one operating main coolant pump sets	Initiating event
6.5	The first signal for reactor scram (is ignored)	The event occurs when reactor power is operating to exceed 75% power and one of main coolant pump sets trip out of.
17.1	The second signal for reactor scram	
20.6	Start of EP control rods removement	
25.6	Start of TG stop valves closing	By the fact of reactor scram in 5 s since the moment of setpoint reaching. The time of stop valves closing is assumed 0.6 s
32.0	Start of BRU-A opening in steam lines of SGs	Pressure in the steam lines exceed 7.2 MPa Control pressure is 6.67 MPa
3600.0	End of calculation	

The calculation results is illustrated from figure 3 to figure 8.

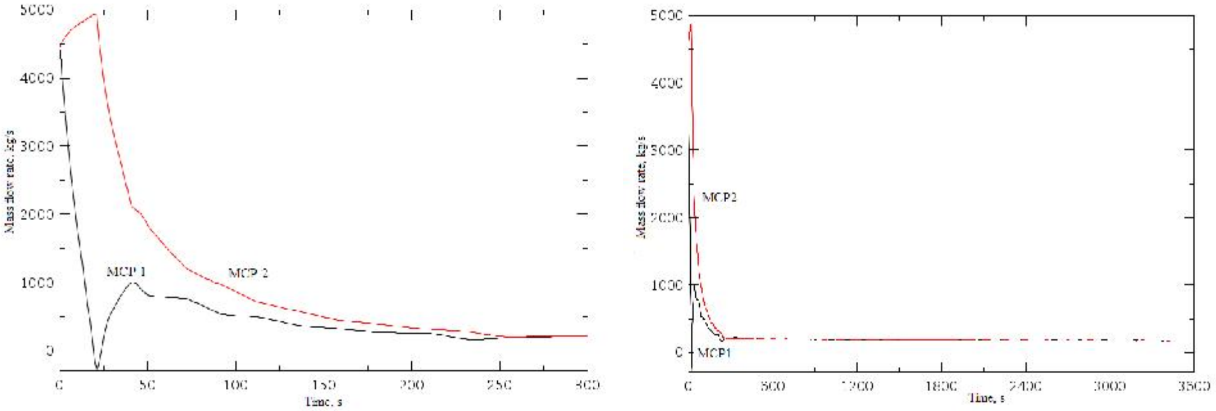


Figure 3: Coastdown of main coolant pump.

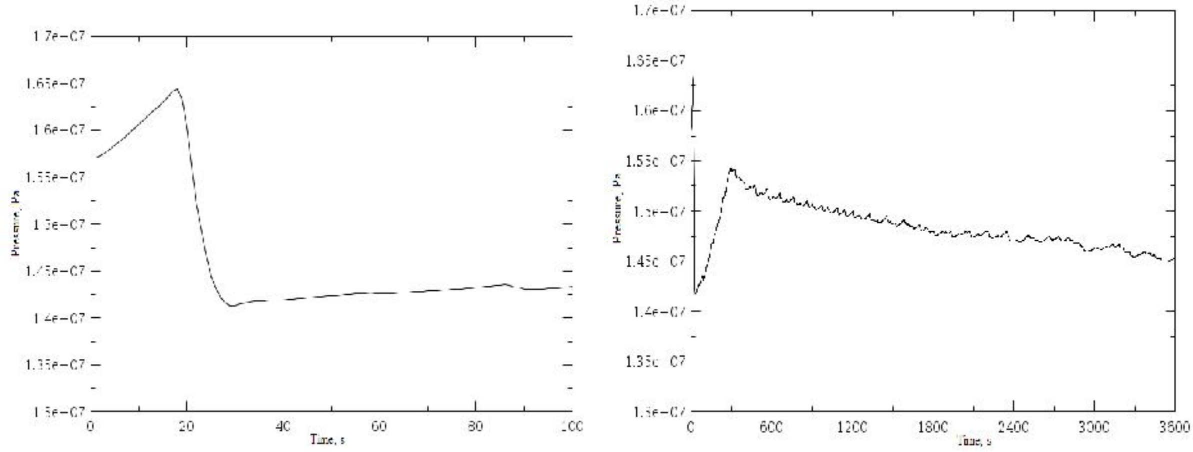


Figure 4: Outlet pressure versus time.

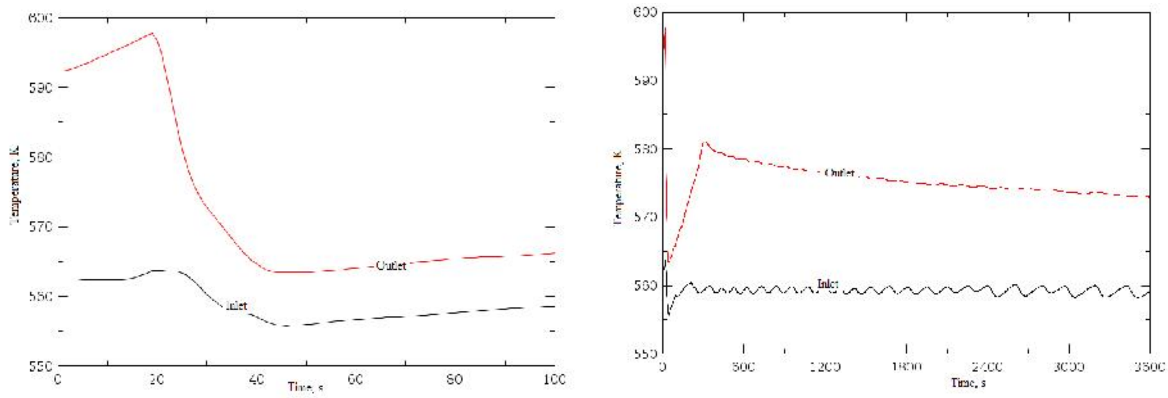


Figure 5: Inlet and outlet temperature.

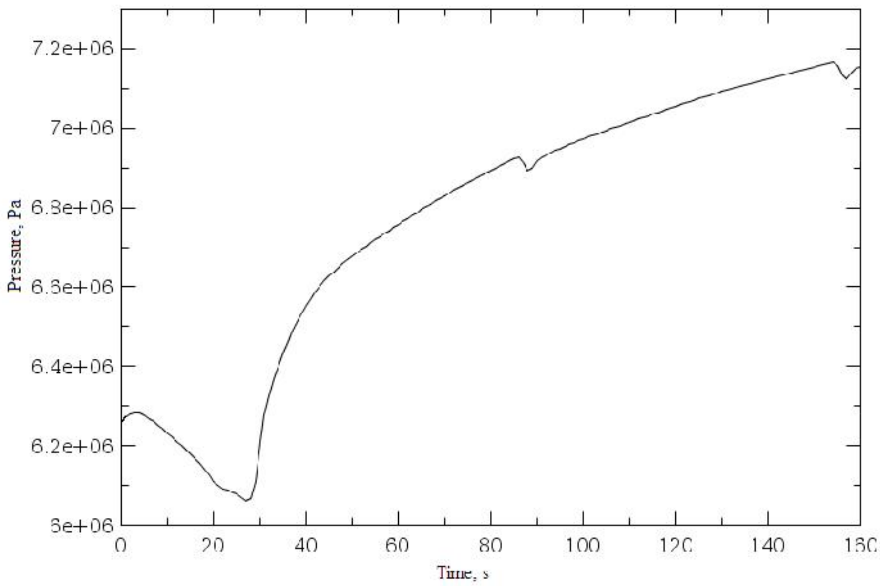


Figure 6: Head SG pressure.

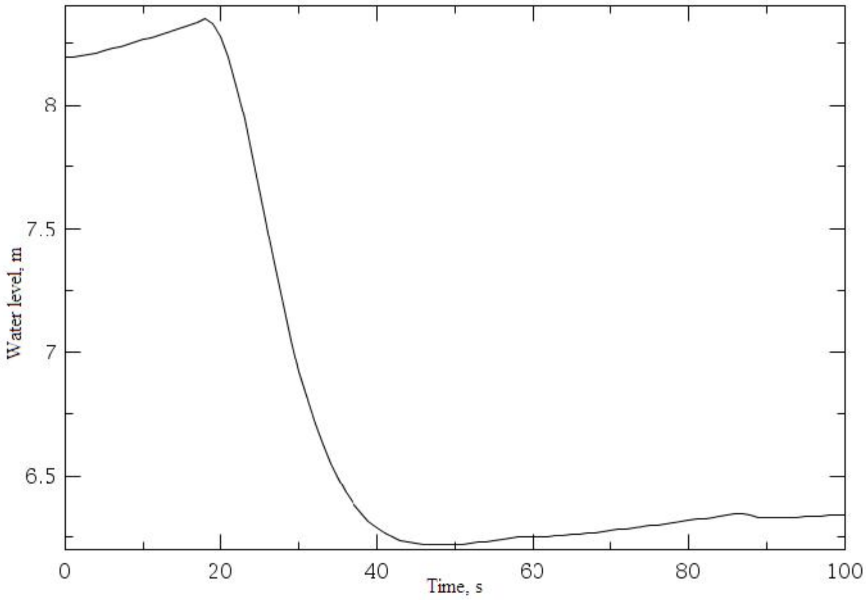


Figure 7: Water level of pressurizer.

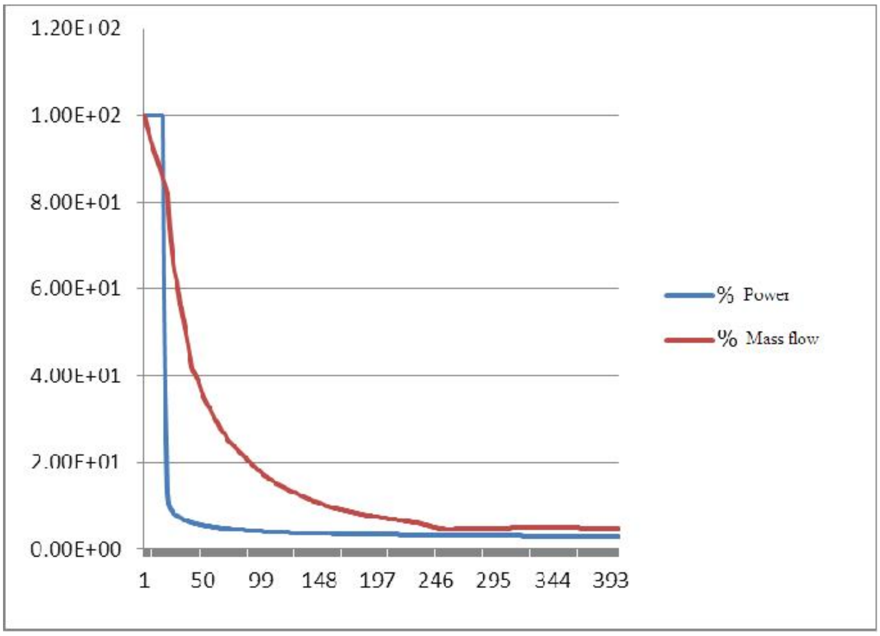


Figure 8: % power and % mass flow rate change versus time.

The calculation results showed that the reactor was safety during occurring the transient. In figure 8, it explain the outlet pressure and temperature changes.

Trip out of two main coolant pumps:

The senarior was trip out of two main coolant pumps when the reactor was operating at 100% power. The events is showed in table 5.

Table 5: The events of trip out of one main coolant pumps [1].

Time, s	Event	Setpoint for actuation
0.0	Trip out of one operating main coolant pump sets	Initiating event

6.5	The first signal for reactor scram (is ignored)	The event occurs when reactor power is operating to exceed 75% power and one of main coolant pump sets trip out of.
8.0	Start of EP control rods removement	
13.0	Start of TG stop valves closing	By the fact of reactor scram in 5 s since the moment of setpoint reaching. The time of stop valves closing is assumed 0.6 s
22.5	Start of BRU-A opening in steam lines of SGs	Pressure in the steam lines exceed 7.2 MPa Control pressure is 6.67 MPa
3600.0	End of calculation	

The calculation results of this transient is illustrated from figure 9 to figure 14.

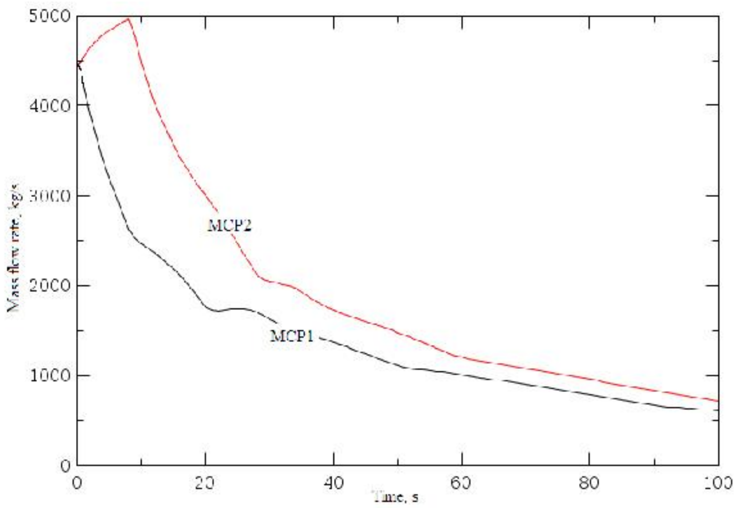


Figure 9: Coastdown of the main coolant pump.

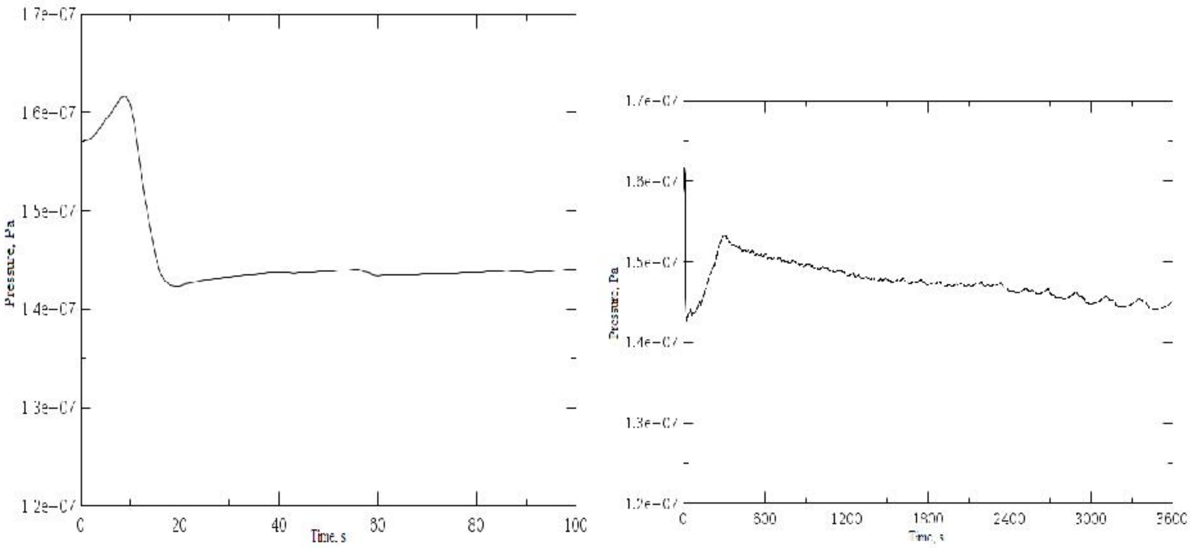


Figure 10: Outlet pressure versus time.

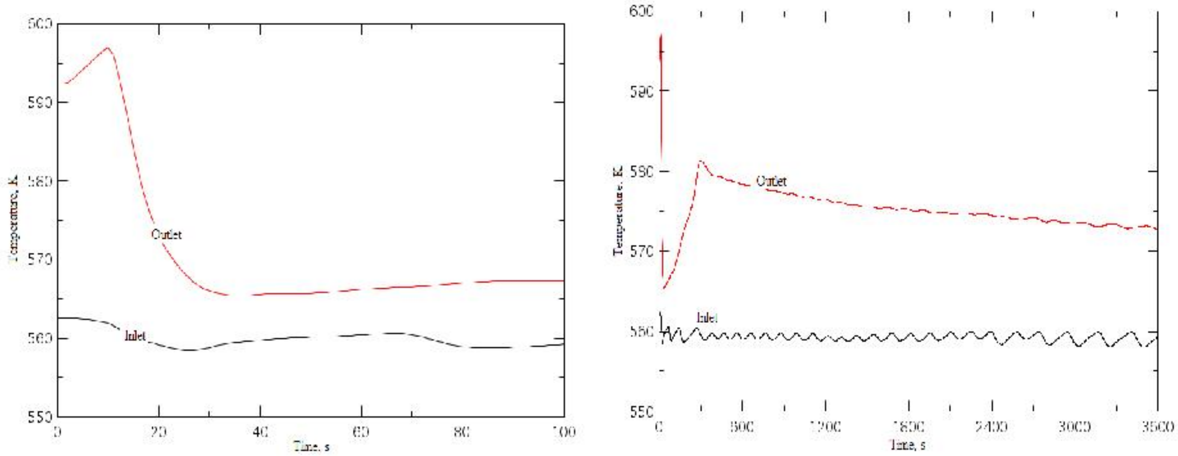
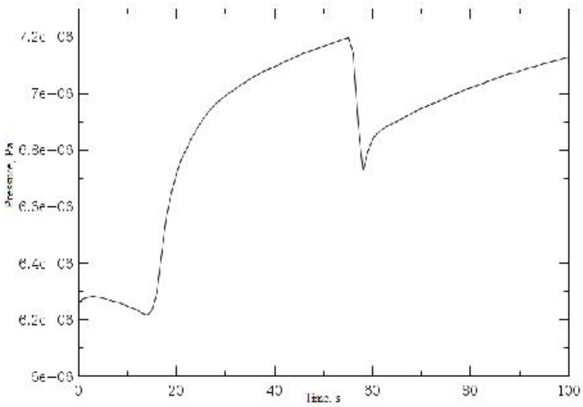


Figure 11: Inlet and outlet fluid temperature.



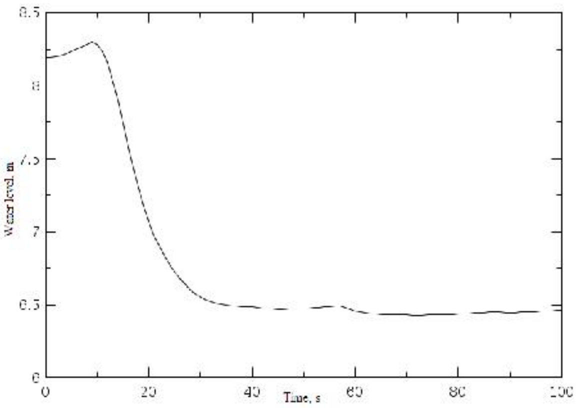


Figure 12: Head SG pressure. **Figure 13:** Water level of pressurizer.

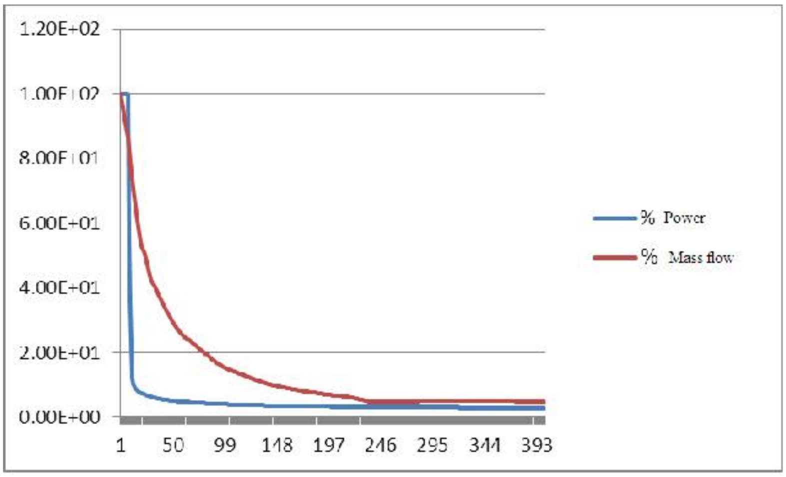


Figure 14: % power and % mass flow rate change versus time.

The thermal hydraulic phenomena are the same with two transients, be only difference changes versus time. The reactor was safety during occurring the transients (trip out of one or two main coolant pumps).

5. CONCLUSION

The subject's contents were studied the technology of VVER-1000 reactor and modeled the thermal hydraulic systems of VVER-1000 in the steady state and the transients. The calculation results compared the design data and analysised versus time. The limitation of the transient calculations is not calculated MDNBR (Minimum Departure from Nucleate Boiling Ratio). Actually, MDNBR is one of the shutdown signals in the transient (trip out of one or two main coolant pumps). Thus, the modeling should be validated and verified to get better results.

The studied contents were enhanced the experience of the working group. The productions of the study are the final report and one paper. The name of the paper: thermal hydraulic analysis of loss of flow accident in VVER-1000 reactor using RELAP5 code. This paper is preparing to present at the national scientific conference of young staff in october 2014.

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