Chapter 4

Simulation results and discussions

From the ECCS model, the simulation is run at 100% full power in steady state condition. Fuel sheath temperature in channel #1,2,3,4 is 310.64, 310.68, 310.74, 310.68 °c , respectively. The pressure at ROH1 and ROH2 is about 10000 kPa. These fuel sheath temperature and ROH pressure are approximately the same as the values from existing CANDU-9 simulator. The button malfunction is push to insert 100% pipe break malfunction. The major event sequence for this break is shown in Table 4.1.

Table 4.1 Event sequence for 100% break near RIH1

Event	Time (second)
Break initiation	0.0
Reactor trip	1.0
LOCA signal	15.0
Open gas isolation valves and RWT valves	28.0
Rupture disc RD1 bursts	33.0
Rupture disc RD2 bursts	33.0
Rupture disc RD3 bursts	33.0
Rupture disc RD4 bursts	33.0
Rupture disc RD5 bursts	33.0

Table 4.1 Event sequence for 100% break near RIH1 (continue)

Rupture disc RD6 bursts	33.0
Start recovery pumps	48.0
Open sump isolation valves	68.0
Close all gas isolation valves	115.0
Open low pressure isolation valves	126.0

The reactor will be shut down 1.0 seconds after the break initiation. Lack of the data from CANDU-9 safety analysis report about the reactivity change after the break, the reactivity change is emulated using the data from Pickering, CANDU-6 nuclear station, which shows that the reactivity will rise up from +1 mk to +4 mk in 1 second after the break, leading to reactor trip due to high neutron log-rate. From existing CANDU-9 simulator, -84 mk reactivity is inserted to trip the reactor in less than 2 seconds. Simultaneously after the break, fuel sheath temperature increases significantly because of increasing reactivity which increases reactor power. In addition, loss of coolant during the break reduces the capacity to remove heat from the reactor core. More importantly, heat transfer coefficient decreases sharply due to the effect of the higher coolant temperature. Again, in this model, heat transfer coefficient during the break, using the data from Pickering nuclear station safety analysis report, is emulated. As soon as the break occurs, there is the reverse flow from ROH2 back to the broken fuel channel. Due to the loss of the coolant through the break, the flowrate in the fuel channels decreases until it is less than 100 kg/sec, which takes about 14 seconds after the break, that will result in decreasing the heat transfer coefficient from 36.362 to 0.5 kJ/sec-°c in 10 seconds. The fuel sheath temperature will rise up from approximately 310 °c to 937 °c in channel #1, the broken channel. Figure 4.1 show fuel sheath temperature in channel #1-4.

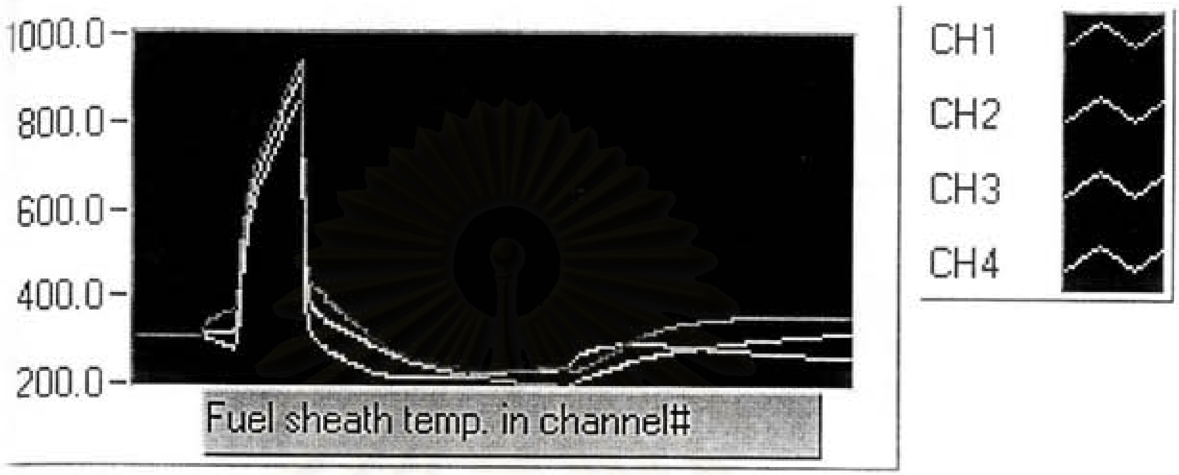

Figure 4.1 Fuel sheath temperature in channel#1-4

As soon as the break occurs, the pressure at ROH1 and ROH2 decreases very rapidly because of depressurization in the PHT system from 10000 kPa to atmospheric pressure in less than 10 seconds which is comparatively sensitive comparing to the data from AECL's simulation, which was verified by the data obtained from AECL Research Whiteshell Laboratories, that takes more than 90 seconds to reach that pressure. In reality, the pressure should drop very rapidly when the break occurs to the highest local fluid saturation pressure[5]. But, in this model, energy equation used to calculate temperature is solved outside network solver. The pressure in the system is calculated by mass and momentum equation. Therefore, loss of coolant in the channel brings down the pressure directly. Lower than alarm set-point at 7000 kPa, this pressure will initiate alarm signal showing ROH2 LOW PRESSURE alarm following by

ROH1 LOW PRESSURE alarm on alarm bar in 2 and 6 seconds, respectively. Figure 4.2 shows pressure decreasing in ROH1 and ROH2.

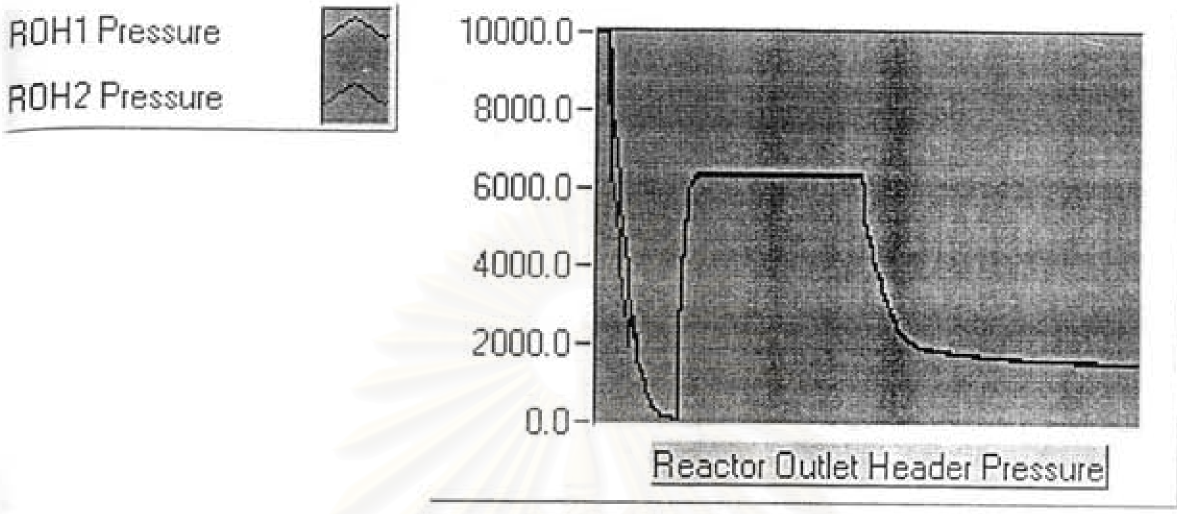

Figure 4.2 ROH1 and ROH2 pressure after 100% pipe break

Receiving two alarm signals, LOCA signal is initiated showing LOCA alarm on alarm bar in 15.0 seconds after the break which is quick enough to send the signal to open gas isolation valves and reserved water tank (RWT) valves. From AECL's simulation, the LOCA signal would be alarmed in 15.5 seconds.

28.0 seconds after the break, all RWT valves and gas isolation valves will be open. The operation of this stage is shown in ECCS1 screen (Figure 3.13). The flowrate of the water from reserved water tank to reactor building via RWT valves is about 3820 kg/sec. After gas isolation valves are open, the pressure in water tanks increases from 200 kPa to 6.7 MPa due to gas leaving from gas tanks. The pressure upstream of rupture disks reaches 2000 kPa , the same as pressure obtaining from AECL's simulation. Rupture disk (RD) 6 which is the rupture disk separating between ROH2 and ECCS burst in 33.0 seconds after the different pressure between upstream and downstream of that rupture disk is greater than 300 kPa. The water is injected into PHT system at the rate of 305.82 kg/sec. At the same time, rupture disk 1,2,3,4,5 burst with the water flowrate of 336.73,299.77,299.77,330.95,309.83 kg/sec, respectively. Due to AECL's simulation, rupture disk 6 bursts in 33.6 seconds following by rupture disk 4, 2, 1, 3, 5 in 32.5, 45.1, 45.7, 46.7, 63.7 seconds, respectively. In this model, all rupture disks burst at the same time because the pressure decreases very rapidly in PHT system. So when all gas isolation valves are open, the pressure at the upstream nodes for all rupture disks is greater than the pressure at the downstream nodes. The flowrate of water to all headers is lower than the flowrate that got from AECL's simulation 30%. According to the water injected to PHT system, PHT pressure increases to 6000 kPa (see Figure 4.2) and fuel sheath temperature will drop rapidly from 937 °c to about 450 °c and slowly decrease to 236 °c (see Figure 4.1). Moreover, the moderator in the reactor core also acts as a heat sink at that time. So the fuel sheath temperature in the hottest channel is not gone beyond the maximum of the fuel cladding temperature at 1204°c. Contrary to the values from this model, the pressure from AECL' simulation does not increase due to the water injected into PHT system. And it takes more than 100 seconds for fuel sheath temperature to decrease to 310°c. In this model, algorithm number 853 was written to calculate fuel sheath temperature in the channels. This algorithm worked properly in normal condition. But, in this case, it is difficult to define fuel sheath temperature when there is a little coolant in the fuel channels. As the cold water first comes in contact with the fuel cladding, it will be exposed to the fuel-rod temperatures considerably in excess of the water-saturation temperature. Initially, the water will not be able to wet the surface, and thus pool-film boiling exists. The surface above this level will experience steam cooling. The water soon will be able to penetrate the steam film and nucleate boiling will result[11]. Lack of that information, it is assumed that after the water from injection phase, greater than 100 kg/sec, is injected into all headers, heat transfer coefficient will switch back to the values in normal condition, which takes about 33 seconds after the break, that causes fuel sheath temperature to drop very rapidly.

48.0 seconds after the break, recovery pumps P1 and P2 will be started in circulation mode waiting for the signal to open sump isolation valves. This operation is shown in ECCS2 screen. In this mode, the recovery pump flowrate is about 150 kg/sec corresponding to the design data from AECL. Due to the ECCS description for the CANDU-9, recovery pumps will start after receiving LOCA signal. But, for clearly understanding the step of the operation of ECCS from the start-up sequencer, recovery pumps will be started after gas isolation valves opened. To show the main events sequence, ECCS2 screen provides the button to show start-up sequencer.

68.0 seconds after the break, the water level in reactor building (RB) reaches the setpoint at 1.2 m above the ground. The signal is generated to open sump isolation valves. The pumps will operate in that mode until the water level in one of four water tanks reaches the level at 10.0 m in 115.0 seconds after the break and then gas isolation valves are close. Consequently, the pressure in PHT will decrease to about 1800 kPa. In the CANDU-9 description, the setpoint to close gas isolation valves is 5.0 m. But the setpoint at 10.0 m was used in this model for quickly observing the response of the fuel sheath temperature after the injection phase finished. Therefore it should take more time to close gas isolation valves and to open low pressure isolation valves if the setpoint at 5.0 m is implemented.

126 seconds after the break, the signal to open low pressure isolation valves is generated. Flowrate to all headers is about 150 kg/sec, the same value from AECL's design data. In recovery phase, according to reducing in flowrate to headers, the fuel sheath temperature will continue to go up and remain constant at 350 °c.