Chapter 3

Computer Simulations

The simulation of the emergency core cooling system for a 900 MW CANDU-9 nuclear power plant has been developed using an object oriented programming language. Defining the scope and description for ECCS, first, the process equipment was modeled to represent the equipments and then the hydraulic network model was built to represent the dynamic flow and pressure in the system. These two models were merged together to form a working model. After that, the control system model was added to the working model. To observe the power change during the break, neutronic model was created. Moreover, thermalhydraulic model was built to observe the fuel sheath temperature. Finally, the graphical user interface screens were built with LabVIEW to display the necessary parameters; flow rate, pressure, temperature and to control any equipment by operator.

3.1 Computer code

The thermalhydraulic of primary and ECCS circuits are simulated by using the computer code, CASSIM. CASSIM is made up of a dynamic linked library (DLL) of generic algorithms, consisting of supporting Fortran subroutines. Generic software algorithms are developed corresponding to physical plant components such as a process, a logical unit, or equipment (e.g. valve)[7].

CASSIM is a simulation development system based on three components:

-CASSBASE: the database engine which is used to manage the library of generic algorithms, and to connect the blocks in a model together. Moreover, it is also used to manage the hydraulic flow networks.

-CASSENG is the real-time simulation run-time engine. It is used to make a calculation from the model data file. The simulation can be controlled by using command such as “freeze” , “iterate”, “run”. CASSENG supports Dynamic Data Exchange (DDE), so that LabVIEW is used to represent the plant’s simulated data via its graphical user interface.

-LabVIEW is the user interface development environment for the purpose of developing user-friendly graphical user interfaces for simulator applications. Graphical screens with buttons, icon symbols, pop-up dialog, etc. can be created using LabVIEW for Windows. Through either DDE or TCP/IP, user interface screens request data from the simulation running in CASSENG for display and monitoring.

3.2 Assumptions

To simplify ECCS model, the following assumptions were made

- Only main equipments shown in Figure 3.1 were simulated. The air compressors, fill valves, drain valves, and vent valves were ignored. Without these equipments, the simulation can performs effectively.

- The pressure in the gas tanks was constant at all time so that the water injection rate from water tanks to HTS was constant.

- The fill valves, drain valves and vent valves worked perfectly during the operation of ECCS.

- Only one control channel was implemented. Another two channels were duplicated from the former.

- A large pipe break at the outlet of RIH1 was simulated, because the most severe consequence result from this case.

3.3 Process Equipment Modeling

All process equipments in Figure 3.1 are simulated by creating the blocks to represent the equipments in the model. After studying the ECCS design description, the model was divided into three modules, namely; reserve water tank, injection and recovery module. Reserve water tank module consists of reserve water tank and isolation valves, which are named starting with WIJ for these blocks. This module is shown in Figure 3.2. Injection module, which is shown in Figure 3.3, contains gas tanks, gas isolation valves, water tanks and rupture disks. All blocks in this module would be named starting with IJT. There are sump isolation valves, recovery pumps, low pressure isolation valves, test/recirculation valves and heat exchangers in recovery module. All blocks would be named starting with RCR. Figure 3.4 shows recovery module.

To identify the beginning and the end of each modules, the first and last blocks for each module are usually marker blocks. For instance, WIJ_BEGIN and WIJ_END, which algorithm number 398 MARKER is chosen for these blocks, are the first and the last block for reserve water tank module. Marker blocks do not execute any simulation code, and it only serves the purpose of enclosing the blocks belonging to a particular system, so that the beginning and the end of the system is clearly defined. From Figure 3.1, the blocks for each equipment i.e. recovery pumps, gas isolation valves , reserve water tank etc. were created and generic algorithm was chosen to represent the simulation of a piece of equipment and the inputs, outputs, and coefficients of the blocks were also defined.

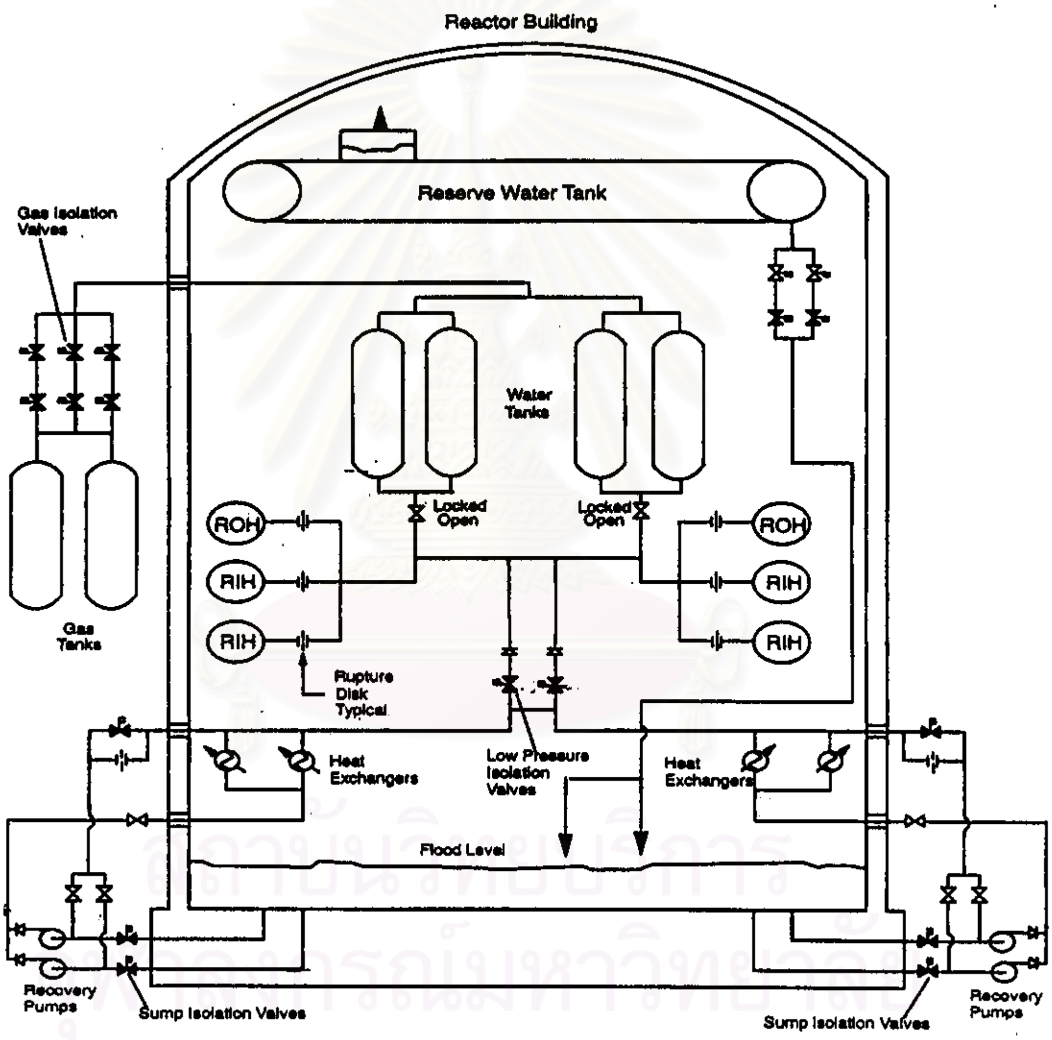


Figure 3.1 Emergency Core Cooling System[8]

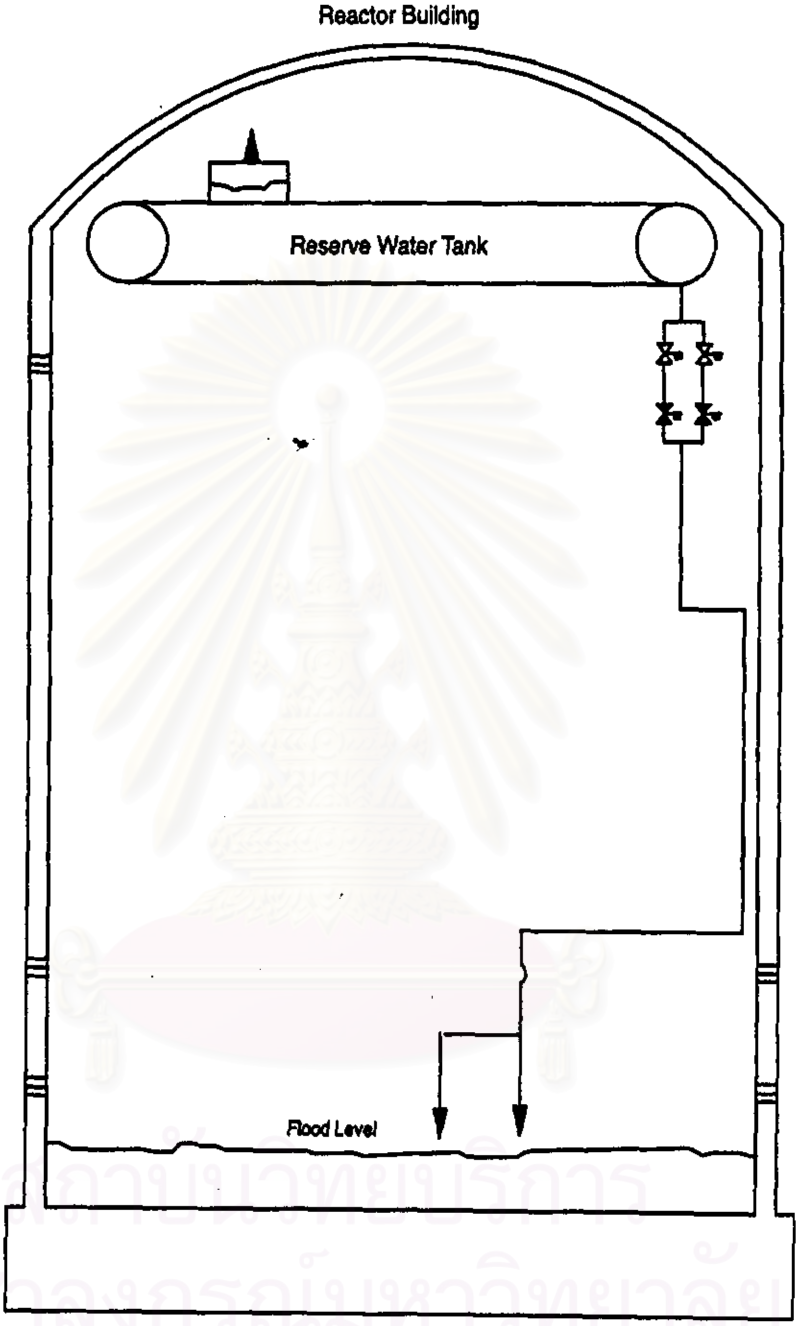


Figure 3.2 Reserve Water Tank Module

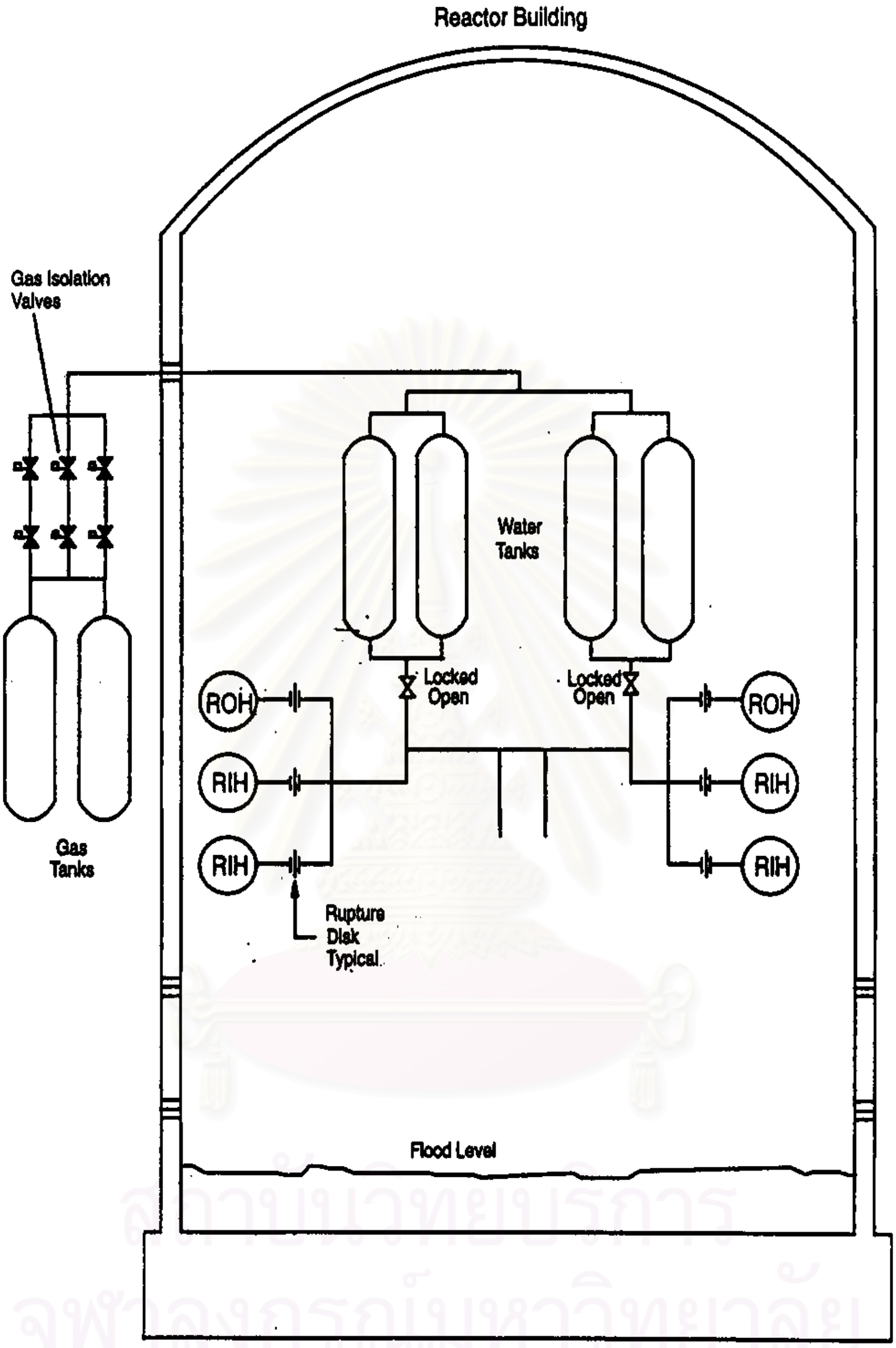


Figure 3.3 Injection Module

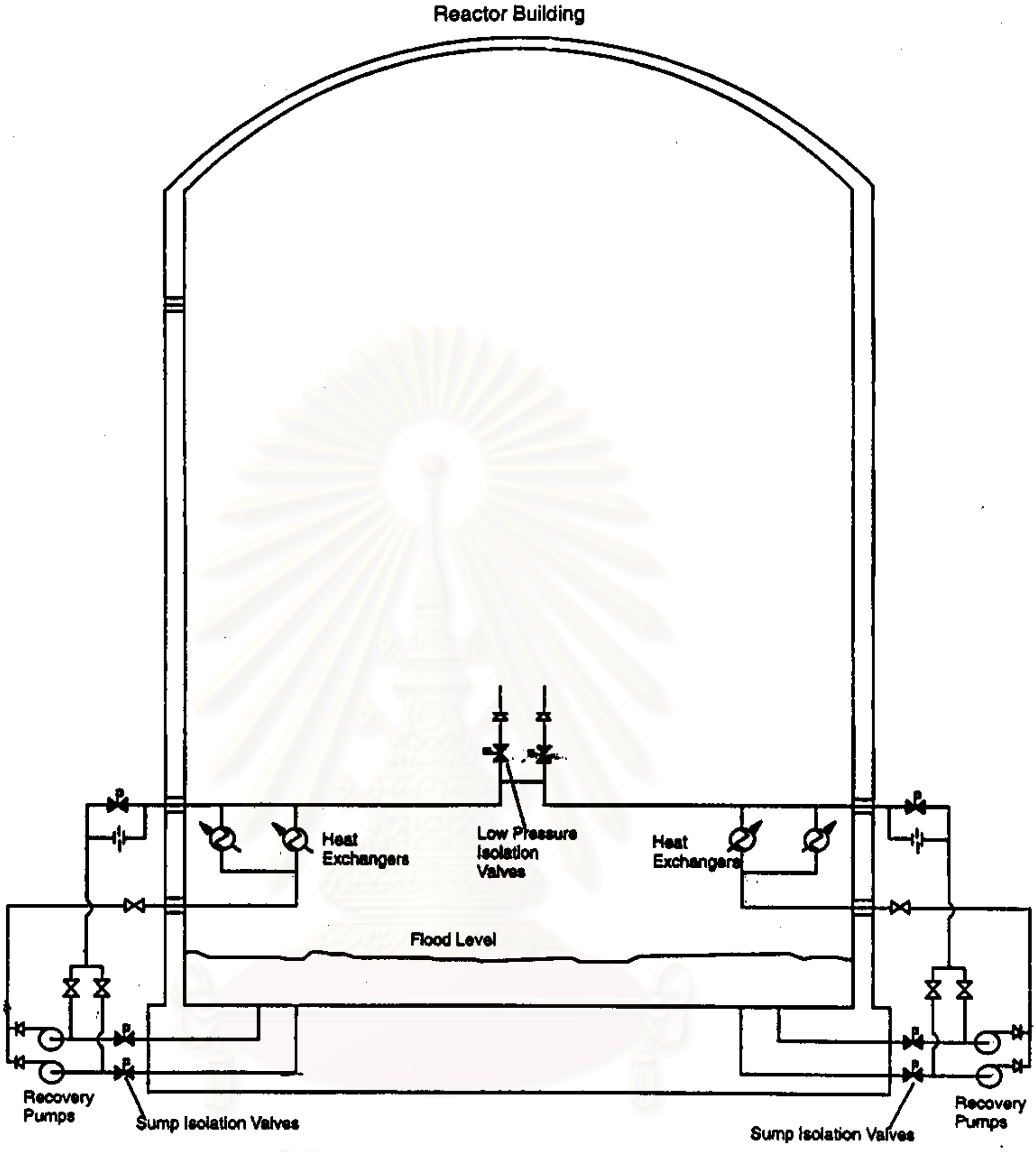
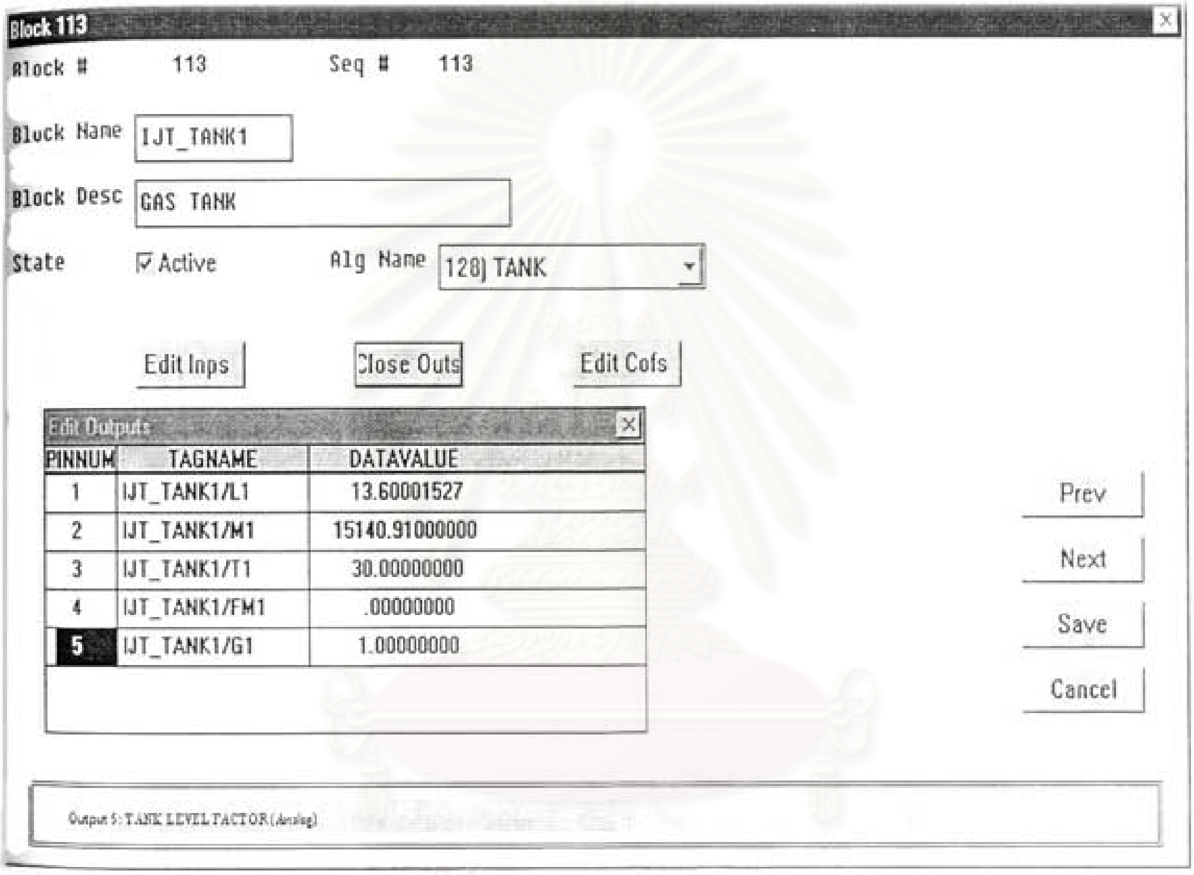


Figure 3.4 Recovery Module

For example, to create the block for gas tank, in CASSBASE, open CASSBASE/CHWT/ECCS and choose any file name. Click new to create new block and name it as IJT_TANK1. Choose algorithm number 128, which represent for simple tank and enter description for the block. For input of the block , this tagname can be connected from the output coefficient of any blocks or can be a constant value. Enter number to initialize the blocks for inputs, outputs and coefficients. Figure 3.5 shows gas tank block. For more detail in how to define a system ID and create new block ,please refer to CASSIM Tutorial Chapter 2.2[9]. All process equipment blocks will be shown in Table 1 in Appendix A1.



Block # 113 Seq # 113

Block Name IJT_TANK1

Block Desc GAS TANK

State ☑ Active Alg Name 128] TANK

PINNUM	TAGNAME	DATAVALUE
1	IJT_TANK1/L1	13.60001527
2	IJT_TANK1/M1	15140.91000000
3	IJT_TANK1/T1	30.00000000
4	IJT_TANK1/FM1	.00000000
5	IJT_TANK1/G1	1.00000000

Output 5: TANK LEVEL FACTOR (Analog)

Figure 3.5 Gas tank block.

3.4 Hydraulic Network Modeling

Finishing all process model, hydraulic network is built to calculate pressure and flow rate in the system. In CASSIM, flow and pressure are calculated by network solver using mass and momentum equation in matrix calculation for incompressible flow system. For energy equation, it is calculated outside the network. To create nodal diagram, first, external node and internal node will be defined. After that all blocks representing nodes and links are created. Then the inputs, outputs and coefficients are defined in order to obtain pressure and flow calculation.

It is important to estimate node capacitance and pressure drops to initialize the network to meet the initial state condition. The capacitance of the node can be estimated from the volume of the piping involved. The control volume of a node may be calculated as the sum of half of the volume of piping upstream of the node and half of the volume of piping downstream of the node.

Assumed a constant control volume:

$$\mathrm{M} = \rho \mathrm{V}$$

$$\frac{dM}{dt} = \rho\frac{dV}{dt} + V\frac{d\rho}{dt}$$

as $\frac{dV}{dt}$ is zero for constant control volume,

$$\frac{dM}{dt} = V\frac{d\rho}{dt}$$

From mass balance equation:

$$\frac{dM}{dt} = \mathrm{Win} - \mathrm{Wout}$$

The pressure equation is defined as:

$$\mathrm{C}\frac{dP}{dt} = \mathrm{Win} - \mathrm{Wout}$$

hence

$$C\frac{dP}{dt} = V\frac{d\rho}{dt}$$

$$C = V\frac{d\rho}{dP}$$

C = capacitance of control volume, kg/m^3/kPa

M = total mass in the control volume, kg.

V = volume of the control volume, m^3.

ρ = density within the control volume, kg/m^3.

Win = mass flow in control volume, kg/sec.

Wout = mass flow out of control volume, kg/sec.

Capacitance of the node can be calculated from the equation above. The control volume of the node, V, is the estimate of the piping volume belonging to the node. The value $\frac{d\rho}{dP}$ is the reflection of the compressibility of the fluid in the node. For incompressible fluids, this value will be very small. A typical value for water at 40 °C is 4.43 E-4 kg/m^3/kPa[9].

By using empirical approach, a quick estimate for the pressure for each of the node can be obtained. In this model, the overall pressure drop across the whole pipe was given from AECL's ECCS simulation. From Figure 3.1, the number of the valves involved and the number of links between all branches were set up. Then pressure drop for each link could be calculated. See detail for pressure drop calculation in Appendix A2

To create the network blocks, the system name for these blocks must start with NH. For stability of the network, hydraulic network model for the simulation was separated into 5 nodal diagrams; NHW, NHI, NHJ, NHR and NHM, as shown in Figure 3.6-3.10

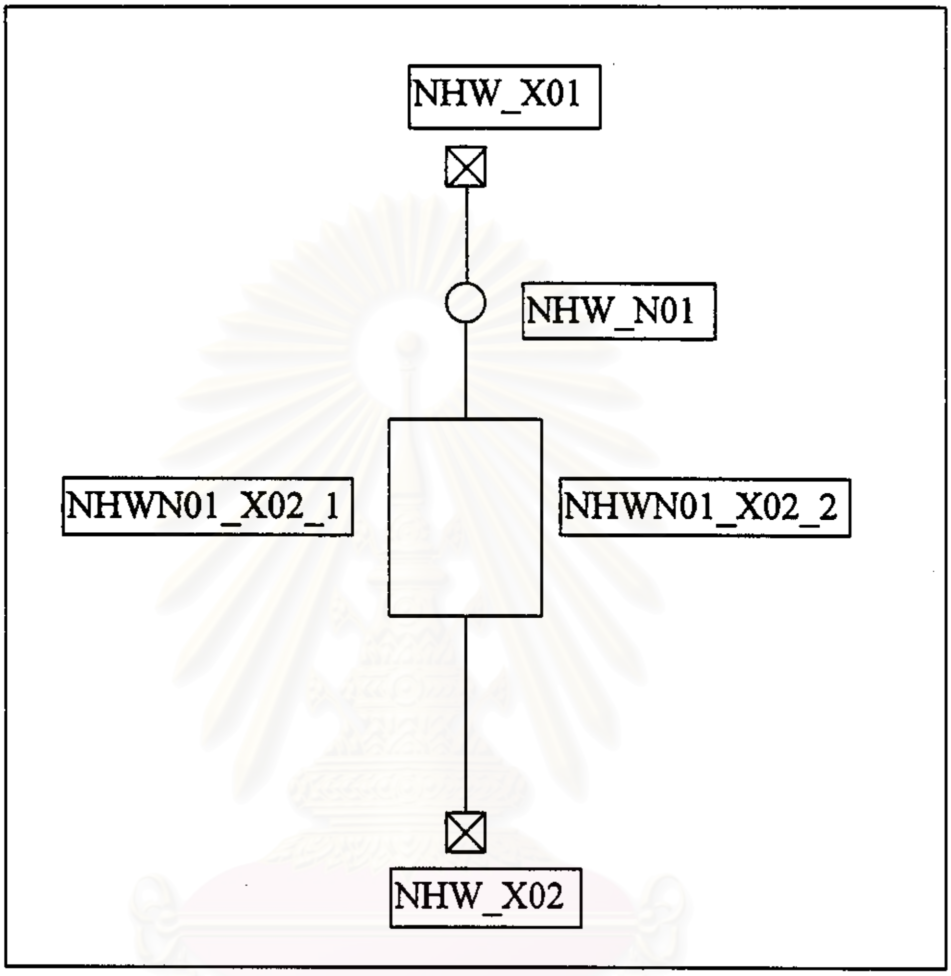


Figure 3.6 Nodal diagram for NHW.

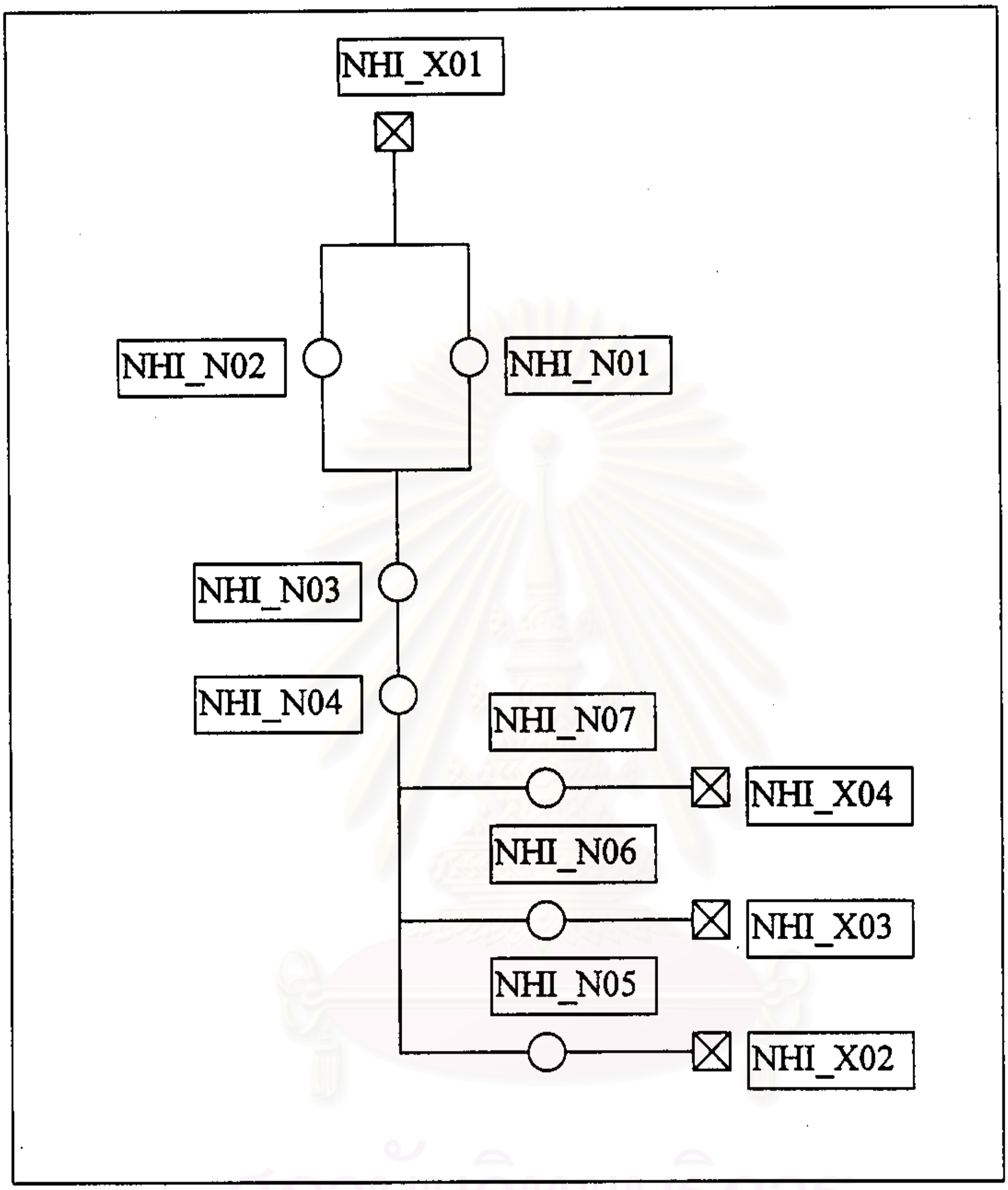


Figure 3.7 Nodal diagram for NHI.

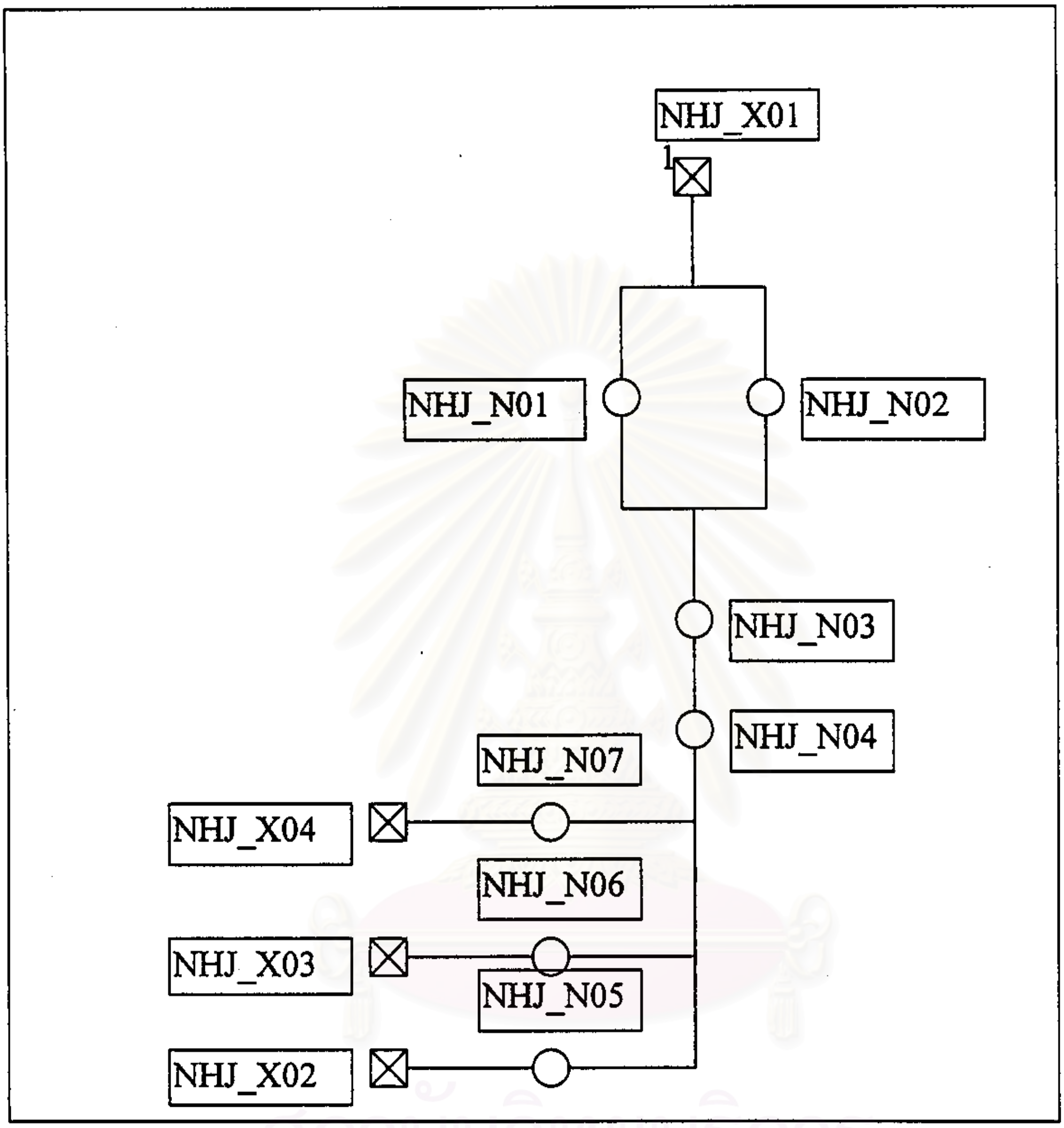


Figure 3.8 Nodal diagram for NHJ.

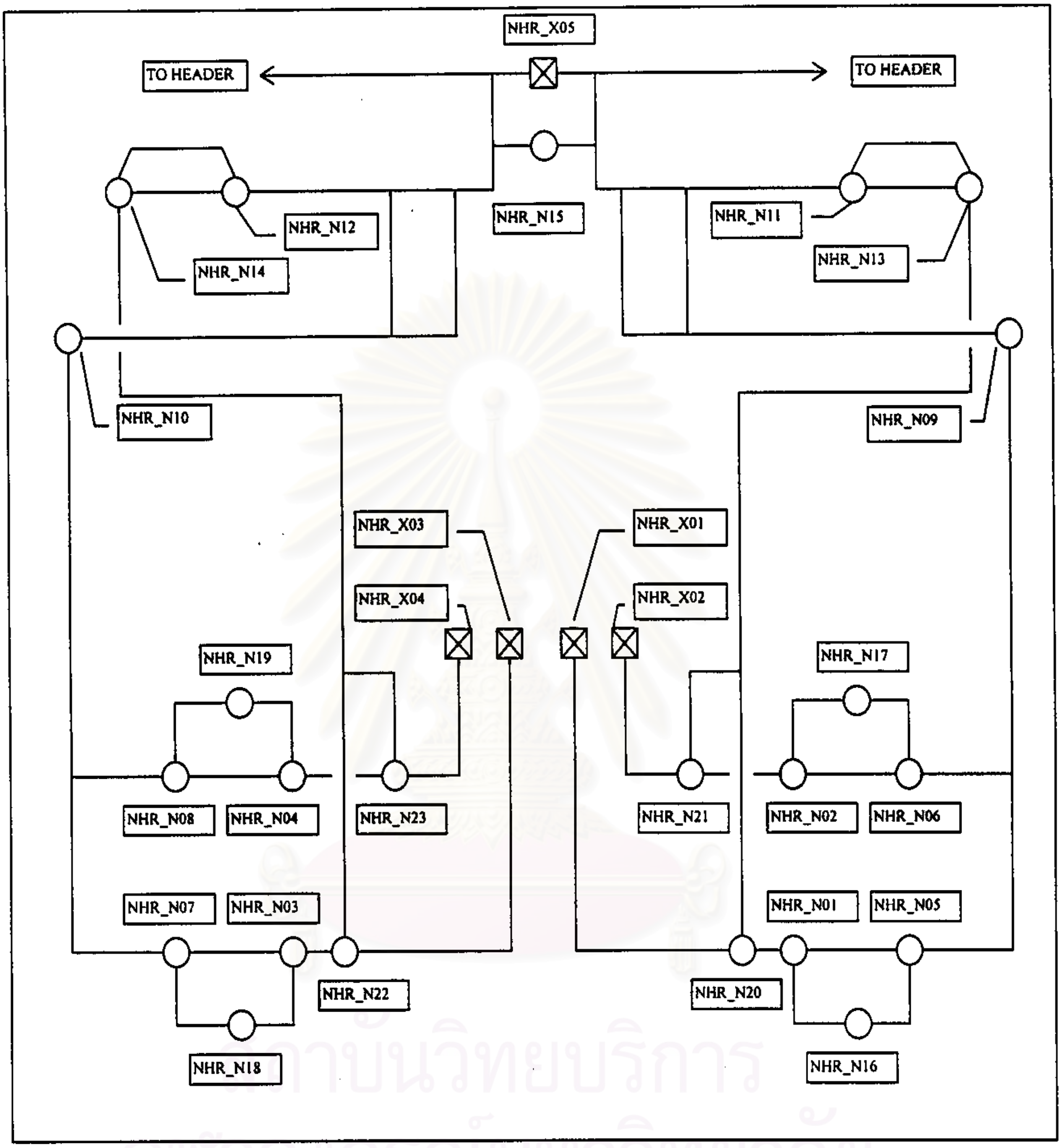


Figure 3.9 Nodal diagram for NHR.

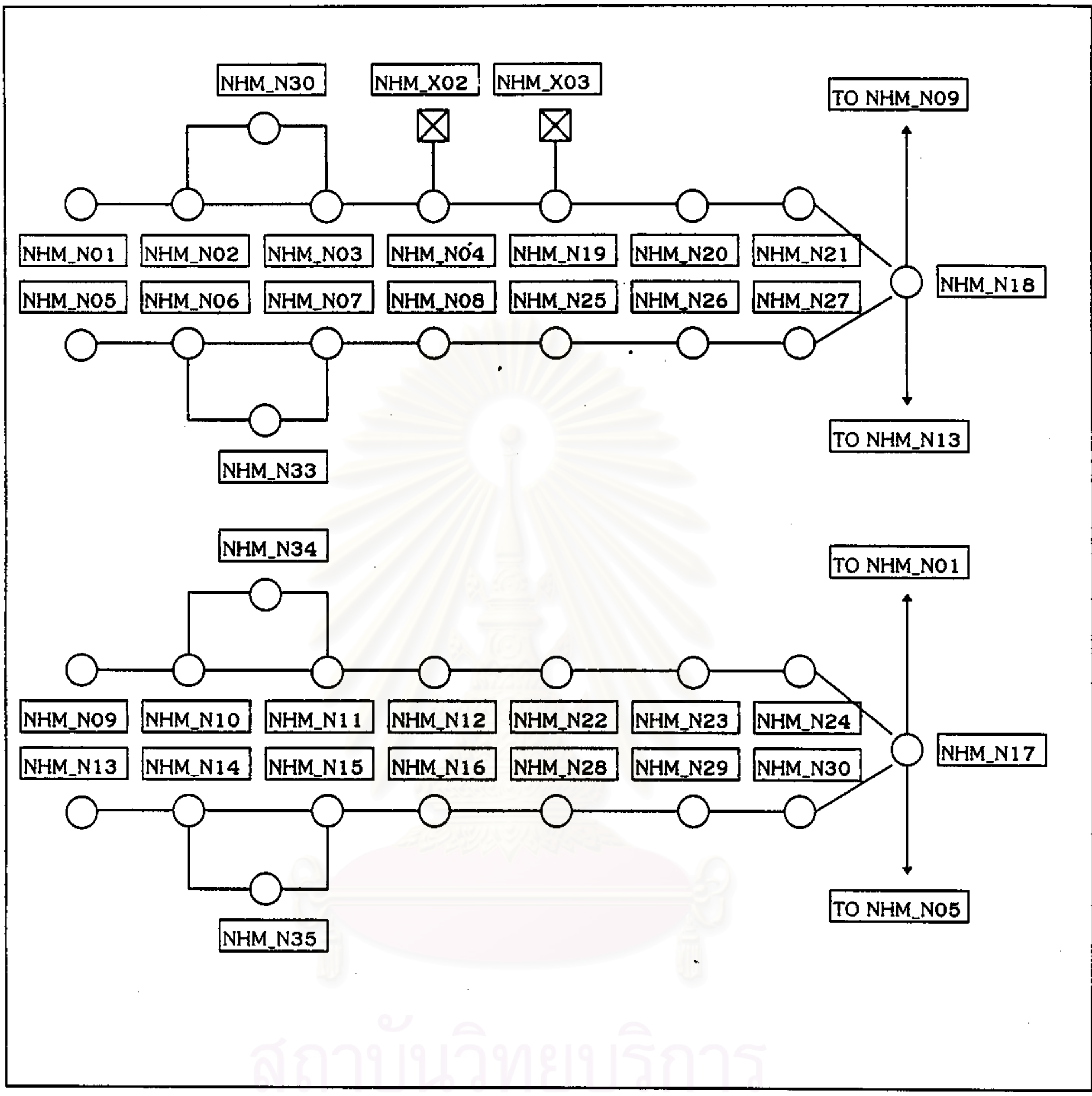
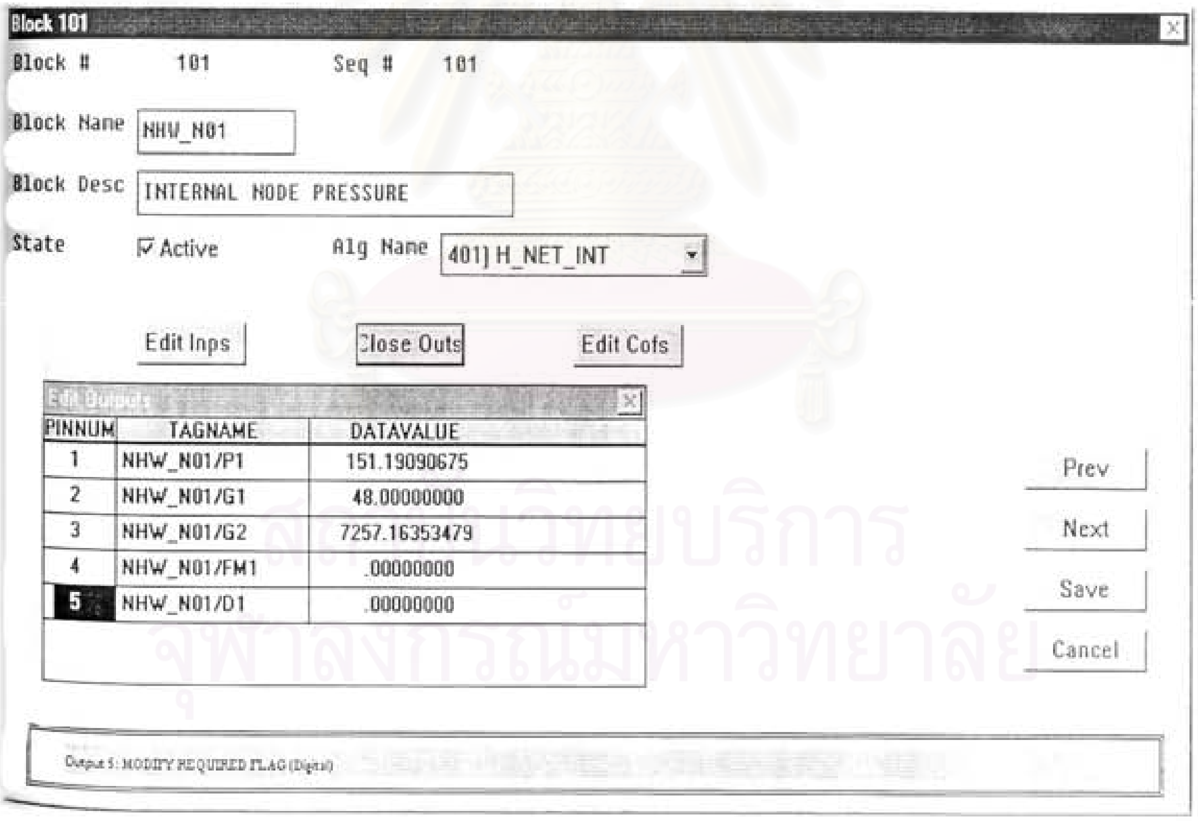


Figure 3.10 Nodal diagram for NHM.

NHW is the nodal diagram to calculate flow and pressure for reserve water tank module in Figure 3.2. From the nodal diagram in Figure 3.6, first, after creating the marker block NHW_BEGIN, the external node block

NHW_X01, representing the pressure in reserve water tank, was created. Then internal node block NHW_N01, which the pressure in this node will be calculated simultaneously by the network solver, was created following by the external node block NHW_X02. After that branch/link block NHWX01_N01, was built to calculate flow between NHW_X01 and NHW_N01 node as well as NHWN01_X02_1 and NHWN01_X02_2 to calculate flow between NHW_N01 and NHW_X02 node. Finally, to finish the network block for NHW system, the marker block NHW_END, was created. After the network blocks were created, the NETWORK GENERATE utility in CASSIM must be run, so that auxiliary blocks required by the network solver would be created. Figure 3.11 shows NHM_N01 block.



Block # 101 Seq # 101

Block Name: NHW_N01

Block Desc: INTERNAL NODE PRESSURE

State: ☑ Active Alg Name: 401] H_NET_INT

PINNUM	TAGNAME	DATAVALUE
1	NHW_N01/P1	151.19090675
2	NHW_N01/G1	48.00000000
3	NHW_N01/G2	7257.16353479
4	NHW_N01/FM1	.00000000
5	NHW_N01/D1	.00000000

Output 5: MODIFY REQUIRED FLAG (Digital)

Figure 3.11 NHW_N01 block

NHI is the nodal diagrams for the right hand side of the injection module in Figure 3.3. According to constant pressure in the gas tanks, the external node for gas tanks is not simulated. The external node NHI_X01 was created to represent the pressure in the water tanks following by internal nodes NHI_N01 to NHI_N07, which are the nodes for the pressure in the injection line, and external nodes NHI_X02 to NHI_X04, showing the pressure in the PHT system. Figure 3.7 shows NHI nodal diagram. Once all external and internal nodes were created, the same procedure to create NHW nodal diagram was applied.

For NHJ nodal diagram in Figure 3.8, the left hand side of the injection module in Figure 3.3 , was created as same as NHI nodal diagram.

The large and complicated one of the network is NHR nodal diagram in Figure 3.9, which represents the recovery module in Figure 3.4. The external nodes NHR_X01 to NHR_X04, for RB pressure, were created. The bypass pressure internal node NHR_N20, was built. Then the internal node NHR_N01, was built to show the suction pressure of the recovery pump P1 following by NHR_N05, the discharge pressure of the recovery pump P1. To represent bypass pressure of the pump P1, NHR_N16 was created. Duplicating those blocks and changing the name for the recovery pumps P2 to P4, the inlet heat exchanger pressure, NHR_N09, was built. After that the inlet and outlet pressure for test/recirculation line valve, NHR_N11 and NHR_N13, were created. NHR_N12 and NHR_N14 were created by duplicating and changing the name for the former. Finally, after creating NHR_N15, the bypass pressure for the two loops, NHR_X05 was built to show the pressure in the injection phase. Again the same procedure to build the branch/link blocks and enter all inputs, outputs and coefficients will be used.

To simulate primary heat transport system during the break, hydraulic network using in the existing CANDU-9 model was modified. External nodes NHM_X02 and NHM_X03 were created to simulate the break. And also internal nodes NHM_N31 to NHM_N34 were created to simulate bypass flow during the pumps shut down. For more detail in how to create network model, please refer to CASSIM Tutorial Chapter 2.3[9]. All network blocks will be shown in Table 2 in Appendix A1. Generating all networks using NETWORK GENERATE utility, merge process model with hydraulic network model using MERGE function in CASSBASE.

3.5 Control System Modeling

According to control descriptions, there are three control channels in ECCS; L, K and M channel. To simplify the system, only one control channel was simulated in this model. Control system is divided into 2 areas: analog controls, digital controls. The blocks to represent analog and digital control in the system were built after studying the control and monitoring descriptions in the previous chapter. Furthermore, for automatic initiation to start up the simulation, start-up sequence blocks were created. Moreover, to control equipment in auto, manual or standby mode, equipment control blocks would be done.

3.5.1 Analog Control Blocks

From the previous chapter, control and monitoring loops, such as flow, pressure, level and temperature loops, are simulated by these blocks. These blocks show parameters like level, temperature, flow. A transmitter algorithm is chosen to model a generic transmitter. Function like, noise, malfunctions of indications as well as high/low operating alarms are available in this transmitter algorithm. All analog control blocks will be shown in Table 3 in Appendix A1.

3.5.2 Digital Control Blocks

Switch algorithm is chosen for these blocks. It will perform the function of comparing the input (measured value) to the set-point, and changes the output accordingly, depending on which is greater in value. However, this algorithm has the added feature to fail the switch open or close as malfunction irrespective of what the input value is. All digital control blocks will be shown in Table 4 in Appendix A1.

3.5.3 Start-up Sequence Blocks

To start all equipments automatically and complete within the allocated time, start-up sequence will be used. There were four start-up sequences in this model. For each start-up sequence consisted of a sequencer block which its outputs connected to control logic for requesting the start/open or stop/close a step-complete block to check that the condition for completing a particular step (known as tie-back) was fulfilled and permissive blocks to check that all conditions were completed before sending request signal to sequencer block. The sequencer is capable of generating a combination of 20 different independent output signals. Which signals to generate for each step in a sequence depends on a parameter called the decimal number for that step. Decimal number for a step is calculated by the following formula:

$$\text{Decimal number} = \sum_i \left(2^{\text{output\#(i)-1}}\right)$$

Where i = the number of independent outputs for a step

output# = output number a integer

All sequence blocks will be shown in Table 5 in Appendix A1.

3.5.4 Equipment Control Blocks

From chapter 2, component control and monitoring were studied to how to control and monitor the equipments. The equipments may be controlled in AUTO or STANDBY mode. Some equipments may be manually open or start. Main equipment i.e. recovery pumps, low pressure isolation valves are usually controlled remotely in the control room or locally at the location of the equipment. For each equipment consists of OPRSTCL, AUTOSTMAN and BREAKER algorithm. OPRSTCL algorithm is used for controlling the equipment remotely by processing the start or stop requests from the user interface. AUTOSTMAN algorithm is used in conjunction with OPRSTCL algorithm to process signal from control logic to start or stop equipment under AUTO or STANDBY mode. OR algorithm is used for open/reset or close only for motorized valves to select the signal between open and reset or close and reset. BREAKER is the algorithm commanding to start or stop the equipment. After these blocks were created, again, the inputs, outputs and coefficients must be defined. All equipment control blocks will be shown in Table 6 in Appendix A1.

After creating all control blocks, merge these blocks to the combination of blocks between process and network blocks.

3.6 Neutronic Modeling

The algorithms in CASSBASE provide only general functions for equipment and control logic. Thus, in order to observe the power change during the break, algorithm number 850 was used to write the equation in FORTRAN language. This algorithm shows the effects of reactivity change that increases due to steam void in the fuel channel during the break on reactor power and decreases significantly in few seconds after increasing power are arrested by fast reactor trip.

Consider power change due to reactivity, $\frac{Pt}{P_0}$. From equation[10]

$$\frac{Pt}{P_0} = \frac{\beta}{\beta - \Delta k} \exp\left\{\frac{\Delta k}{\tau * (\beta - \Delta k)}\right\}.t \;-\; \left(\frac{\Delta k}{(\beta - \Delta k)}\right) \exp\left\{-\left(\frac{\beta - \Delta k}{l}\right)\right\}.t$$

where

P_t = reactor power after reactivity change, MW

P_0 = reactor power before reactivity change, MW

Δk = reactivity change, mK

β = neutron lifetime = 0.086 sec

τ = average lifetime = 13 sec

l = prompt neutron lifetime = 0.001 sec

Here all six delayed neutron groups were lumped into one with an average lifetime of τ. From Table 3.1, this value must be 8.5/0.65 =13 seconds. l is the prompt neutron lifetime of 0.001 seconds. Table 3.1 lists the fission yields (in %), the half lives and average lifetimes of the six delayed neutron groups produced by thermal fission of U-235.

Table 3.1 Delayed neutron data for thermal fission of U-235

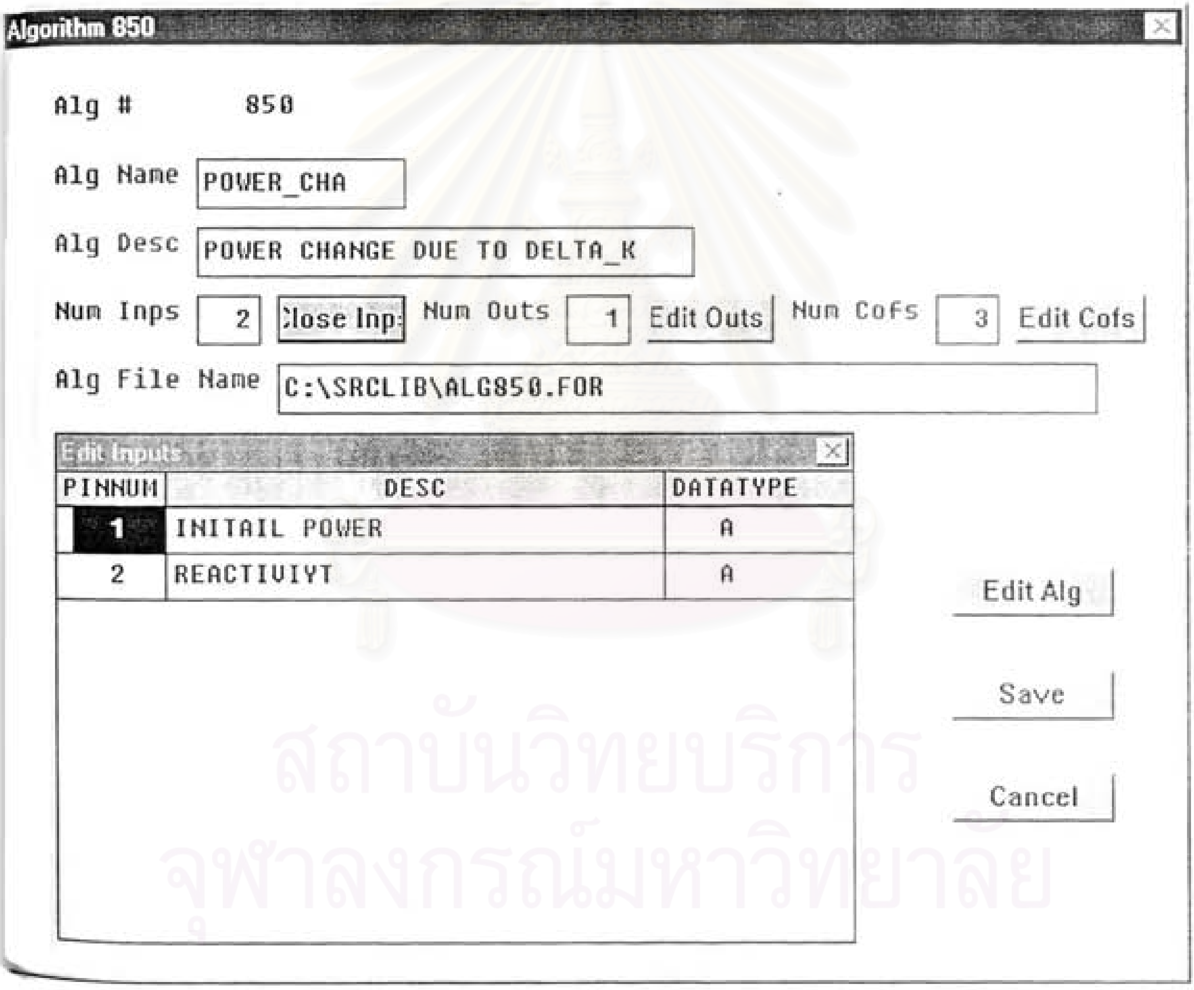
Group	Yield (%)	Halflife (s)	Lifetime (s)	Yield*Lifetime
1	0.0215	55.72	80.40	1.729
2	0.142	22.72	32.78	4.655
3	0.127	6.22	8.98	1.140
4	0.257	2.30	3.32	0.853
5	0.075	0.61	0.88	0.066
6	0.025	0.23	0.33	0.009
Total	$\beta = 0.65$			8.5%

The product of the yield and lifetime is determined for each group, and the total of this column is found to 8.5. The average lifetime of all neutrons, prompt and delayed, is divided by the total yield of 100%. This comes to 0.085 seconds. The neutron lifetime of a generation, β, is then weighted average lifetime plus the slowing-down time and the diffusion time in the moderator. The latter is typically 0.001 seconds, and so the neutron lifetime is,

$$\beta = 0.085 + 0.001 = 0.086 \text{ seconds.}$$

Lack of the data of reactivity change during the break in CANDU-9 safety analysis report, reactivity change from +1 mk to +4 mk in 1 seconds will be assumed using the data from Pickering station, CANDU-6 nuclear station.

To write this algorithm in CASSBASE/CHWT/ECCS at Algorithm utility, open algorithm number 850, use Edit Alg command to write the program and save in alg850.for (see Figure 3.12). Finishing writing this algorithm, compile it in Watcom FORTRAN to get the object file by going to dos prompt in C:\SRCLIB, use command ADDTOLIB alg850.for to add the algorithm compiled to the library, and use command COPY CASSIM.DLL C:\CASSENG to copy that file to CASSENG.



Alg # 850

Alg Name POWER_CHA

Alg Desc POWER CHANGE DUE TO DELTA_K

Num Inps 2

Num Outs 1

Num Cofs 3

Alg File Name C:\SRCLIB\ALG850.FOR

PINNUM	DESC	DATATYPE
1	INITAIL POWER	A
2	REACTIVIYT	A

Figure 3.12 Algorithm 850

3.7 Thermalhydraulic Modeling

In nuclear reactor, the thermal energy released in fission in the fuel rods is transferred by heat conduction to the surface of the rod. To observe the fuel sheath temperature of the fuel in the channel, algorithm number 853 was used to write the equation in FORTRAN language. This algorithm shows heat conduction from the center to surface of the fuel.

Consider a long cylindrical fuel. Assumed that heat is produced at the constant rate q''' with in the rod. From equation[10]

$$T = T_m - \frac{q'''r^2}{4k_f}$$

This equation can be written as

$$T_s = T_m - \frac{q'''d^2}{16k_f}$$

where d is the diameter of the fuel, T_m is the temperature at the center of the fuel, and T_s is the temperature at the surface of the fuel. The average fuel temperature is defined as the average of the temperature at the center and the surface of the fuel.

$$\overline{T} = \frac{Ts + Tm}{2}$$

or $\quad Tm = 2\overline{T} - Ts$

substitute for T_m

$$T_s = 2\overline{T} - Ts - \frac{q'''d^2}{16k_f}$$

or $$q''' = \frac{32(\overline{T} - Ts)k_f}{d^2}$$

We apply energy balance on the core.

$$mc_p \frac{d\overline{T}}{dt} = Q_{100} - \frac{32(\overline{T} - Ts)k_f}{d^2}\left(\frac{m}{\rho}\right)$$

$$\frac{d\overline{T}}{dt} = \frac{Q_{100}}{mc_p} - \frac{32k_f(\overline{T} - Ts)}{d^2 c_p \rho} \qquad (1)$$

where Q_{100} is energy release by fuel core at full power, KW.

It is very conservative to use surface fuel temperature as fuel sheath temperature, because the possible maximum cladding temperature can not be higher than this value. Steady state balance across fuel sheath is assumed. For one fuel element, heat transfer to sheath will be

$$Q = \frac{32(\overline{T} - Ts)k_f}{d^2} V$$

$$= \frac{32(\overline{T} - Ts)k_f}{d^2}\left(\frac{\pi d^2 l}{4}\right)$$

where V is the volume of one fuel element, m^3.

From equation

$$q'' = h(T_c - T_b)$$

For one fuel element, heat transfer to coolant will be

$$Q = hA_c(Ts - \overline{Tc})$$

$$= h\pi dl(Ts - \overline{Tc})$$

where $\overline{Ts}$ is the average temperature of fuel sheath and $\overline{Tc}$ is the average temperature of the coolant.

Equaling both equation for heat transfer to sheath and coolant;

$$\frac{32(\overline{T}-Ts)k_f}{d^2}\left(\frac{\pi d^2 l}{4}\right)=\text{h}\pi\text{dl}(Ts-\overline{Tc})$$

$$\frac{32(\overline{T}-Ts)}{4}\text{k}_f\pi\text{l}=\text{h}\pi\text{dl}(Ts-\overline{Tc})$$

$$(\overline{T}-Ts)=\frac{hd}{8k_f}(Ts-\overline{Tc})$$

$$\overline{T}=Ts+\frac{hd}{8k_f}(Ts-\overline{Tc})$$

From equation (1), using backward difference will give

$$\frac{\overline{T}-\overline{T}*}{\Delta T}=\frac{Q_{100}}{mc_p}-\frac{(\overline{T}-Ts)}{\tau}$$

where $\tau = \frac{d^2 c_p \rho}{32k}$

This equation can be written as

$$\overline{T}-\overline{T}*=\frac{\Delta T*Q_{100}}{mc_p}-\frac{(\overline{T}-Ts)}{\tau}\Delta T$$

$$\overline{T}+\frac{\Delta T}{\tau}\overline{T}=\frac{\Delta T*Q_{100}}{mc_p}+\frac{\Delta T}{\tau}Ts+\overline{T}*$$

$$(1+\frac{\Delta T}{\tau})\overline{T}=\frac{\Delta T*Q_{100}}{mc_p}+\frac{\Delta T}{\tau}Ts+\overline{T}*$$

$$\overline{T}=(\frac{\Delta T*Q_{100}}{mc_p}+\frac{\Delta T}{\tau}Ts+\overline{T}*)/(1+\frac{\Delta T}{\tau}) \tag{2}$$

where

m = mass of fuel in one channel = 31400 kg

c_p = specific heat capacity of fuel = 0.32 kJ/sec-kg-°c

k_f = thermal conductivity of fuel = 0.0027 kJ/kg-°c

ρ = density of fuel = 10600 kg/m^3

h = heat transfer coefficient = 36.362 kJ/sec-°c

These parameters came from the existing CANDU-9 simulation. Assumed that these parameters are constant during the break except for heat transfer coefficient that will change due to the coolant condition changing from single phase to two phase flow. Lack of the data of heat transfer coefficient changing during the break, this value was obtained from safety analysis report for Pickering station, CANDU-6 nuclear station. From the graph in that documents, assumption that heat transfer coefficient will decrease from 36.362 to 0.5 kJ/sec-°c in 10 seconds after the reverse flow in the fuel channel is less than 100 kg/sec and keep constant at 0.5 kJ/sec-°c until the water, which is greater than 100 kg/sec, is injected into ROH2 entering to the fuel channel that will switch the heat transfer coefficient back to the value in normal reactor operation is made. Equation (2) were used to write the algorithm to calculate average fuel temperature in algorithm number 853. The same procedure writing algorithm 850 will be used for this algorithm. See detail for this algorithm in Appendix A3.

3.8 User Interface

To interface with user interface screens, the block using non-moveable algorithm was created. Because the inputs, outputs and coefficients in this block will not be moved during the simulation running. In CASSBASE, algorithm 452 NON-MOVEABLE is used like wiring terminal rack for interfacing the simulation model with CASSENG. NMB_CRT_ECCS was created and hooked up with any blocks having the data that wants to show on ECCS screens. Then Equipment Interface Block (EIB) was created for each equipment to allow user to control the AUTO, MANUAL and STANDBY states, and START (OPEN), STOP (CLOSE), or RESET. All EIB are shown in Table 7 in Appendix A1.

For showing alarms on ECCS screens, NMB_ALM_ECCS was created by using non-moveable algorithm to bring all alarm points which was scattered throughout the model to one block. Each alarm signal is a digital signal, FALSE (0.0) for no alarm and TRUE (1.0) for alarm on.

To implement malfunction, MALF_MASTER1 block was created to receive all malfunction requests to one block and dispatch the malfunction to the appropriate component in the model. That malfunction requests were past to MALF_DECORDER1 block created to select between analog and digital malfunction and connect to analog malfunction handler block if a malfunction is an analog malfunction or connect to digital malfunction handler block if a malfunction is an digital malfunction. All malfunction blocks are shown in Table 8 in Appendix A1.

3.8.1 ECCS Screens

ECCS screens consist of 4 screens; ECCS1, ECCS2, ECCS3, ECCS4. There are two steps to build ECCS screens. First, the front panel is created and then the diagram panel is built. To create the front panel, the template screen is created to use for all ECCS screens. This template contains alarm bar at the top of the screen that changes the color from grey to red as it is activated. The bottom of the screen, from left to right, screen name and changing screen button are provided. Then the indicator for fuel sheath temperature and average coolant temperature in channel # 1,2,3,4 are located following by simulator control bar, which is provided for user to run, to freeze, to insert malfunction and to reload simulation model.

ECCS1 screen consists of reserve water tank, four of RWT isolation valves, two of gas tanks, four of gas isolation valves in RWT and IJT model including indicator showing pressure, flow, level. This page represents the operation of injection phase in ECCS.

To build ECCS1 screen using LabVIEW, the front panel is created using the template described above. Then bitmap of piping between equipment is drawn. After that the symbol of equipment like gas isolation valves, gas tanks and indicators i.e. pressure, flow is inserted into this front panel. Figure 3.12 shows ECCS1 front panel.

The next step after finishing front panel is to work on the diagram panel. For typical ECCS diagram panel, DDE Open All subVI is used to open all DDE connections before entering the while loop. Inside the while loop, DDE Request Multiple subVI is used to retrieve the block of simulation values through DDE from non-moveable block, NMB_CRT_ECCS. Connected to the previous subVI is Array to Cluster subVI to convert the output array of double precision values in cluster. After that unbundle the cluster into individual values and hook up each value to the corresponding indicator for output. Out of the while loop, DDE Close All subVI is connected to the cluster to close the DDE connections. Figure 3.14 shows ECCS1 diagram panel.

ECCS2 screen consists of four of recovery pumps, four of sump isolation valves, two of low pressure isolation valves in RCR model including indicators to show pressure, temperature, and flow. The operation of recovery phase is shown here. Moreover, start-up sequencer screen is created to show the sequence of operation during ECCS. To show this screen, push start-up sequencer button. This screen will show the sequence of the main events of ECCS by showing the triangle in front of the operating step. In normal operation, the green light will be shown in this screen. If there is any failure to start any step in the sequencer, the red light will be ignited. Figure 3.15-3.16 show start-up sequencer front panel and diagram panel, respectively.

For ECCS3 screen, indicators showing flow and temperature in all fuel channels, pressure in RIH and ROH are shown here. And also the graphs of fuel sheath temperature and average coolant temperature are provided. The change of the fuel sheath and coolant temperature can be clearly observed from this page.

For the purpose of observing the important and interested parameters together in one page in the form of graph to make it easy for operator to compare the values of the parameters, ECCS4 screen is created.

The method to build ECCS2, ECCS3 and ECCS4 front panel and diagram panel is the same procedure ECCS1 front panel and diagram panel were created. Figure 3.17-3.22 show ECCS2, ECCS3, ECCS4 front panel and ECCS2, ECCS3 and ECCS4 diagram panel, respectively.

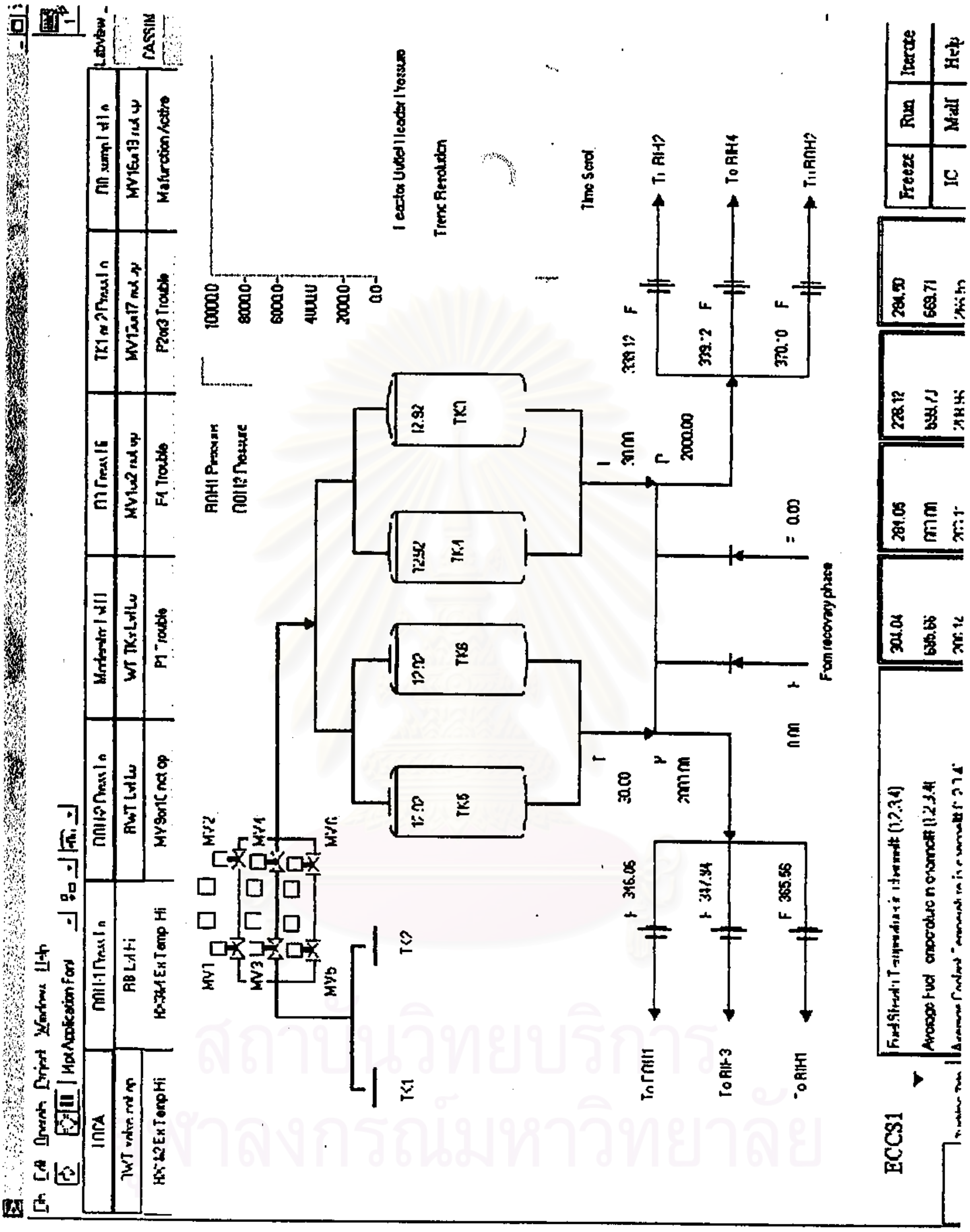


Figure 3.13 ECCS1 front panel

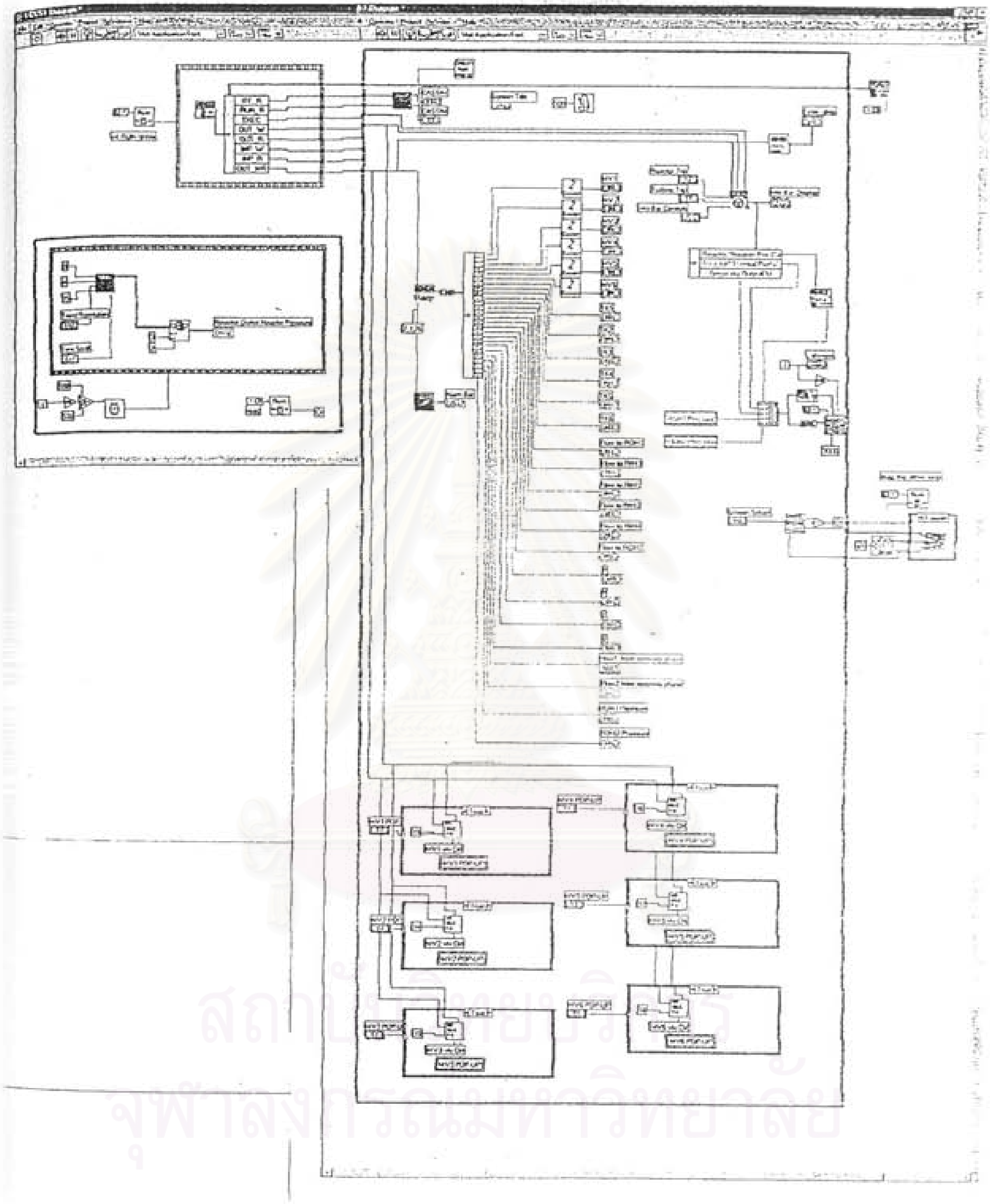
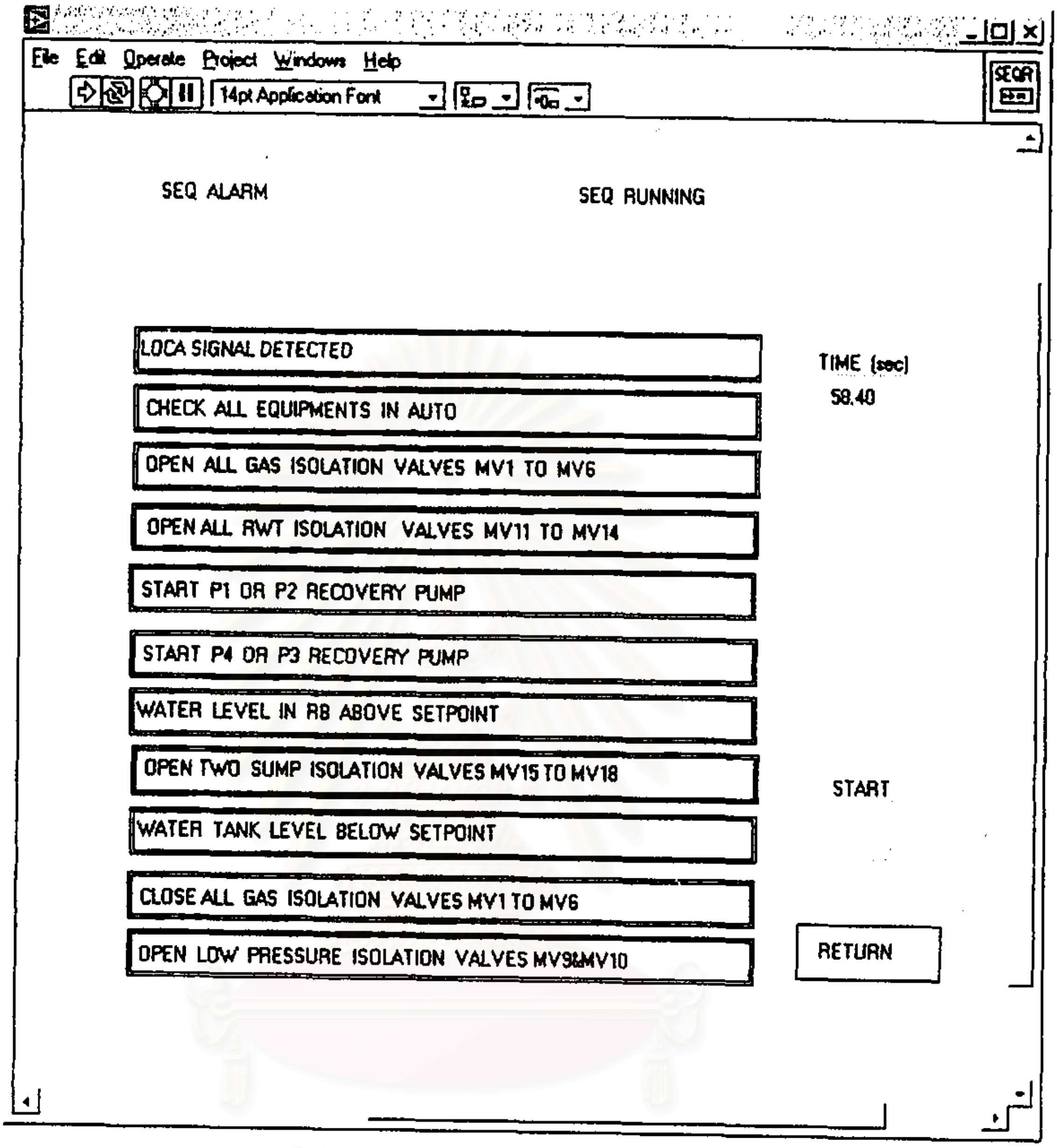


Figure 3.14 ECCS1 diagram panel



LOCA SIGNAL DETECTED

CHECK ALL EQUIPMENTS IN AUTO

OPEN ALL GAS ISOLATION VALVES MV1 TO MV6

OPEN ALL RWT ISOLATION VALVES MV11 TO MV14

START P1 OR P2 RECOVERY PUMP

START P4 OR P3 RECOVERY PUMP

WATER LEVEL IN RB ABOVE SETPOINT

OPEN TWO SUMP ISOLATION VALVES MV15 TO MV18

WATER TANK LEVEL BELOW SETPOINT

CLOSE ALL GAS ISOLATION VALVES MV1 TO MV6

OPEN LOW PRESSURE ISOLATION VALVES MV9&MV10

TIME (sec) 58.40

Figure 3.15 Start-up sequencer front panel

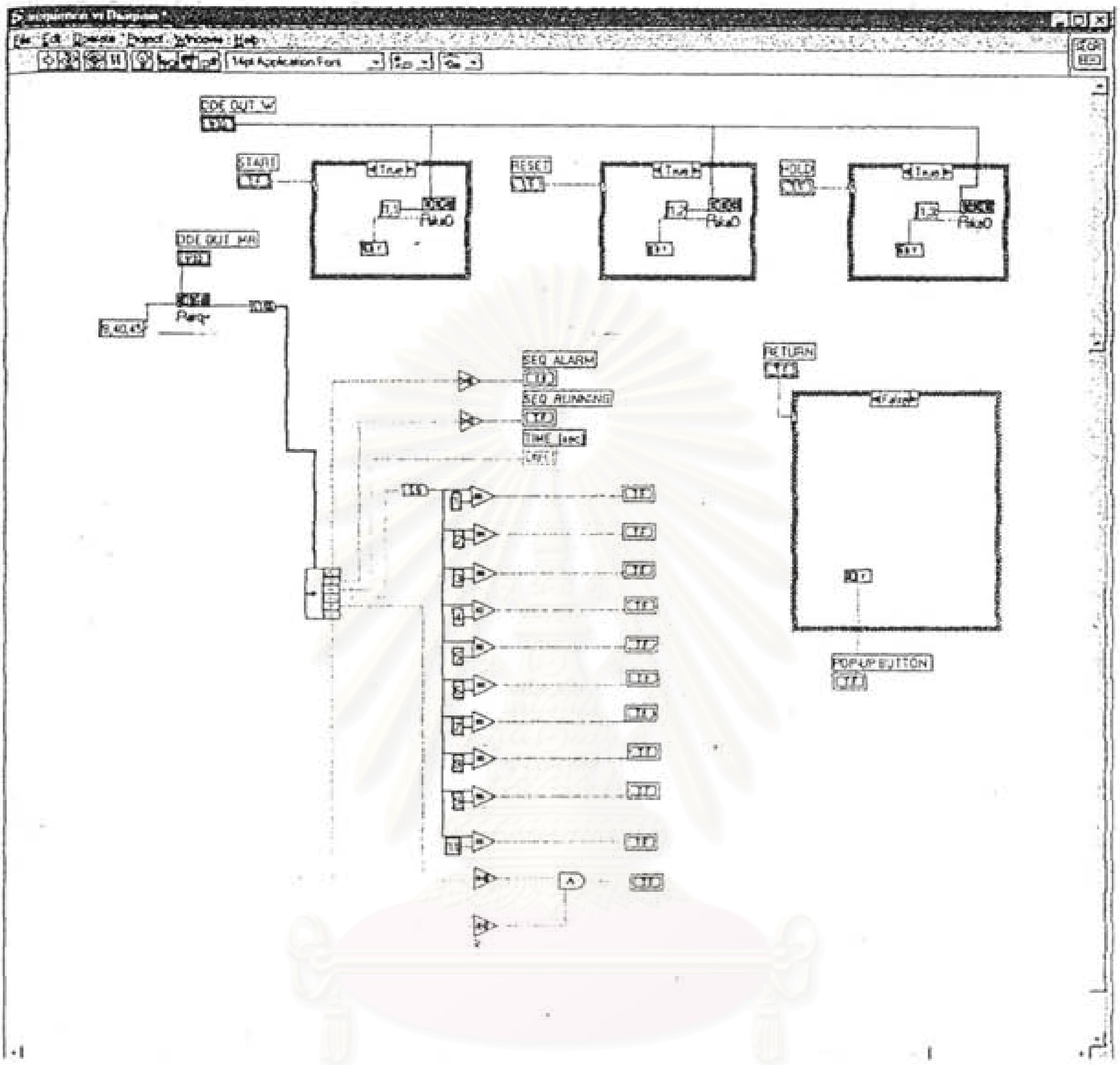
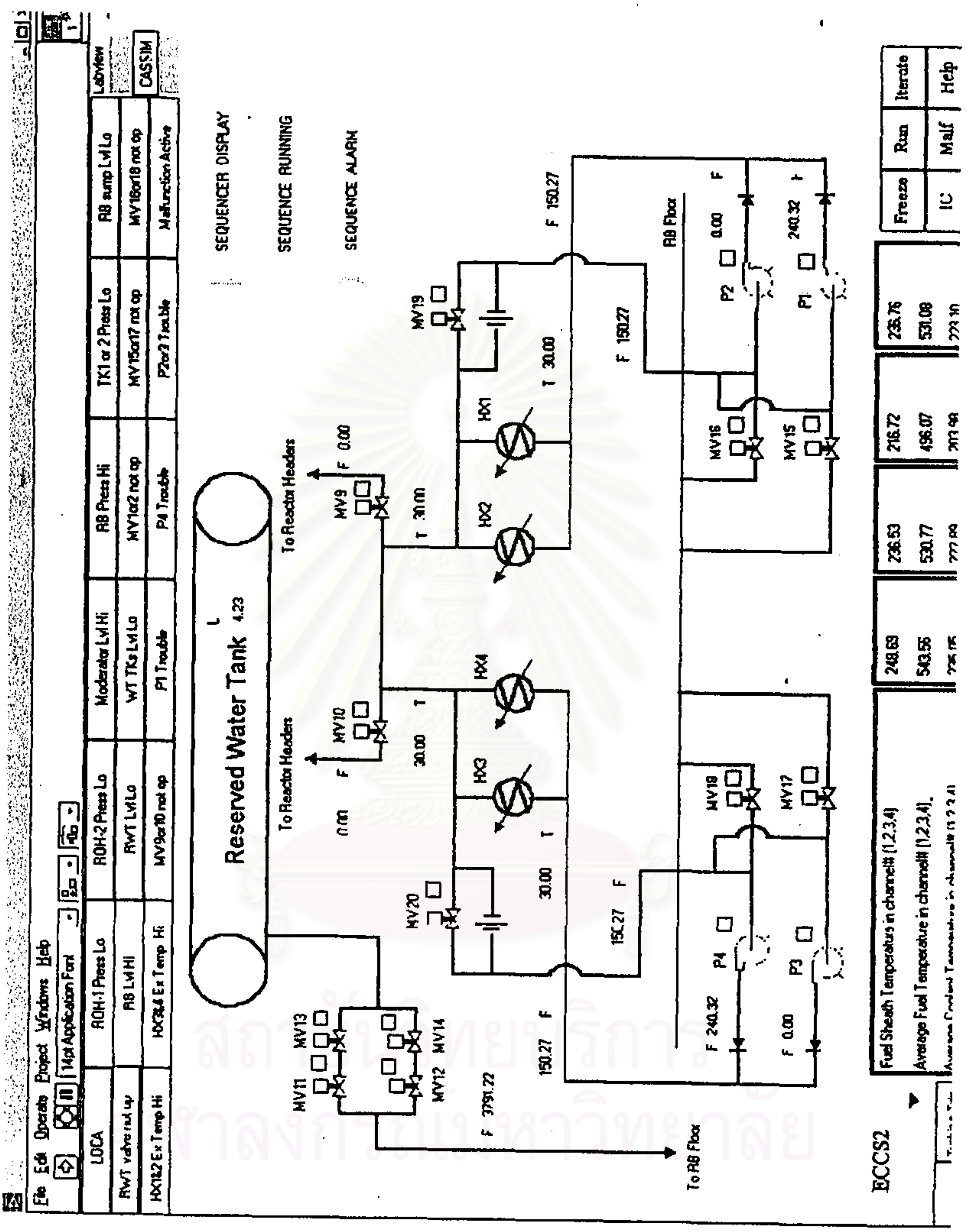


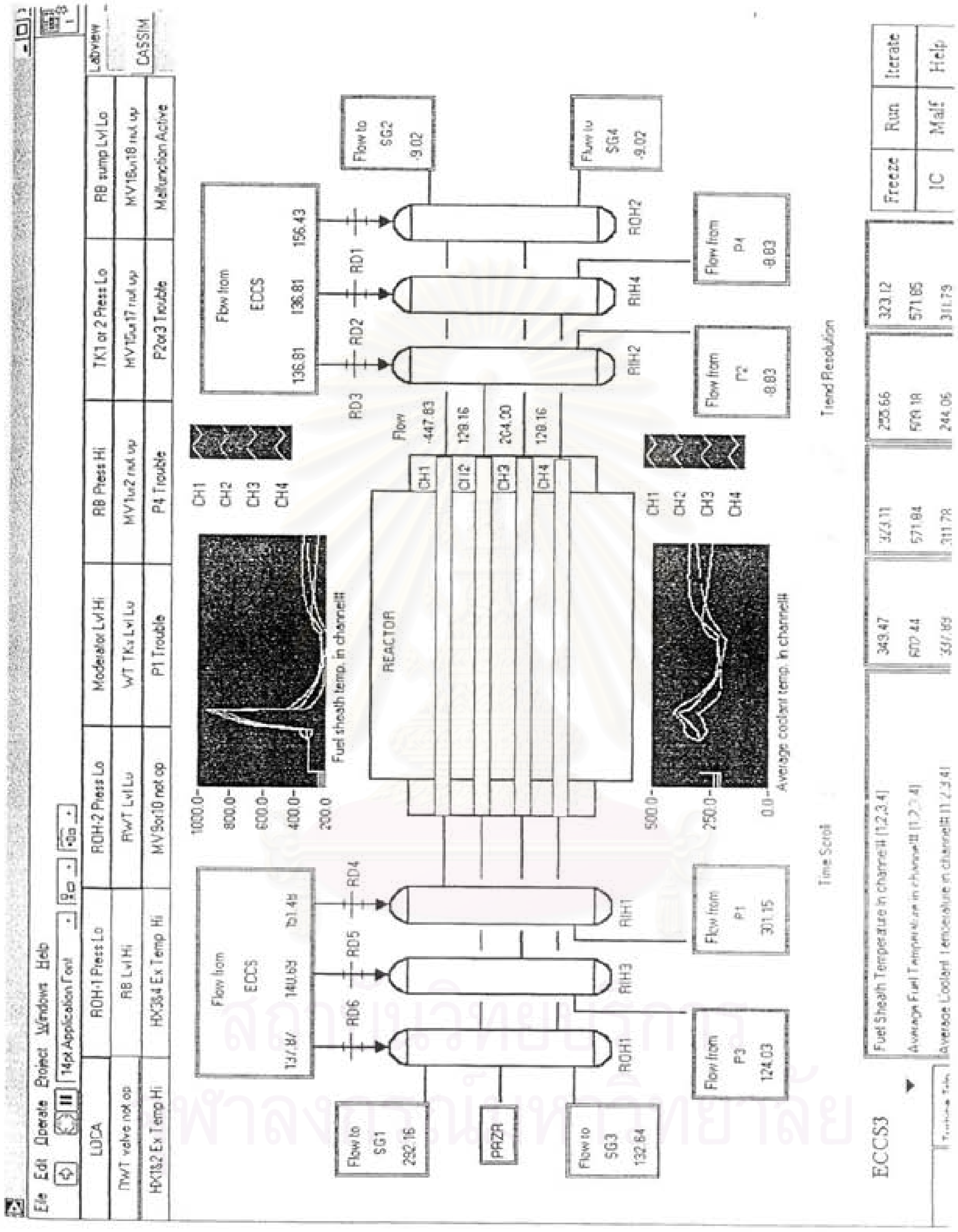
Figure 3.16 Start-up sequencer diagram panel



LOCA	ROH-1 Press Lo	ROH-2 Press Lo	Moderator Lvl Hi	RB Press Hi	TK1 or 2 Press Lo	RB sump Lvl Lo	Labview
RWT valve not op	RB Lvl Hi	RWT Lvl Lo	WT TKs Lvl Lo	MV1or2 not op	MV15or17 not op	MV16or18 not op	
HX1&2 Ex Temp Hi	HX3&4 Ex Temp Hi	MV9or10 not op	P1 Trouble	P4 Trouble	P2or2 Trouble	Malfunction Active	CASSIM

Fuel Sheath Temperature in channel# [1,2,3,4]	249.69	236.53	216.72	235.76
Average Fuel Temperature in channel# [1,2,3,4],	543.56	530.77	496.07	531.08

Figure 3.17 ECCS 2 front panel



LOCA	ROH-1 Press Lo	ROH-2 Press Lo	Moderator Lvl Hi	RB Press Hi	TK1 or 2 Press Lo	RB sump Lvl Lo	Labview
RWT valve not op	RB Lvl Hi	RWT Lvl Lo	WT TKs Lvl Lo	MV1or2 not op	MV15or17 not op	MV16or18 not op	
HX1&2 Ex Temp Hi	HX3&4 Ex Temp Hi	MV9or10 not op	P1 Trouble	P4 Trouble	P2or3 Trouble	Malfunction Active	CASSIM

Fuel Sheath Temperature in channel# (1,2,3,4)	349.47	323.11	255.66	323.12
Average Fuel Temperature in channel# (1,2,3,4)	607.44	571.84	609.18	571.85
Average Coolant Temperature in channel# (1,2,3,4)	337.89	311.78	244.06	311.79

Figure 3.18 ECCS3 front panel

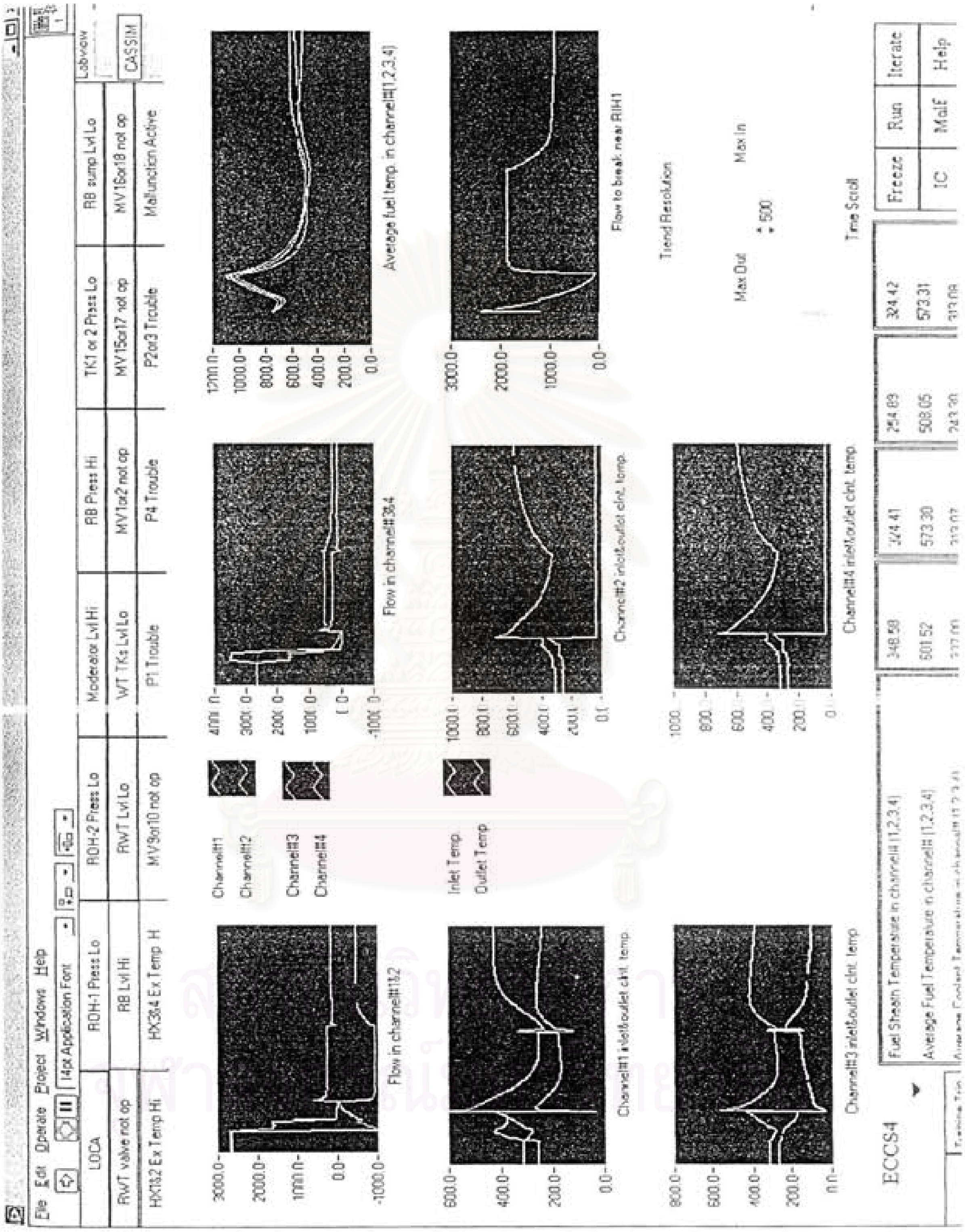


Figure 3.19 ECCS4 front panel

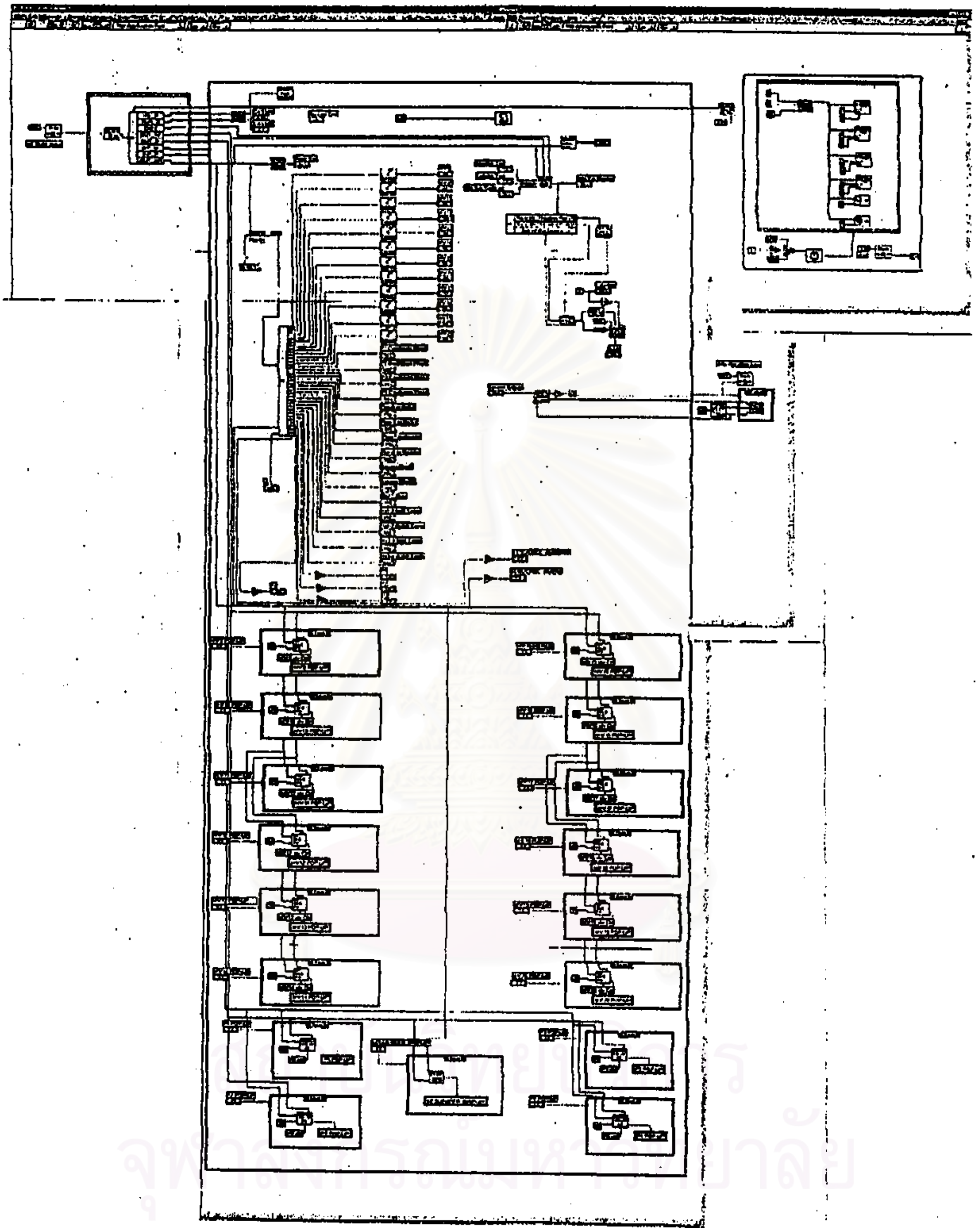


Figure 3.20 ECCS2 diagram panel

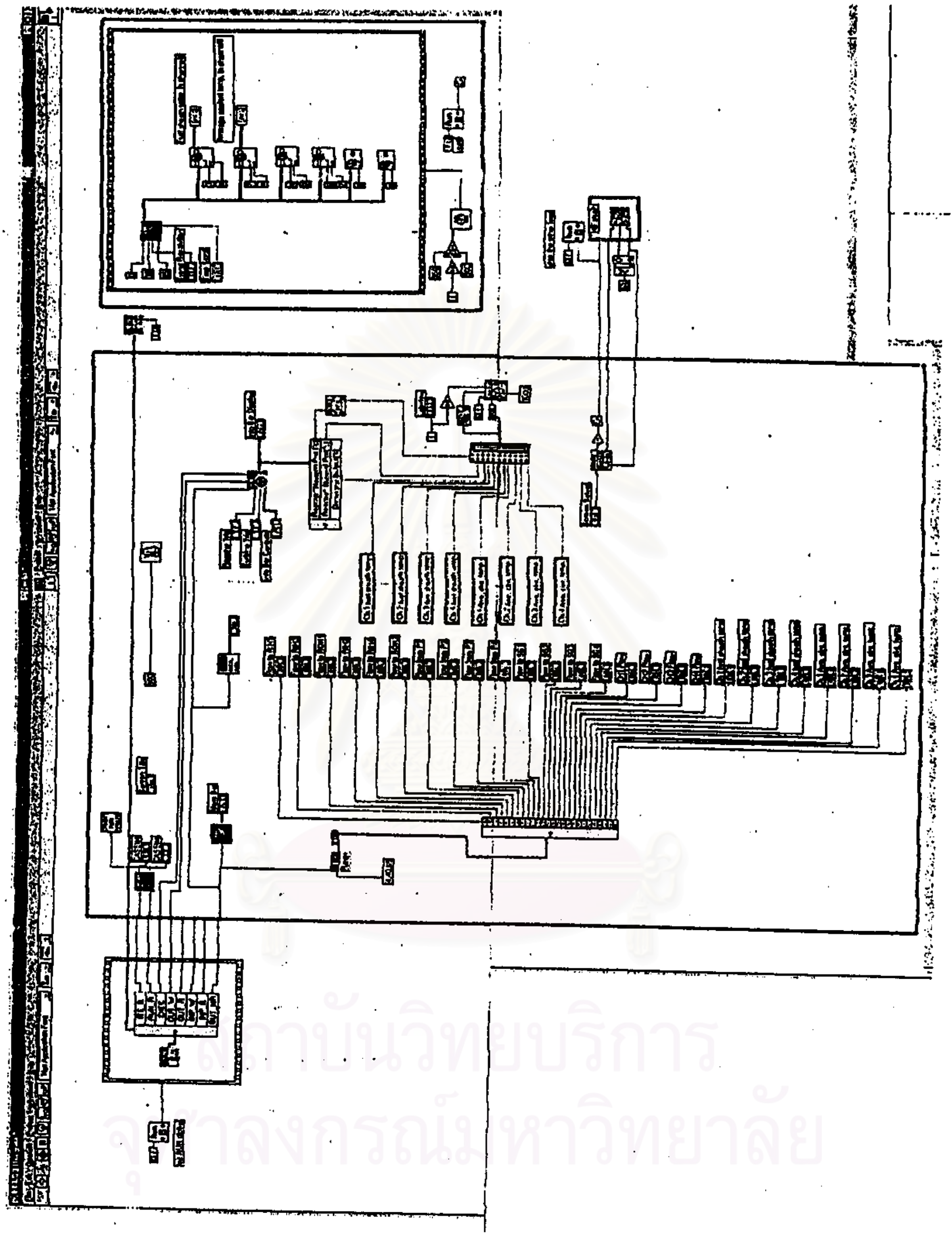


Figure 3.21 ECCS3 diagram panel

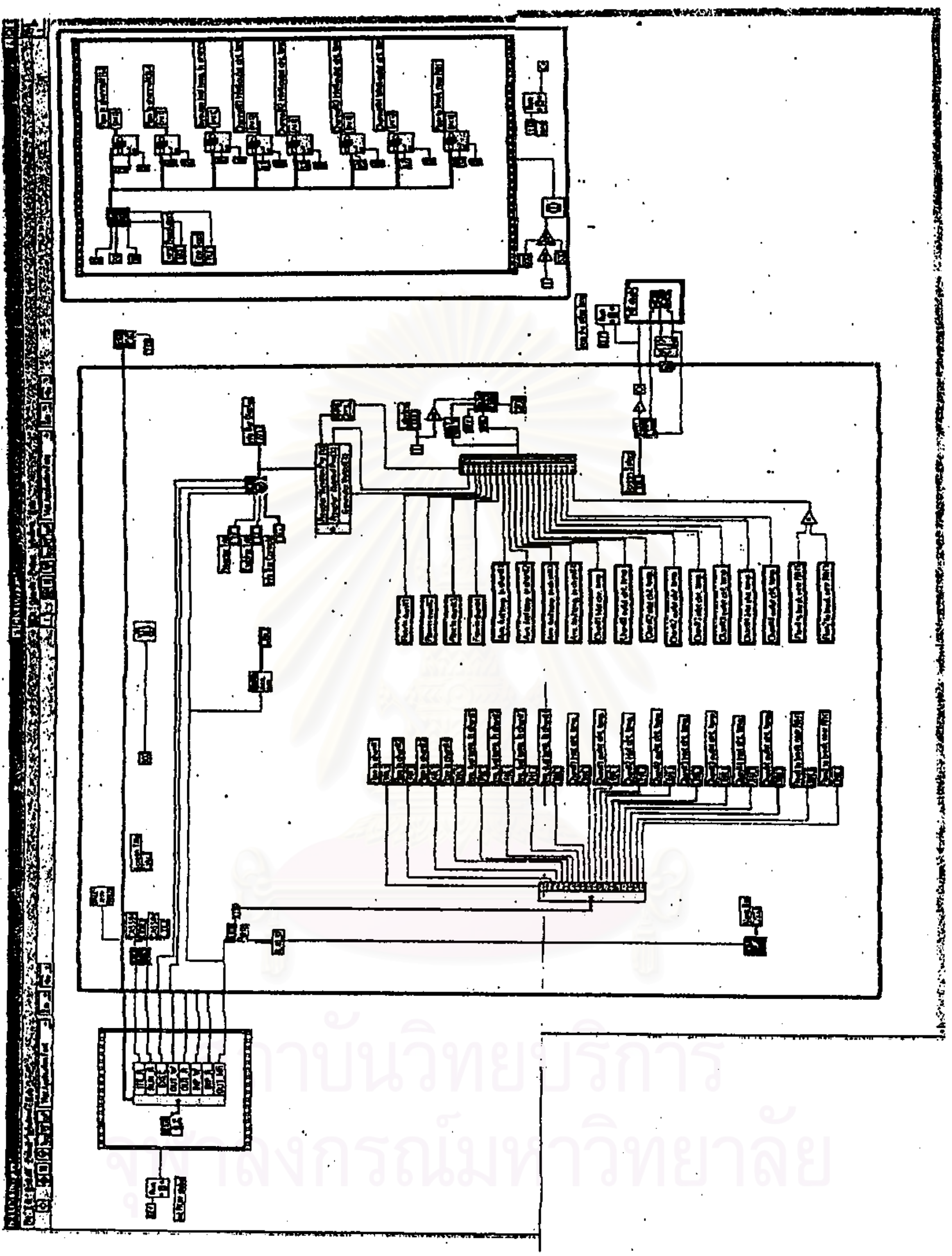


Figure 3.22 ECCS4 diagram panel