COMPUTER CODE VERIFICATIONS FOR PHT PURIFICATION SYSTEM

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ABSTRACT

The purification system in the PHT is designed for low pressure and is normally connected to the high pressure HT system. The purpose of this paper is to demonstrate how a hydraulic computer code and the SOPHT (Simulation of Primary Heat Transport) code are used to verify the design of the purification system for normal, and upset operating conditions, respectively.

INTRODUCTION

The purification system in the Primary Heat Transport (PHT) is designed for 1.38 MPa(g) and is normally connected to the high pressure PHT system, which is designed for 11.0 MPa(g). The boundary of high and low pressure is located immediately downstream of the Level Control Valves (LCVs). A simple control scheme has been standardized for Ontario Hydro Candu stations, for these LCVs to act as both the bleed condenser level control and temperature/pressure control for the purification system.

For normal operating conditions, the two level control valves reduce the pressure to well below the purification design pressure (eg. 500 KPa(g)). During certain upset conditions (eg. Loss of Class IV power, Total Loss of Feedwater, etc.) following the heat transport relief into the bleed condenser, the LCVs will open fully because of high bleed condenser level and pressure. Also, the pressure downstream of LCVs will reach 1.1 MPa(g) causing the purification bypass valve to open automatically. If the open bypass valve does not reduce the pressure in the purification system sufficiently, a relief valve is set to open at 1.31 MPa(g) to protect the purification piping and components. In practice, the opening of the bypass valve will induce a very large flow through the bleed cooler and inhibit the capabilities of the bleed cooler to cooldown the primary coolant to the desirable temperature. In turn, a temperature override control loop is set to close the LCVs. This control action is effectively to protect the purification system from high pressure and high temperature.

The purpose of this paper is to demonstrate how a hydraulic computer code (**Waternet**) [Ref. 1] and the **SOPHT** code [Ref. 2] are used to verify the design of purification system for normal, and upset operating conditions, respectively. For normal operating conditions, it is undesirable for the purification bypass valve to be open. Therefore, a hydraulic analysis as modelled in Figure 1 was performed to verify the margins of design of the

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purification system under normal plant operations. For upset conditions, a SOPHT analysis as modelled in Figure 2 can be performed for the transient conditions.

DESCRIPTION OF PURIFICATION SYSTEM

The purification system is designed to reduce the activity, and to minimize the level of soluble and insoluble impurities, and to assist in maintaining the specified chemical conditions in the primary heat transport system. The system consists of filters (in parallel) connected in series with a set of ion exchange (IX) columns (in parallel) and associated piping network with control and relief valves. PHT coolant from bleed condenser is cooled by the bleed cooler before entering the purification system and the purified coolant goes to D_2O storage tank/feed pump suction. The filters will remove the crud which is carried by the bleed flow from the PHT system. The ion exchange columns will remove the soluble corrosion products and fission products which may have been released from fuel defects. The IX columns also control the apparent pH of the PHT coolant in order to minimize corrosion.

Under normal condition, a purification flow of 10.4 Kg/s is sufficient to meet the purification requirements. In this case, only one D_2O feed pump is required to provide cooling flow from the bleed condenser and for inventory control in the PHT system. Under conditions of high activity level in the PHT system, higher purification flows may be required. The purification flow can be varied by biasing the bleed valves (CV5/6 in Fig. 2). As the purification flow is increased, the more filters and/or more IX columns can be valved-in. The maximum flow is about 45 Kg/s which gives a purification half life of one hour. At such a flow rate, all filters and IX columns have to be valved-in and the operation of both D_2O feed pumps is required.

Hydraulic Analysis of the Purification System

The bleed condenser associated circuits are shown in figure 1. From the bleed condenser outlet to the HT feed pump suction/D_2O storage tank, the major pressure drops are across the bleed condenser level control valves and bleed purification system. Pressure drops in connection piping and across the bleed cooler are small in comparison. The purification system is modelled as a resistance, ie. it produces a pressure drop but no heat exchange.

The flow through the level control valves is given by :

$$Q_{out} = C_v L_v \sqrt{P_{bc} - P_{purif}} \qquad \textbf{(A)}$$

where,

P_{bc} = bleed condenser pressure, normally 1620 KPa(g).

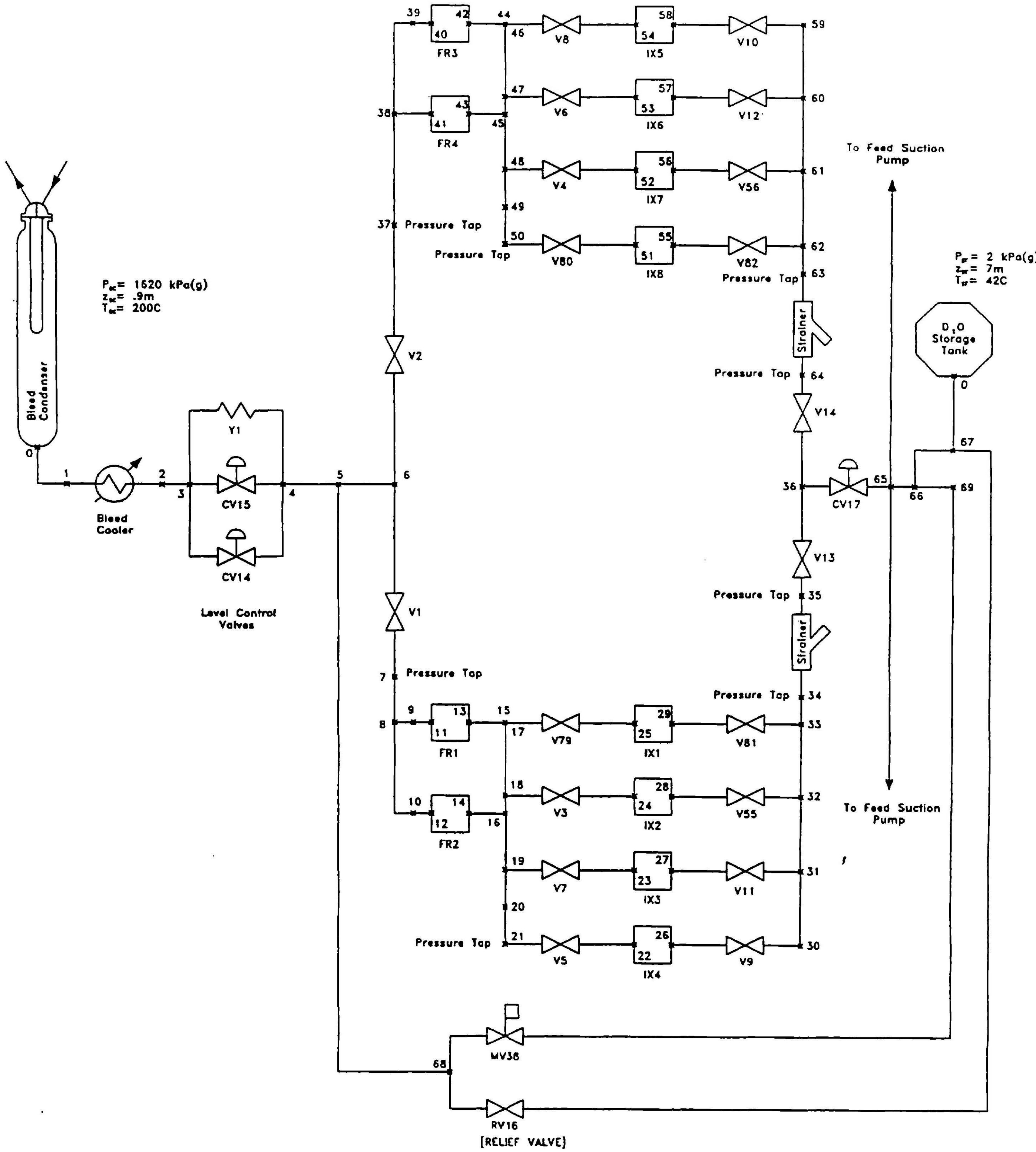


FIG. 1 : Node – Link Diagram of PHT Purification Circuit [Bruce 'A']

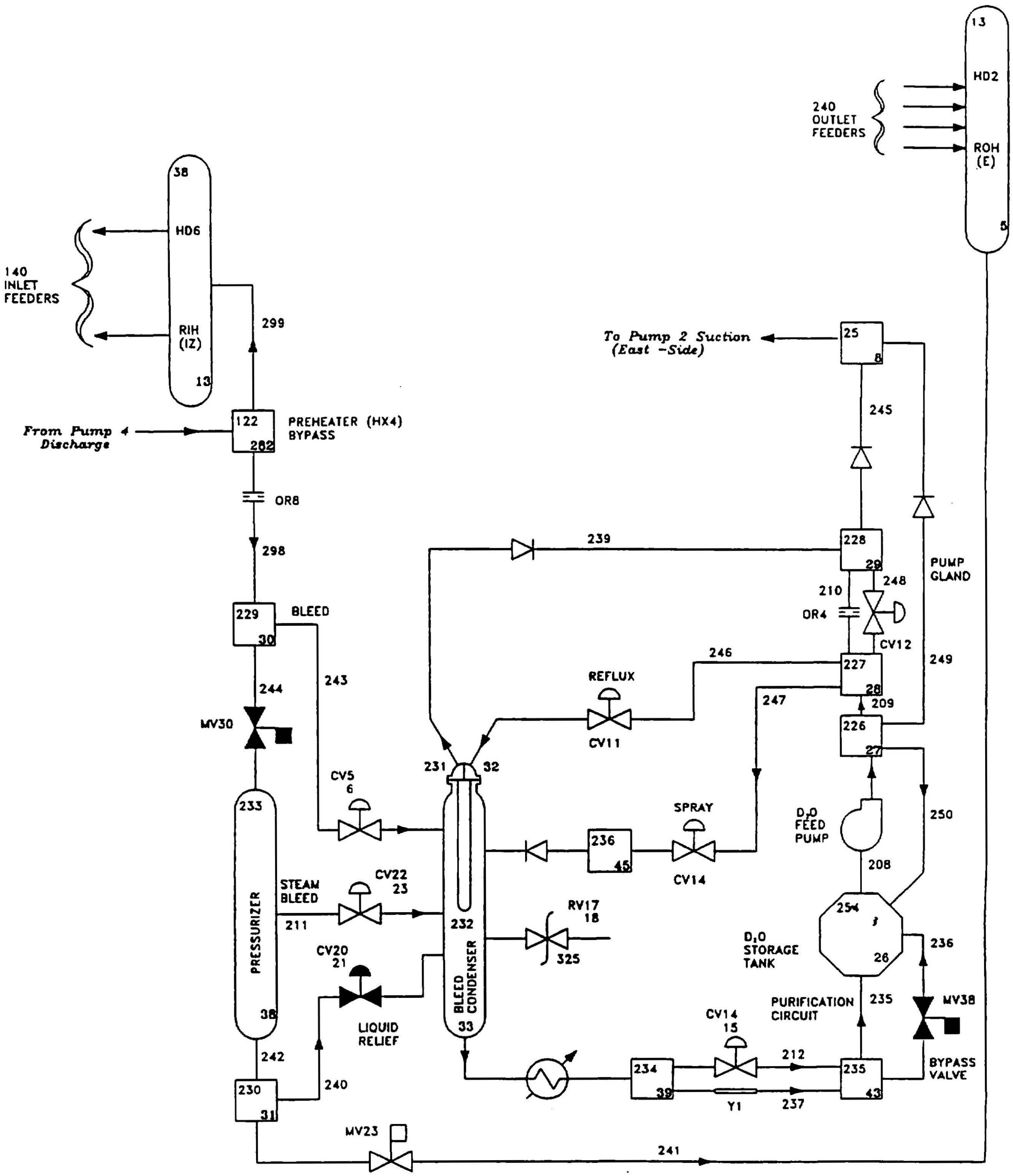


FIG. 2 : SOPHT Node – Link Diagram for Bruce 'A' PHT Pressure and Inventory Control

P_{purif} = Pressure immediately upstream of purification system, KPa(g).

C_v = bleed condenser level control valves constant, as shown in Figure 3.

$$\frac{Kg/sec}{\sqrt{kPa}}$$

L_v = lift of LCVs, fraction.

Q_{out} = bleed condenser D_2O coolant outflow, Kg/sec

The pressure drop across the purification system is given by :

$$P_{purif} - P_{out} = R_{purif}Q^2_{out} \qquad \textbf{(B)}$$

where,

P_{out} = pressure downstream of purification system KPa(g), which is also the D_2O storage tank pressure plus static head.

R_{purif} = resistance of purification system,

$$\frac{KPa}{(Kg/sec)^2}$$

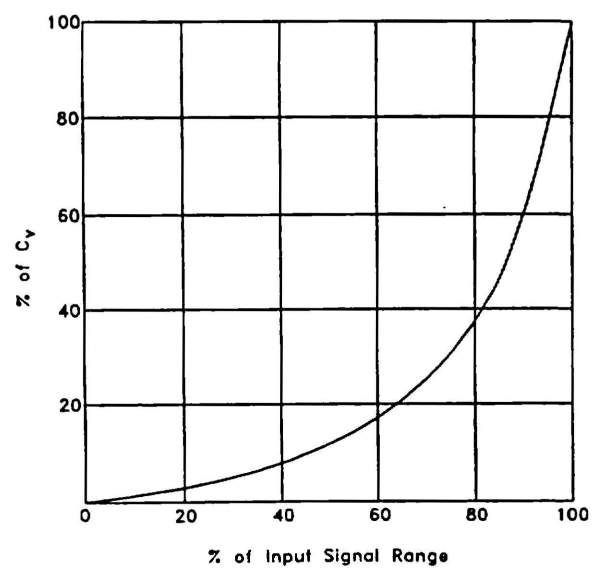


Fig. 3 : Level Control Valve – Flow Coefficient

Combining equations (A) and (B) and eliminating the variable P_{purif}, yields an expression for Q_{out} :

$$Q_{out} = \sqrt{\frac{P_{bc} - P_{out}}{R_{purif} + \frac{1}{(C_v L_v)^2}}} \qquad \text{(C)}$$

The D_2O storage tank is a horizontal carbon steel vessel connected to feed pump suction with enough $NPSH_a$. It is designed to store all the D_2O swell from a unit HT system from Cold to Zero Power Hot, and hold it in readiness for return when the need arises. The tank pressure is held at about 2 KPa(g) during the normal plant operating conditions by being connected to a large inflatable - deflatable neoprene rubber balloon for Bruce 'A' design (Note that due to decay of rubber balloon, Bruce 'A' storage tank vapour pressure is being revised to interface with helium supply control only without rubber balloon). This in turn maintains a constant pressure of about 140 KPa(g) at the feed pump suction header where the purification system safety relief valve (RV16) discharge line is located.

The level of the liquid in the bleed condenser is controlled at the desirable level by regulating two LCVs to achieve the bleed flow out of the condenser. These two LCVs are interlocked with duplicated condenser level loops so that failure of one valve will not bottle up the condenser outflow. The LCVs are of equal percentage type, in which equal increments of movement produce equal percentage changes in flow. It is desirable to have a valve movement from 20 percent to 40 percent causing a flow change from 5 to 10 percent for level control. Therefore, the selection of LCVs is very important as defined in the valve specification sheet [Ref. 3].

The equal percentage control valve characteristics can be shown as :

$$Q = Q_{min} R^{S/S_{max}} \qquad \text{(D)}$$

where,

Q = flow rate (Kg/sec)

Q_{min} = minimum flow rate (kg/sec) when the stem is at one limit of its travel. eg. Q_{min} = 3 Kg/sec for CV14/15 in Bruce 'A'.

Q_{max} = maximum flow rate (Kg/sec)

S = valve stem position (m)

S_{max} = maximum stem position (m)

R = Rangeability, as the ratio of Q_{max}/Q_{min}.

eg. R = 6.875 for 3332-CV14/15 in Bruce 'A'.

With normal flow of 10.4 Kg/sec through two LCVs, one can find the valve opening position from equation (D) as 28.5 % for the LCVs of Bruce 'A'. This is a desirable position for the control valves and level control schemes.

Purification System Resistance by Waternet Code.

From the equation (C) above, the purification flow is dependent upon the R_{purif} and C_vL_v during the normal operating conditions. In order to simplify the calculation and to be conservative as far as the pressure upstream of the purification system (ie P_{purif}) is concerned, the Level Control Valves (LCVs) are assumed fully open so that the value of C_vL_v is constant in the equation (C).
The Waternet code model of the purification system as shown in Figure 1 was calculated by the flow rate versus pressure drops in a piping system. Values of purification flow rate and corresponding values of pressure at RV16 (ie. inlet of purification system) were tabulated for different configurations of filters (FR) and IX columns valved-in under one LCV or two LCVs in service. The four configurations were : 2 FRs and 3 IXs, 2 FRs and 4 IXs, 4 FRs and 6 IXs, and 4 FRs and 8 IXs for Bruce design. Purification flow rate varied by manipulating the K factor of MV38 from 0 to infinity (ie. closed). For a filter K of 20 and IX column K of 38 (about 65 % dirty component), the results are plotted in Figure 4. Under normal operating conditions, it is undesirable for the bypass valve (MV38) to open automatically at 1.1 MPa(g). As a result from this hydraulic code as shown in Figure 4 the purification flow can be up to 25 Kg/sec for the four configurations, without resulting in opening of bypass valve (MV38). Normal purification flow is about 10.4 Kg/sec, with the LCVs (3322-CV14,CV15) about 30 % open. This permits, under normal operating conditions, very large margins of flow variation for the manipulation of the purification bias by the operator.

UPSET OPERATING CONDITIONS

The design of PHT Pressure and Inventory Control can be generally represented by a typical Bruce 'A' design as shown in Figure 2. When the reactor power is operating under the upset transient conditions from 100 percent full power, there can be a significant inflow to the bleed condenser from the Heat Transport System (called by Pressure and Inventory Control) and outflow from the bleed condenser to purification system by analog level controllers. This dynamic operating transients from the bleed condenser to D_2O storage tank/Feed pump suction can be analysed by the SOPHT code. In turn, the purification system and associated bypass motorized valve status can be evaluated; and the D_2O flow through the bleed cooler can be derived.

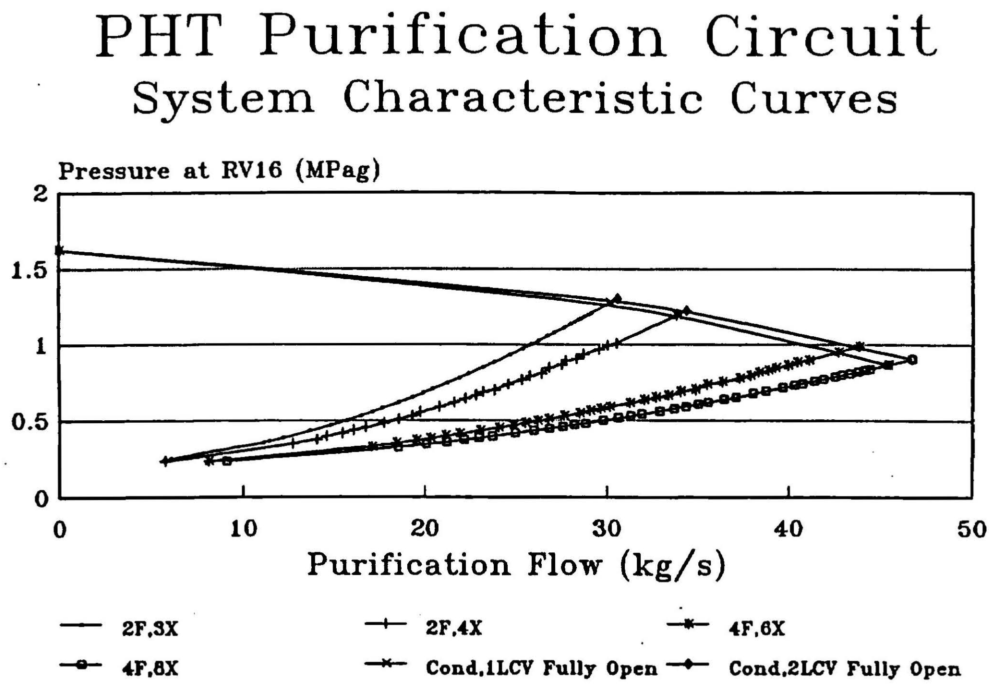
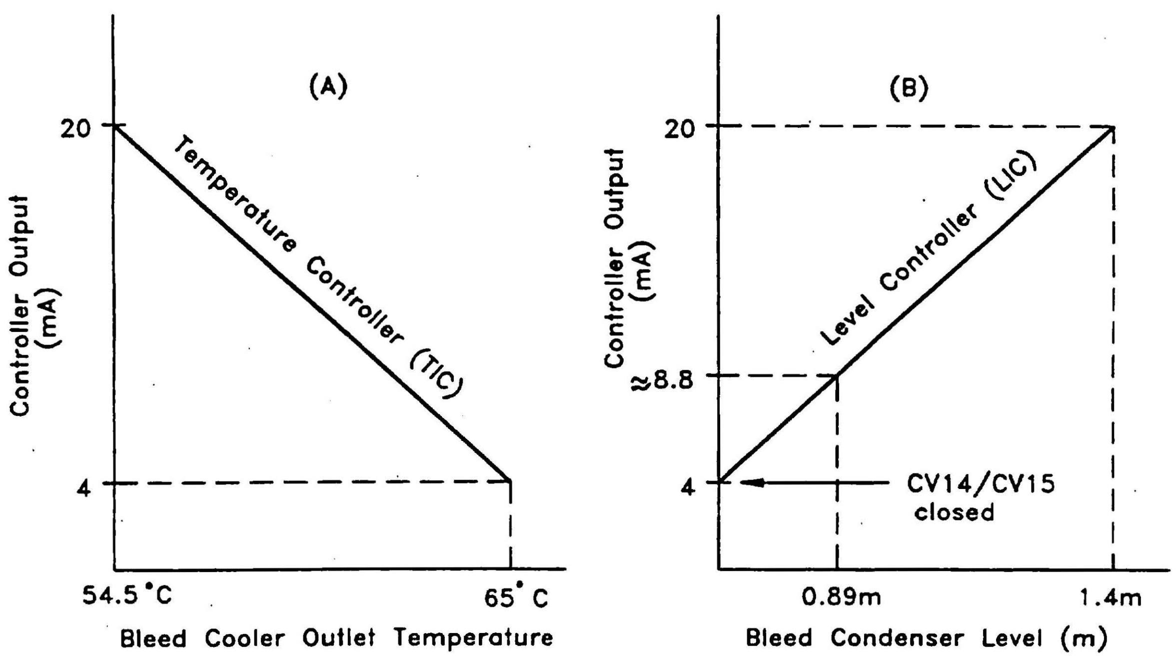


Figure 4 : Bruce 'A' – Purification
Note : Filter K=20 ; IX Column K=38

Figure 4 : Bruce 'A' – Purification



Control Signal to Bleed Condenser LCV's = Low Selector (LM) of TIC/LIC
= Minimum Signal of (A) or (B)

Figure 5 : Bleed Cooler Temperature Override Scheme

The transients listed below which fall into the upset conditions have been analyzed.

i) Loss of class IV power.
   (a) H.T. Pumps Trip Credited.
   (b) H.T. Pumps Trip Not Credited.
ii) Two pump trip remoted from the pressurizer. (Stepback)
iii) Total loss of feedwater.
iv) Liquid Relief Valves (LRVs) fail open. (Note that this transient is not part of design specification transient of the Station)
v) Turbine trip.
vi) Reactor trip.

As shown in Figure 2, the bleed condenser accommodates bleed and relief flows from main heat transport system as well as steam bleed flow from the pressurizer. The control of these valves by digital computer has been well described in the corresponding Station Design Manuals. However, the changes of these inflow control valves will affect the outflow from the bleed condenser. Thus, the control of outflow from bleed condenser by analog controllers is described in detail at the section below.

Bleed Cooler Temperature Override Scheme

Bleed cooler outlet temperature measurement is used to override bleed level signals to level control valves (CV14/15) to cover for certain transient conditions where the opening of the purification bypass valve (MV38) induces a very large flow through the cooler and inhibits the capabilities of the bleed cooler to cooldown the primary coolant to the desirable temperature. Under these conditions, the temperature override will close the LCVs to limit the bleed cooler outlet temperature to a maximum of 65°C at the expense of bleed condenser level control. The temperature override control scheme is shown in Figure 5. The bleed condenser level controller is proportional plus integral for Bruce design. The level controller output will be such that at 0.89 m (setpoint), the demand is about 30% and at 1.4 m, the demand will be 100%. The temperature controller output will be such that at 54.4°C (setpoint), the demand is 100% (reverse action) and at 65°C, the demand will be zero. The control signal to the bleed condenser LCVs will be derived from the "Low Selector" (LM) of either the proportional level controller (LIC) or proportional temperature controller (TIC) as shown in Figure 5.

The level controller is propotional plus integral, it can be expressed by :

$$P = K_p E_p + K_p \frac{1}{T_1} \int E_p dt \qquad \textbf{(E)}$$

where,

P = controller output.

K_p = propotional constant.
(ie. K_p = 100/PB, where PB is the propotional Band (%).

T_i = reset (integral) time, second.

E_p = error between the measured value and setpoint of the variable (ie. level).

The bleed cooler, just upstream of the LCVs, is the horizontal U-tube type heat exchange. The primary coolant (D_2O) flows through the tube-side and the service (cooling) water through the shell-side. At normal operating conditions, D_2O from the bleed condenser is cooled from about 204°C to below 52°C at the rated flow of about 10 Kg/sec. If for any reason the bleed cooler outlet temperature rises above 65°C, the LCVs are closed by a signal from the temperature controller (TIC) which override the level control signal from level controller (LIC).

Results of SOPHT Simulations for the Upset Conditions.

The SOPHT analysis for the model shown in Figure 2 for the upset conditions was performed on the IBM RISC/6000 Model 550 computer. The results of transient analyses are summarized in Table 1. For all transients except the turbine trip and reactor trip, the Level Control Valves (LCVs) closed due to bleed cooler temperature override control which precluded the purification system from high pressure as shown in Figure 6.

CONCLUSION

Under normal operating conditions, it is unlikely to have purification bypass valve (MV38) opened as per Figure 4. However, if the bypass valve did open, there is a CRT alarm annunciation for "HIGH PURIF. PRESS. MV38 OPEN" to warn the Operator; and the Operator action is required to close the valve so that the specified chemical conditions of the PHT system can be maintained.

The dynamic responses of PHT system under the abnormal operating conditions can be simulated by SOPHT code for nuclear system design, eg. PHT purification system as described in this paper. It is concluded that the typical Bruce 'A' purification system relief valve (RV16) will not open under the upset operating conditions as shown in Figure 6. In turn, a high pressure purification system design, such as CANDU-600, can be exempted from implementing more equipment (eg. intercoolers).

ACKNOWLEDGE

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REFERENCES

Figure 6 : Purification System Pressure Transients
Pressure Upstream of Relief Valve

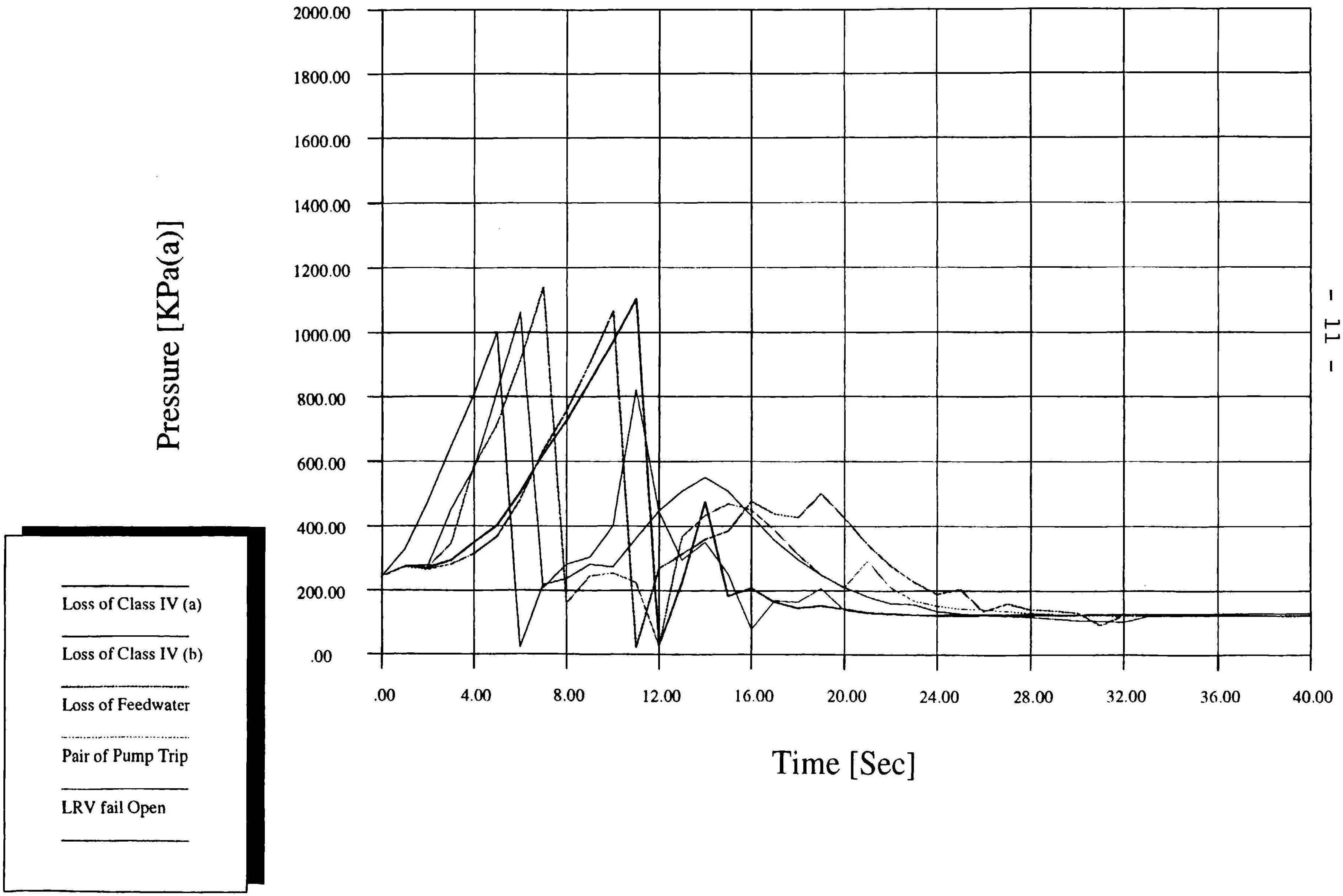

Figure 6

1. "Waternet" User's Manual : Computer Analysis of Flow in Pipe Networks Including Extended Period Simulations by Don J. Wood, University of Kentucky, Lexington, Kentucky, 40506, USA.

2. C.Y.F. Chang and J. Skears, "SOPHT - A Computer Model for CANDU-PHWR Heat Transport Networks and Their Control", Nuclear Technology, Vol. 35, No. 3, P 591-602, October 1977.

3. Bruce NGS 'A' - Design Manual (DM-21-33300/63330), "Heat Transport System Pressure Control, Feed, Bleed and Relief System", Appendix E, Issued 1984-10-23.

Table 1

Transient Events	Reactor Regulation System Responses after the initiating event	Time to open purification bypass valve	Bleed Condenser Pressure (kPa(a))	Maximum Bleed cooler flow rate
Loss of Class IV power (HT pumps trip credited)	Stepback initiated at 0 sec, SDS1 (low flow trip) at 3.7 sec	12.0 sec	2340 kPa(a)	* 42 kg/sec
Loss of Class IV power (HT pumps trip not credited)	Stepback (high HT pressure) at 2 sec. SDS1 (high HT pressure trip at 2.68 sec)	6.5 sec	4620 kPa(a)	* 72 kg/sec
Two pumps trip (remoted from the pressurizer)	Stepback (HT pump trip) at 0 sec. Stepback (High HT pressure at 1.75 sec)	7.3 sec	2887 kPa(a)	100 kg/sec
Total loss of feedwater	Setback (High PRZR level) at 6 sec. Stepback (High HT pressure) at 11 sec, stepback (High steam pressure) at 12 sec.	10.9 sec	2905 kPa(a)	100.5 kg/sec
LRVs fail open	No response (100% FP)	6.0 sec	2985 kPa(a) (eventually to bleed condenser relief valve setpoint)	111.5 kg/sec
Turbine trip	Stepback (Turbine trip) initiated at 0 sec. Setback (High steam pressure) at 2 sec	Not applicable	1500 kPa(a)	Decreasing to zero due to BC reflux cooling.
Reactor trip	Reactor trip initiated at 0 sec.	Not applicable	1500 kPa(a)	same as above

(*) Due to loss of service water on the shell side of cooler, the LCVs are not fully open.