Lesson 8: HEAT TRANSPORT CONTROL SYSTEMS

MODULE 1: FEED AND BLEED PRESSURE CONTROL

At the end of this module, you will be able to:

1. **State the general purpose of the HTS *Feed & Bleed* system.**

2. **Sketch & label a simplified Feed & Bleed system and briefly describe one cycle of operation.**

3. **Identify feed & bleed flow paths on a supplied diagram and locate key HTS components.**

4. **Describe the wide range feed & bleed control operation by referring to a provided diagram to explain the interaction of key control devices.**

5. **Describe the narrow range feed & bleed control operation by referring to a provided diagram to explain the interaction of key control devices.**

6. **Sketch and describe the feed valve and bleed valve operational curves with and without *bleed bias* applied to explain the coordination of the split range control.**

MODULE 1: FEED AND BLEED PRESSURE CONTROL

Introduction

- **The purpose of the Heat Transport System (HTS) is to *transfer the heat* generated by the fission process in the reactor *to the steam generators*.**
- **The heat transfer medium is pressurized heavy water and the principle control for this system will be the regulation of the pressure within the heat transport system.**
- **The heat transport system must be able to respond to *disturbances* from either the reactor (*source*) or turbine side *(sink*) of the energy balance.**
- **The means of pressure control varies and is either a *feed & bleed* or a *pressurizer* vessel as the primary control system, but with feed and bleed for inventory control. Both methods will be discussed.**

Feed and Bleed Pressure Control

- **The HTS is essentially an enclosed loop system (Figure 1) normally maintained at a pressure of approximately 10 MPa.**
- **Any deficiencies in pressure will be corrected by *feeding additional D_2O* into the system from the pressurizing pumps. Conversely, any excess of pressure will be countered by *bleeding D_2O* from the system to the bleed condenser.**
- **The system must be capable of being controlled over the range 0 - 10 MPa, (i.e., from a *cold shutdown* state to a *pressurized, hot condition*. Control over this wide range is divided into two regions: *wide* (0-12 Mpa) and *narrow* (6-12 MPa).**

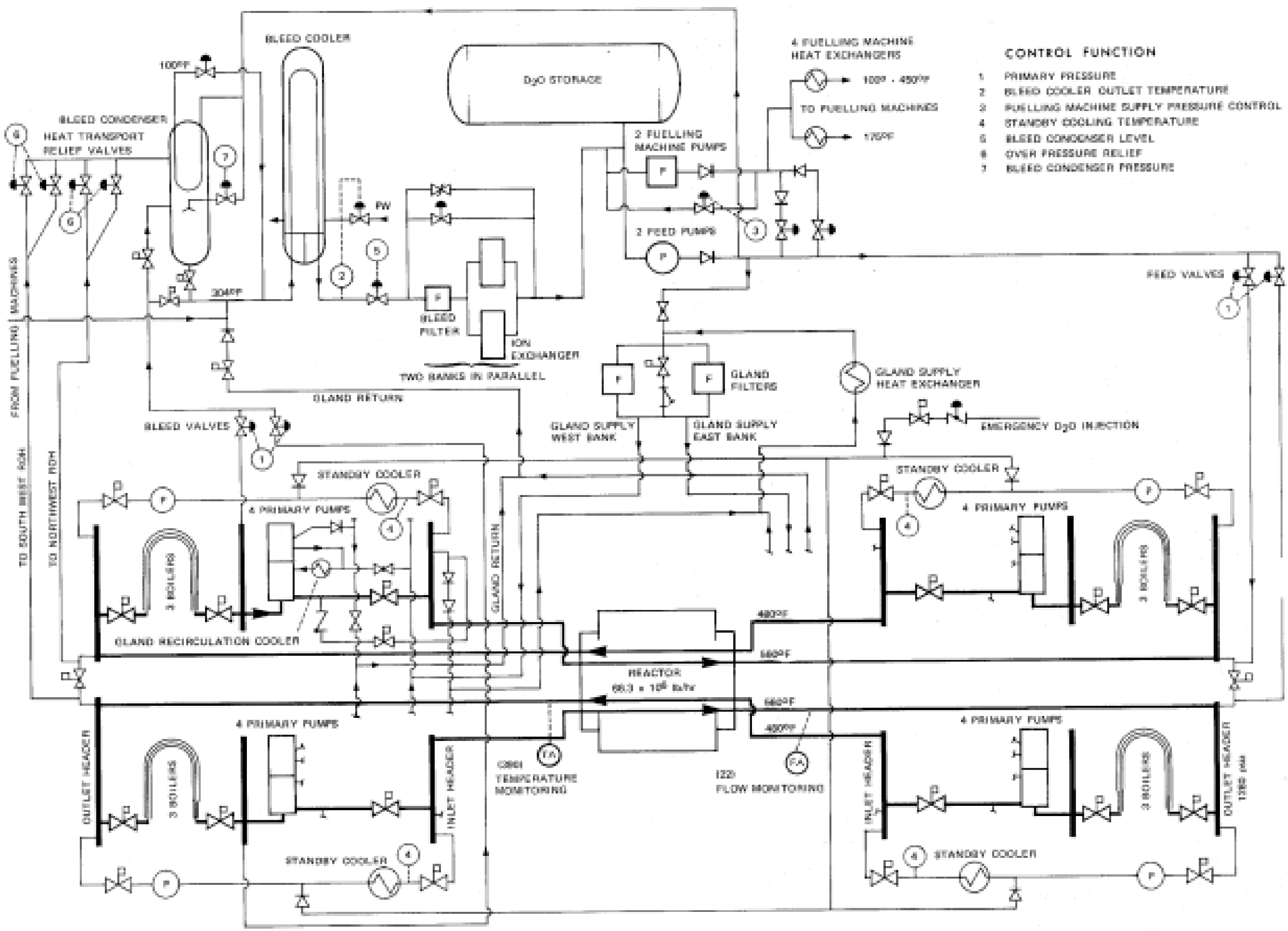


Figure 1: 500 MWe CANDU Heat Transport System with Feed and Bleed Pressure Control.

Control Ranges

(a) *Wide Range* Control is used when warming-up or cooling-down the system up to or from its normal operating state. It is a “coarse", lower gain (say 0-12 Mpa) , control system.

(b) *Narrow Range* Control is used to control the system pressure at its normal operating setpoint, i.e., a "fine", higher gain (say 6-12 Mpa) , control system.

The basic method of control both in wide and narrow ranges is to drive the feed and bleed valves from a single control signal, i.e., a *split range* control system.

- The reactor outlet header pressure is sensed by a pressure transmitter (PT).
- This pressure signal is fed to the *direct acting* pressure controller (PIC) the output of which is split ranged to a fail-closed *bleed valve* and a fail open *feed valve* via two I/P transducers.
- With the pressure at the setpoint (50% - 12 mA signal) neither feed nor bleed action is required and *both valves could be closed*.
- If the *pressure is above the setpoint*, the increased signal from the PIC would *drive the bleed valve open* (with feed valve closed) - so pressure can be bled off.
- The opposite would be true for *too low a pressure in the HTS*, i.e., *feed valve opens* on the decreasing signal from the pressure controller while the bleed valve is closed - pressure builds up.

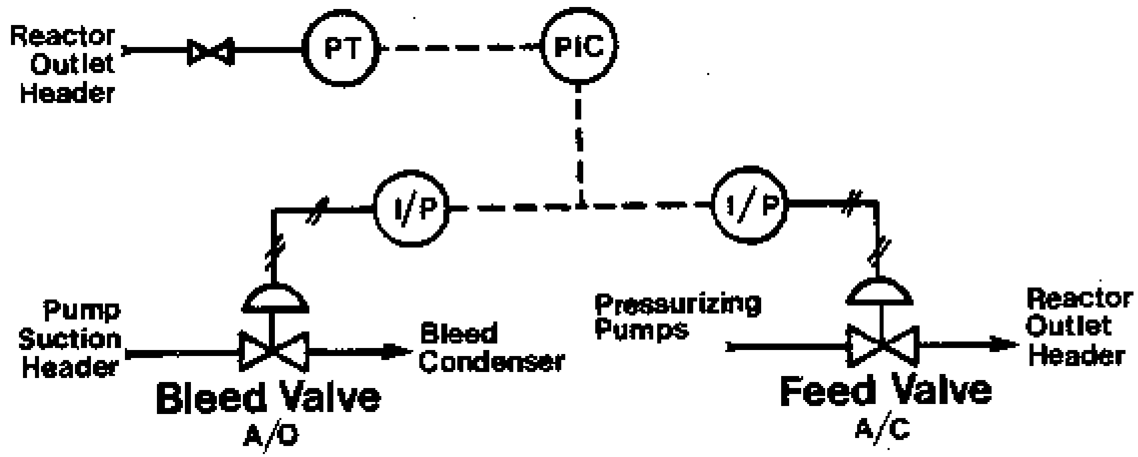


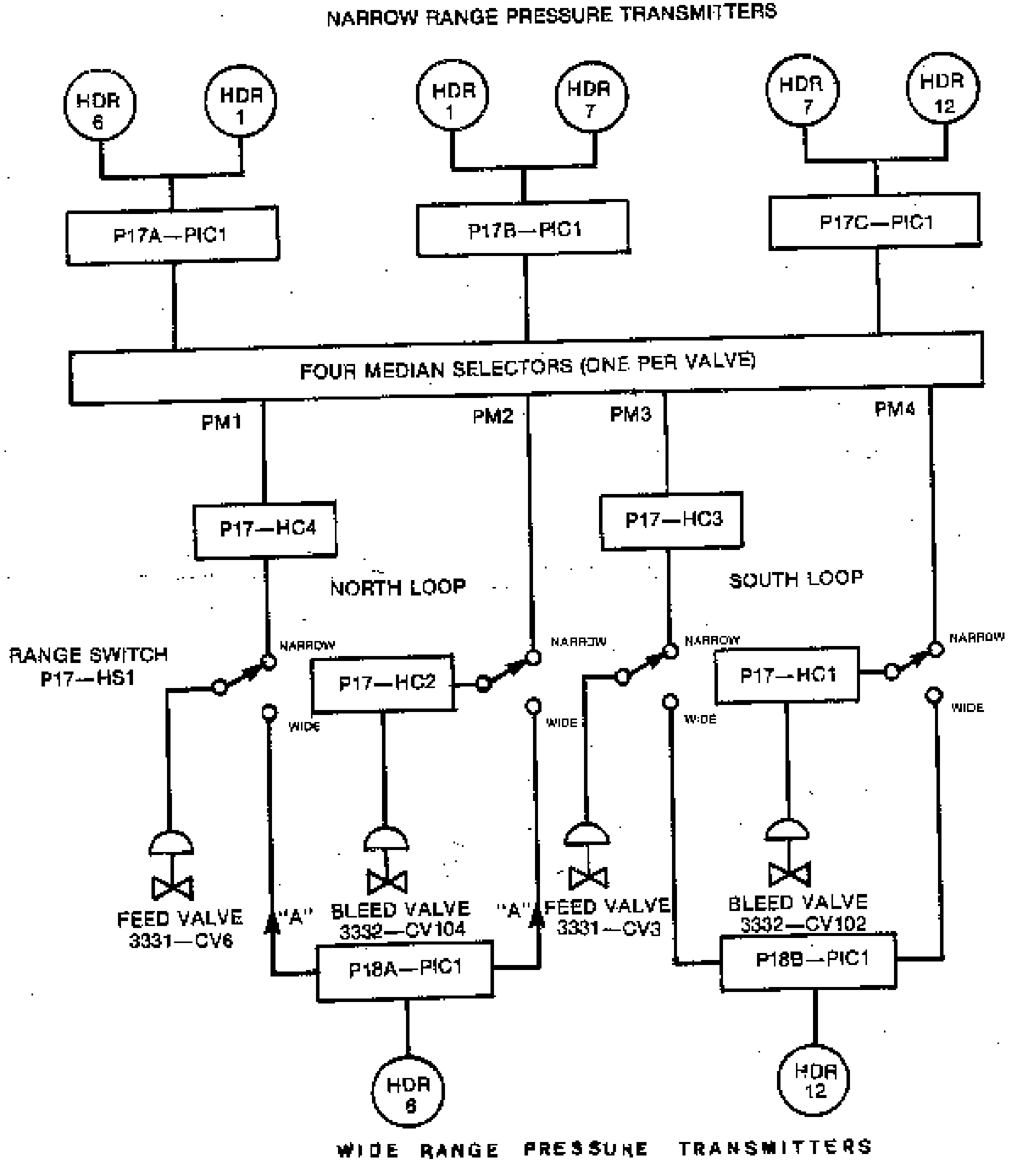
Figure 2: Simplified Split Range Feed and Bleed Control System.

HTS Pressure Control by Feed and Bleed

Wide Range Control

Refer to Figure 3 and locate:

- **the two pressure transmitters on Headers 6 and 12, i.e., one on the north loop and one on the south.**
- **Each transmitter provides a signal for a pressure controller, (PI8A-PIC1, PI8B-PIC1) each of which drives a feed and bleed valve combination.**
- **Note that the bleed valve signal is routed via hand (manual) controllers HC1 and HC2. The use of these controllers will be discussed later.**



As already mentioned, this wide range control is used only for warmup and cool down operations. Essentially in the *warmup condition* the *bleed valve will be opened continuously* with feed valves closed in response to the rising system temperature causing inventory swell & pressure increase. This excess D_2O is routed via the bleed valves to the D_2O storage tank.

Conversely, during *cool down operations* the feed valve will need to be opened with bleed valve closed to provide makeup D_2O in order to maintain the HTS inventory as it shrinks.

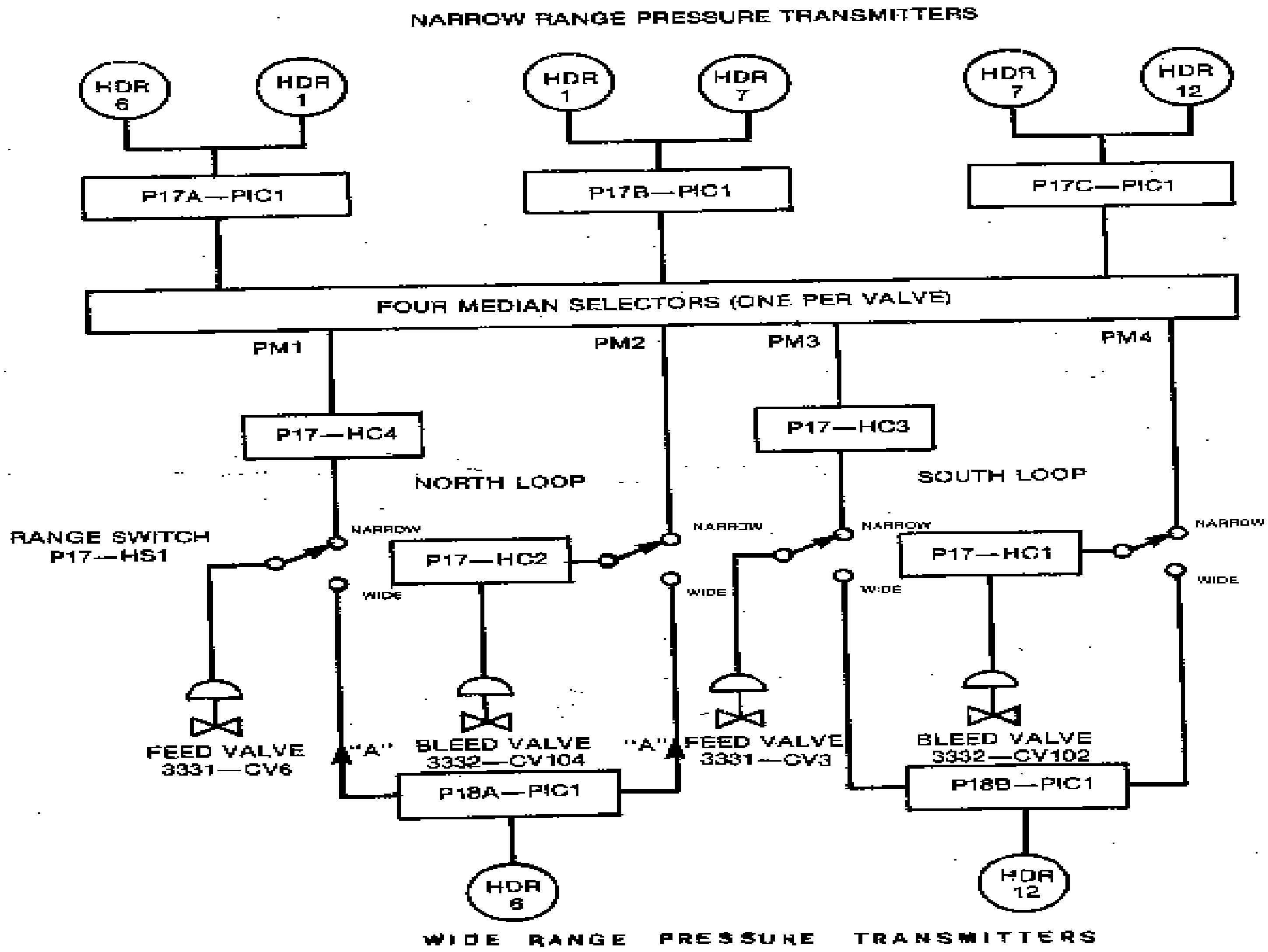


Figure 3: Heat Transport Pressure Control Scheme.

Narrow Range Control

Narrow Range **pressure control of the HTS is required at the operating state to provide the necessary pressure regulation and to prevent large pressure transients. The narrow range pressure control system drives the feed and bleed valves with a *median* (in order to reject irrational values) control signal selected from three controllers which accept averaged signals from six pressure transmitters (Figure 3). The narrow range system can be considered as consisting of three measurement branches: P17A, P17B, and P17C.**

- **Locate the P17A branch with pressure transmitters on headers 1 and 6.**
- **These two current signals are averaged and input as the measurement signal for control P17A - PIC1.**
- **Similarly, the averaged pressure measurement signals are compared to the set points by the three controllers and corrective control signals are produced.**
- **The three narrow range pressure setpoints are *staggered* (e.g. 8.6, 8.7 and 8.8) to prevent the controllers 'fighting' for control.**
- **These control output signals are applied to four *median select relays* (PM-1, 2, 3, 4) which will select the median control signal (reject the high and low signals).**
- **The four median selectors should block any irrational signals caused by instrumentation faults.**
- **The normal setup will be for P17B-PIC1 to be set to the system setpoint as its inputs are from both the north and south loops of the HTS.**
- **Note that much of this *control equipment redundancy* has now been replaced by *software logic*, providing a simpler control systems that is easier to operate and maintain.**

Narrow Range Control (continued)

- **The median control signal passes to the bleed valves manual stations HC-1, and HC-2 via the wide/narrow range switch contacts.**
- **This control signal is also fed directly to the feed valves manual stations HC-3 and HC-4.**
- **The outputs of these manual stations are then passed through the wide/narrow range switch contacts to the feed valves.**
- **Note that the bleed valve hand stations are available in both wide and narrow ranges, while the feed valve hand stations can only be used in narrow range.**
- **If narrow range pressure control is selected, the *same median control signal* will be applied to all four control valves.**
- **The auto/manual stations for the bleed valves (CV102, CV104) have an *adjustable bias* provision so that an extra constant component can be added to the median signal.**
- **The bias value will cause the *bleed valves to be more open* than the median control signal would request. *Increasing the bias will increase the bleed rate*, raising the purification flow.**
- **In case of a median selector relay malfunction, the auto/manual station can be switched to allow manual control of the valve position.**

- **The pneumatic signals applied to the feed and bleed valve actuators are amplified (times 2) to 40-200 kPa(g) to provide the actuators with a *larger working force* due to high application pressures.**

- **The feed and bleed valves are *single seated globe valves* with *linear flow characteristics*.**

- **These valves are *split ranged* from the median control signal as shown in the following table:**

VALVE OPERATING RANGES

	OPEN	CLOSED
Feed Valve (A/C)	100 kPa	140 kPa
Bleed Valve (A/O)	200 kPa	140 kPa

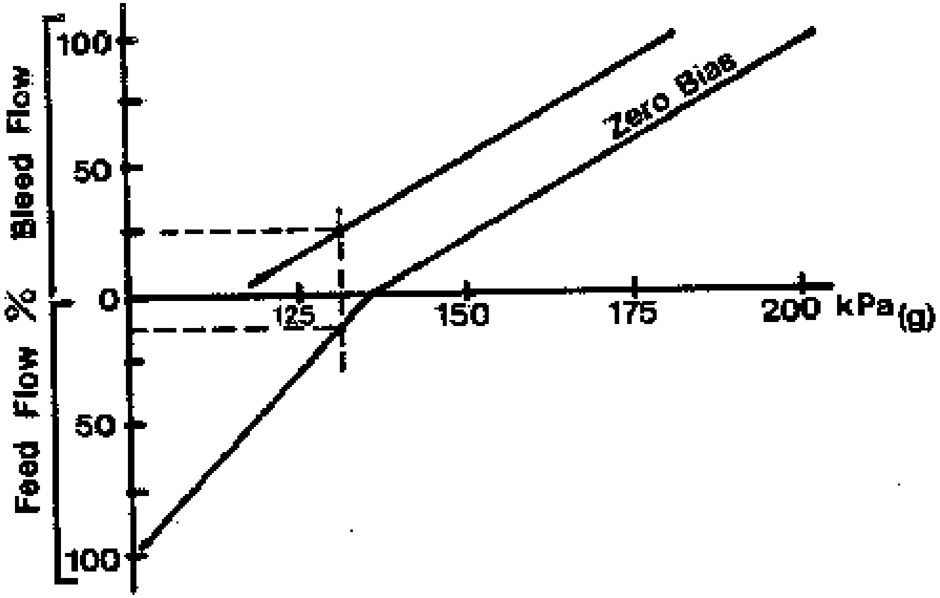


Figure 4: Feed and Bleed Flows vs Control Signal.

- The *gain of the feed valve* can be seen (Figure 4) to be *greater than that of the bleed valve*.
- If a pressure fluctuation causes a small change in control signal, the feed flow will be affected to a greater extent than will be the bleed flow.
- The system response can be visualized with the feed valves throttling to correct minor pressure deviations, while the *bleed valves pass a relatively constant flow*. This constant outflow simplifies the problem of controlling the bleed condenser pressure.
- Under normal operation, the feed valves would appear closed (inflow supplied from reflux and main pump gland in-leakage) with the bleed valves slightly open.
- The dynamic rate of response, to pressure and temperature transients, of a feed and bleed type system is limited (2.8 ° C/min).
- During normal power maneuvering, efforts are made to keep the average HTS temperature, and therefore pressure, relatively constant thus avoiding large changes in D_2O inventory for those systems which do not have a pressurizer.

MODULE 1 ASSIGNMENT: FEED AND BLEED PRESSURE CONTROL

1. **State the general purpose of the HTS Feed & Bleed system.**

2. **Sketch & label a simplified Feed & Bleed system (show the HTS as a block) and briefly describe one cycle of operation.**

3. **Identify and explain feed & bleed flow paths on a supplied diagram and locate key HTS components.**

4. **Describe the wide range feed & bleed control operation by referring to a provided control diagram to explain the interaction of key control devices.**

5. **Describe the narrow range feed & bleed control operation by referring to a provided control diagram to explain the interaction of key control devices.**

6. **Sketch and describe the feed valve and bleed valve operational curves with and without bleed bias applied to explain the coordination of the split range control.**

7. **Why is the air signal provided for the Feed & Bleed valves higher than the normal pneumatic pressure signals for pneumatic valves?**

Lesson 8: HEAT TRANSPORT CONTROL SYSTEMS

MODULE 2: PRESSURE CONTROL BY PRESSURIZER

At the end of this module, you will be able to:

1. **Sketch a simplified heat transport system with *pressurizer* and refer to this sketch to explain the solid mode HTS operation.**

2. **Sketch a simplified heat transport system with pressurizer and refer to this sketch to explain the normal mode HTS operation.**

3. **State the approximate saturation conditions in the pressurizer for full power operation.**

4. **Briefly describe the method of achieving pressurizer pressure control and describe one cycle of pressure excursion to show the operation of heaters and steam bleed valves.**

5. **Sketch a control signal output barchart (4-20 mA) and mark on this chart the relative signals you would apply for heater control (On/Off, Variable) and Steam Bleed valves. Include any deadband that you may think would be prudent.**

6. **Sketch a typical pressurizer level characterization curve vs reactor power (0-100%FP). Explain why it is important to accurately characterize this level curve.**

7. **Explain how pressurizer level control is accomplished by feed & bleed action in normal mode.**

MODULE 2: PRESSURE CONTROL BY PRESSURIZER

Introduction

For a system equipped with a. pressurizer, control is still divided into two modes.

- **The *solid mode*, which is the *wide range* control system, is used for warm-up and cool-down operations. The pressurizer is isolated from the system by MV1 and control is by a feed and bleed split range pressure control system as previously described.**
- **Under *normal mode*, at power, operating conditions pressure control is provided by the pressurizer.**

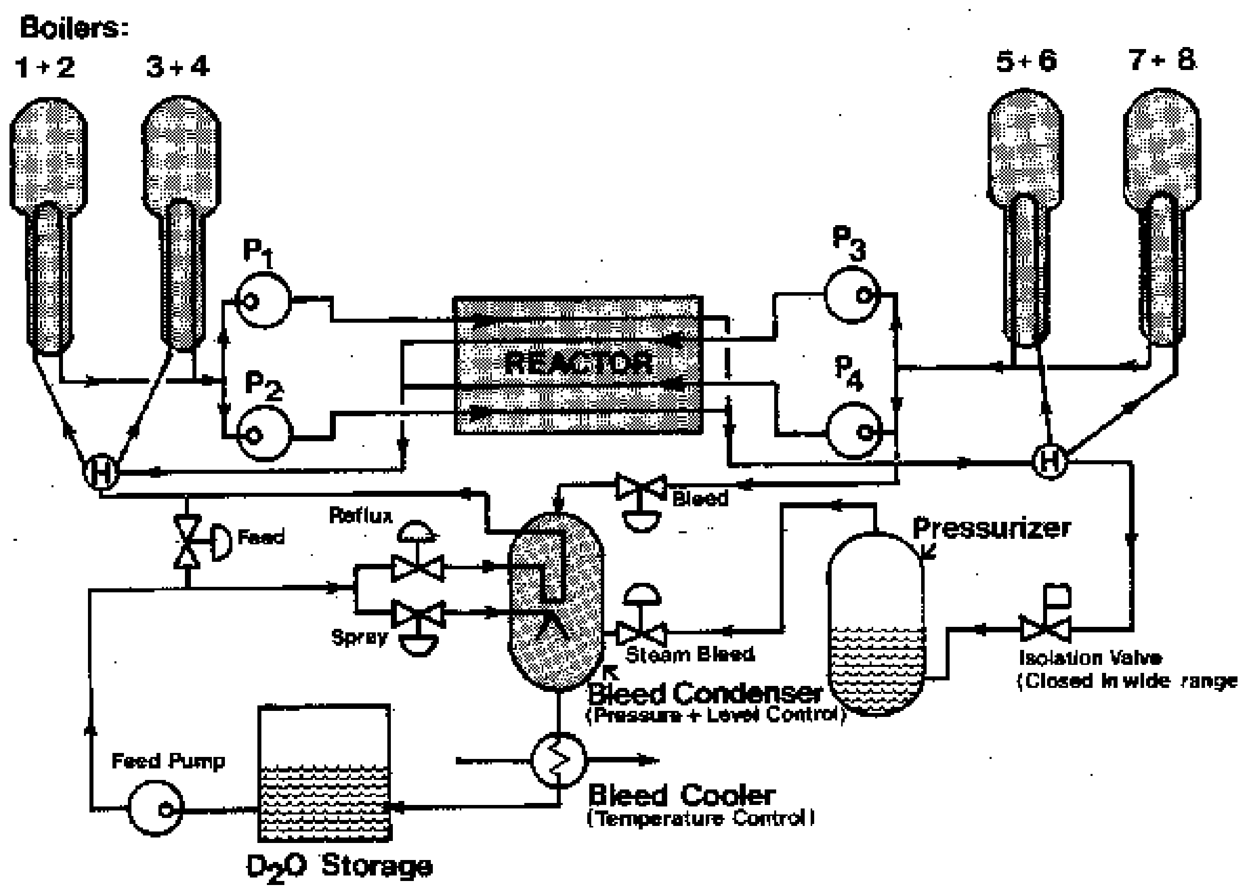


Figure 1. Stylized CANDU Heat transport System with Pressurizer.

Wide Range (Solid Mode) Control

- **When in the *solid mode*, saturation conditions are established in the pressurizer (9.9 MPa(g), 310° C).**
- **This saturation pressure is established by a combination of *electric heaters* and *steam bleed valves*.**
- **If the pressure is too high, the control system will switch off all heaters, if the pressure continues to rise, the control system will then open the steam bleed valves.**
- **Usually the pressure is maintained relatively constant with *one variable heater* on for ambient losses and the steam bleed valves closed.**
- **The opposite occurs if the pressure is too low, i.e., steam valves close and heaters are progressively switched on.**
- **It is also necessary to prevent heater operation if an insufficient level of D_2O is present in the pressurizer. If the level is too low all heaters will switch off by the logic of the *low pressurizer level interlock*.**

Narrow Range (Normal Mode) Control

- **Pressure control under *normal mode* is performed exclusively by the pressurizer.**
- **The isolation valve MV1 is opened and the HTS pressure is controlled by manipulation of the heaters and the steam bleed valves.**
- **The feed and bleed system is controlled on *pressurizer level* and is used only for purification and inventory control purposes.**
- **During power increases the heat transport fluid expands and the excess (swell) flows into the pressurizer.**
- **It is most important that the pressurizer should never become full of liquid as it must always have a vapour (steam) space in order to be able to absorb pressure changes.**
- **The pressurizer level curve is *characterized* to reflect expected inventory changes (about 3 meters) from ZPH to FP.**
- **The reactor power should be able to be maneuvered up or *down without requiring a change to the feed and bleed valve positions*.**
- **If the pressurizer level deviates from the characterized setpoint level curve, the control system will operate the feed and bleed valves to correct for the inventory disturbance.**

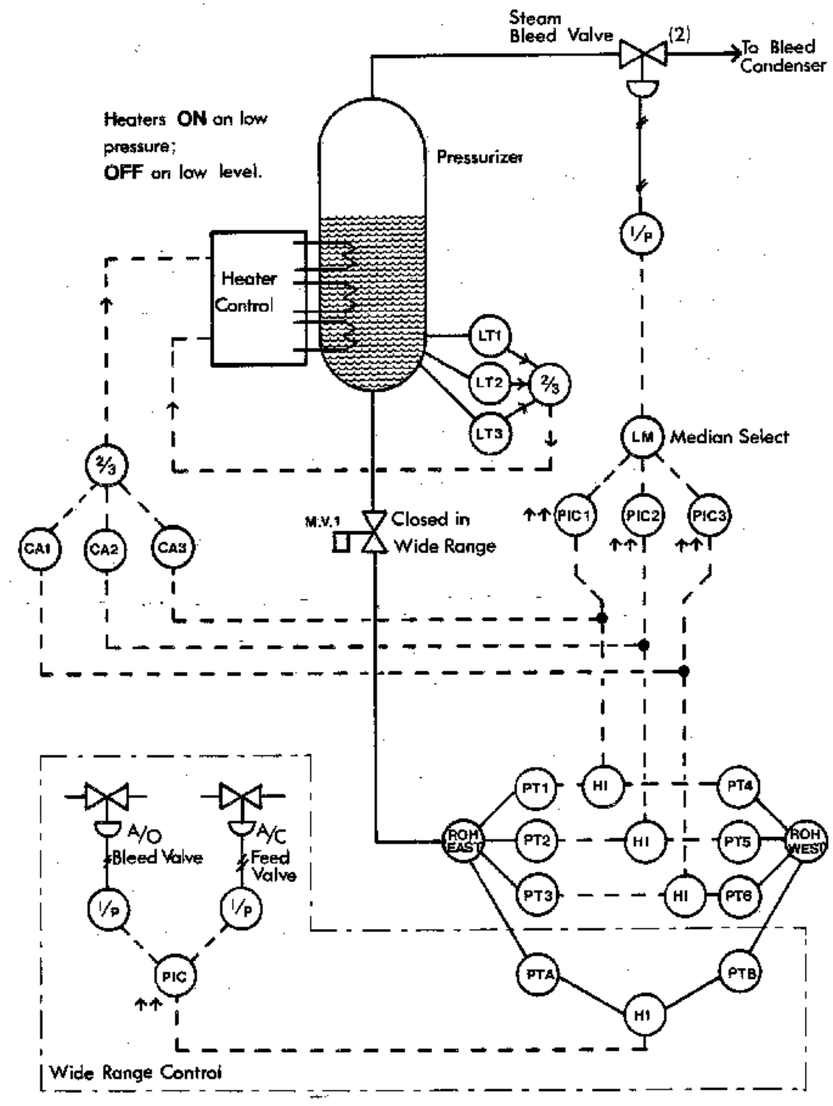
Pressurizer Instrumentation and Control Logic

- **Heat transport system pressure is sensed by six pressure transmitters PT1-6 arranged three to each reactor outlet header.**

- **Paired transmitters, one from each header, have their outputs routed via a high signal selector (HI) eliminating the effect of a transmitter which fails to zero output (the usual failure mode).**

- **Each of the three high signals is then routed to a direct acting pressure controller (PIC1 - 3), the outputs of which are fed to a median select circuit which provides the signal for the steam bleed valves and the variable heater.**

- **Low pressure is sensed by current sensors (CA1-3) which will switch on the on/off heaters to raise pressure.**
- **The "heater on" signals are dependent on there being sufficient D_2O in the pressurizer. This conditioning is achieved by the triplicated level transmitters (LT1 - 3) and the two out of three logic (2/3) module, i.e., low level - heaters switched off.**



Pressurizer level Control

- **The level in the pressurizer is characterized to rise (say from 3 to6 meters) as power level is increased (from ZPH to FP) to accommodate the HTS inventory expansion. This is done for two reasons:**

(a) to minimize the use of the feed and bleed system and thus ensure the bleed condenser and bleed cooler have a reasonably constant load.

(b) to provide an immediate inventory make-up to the HTS to maintain pressure control in the event of a reactor trip when D_2O shrinkage, due to the loss of heat source, is at a maximum.

- **The pressurizer is also fitted with *pressure release valves*. In the event that the pressurizer pressure rises above its normal control limits, these pressure relief valves discharge to the bleed condenser, protecting the pressurizer from an overpressure condition while ensuring that there is no loss of fluid from the heat transport system.**

Figure 2: Pressurizer Instrumentation and Control Logic.

Lesson 8: MODULE 2 Assignment : PRESSURE CONTROL BY PRESSURIZER

1. Sketch a simplified heat transport system with pressurizer and refer to this sketch to explain the Solid Mode HTS operation.

2. Sketch a simplified heat transport system with pressurizer and refer to this sketch to explain the Normal Mode HTS operation.

3. State the approximate saturation conditions in the pressurizer for full power operation.

4. Briefly describe the method of achieving pressurizer pressure control and describe one cycle of pressure excursion to show the operation of heaters and steam bleed valves.

5. Sketch a control signal output barchart (4-20 mA) and mark on this chart the relative signals you would apply for Heater Control (On/Off, Variable) and Steam Bleed valves. Include any deadband that you may think would be prudent.

6. Sketch a typical pressurizer level characterization curve (meters) vs reactor power (0-100%FP). Explain why it is important to accurately characterize this level curve.

7. Explain how pressurizer level control is accomplished by feed & bleed valve action in Normal Mode.

Lesson 8: HEAT TRANSPORT CONTROL SYSTEMS

MODULE 3: HEAT TRANSPORT BLEED CONDENSER CONTROL

At the end of this module, you will be able to:

1. **Sketch and describe a simplified Bleed Condenser *Reflux Pressure control* system.**

2. **Sketch and describe a simplified Bleed Condenser *Spray Pressure control* system.**

3. **State the approximate operating saturation conditions within the bleed condenser .**

4. **Sketch and describe the *bleed condenser level control* system.**

5. **Sketch and describe a *bleed cooler heat exchange temperature control* loop and describe the operation.**

6. **Describe the *temperature override* of the bleed condenser level control.**

7. **Given a simplified HTS diagram, be able to identify the following control valves:**
   Reflux, Spray, Pressurizer Isolation, Bleed Condenser Level, HTS Feed, HTS Bleed

8. **Briefly explain the operational change applied to the bleed condenser following a reactor trip or a turbine trip.**

MODULE 3: HEAT TRANSPORT BLEED CONTROL

Introduction

- **Any bleed flow from the Heat Transport System as a result of either *too high a pressure* or deliberately induced bleed flow *for clean up purposes* must be reduced in pressure and temperature before passing through the ion exchange systems and on to D_2O storage.**

- **This is accomplished by the combination of the *bleed condenser* and *bleed cooler* with control requirements as follows:**

(a) To lower pressure and temperature from approximately 9.0 MPa at 265° C to approximately 2 MPa and 205° C in the bleed condenser, i.e., *Bleed Condenser Pressure Control*.

(b) To maintain an adequate inventory in the bleed condenser, i.e., *Bleed Condenser Level Control.*

(c) To lower the temperature of Bleed outflow from the bleed condenser to approximately 45° C before passing through the I/X columns, i.e., *Temperature Control of Bleed Cooler*.

(d) In order to avoid breakdown of IX resins by a bleed temperature in excess of approximately 70° C, to provide a means of effective temperature control of the bleed cooler at the expense, if necessary, of the control function listed in (b), i.e., *Temperature Override of Bleed Condenser Level Control.*

Bleed Condenser Pressure Control

- **The preferred method of bleed condenser pressure control is by throttling the *reflux valve (CV111).***

- **The backup method of pressure control, *spray valve (CV113)* regulation, is not as desirable because it results in extra flow through the IX columns and promotes degassing of the D_2O in the condenser.**

- **Both the reflux and the spray valve are equipped with *air to open actuators*.**

- **Both reflux and spray controllers have *direct control actions* so that the control signal will increase as the pressure rises above the setpoint**

- **The set points of the two pressure control loops are *staggered* (1.6 & 1.9) with the reflux set point the lowest (approximately 1.6 MPa).**

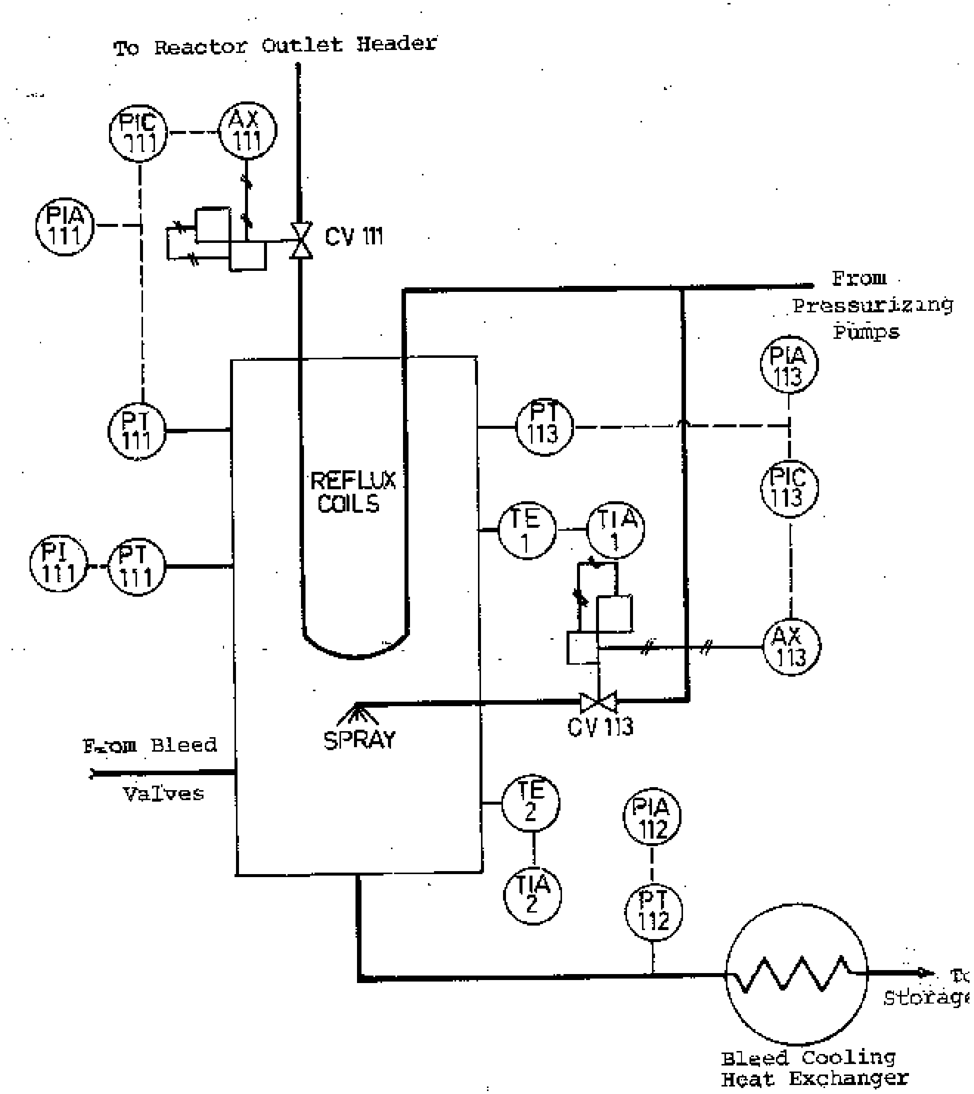


Figure 1: Bleed Condenser Pressure Control.

Bleed Condenser Pressure Control (continued)

- **As long as the pressure is successfully controlled by the reflux method, the spray valve will not be opened (i.e. pressure will be below the spray controller setpoint)**

- **The set point for the spray controller is approximately 1.9 MPa or 300 kPa above the reflux set point.**

- **Should the bleed condenser pressure rise unchecked by the reflux system, the spray controller will begin to drive the spray valve open.**

- **A high bleed condenser pressure condition will be annunciated when the bleed condenser pressure rises to 2.24 Mpa.**

- **The spray valve opening is inhibited on high bleed condenser level to *avoid filling the condenser solid* and pressurizing to spray valve discharge pressures.**

Bleed Condenser Level Control

- During normal system operation, the bleed condenser level is regulated by ***throttling an outflow control valve*** (CV122 or CV123).
- This control problem can be considered, in general, as the level control of a tank by outflow regulation where the tank is supplied with a non constant inflow.
- A ***duplicated*** system is employed with ***staggered set points*** for the identical level loops.
- Consider the level loop identified with tag number 122 (LT-122 to CV122) in Figure 2
- The control valve (CV122) on the outflow line is an air to open globe valve.

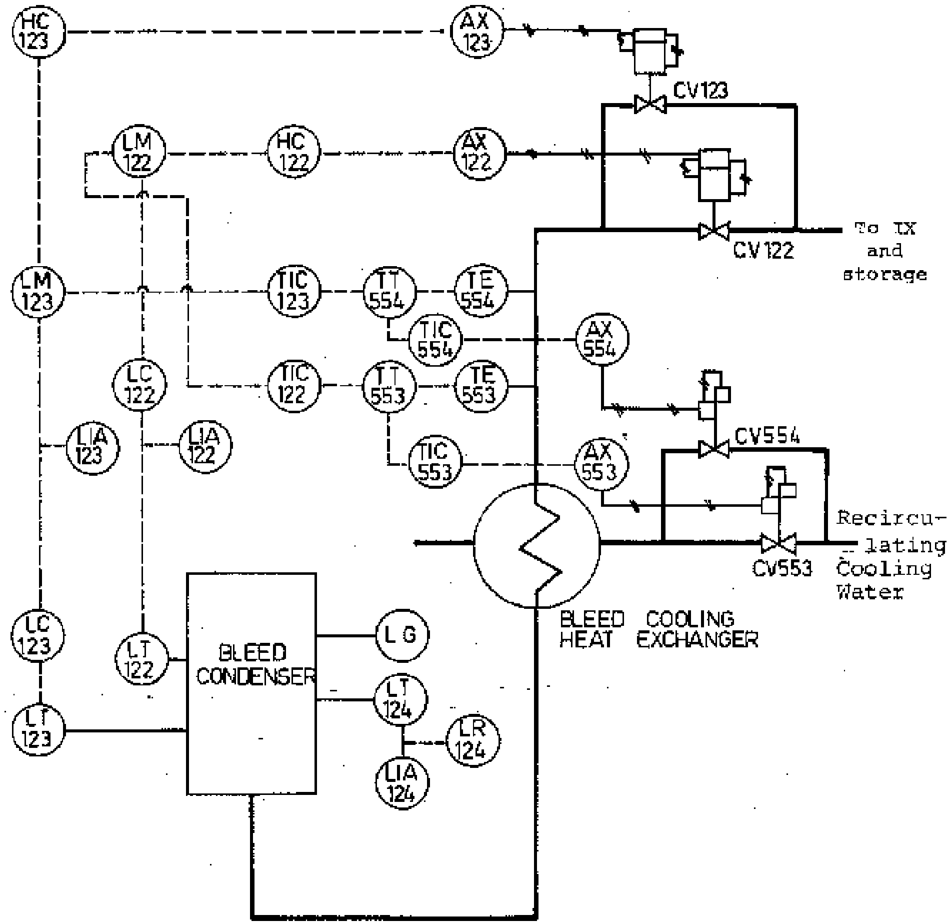


Figure 2: Bleed Condenser Level and Bleed Temperature Control.

- If the level in the bleed condenser sensed by LT-122 is too high, the valve must be driven more open - LC122 is a ***direct acting*** controller.

Bleed Condenser Level Control (continued)

- **The signal from the direct acting LC-122 is fed to a *low select relay* (LM-122) which will pass the lowest of the two signals applied, (e.g., 10 mA and 12 mA input, 10 mA output).**
- **Assume at this time that the level control signal is the lowest signal input to LM-122.**
- **The selected lowest signal is directed from LM-122 to an auto/manual station (HC-122) so that manual control of the outflow valve is possible if the controller becomes inoperative.**
- **The control signal from the auto/manual station then drives an I/P transducer (AX122) which allows the electronic loop to be interfaced with the pneumatic actuator of CV122.**
- **The operation of the level loop tagged 123 is identical to 122 except that the set point of LC-123 is approximately *twenty percent higher* than the set point of LC-122. (LIC-122 set point: 60%, LIC-123 set point: 82%).**
- **As long as the level is regulated by loop 122, the back up loop 123 will be inactive and CV-123 will remain closed.**
- **These setpoints can be alternated on a duty cycle basis (say three months) to ensure equal work periods for both loops.**

Bleed Cooler Effluent Temperature Control

The effluent temperature of the bleed cooler is regulated by a duplicated system consisting of the control loops tagged 553 and 554. Consider the loop tagged 553 in Figure 3.

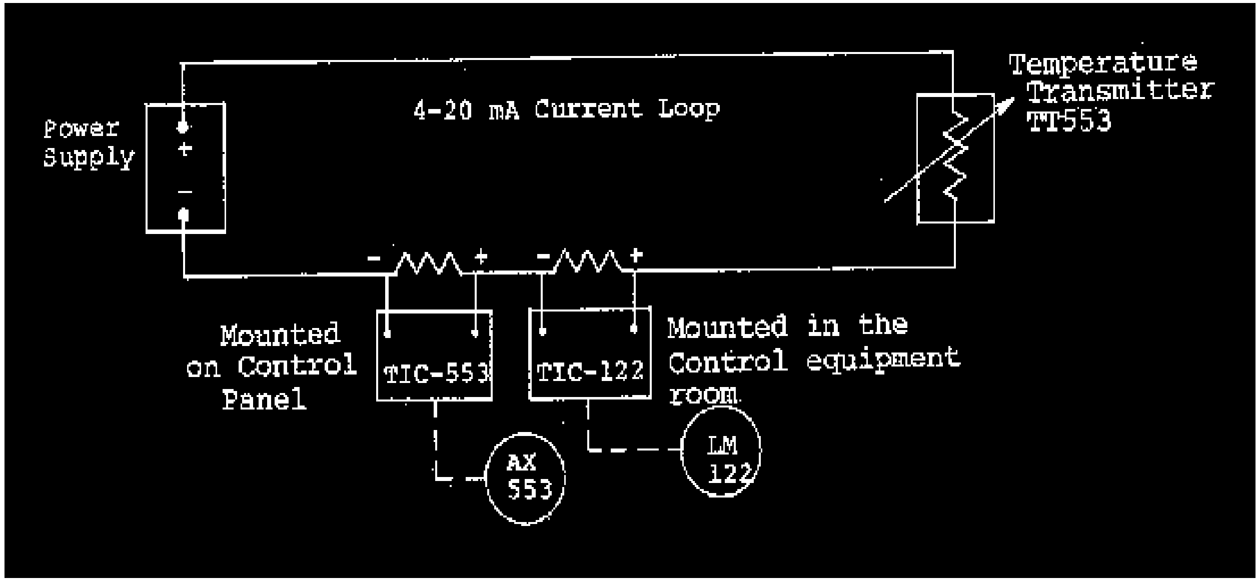


Figure 3: Two Controllers Monitoring the Same Current Signal.

- **The effluent temperature is sensed by an RTD which produces a change in resistance proportional to the measured change in temperature.**
- **This change in resistance is then converted to a corresponding mA signal by TT-553.**
- **The current signal from the temperature transmitter is applied as the input to two temperature controllers (TIC-553, TIC-122) which are connected in series in the transmitter circuit. The function of TIC-122 will be discussed in the next section on temperature override.**
- **Temperature control valve (CV-553) is an air-to-open valve.**

Bleed Cooler Effluent Temperature Control

- **Temperature controller 553 is *direct acting* so that an increase in effluent temperature will cause the air to open control valve (CV-553) on the recirculating cooling water line to be driven more open.**

- **The temperature control loops are identical but with *staggered* set points. The set point for the back up controller (TIC-554) is approximately 6° C higher than the set point for TIC-553.**

- **For normal operation, TIC-553 will be able to maintain the desired temperature by throttling CV-553.**

- **Control loop 554 will appear inoperative with CV-554 closed unless the temperature begins to rise well above the TIC-553 setpoint.**

- **This control application has also used a small TCV in parallel with a large TCV with both valves driven by a common control signal. The small TCV accommodates low bleed flow conditions while the large TCV will drive open if large bleed loads are applied.**

Temperature Override of Level

- **The bleed cooler effluent temperature must not rise to 60° C or chloride ions will be released from the IX resin. (Chloride ions can cause stress corrosion cracking in the system materials.)**
- **For normal operation, the bleed cooler outflow valve (CV-122) is positioned as a function of the control signal from *direct acting* LIC-122.**

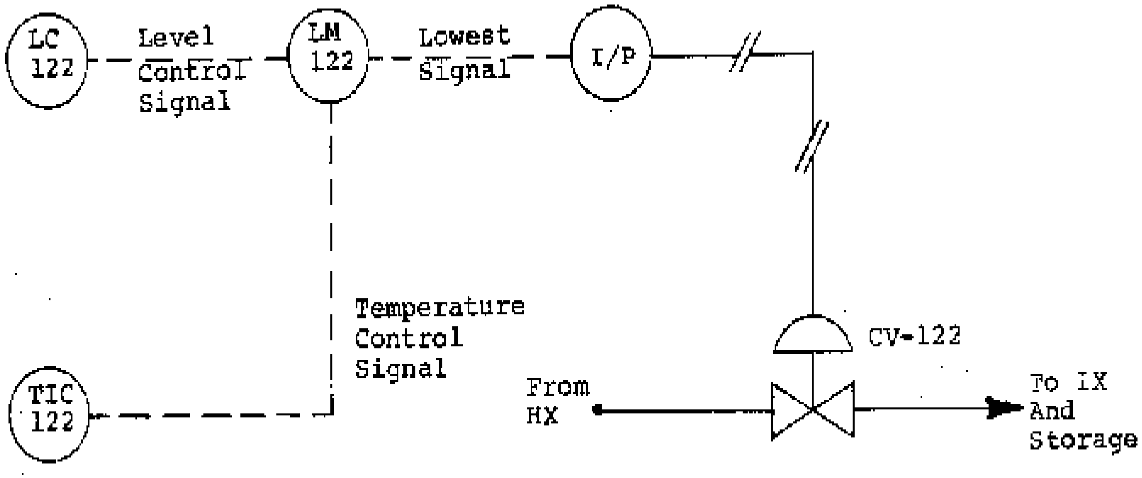


Figure 4: Interconnection of the Level and Temperature Controllers.

- **Temperature controller TIC-122 has *reverse action*.**
- **Low select realy (LM-122) selects the *lowest* of the signals from direct acting LIC-122 and reverse acting TIC-122.**

Temperature Override of Level (continued)

Assume that the bleed rate is increased due to some transient condition so that the bleed condenser level begins to rise.

- **Since the level controller is direct acting, the *level control signal will increase* as the level rises**
- **Air-to-open CV-122 will be driven more open to increase the bleed condenser outflow rate.**
- **The bleed cooler *effluent temperature will now begin to rise* due to the increased bleed flow.**
- **Temperature controller TIC-122 is *reverse acting* so that as the temperature rises, the *control signal decreases*.**
- **The rising level control signal and the falling temperature control signal are input to the low select relay.**

Temperature Override of Level (continued)

- **Once the signal from TIC-122 becomes the *lowest* of the two signals sensed by LM-122, then the *temperature controller will be regulating* the control valve (CV-122) position**
- **Notice that the air-to-open CV-122 now drives more closed due to the lower signal selection. In this manner, the temperature control signal *overrides* the level control signal.**
- **The reduced flow of hot bleed and the increased flow of cooling water to the heat exchanger (requested by TIC-553) will now be able to return the effluent temperature to the set point.**
- **A low limit is applied to the temperature controller signal (TIC-122) to limit the closing of the level valve (CV-122) to 10% of stroke.**
- **This prevents the complete closure of the level valve by the temperature override signal and the accidental lock-up of a hot pocket of bleed at the temperature detectors.**

Response to a Reactor Trip

- **For a feed and bleed type system, a reactor trip would cause an increase in feed valve opening with bleed valves going to a minimum opening position (i.e. the bias value) in an attempt to prevent inventory shrinkage due to the gross energy mismatch that exists under such conditions while the turbine is still removing heat from system.**
- **It is necessary to reachieve the energy balance as as soon as possible by reducing the magnitude of the heat sink applied, i.e., a fast speeder gear runback.**
- **The reduced bleed action will require a control response from the bleed condenser level controller - the level will drop a little below the setpoint and the level valves will close.**
- **The reduced outflow from the bleed condenser will also reduce the load on the bleed cooler enabling a reduction in service water flow to the shell side of the cooler.**
- **Where pressure control is by pressurizer the initial shrink in HTS inventory following the reactor trip will be supplied from the pressurizer.**
- **Recall that the level in the pressurizer was ramped up with power increases to provide this initial inventory replenishment.**
- **Again there will be a fast speeder gear run back to re-establish the energy balance at a lower power level.**

Response to Turbine Trip

- **In this case the energy input source is greater than the unit heat sink. Consequently, the HTS system inventory will *begin to swell* due to the increased temperature causing the pressure to rise.**
- **A feed and bleed system will require *maximum bleed* action with the feed valves going to the fully closed position.**
- **This extra bleed will require additional pressure control action in the bleed condenser possibly by commencement of spray action.**
- **The additional bleed, plus any spray flow, will require an increased outflow from the bleed condenser *to maintain level*.**
- **This increased outflow will, in turn, increase the cooling requirements from the bleed cooler.**
- **The temperature override of bleed condenser level control may be initiated for a short period of time depending upon the degree of energy mismatch.**
- **For a pressurizer system the HTS swell will be *accommodated by the pressurizer* with the steam bleed valves opening to relieve the pressure.**
- **A turbine trip will initiate a reactor stepback thus reducing the energy input to the system. If for any reason this stepback does not happen, the high pressurizer level condition will cause a reactor setback.**

Simplified Overall HTS Control Scheme

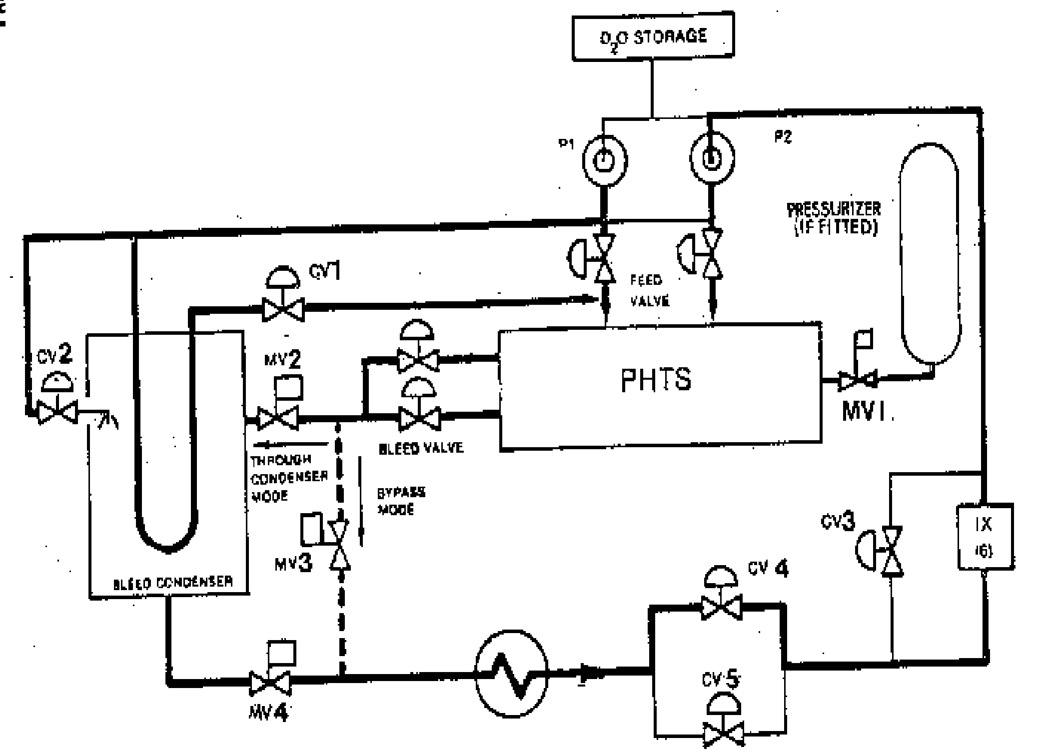


Figure 5: Overall Control Scheme for HTS.

The principle control valves and their role in the overall HTS control scheme are as follows:

<u>Reflux flow control valve</u> (CV1) - primary means of bleed condenser pressure control.

<u>Spray flow control valve</u> (CV2) - secondary means of bleed condenser pressure control. Operates only when reflux control is insufficient to limit pressure.

<u>Ion exchange column bypass</u> (CV3) - opens to bypass IX when flow through columns limited by high DP.

<u>Bleed condenser level control valves</u> (CV4 /CV5) - control level in the bleed condenser by throttling of outflow. Temperature control of bleed effluent can override level control of these valves.

Hear Transport System Isolation Valves

Pressurizer Isolation valve (MV1) - Closed when in solid mode; open in normal (at power) mode.

Establish through bleed condenser mode (MV2). - when MV2 is open, bleed flow is allowed to flow into the bleed condenser.

Condenser Bypass Mode (MV3) - when MV3 is open, the bleed condenser is bypassed and bleed flow is directed to the bleed cooler.

Bleed Condenser Outflow Isolation (MV4) - when the bleed condenser is bypassed, MV4 is also closed (as is MV2). When the through condenser mode is established both MV2 and MV4 must be opened.

MODULE 3 Assignment : HEAT TRANSPORT BLEED CONDENSER CONTROL

1. **Sketch and describe a simplified Bleed Condenser Reflux Pressure control system.**

2. **On the sketch for question #1, include a simplified Bleed Condenser Spray Pressure control system and describe its operation.**

3. **State the approximate operating saturation conditions within the bleed condenser .**

4. **Sketch and describe a bleed condenser level control system.**

5. **Sketch and describe a bleed cooler heat exchange temperature control loop and describe the operation.**

6. **Describe the temperature override logic of the bleed condenser level control.**

7. **Given a simplified HTS diagram, be able to identify the following control valves:**
   Reflux, Spray, Pressurizer Isolation, Bleed Condenser Level, HTS Feed, HTS Bleed

8. **Briefly explain the operational change applied to the bleed condenser following a reactor trip or a turbine trip.**

Lesson 8: PHT P&IC CONTROL PROGRAM REVIEW
Module 4 – P&IC OVERVIEW

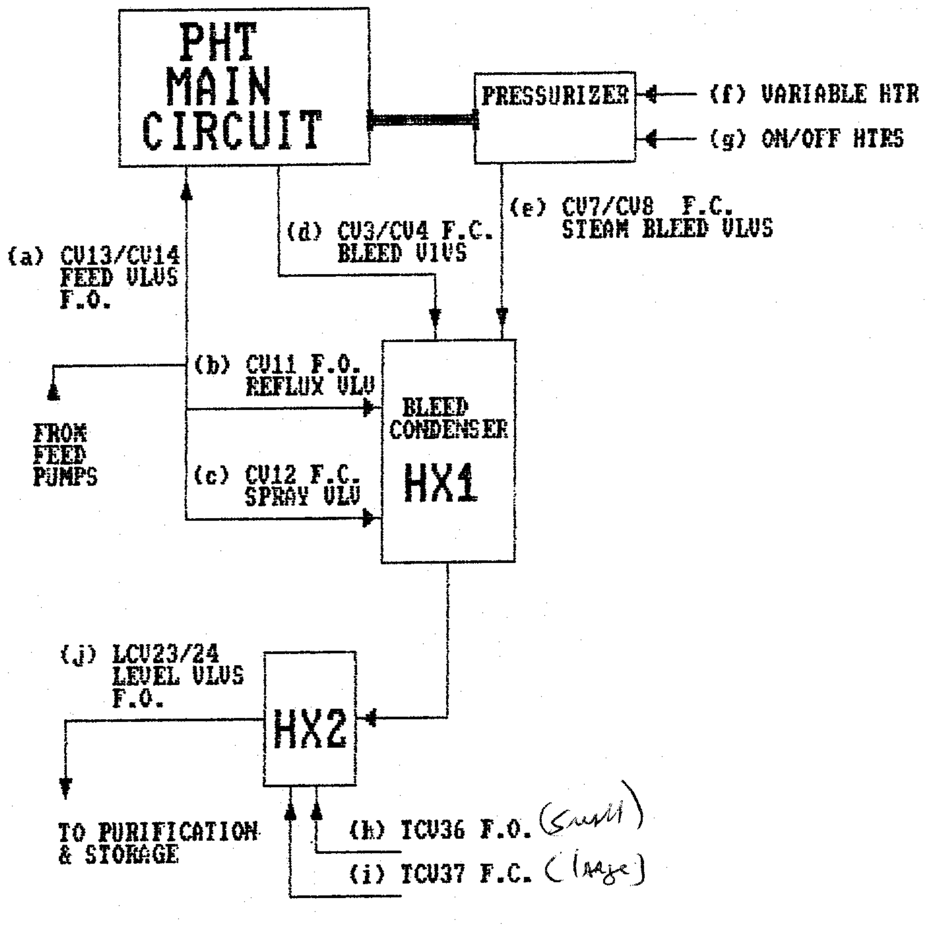
This information is intended to supplement the controls lectures with additional information on the digital control computer application to Primary Heat Transport Pressure and Inventory Controls with implementation details.

PRIMARY HEAT TRANSPORT
- PRESSURE and INVENTORY CONTROL OVERVIEW

- The primary heat transport system (PHT) is the system which transfers the heat energy from the reactor **(*heat source*)** to the boilers (***heat sink***).
- It is important that the PHT is able to accommodate ***some mismatch in energy*** between the reactor and the boilers as these systems are very dynamic and can be subjected to unexpected upsets.

- The PHT accepts an approximate 45 C temperature increase across the reactor (from Reactor Inlet Header @ 265 C to Reactor Outlet Header @ 310 C)
- This energy change is passed to the boilers so that the temperature at the pump suction is approximately 263 C.

- The heat transport system consists of the ***main circuit***, the ***pressurizer***, the ***bleed condenser***, the ***bleed cooling heat exchanger*** and the ***purification circuit***.
- It is very important to consider all aspects of the heat transport system interactions as there is a ***high degree of coupling*** between interfaced systems and so interaction effects can be significant (and perhaps unexpected).



<u>FIGURE #1: KEY COMPONENTS AND INTERACTIONS</u>
FOR THE HTS PRESSURE AND INVENTORY CONTROL

Main Circuit

- The mission for the main circuit is to maintain a ***cooling flow*** across the fuel in the reactor core.

- To do this, a subcooling saturation margin must be maintained to ensure that coolant boiling does not occur to provide adequate heat transfer while preventing cavitation of the main circuit pumps.

- The inventory inputs to the main circuit are the flows from the ***Feed*** valves (CV13 and CV14) and the ***Reflux*** valve (CV11) and as well the ***gland seal flows*** for the main pumps.

- The gland seal flows maintain a relatively ***constant low flow*** value while the feed and reflux flows are controlled as part of the pressure and inventory logic.

- The total flow into the heat transport system is monitored such that if the ***reflux*** flow increases (i.e to control the bleed condenser pressure) , the feed flow is ***decreased*** to keep the ***total*** inflow relatively constant.

- Inventory will also be transferred to the main circuit, to sustain the main circuit pressure, from the pressurizer if the main circuit pressure is too low - that is if the pressure in the HTS is below that in the pressurizer.

- The inventory outflows from the main circuit are via the ***Bleed*** valves (CV3 and CV4) to the bleed condenser and as well to the ***pressurizer*** if the main circuit pressure is too high - that is, the pressure of the HTS is above that of the pressurizer.

<u>Pressurizer</u>

- The mission for the pressurizer is to ***immediately*** provide or accept inventory as required to maintain the main circuit pressure at the specified design value (usually 9.9 Mpa at power conditions).

- The pressurizer is a large vessel which is controlled at saturated conditions via ***heater controls*** to provide a pressure source for the main circuit.

- If the main circuit pressure is low, inventory will flow ***from the pressurizer*** to the main circuit outlet header via the connection nozzle.

- If the outlet header pressure is too high, expansion inventory will flow from the main circuit ***into the pressurizer*** via the connection nozzle.

- In this way, the pressurizer acts as a giant snubber or dashpot to accept or give up inventory in an attempt to keep the main circuit pressure quite stable.

- Direct inventory transfers into or out of the pressurizer are via the connection nozzle to the ***reactor outlet header***. As mentioned, there are ***five heaters*** in the pressurizer which are used to raise the pressurizer to saturated conditions.

- One of these heaters is designated as a ***variable heater*** which should be on approximately 35% to accommodate for ***ambient system heat losses***. Once the selected variable heater approaches maximum signal, the remaining four heaters are all automatically switched on in an on/off manner.

<u>Pressurizer…continued</u>

- ***Steam bleed valves*** (CV7 and CV8) provide pressurizer over-pressure control regulation. As the pressure increases, the four on/off heaters will be switched off and then the variable heater signal will decrease until it reaches 0%.

- There is then a ***deadband*** of a few percent with no heaters (to allow the pressure to stabilize without any unnecessary inventory transfer).

- If the pressure continues to increase (say due to a compressive effect by too much inventory being transferred from the reactor outlet header into the pressurizer via the connection nozzle), then the steam bleed valves will begin to be stroked proportionally more open.

- The steam flow from the pressurizer (which should help drop the pressurizer pressure) is ***transferred into the bleed condenser*** - so the inventory remains within the heat transport system boundary.

- As well, ***High Pressure Relief Valves*** are also provided on the pressurizer, ***independent of the control system***, so that if the pressure rises too high, the PRV's will discharge steam directly to the bleed condenser to protect the integrity of the pressurizer.

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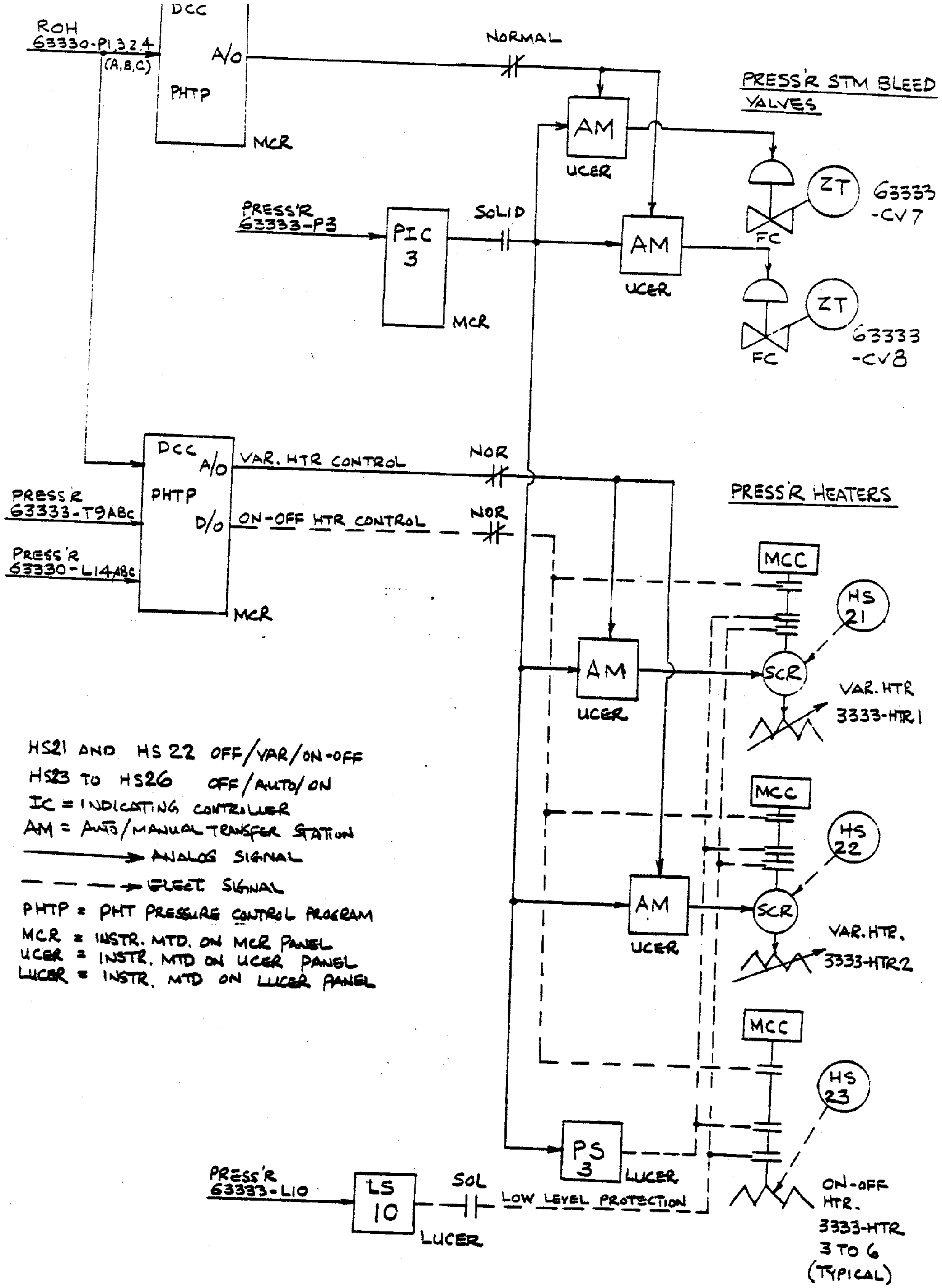

FIGURE# 2 STEAM AND HEATER CONTROL LOGIC

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Bleed Condenser

- The bleed condenser is an intermediate ***pressure reduction vessel*** which accepts inventory from the heat transport system (at pressures of 9.5 MPa @ 265 C) via the bleed valves.

- The bleed condenser also provides the hydraulic driving head to force blled flow through the bleed cooler heat exchanger, the level control valves, the filter and ion exchange column before reaching the feed pump suction or the heavy water storage tank.

- The bleed condenser is usually controlled at ***1.6 MPa*** pressure which has a saturation temperature of approximately ***204 C***. Pressure control is either by ***cooling reflux flow*** through a U-tube type heat exchanger inside the bleed condenser or by ***cooling spray flow*** which is injected directly into the bleed condenser vapour space.

- Steam can also be admitted to the bleed condenser from the pressurizer via the ***steam bleed control valves*** or via the ***high pressure relief valves***.

- In addition, cold inventory can be introduced to the bleed condenser via the spray cooling valve (CV12).

- Reflux control (cooling flow through exchange coils) provides the ***primary pressure control*** for the bleed condenser via CV11 but this flow does not provide an inventory input to the bleed condenser.

- Outflow from the bleed condenser is via the ***level control valves*** LCV 23 and LCV 24 which are used to regulate the bleed condenser level to approximately the 1 meter posiiton. This bleed condenser outflow actually passes through the bleed cooler heat exchanger.

<u>Bleed Cooling Heat Exchanger</u>

- This heat exchanger accepts fluid from the bleed cooler at approximately 202 C and cools this fluid flow to about 54 C.

- The flow rate from the bleed condenser to the bleed cooler is determined by the ***bleed cooler level control valves*** so that if the inflow to the bleed condenser is increased, the level would begin to be forced up and would require an increase in outflow to maintain the bleed condenser level.

- This increased opening of the bleed condenser level valves will increase the flow through the bleed cooler heat exchanger, presenting a ***larger cooling load*** for the bleed cooler.

- Two control valves are provided in a ***split range manner*** on the recirculated cooling water (RCW) system to provide shell side cooling for the bleed cooler heat exchanger.

- A ***small*** temperature control valve (TCV-36) is adequate for low bleed flow loads (say up to 15 Kg/sec), but a ***larger*** TCV (TCV-37) is activated for larger flows to prevent significant temperature variations.

- The bleed cooler heat exchanger should be able to handle flows of up to 40 Kg/s while maintaining the temperature below 60 C.

- It is important to maintain the temperature below 70 C since higher temperatures than this can effect the IX resin and release chloride ions to the heat transport circuit. Chloride ions can then lead to long term damage by initiating ***stress corrosion cracking*** (SCC), and so these conditions must not be allowed to occur.

Bleed Cooling Heat Exchanger…..continued

- A second, ***temperature override control system*** is provided to monitor the ***outlet temperature*** from the bleed cooler heat exchanger.
- If the bleed cooler outlet temperature rises above 60 C, then the ***override controller*** begins to ***assume control*** of the bleed condenser level valve and closes it in so that the hot flow through the bleed cooler tube side is reduced while the cooling flow through the shell side is maximum.
- In this manner with ***maximum coolant*** and ***minimum hot process flow***, the bleed cooler effluent temperature is very quickly reduced below 60 C (i.e. the ***temperature control overrides the level control*** and lowers the temperature).
- Note also, that this is one control tuning opportunity to ***soften (***i.e. reduce the abruptness of the control response - ***decouple*** the interaction***)*** the level response (as we do have available bleed condenser capacity) and to more slowly respond to level changes (perhaps use a ***wider*** proportional band and a ***slower*** reset time).
- If this is done, then ***sudden inventory changes*** to the bleed condenser from the heat transport system are ***more gradually introduced*** to the bleed cooler so that the cooling capacity can be increased in a controlled manner ***without large temperature overshoots***.
- As well, it is important to include ***derivative control*** mode for the bleed cooler temperature controller and to correctly ***split range*** the small and large TCVs (start to open the large TCV once the small TCV is greater than 55% open) to allow ***sufficient response time*** for the cooling RCW flows.
- This is one area to focus on, since some designers allow the small valve to drive fully open before beginning to open the large valve. Such a strategy usually leads to significant temperature overshoot since the effectiveness of the large valve is not established until it is at least more than 10% open and by that time the temperature will have changed significantly.

Purification Circuit

- The flow from the ***bleed cooler heat exchanger*** at 1 MPa and 54 C is now routed through the ion exchange (IX) columns to remove any ionic material (activated corrosion products, fission products from defective fuel bundles or bundle tramp uranium) to ***clean-up*** the heat transport fluid.

- The entire heat transport inventory can be circulated through the IX columns within about 8 hours when the bleed flow is set to 10 Kg/s.

- The IX columns are protected by a differential pressure sensitive bypass circuit such that if the differential pressure across the IX columns becomes too high, the columns are ***bypassed*** by opening a bypass valve and the flow does not pass through the columns.

- This feature is intended to prevent forcing IX resin into the flow path by applying too high a pressure across the IX column which then presents a foreign particulate problem within the heat transport system requiring a further clean-up activity.

The heat transport inventory fluid after the IX columns (or bypass) can then be directed to the ***heavy water storage tank*** (which is the head tank for the pressurizing pumps suction) or can be re-injected into the main circuit at the main pump suction via the pressurizing pumps and the feed valves (CV3 and CV4) or the reflux valve (CV11).

Lesson 8: Module 5: PHT P&IC CONTROL PROGRAM

- This information is intended to supplement the controls lectures with additional information on the digital control computer application for Primary Heat Transport Pressure and Inventory Controls with implementation details.

- The best way to be able to program a control application is to fully understand the necessary operations and then to document these performance requirements as program rules that can then be implemented by control logic.

- This material follows-on from the presentation in P&IC1.doc

Solid Mode Heat Transport Pressure Control - Analog

- Solid mode operation is conducted with the pressurizer ***isolated*** from the main heat transport system.

- Pressure control within the ***solid mode*** heat transport system is completely by operation of the ***feed and bleed*** control valves.

- ***Wide range*** pressure control for the heat transport system is provided by analog control of the ***feed*** (CV13 and CV14) and ***bleed*** (CV3 & CV4) control valves. The feed valves are ***fail-open style*** (to ensure a supply path to the HTS) while the bleed valves are ***fail-closed*** (to prevent an unplanned loss of inventory from the HTS).

- Two pressure controllers are provided (PIC5 and PIC6) and each of these devices controls one feed and one bleed valve via a ***split range control*** strategy.

- The pressure controller (PIC5 or PIC6) must respond to an ***increase*** in pressure by closing the feed valve (by an ***increase*** in signal) and by opening the bleed valve (also by an ***increase*** in signal). Therefore, ***direct action*** (***increase*** in measurement, ***increase*** in control signal) control is required for PIC5 and PIC6.

- An adjustable ***purification bias*** is provided by a manual loading station or hand controller (HC9) which develops an ***additional*** signal that is added to the control signal developed by PIC5 and PIC6 before it is applied to the bleed valves (CV3 and CV4).

- Increasing the ***purification bias*** will cause an increase in bleed flow so that additional feed flow will be required to ***maintain the original mass balance*** condition under the prevailing pressure equilibrium.

- Note that the feed gain is ***greater*** than the bleed gain so that a small change in control signal has a ***larger effect*** on feed than on bleed and so a new ***feed flow/bleed flow balance*** condition can easily be achieved with the higher bleed purification flow resulting from the bias signal.

- This ***purification bias*** is desirable in that a higher clean-up rate can be set to speed up the heat transport clean-up activity (i.e. - complete the PHT inventory clean-up total exchange in 4 hours rather than 10 hours)

<u>Solid Mode Bleed Condenser Pressure Control - Analog</u>

- The reflux valve (CV11) is a ***fail-open*** control valve (air-to-close), but a ***direct acting*** pressure controller (PIC9) is required (as will be explained in a few sentences). If the pressure increases above the setpoint of 1.6 Mpa, then the control signal will increase to provide more reflux flow in an attempt to lower the bleed condenser pressure.

- This signal increase from PIC9 will be ***added*** to the feed signal from PIC5 and PIC6 so that the ***total feed signal*** is increased and the feed valves will close more to reduce the feed flow in compensation for the expected additional reflux flow (i.e. total inflow to the PHT of feed plus reflux remains ***relatively constant***).

- The output signal from PIC9 will also be ***subtracted*** from the pressure control signal from PIC5 and PIC6 to provide a ***decrease*** in control signal to reflux valve CV11 so that CV11 drives more open to ***increase the reflux flow*** to correct for the original pressure increase in the bleed condenser.

- A ***low limit*** function of 10 mA is applied to the PIC5 and PIC6 signals prior to being sent to the subtractor relay. This limiting will prevent large feed demands from PIC5 and PIC6 (i.e. very low signal values) from requesting correspondingly large reflux flows unless they are specifically asked for by PIC9 due to the bleed condenser pressure.

Solid Mode Feed and Bleed and Reflux Operation - Analog

- Assume that the PHT pressure and bleed condenser pressure are steady at their setpoints when the PHT pressure ***drops*** slightly.

- PIC5 and PIC6 will respond to the decrease in heat transport pressure with a decrease in control signal. The feed valves will drive more open and the bleed valves will drive more closed causing a net increase in the ***inventory input*** to the heat transport system.

- Now by this control response, the ***bleed flow*** to the bleed condenser has been ***decreased*** by the change in the control signal from PIC5 and PIC6 and so the bleed condenser pressure will begin to fall.

- At the same time, the control signal to the reflux valve, CV11 will be decreased since the PIC5 and PIC6 signal is lower, so a smaller signal is sent to CV11 - so reflux valve goes more open and reflux flow begins to increase (also helping to raise the PHT pressure back toward the setpoint).

- However, the bleed condenser pressure begins to drop away from the setpoint (due to higher reflux flow and lower bleed flow).

Solid Mode Feed and Bleed and Reflux Operation - Analog...continued

- Now PIC9 responds with a ***decrease*** in control signal, so that a smaller signal is subtracted from the PIC5 and PIC6 signal and so the reflux valve CV11 drives more closed - ***less reflux flow*** to help arrest the pressure drop in the bleed condenser.

- The revised PIC9 control signal decrease is also added to the PIC5 and PIC6 signals for feed control, so the feed is increased marginally to sustain the heat transport pressure with the lower reflux flow. The end result will be ***more feed*** with ***less bleed*** and ***less reflux*** allowing the pressure to stabilize in the heat transport system.

- Now as the heat transport system ***pressure begins to recover***, the heat transport pressure will start to rise so that PIC5 and PIC6 will respond with an increase in control signal which closes in the feed valve and opens the bleed valve to increase the net outflow from the heat transport system.

- The increase in PIC5 and PIC6 signals will close in the reflux valve a little to reduce the reflux flow (helping to correct the rising heat transport pressure problem).

- Now the increased bleed flow will begin to raise the bleed condenser pressure and so PIC9 will respond with an increase in control signal.

- This PIC9 signal is subtracted from the PIC5 and PIC6 signal to drive the ***reflux valve CV11 more open*** (more reflux to correct the bleed condenser pressure) and as well is added to the PIC5 and PIC6 signal to drive the ***feed valve more closed*** (to compensate for the increase in reflux flow).

- The end result will be ***more bleed flow*** and ***more reflux flow*** to balance the bleed condenser pressure, with ***less feed flow*** being supplied to the heat transport system.

Solid Mode Pressurizer Pressure Control - Analog

- In this mode of operation (with the pressurizer ***isolated*** from the main circuit), pressurizer pressure control is maintained by PIC3 driving the ***steam bleed valves*** and the ***heaters***.

- ***Steam bleed valves*** CV7 and CV8 are air-to-open valves and are controlled by PIC3 to correct for a pressurizer ***high pressure*** condition.

- PIC3 is a ***direct*** acting controller so that an increase in pressurizer pressure will cause an increase in control signal which drives CV7 and CV8 more open.

- The PIC3 control signal is also applied to the variable heater (with a suitable ***deadband*** between heater shut-off and steam valve opening) via an inverting I/I transducer.

- As the PIC3 control signal decreases, the inverting I/I will increase the control signal to the variable heater, increasing the heater output. Normally, the variable heater should reach some equilibrium value that just matches the ***ambient heat losses*** for that pressurizer (i.e. 35% signal).

- If the pressure in the pressurizer continues to drop, the PIC3 signal will decrease until a current alarm (PS3) is tripped to turn on the on/off heaters.

- Note that the heaters are protected by a ***low level interlock*** which will not allow power to be applied to the heaters unless the pressurizer level is above 0.9 meters.

<u>Considering Pressurizer Pressure in an *open loop response* manner:</u>

- (assuming we start with a low pressurizer pressure condition)

- If the pressurizer pressure is low, then PIC3 signal will be low and all of the on/off heaters will be energized with the variable heater at maximum.

- The steam bleed valves would be ***closed*** under these conditions.

- Now as the pressurizer pressure increases, the control signal from PIC3 will increase and eventually all of the on/off heaters will be de-energized (just before the variable heater signal begins to decrease from 100%).

- As the pressurizer pressure continues to increase, the PIC3 signal increases and the inverting I/I reduces the signal applied to the variable heater so that less energy is applied to the variable heater.

- Eventually, as the pressure rises, the PIC3 signal will increase such that the variable heater has zero signal applied (i.e. turned off).

- Now a ***deadband*** of approximately 1 mA is applied to the control signal to ensure that the effect of the variable heater being off is recognized before the steam bleed valves begin to open.

- If the pressure continues to rise, the PIC3 signal increases and the ***steam bleed valves*** (CV7 and CV8) begin to drive open (with all heaters de-energized).

- With no heat source and an increasing pressure sink (to the bleed condenser) the pressurizer pressure should begin to drop.

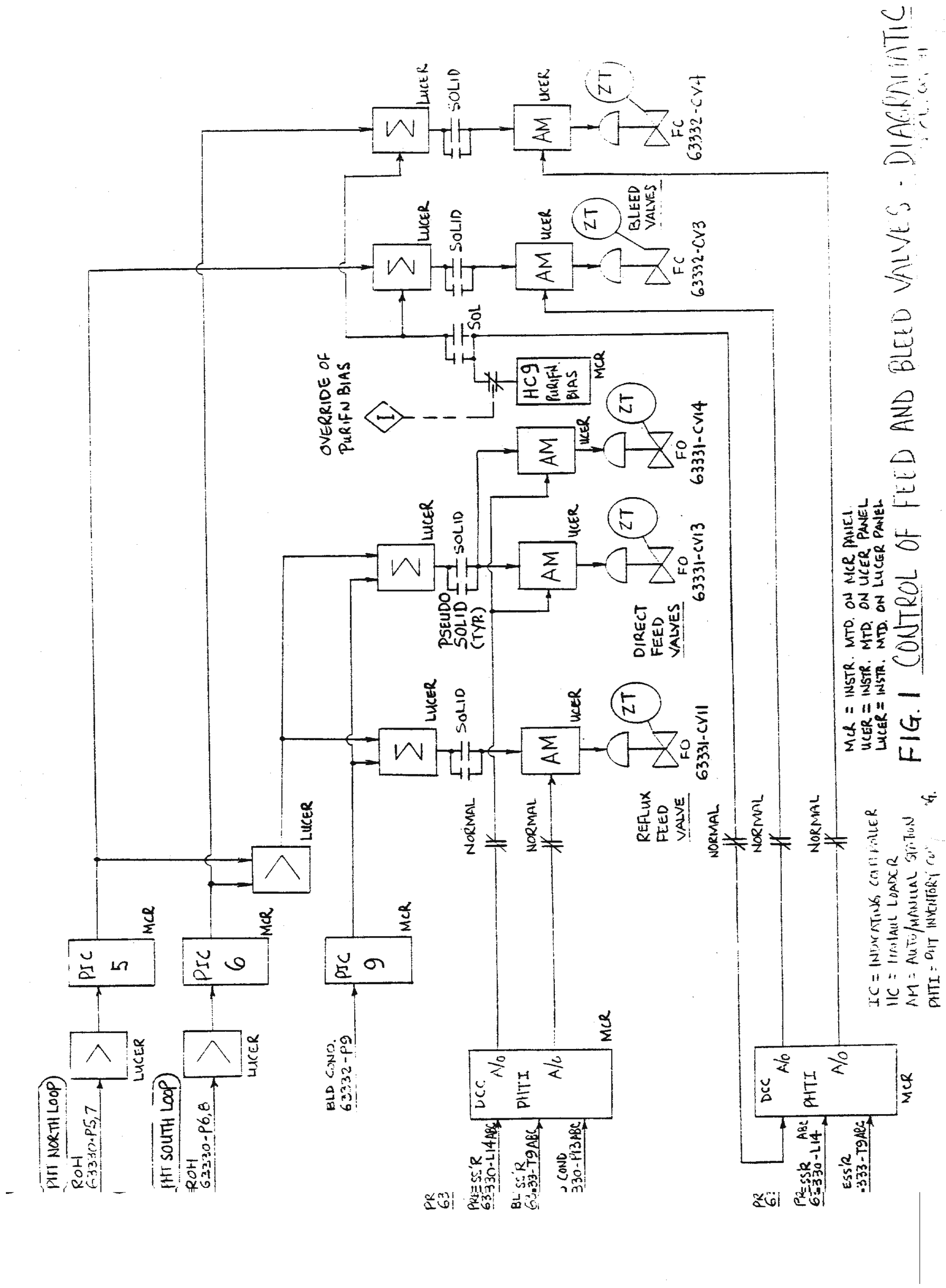


FIGURE #3 CONTROL OF FEED & BLEED VALVES

Bleed Condenser Pressure Control - Reflux Control by DCC

- The preferred bleed condenser pressure control is by ***reflux flow*** under DCC (P&IC Control program).

- The setpoint for the bleed condenser pressure control is ***1.6 Mpa***. Bleed Condenser DCC pressure control of reflux regulation is via CV11 as described previously in concert with the main circuit pressure control in ***solid mode*** or in concert with the pressurizer level control in ***normal mode***.

- That is to say, the request for reflux flow can be inhibited by a large bleed flow request in ***solid mode*** (i.e. heat transport pressure is too high) or by a high pressurizer level condition in ***normal mode*** (i.e. too much inventory). Otherwise, the bleed condenser pressure will be regulated by throttling CV11.

- The interfacing system importance of the bleed condenser pressure control must be emphasized. Changes applied to the ***reflux flow***, as a result of bleed condenser pressure disturbances - perhaps due to a pressurizer level problem - can change the ***total feed flow*** which can effect the ***pressurizer level*** which in turn can alter the ***bleed flow*** again which ultimately has an effect on the ***bleed condenser pressure*** again.

- The control tuning suggestion for bleed condenser pressure control would be to use a ***lower control gain*** and perhaps a slightly ***faster reset rate*** (i.e. ***decouple*** or detune the bleed condenser from the PHT effects) so that bleed condenser pressure problems are responded to in an over-damped (i.e. not in a cyclic) stable manner.

- This approach will allow an initial disturbance to be damped out and eliminated rather than to set up a continuous interacting loop performance of ***excitation*** and ***excitation response*** which can lead to jittery control at all times.

- Note that this has been a problem at some stations in the past contributing to the need for ***early replacement of the bleed condenser reflux U-tubes*** due to vibration/chaffing damage.

Bleed Condenser Spray Control - Back up, Analog Only

- If the bleed condenser pressure control was not successfully controlled by reflux control of CV11, the spray valve CV12 provides a ***back-up bleed condenser pressure control*** means.

- The spray fluid is the discharge (feed flow stream) from the pressurizing pumps and is approximately 54 C which is quite cold in comparison to the flashed saturated fluid at 204 C in the bleed condenser.

- Bleed condenser ***pressure control by spray flow*** is not as desirable as reflux flow since the spray flow places an extra, ***unnecessary inventory load*** on the IX columns as the spray fluid is already clean. As a result, spray control is reserved for use as a back-up control means.

- Spray valve CV12 is an ***air-to-open*** valve so that if the bleed condenser pressure rises above the setpoint, an increase in control signal is required to open CV12 more to provide increased spray cooling to reduce the pressure in the bleed condenser.

- PIC12 is therefore a ***direct*** acting controller (i.e. ***increasing*** measurement, ***increasing*** control signal).

- The setpoint for PIC12 is ***staggered*** or offset above that of the bleed condenser reflux pressure controller by about ***200 KPa***.

- If the reflux controller is unable to maintain the pressure at ***1.6 Mpa***, then as the pressure rises to ***1.8 Mpa***, the spray control will also begin to act.

- Usually, the spray control (which is very effective due to the 150 C temperature difference between the spray and bleed fluids), only needs to ***act for a short period*** of time in order to arrest the pressure increase and to usually allow control to be resumed again by reflux control at the lower pressure.

- The spray control is inhibited if the bleed condenser ***level is high*** (above 3.8 meters) to avoid forcing the bleed condenser from becoming ***solid*** (filled with fluid) because then it will be pressurized to 14 MPa by the feed pump discharge pressure.

Bleed Condenser Spray Control …..continued

- The spray control is also inhibited if the ***bleed condenser pressure is very high*** (above 5 Mpa) as the pressure control is obviously not working and the bleed condenser may well be close to (or returning from) being in the solid state (and there may be a bleed condenser level indication problem).

Bleed Condenser Level Control - Analog LIC12

- The bleed condenser level is controlled by ***outflow regulation*** by manipulating level control valves CV23 and CV24.

- These valves are the ***air-to-open*** style and so if the level rises above the setpoint, the control signal must increase so as to drive the valves more open (i.e. a ***direct*** action control is required for LIC12).

- The bleed condenser level is controlled at approximately 0.9 meters level and there is considerable margin for operation (for example, we had mentioned that a high level inhibit on spray control is applied at levels above 3.8 meters).

- Consequently, it makes sense to take a more relaxed control approach with the bleed condenser level so that load changes applied upstream from the bleed cooler heat exchanger are more easily accommodated.

- For example, assume that the bleed flow suddenly increases from 10Kg/sec to 40 Kg/sec as the inflow to the bleed condenser (say due to ***testing the level control of the pressurizer***). If we are very strict on the level control strategy (i.e. tight tuning) then the change in level will very quickly be passed on to the bleed condenser outflow in order to ***try to keep the level at 0.9 meters*** - this means that the near step change in 30 Kg/s of hot bleed will be passed on as a ***step load change to the bleed cooler heat exchanger*** and it may be difficult to maintain temperature limits during such load changes.

- It would be a superior approach to allow the bleed condenser inventory to accumulate somewhat and to ***gradually ramp up the outflow rate*** as the bleed condenser level rises – so we apply a more gradual change to the heat exchanger.

Bleed Condenser Level Control - Analog LIC12….continued

- To do this, we can again select a relatively ***wide control proportional band*** (i.e. low control gain) with a ***moderate reset rate***. The outflow via CV23 and CV24 will ramp up from 10 Kg/s to 40 Kg/sec over several seconds time (as the bleed condenser level rises to integrate the inflow/outflow differential).

- By subjecting the bleed cooler heat exchanger to a ***ramped load change*** rather than a step load change, we should have more success at maintaining tighter temperature control with little risk of high temperature spikes (note we are solving one control parameter problem (***temperature***) by considering a separate control parameter (***level***)).

- This response will be described in more detail later on in this lesson - but for now it is sufficient to recognize that we can reduce the rate of disturbance changes (where they can be accommodated by existing system capacitances) to facilitate the corresponding downstream control corrections.

PRIMARY HEAT TRANSPORT - PRESSURE and INVENTORY CONTROL

Bleed Cooler Temperature Controller - Analog TIC15

- The bleed cooler ***heat exchanger effluent temperature*** is controlled by temperature control valves TCV36 and TCV37 which admit flows from the recirculated cooling water (RCW) system.

- TCV36 (the ***small valve***) is an air-to-close valve while TCV37 (***the large valve***) is an air-to-open valve. In this way, TCV36 will fail open and TCV37 will fail closed upon loss of instrument air supply.

- The controller for this temperature application, TIC15, is specified with a ***reverse control action*** (***increase*** in measurement, ***decrease*** in control signal). TIC15 should also be specified as a three term controller to provide ***proportional***, ***reset*** and ***derivative control*** response to try to maintain as tight a control as possible on the temperature deviation.

- The TIC15 control signal is ***split ranged*** to the two temperature control valves so that the large valve will just start to open once the small valve has reached 55% open.

- The control signal from TIC15 is applied to a ***direct calibrated*** I/I transducer for TCV36 and a ***reverse calibrated*** I/I transducer for TCV37.

- The valve opening strategy allows time for the large valve to become effective (i.e. provide significant flow) - remember that a control valve will usually follow an ‘S’ curve for general performance with little flow change as the valve first opens (say to about 20% open - particularly if the opening valve is in parallel with an already open valve), then the valve will perform quite effectively from 20 - 80% open followed by a lower flow versus control valve opening characteristic over the last 20% of the valve stroke.

- Originally, this ***split range control*** had been specified with the large valve (TCV37) opening once the small valve reached 100% open. Of course, this approach lead to considerable ***delays in obtaining the necessary additional cooling flow*** from the large valve resulting in large temperature overshoots following load disturbances.

Bleed Cooler Temperature Controller…..continued

- As a result of the poor temperature control, operators repeatedly lowered the temperature setpoint by more than 10 C ***to avoid the high temperature conditions*** (until the control condition could be corrected). Notice that this is an energy wasting situation in that whatever bleed flow has been selected (usually a minimum of 10 Kg/s) must be warmed the extra 10 C at all times upon reinjection into the main circuit.

- As the bleed effluent temperature increases, the control signal from TIC15 decreases. This decrease in control signal is applied to TCV36 (air-to-close) and so the small TCV36 is driven more open.

- If the temperature continues to increase, then the control signal from TIC15 decreases further and eventually drives, via the reverse calibrated I/I transducer, the large TCV37 (air-to-open) open once the signal exceeds the 55% open value for TCV36.

- For a control performance example, assume that the temperature is held at the ***setpoint of 54 C*** with the ***small temperature control valve about 49% open*** which cools a steady bleed condenser outflow of 10 Kg/s (matching the bleed flow from the HTS into the bleed condenser so we have a mass balance condition).

- If the bleed condenser outflow now began to increase (say at an incremental rate of one additional Kg/sec), then TIC15 will respond by decreasing its control signal and driving TCV36 more open.

- TCV36 need only increase a few percent (6%) before the large valve, TCV37, starts to drive open. TCV37 is a much larger capacity valve and very quickly is able to match the cooling capability to the increased ramping heat exchanger load with a peak temperature rise (overshoot) of perhaps 2 C above the setpoint. Note also that TCV36 is still quite effective at providing cooling flow under these conditions.

- These ***control changes*** combined to produce a very effective temperature control loop performance:
  - include derivative mode,
  - tighter TIC tuning (narrower PB),
  - earlier split range opening of TCV37 (more overlap on split range),
  - reducing the magnitude of the applied disturbance (ramp rather than step).

Bleed Cooler Temperature Controller…….continued

- One interesting effect that was noted by the operators for this system during early unit operation was a ***systematic temperature cycle*** for the bleed cooler effluent temperature and this problem was attributed to the tuning of TIC15.

- However, it was later found that this ***temperature cycle*** was actually introduced by problems in the recirculated cooling water system (RCW).

- The temperature cycle was originated in the RCW (to which not very much attention had been paid) and then this disturbance was passed to the bleed cooler by the RCW flow through TCV36 and TCV37.

- The RCW ***flow*** through TCV36 and TCV37 was stable but the ***temperature*** of the RCW was cyclic.

- The lesson to be learned here is to carefully identify all control system ***interfaces*** and clearly establish the ***dynamic performance*** and effects for each interface.

- Many times, a sophisticated control scheme's performance can be unintentionally degraded because of the poor performance of an interfaced system (which may be treated as a trivial system with little importance!).

- Usually, these interfaces can be found by establishing an equilibrium control condition and then setting the control valve to ***manual*** so that the control signal and hence the control valve is fixed.

- Then look to see if the ***controlled parameter is still cyclic*** even though the ***manipulated parameter has been held constant*** - this is usually the hint that some ***external system*** or influence is effecting the control loop performance in an unanticipated manner which must then be explored further in order to apply the necessary remedial action.

Temperature Override of Bleed Condenser Level Control - Analog TIC16

- As mentioned earlier,it is important to not apply a high temperature to the IX resin, otherwise chlorides can be released from the resin to the HTS and these chloride ions can promote ***stress corrosion cracking*** (SCC) in the HTS.

- This condition then is avoided by the use of a ***high temperature override*** on the bleed cooler heat exchanger outflow.

- A second bleed effluent temperature controller, TIC16, monitors the bleed cooler outlet temperature and provides a back-up means of limiting high temperatures. TIC16 is a ***reverse*** acting, ***straight proportional*** controller with a setpoint of 65 C.

- As long as the bleed effluent temperature is below 60 C, the control signal from TIC16 will have no effect (i.e. it is at maximum). The lowest control signal from the ***direct acting*** controller LIC12 and the ***reverse acting*** TIC16 are selected by a low signal selector for application to the level control valves CV23 and CV24.

- Normally, with the effluent temperature at 54 C (well below 65 C), the ***control signal from TIC16 will be maximum*** (since TIC16 is reverse acting).

- This means that the control signal from LIC12 (i.e. some intermediate control signal value - say 25%) will be selected for control of CV23 and CV24 and the level control of the bleed condenser will be as described previously.

- However, as the bleed condenser level rises (***forcing LIC12 output to increase***), the outflow through the bleed cooler heat exchanger becomes higher forcing a higher outlet temperature.

- As the temperature rises above 60 C (since TIC15 is unable to effectively cool the higher bleed flow load), the control signal from TIC16 will begin to ***decrease*** (***since TIC16 is reverse acting***) and at some point the signal from TIC16 (which is decreasing as the temperature rises) will be lower than the signal from LIC12 (which is ***increasing*** as the bleed condenser level rises) and so ***TIC16 will assume control of the level control valves*** (CV23 and CV24).

Temperature Override of Bleed Condenser Level Control - Analog TIC16...continued

- In this way, ***temperature control has overridden the level control***. TIC16 will close-in the level control valves as the temperature rises so that the heat load for the tube side of the heat exchanger has been reduced to ***minimum*** while the cooling flow to the shell side (by TIC15) is ***maximum***.

- The temperature rise should be arrested and the temperature will eventually drop back down below 60 C and normal level control of the bleed condenser can be resumed.

- If the bleed cooler effluent temperature had increased to 71 C (TIC16 apparently unable to control the temperature excursion), then the level valves CV23 and CV24 are tripped closed and the purification bleed flow bias is removed and can not be re-applied until the temperature drops below 54 C.

PHT P&IC Control Program Description - Normal Mode Pressure Control

- In this mode of operation the pressurizer is ***connected*** to the main circuit and pressure control is maintained by the PHT program operating the ***heaters (to raise HTS pressure)*** or driving the ***steam bleed valves (to lower the HTS pressure).***

- The selected ***variable heater*** (Heater #1 or #2) is controlled proportionally by the DCC to correct for reactor outlet header pressures (ROH) below the setpoint of 9.9 Mpa.

- The pressure gain for the variable heater is 8.75 which means that if the pressure drops to 9.785 MPa, the variable heater will be at maximum.

- If the pressure rises above 9.9 MPa, the variable heater signal will be zero. If the pressure is at the setpoint (9.9 MPa) , then the error is zero and the proportional control term is the ***bias term***.

- The variable heater signal will increase if the ***pressure*** decreases below the ROH pressure setpoint or if the pressurizer inventory ***temperature*** decreases below the computed pressurizer saturation temperature setpoint. This is an anticipatory control strategy in that we know if the pressurizer inventory is below saturation temperature, that we will have a negative pressure excursion soon.

- The bias value is ***tuneable*** temperature component parameter so that ***ambient losses*** can be compensated for. The ambient losses required approximately 35% variable heater signal to maintain the ROH pressure at 9.9 MPa.

- The variable heater will be controlled by the DCC to maintain the ROH ***pressure at 9.9 MPa*** with the pressurizer ***temperature at 309.6 C***.

- The on/off heaters (Heaters #3 - #6, and as selected either #1 or #2) will be activated if the ROH pressure drops below 9.78 MPa. The on/off heaters will remain on until the ROH pressure rises above 9.817 MPa. At this pressure, the variable heater would be approximately 73% on and should be able to restore the pressure to 9.9 Mpa (i.e. exceeds the ambient losses).

- The on/off heaters control logic also have a ***temperature component*** that will turn the on/off heaters on if the pressurizer temperature drops more than ***3.5 C*** below the computed pressurizer saturation temperature.

- The on/off heaters will remain on ***due to temperature*** until the temperature rises to ***within 2.8 C*** of the computed saturation temperature setpoint.

PHT P&IC Control Program Description - Normal Mode Pressure Control

- If the temperature should rise above 9.9 MPa while the on/off heaters are on due to the low pressurizer temperature, the on/off heaters will be ***tripped off by the positive ROH pressure error signal*** (i.e. pressure greater than 9.9 Mpa overrides the low temperature condition).

- As mentioned previously, a low pressurizer level override is provided to protect all the pressurize heaters. If the pressurizer level is below 0.9 meters, then all heaters will be tripped off and power can not be applied to the heaters until the pressurizer level rises above 0.9 meters.

- The steam bleed valves CV7 and CV8 are controlled by the DCC to correct for high reactor outlet header pressures.

- A deadband of 0.03 MPa above the setpoint of 9.9 MPa must be exceeded before the steam bleed valves will begin to drive open.

- A control gain of 5.5 is provided so that CV7 and CV8 will drive from ***closed to open*** as the reactor outlet header (ROH) pressure changes from 9.93 to 10.11 MPa.

Normal Mode Pressurizer Pressure & Temperature DCC Signal Selection

- ***Triplicated*** narrow range pressure transmitters are provided for each of the four ROHs.

- If all three pressure transmitter signals for that header are rational, the ***median*** signal is selected as the representative pressure signal for that header.

- The ***highest*** of the four ROH median pressure signals is then selected for use in the pressure error calculations.

- If one of the ROH triplicated pressure transmitter signals is rational but ***drifted*** (i.e. differs from the other two ROH pressure signals by more than 0.06 MPa), that signal is alarmed and rejected from use by the control program.

- Under these conditions (i.e. one drifted transmitter), the ***higher of the remaining two pressure transmitter signals*** for that header is selected as the representative pressure signal for that header.

- If all of the triplicated pressure transmitters for a header are drifted (i.e. not validated but are rational) the condition is annunciated and the ***highest pressure*** signal is selected to represent the pressure in that header.

Normal Mode Pressurizer Pressure & Temperature DCC Signal Selection...continued

- If one of the header pressure transmitter signals is irrational, the irrational signal is alarmed and rejected.
- The ***higher*** of the two rational signals is selected to represent the header pressure.
- If two pressure transmitter signals for a header are irrational, the condition is annunciated and the remaining rational signal is selected to represent the pressure in that header.
- If all three ***narrow range pressure transmitters*** for a header are irrational, the ***wide range pressure transmitter*** signal for that header is selected to represent the pressure in that header.
- If all three narrow range pressure transmitters and the wide range pressure transmitter for one header are irrational, then no pressure signal exists for that header, and the P&IC control program will ***fail-off***.
- The pressurizer temperature signals are processed in an identical manner to the pressure signals.
- The drift range for the pressurizer temperature signals is 3.5 C.
- If the triplicated pressurizer temperature narrow range and the wide range temperature backup signals are all irrational, the control program will ***fail-off***.

Normal Mode pressurizer Level DCC Control

- In this mode of operation, the pressurizer is connected to the main circuit and the pressurizer level is controlled by the PHT program driving the ***feed valves*** (CV13 and CV14) and the ***bleed valves*** (CV3 and CV4).

- As well, the operation of the reflux valve (CV11) must also be considered as the reflux flow contributes to the ***net inflow*** to the HTS.

- If the pressurizer level is low, the DCC will tend to drive the feed valves more open and the bleed valves more closed to restore the level back toward the setpoint in a proportional only fashion.

Pressurizer Level Setpoint Reactor Power Compensation

- The pressurizer ***level setpoint*** (for four pump operation) is ramped from 3.64 meters (at ZPH) to 6.43 meters (at 100%FP) to compensate for HTS main circuit ***inventory expansion (swell) over the power range*** operation.

- For example, if the power is increased from some steady state value, the inventory would swell causing a level increase in the pressurizer.

- However, if the pressurizer level setpoint ***correctly characterizes*** this level versus power change, then the setpoint will rise as the level is changing so that ***no level error*** is recognized.

- This is a very desirable achievement since power changes do not then require any changes to the feed and bleed equilibrium condition in order to maintain the correct pressurizer level.

Normal Mode pressurizer Level DCC Control..continued

- Note that if the level curve is incorrectly characterized, that a considerable inventory transfer must take place. If the setpoint is raised too quickly, ***unnecessary feed flow*** is requested to try to achieve the new higher level setpoint and then once the main circuit inventory actually expands, this additional inventory must be bled back out via the bleed valves to again lower the pressurizer level to the setpoint level.

- The reactor power value from the reactor regulating control program (i.e. PLIN = reactor linear power value) is filtered and then used to calculate the pressurizer level setpoint. The filter parameters are tunable to allow the implementation of correct pressurizer level characterization.

- However, if the PLIN value is ***irrational*** (i.e. beyond design specification limits) or ***stale*** (i.e. not updated within the expected program execution iteration time), then a ***default setpoint*** is substituted for the calculated value.

- The default setpoint is 6.43 meters (the normal 100%FP value where the plant is normally expected to operate) but if RRS is turned-off on the master DCC at low power, the pressurizer level would suddenly be revised to 6.43 meters requiring an extensive inventory transfer by feed flow into the main circuit (requiring operator intervention to restore the correct level).

Pressurizer Level Setpoint ROH Pressure Compensation

- If the ***ROH pressure*** increased above the pressurizer pressure, the hydraulic transfer of inventory from the PHT to the pressurizer would cause the pressurizer level to rise.

- An ROH ***pressure compensation term*** is applied to the pressurizer level setpoint. In such cases, the pressurizer ***level setpoint*** would have an ***inventory transfer term*** added to it so that ***both the setpoint and the level would increase together*** so as to not require any interim corrective feed and bleed.

- Note that if this was one small cycle that as the ROH pressure increased, the transfer of inventory to the pressurizer would begin. At the same time, the pressurizer level setpoint is increased as a function of the ROH pressure change so that the pressurizer level and setpoint change together with ***no change in level error*** occurring.

- Then as the ROH pressure subsides, the transfer of inventory back to the main circuit begins. The lower ROH pressure causes a lower pressurizer level setpoint and so the setpoint follows the level down with the ***level error again unchanged*** and we have not complicated the original disturbance with unnecessary feed and bleed corrections that would then, in-turn, have to be compensated for.

Pressurizer Level Setpoint Steam Generator Pressure Compensation

- Similarly, a ***steam generator pressure compensation term*** is provided for the pressurizer level setpoint.

- This feedforward factor will shift the ***pressurizer level setpoint*** slightly as a function of the change in steam generator pressure.

- For example, if the steam generator pressure increased by 50 KPa, the HTS inventory would ***swell slightly*** (due to the higher heat sink temperature causing a higher ROH temperature and in turn a higher pressure). This swell would cause the ***pressurizer level to begin to rise***.

- The steam generator pressure compensation term would add a small amount to the pressurizer level setpoint so that the setpoint would start to rise as soon as the steam generator pressure changes to keep the level error term effectively zero and will be very close to the actual level change caused so that no unnecessary bleed flow would be requested.

- These ***setpoint compensation terms*** (reactor power, ROH pressure, SG pressure) are examples of trying to ***eliminate small disturbances*** from having a control effect so that the cumulative control response is ***more stable*** with a minimum of unnecessary manipulated variable changes being applied.

Rapid Power Increase Effects on the Pressurizer

- It should be noted that an increase in pressurizer level will cause a ***rapid increase in pressurizer pressure*** as the steam above the pressurizer liquid is compressed.

- The pressurizer level changes should be made ***relatively slowly*** and in ***small increments*** to avoid overpressure conditions.

- At the same time, inventory transfers to the pressurizer can cause the ***temperature*** at the base of the pressurizer to decrease as the colder ROH fluid is forced into the pressurizer (assuming operations below 100%FP)., likely requiring the operation of the on/off heaters under temperature control.

- Power increases should be made over a series of incremental power steps (say 10%FP) with short pauses between maneuvers to allow time for the pressurizer (and other systems) to re-achieve thermal equilibrium and for the operator to assess the key indicators so as to confirm the unit status.

Pressurizer Level Curves for 2 & 3 Pump Operation

- If a heat transport pump trips, the reactor is immediately stepped-back to 60%FP by dropping the mechanical control absorbers (MCA) partially into core.

- Since the total heat transport flow rate will be reduced by the loss of a main pump, the ***temperature rise across the core*** should be expected to increase resulting in a net inventory swell.

- To compensate for the different inventory swell and possible ROH boiling for 3 or 2 pump operations, the pressurizer level setpoint is modified to ***request a higher level value*** than would be the case for four pump operation.

- The 3 pump operation would request the pressurizer level setpoint to be 6.43 meters at and above 75%FP (rather than to 100%FP). The pressurizer level setpoint is calculated from 3.64 meters (ZPH) to 5.45 meters (@50%FP) and then more steeply to 6.43 meters (@ 75%FP) to accommodate the expected HTS swell due to the higher outlet temperatures.

- For example, if the pressurizer level was at 6.43 meters at 100%FP and an HTS pump tripped , the reactor would step-back to 60%FP.

- The pressurizer level setpoint would remain at 6.43 meters until the filtered PLIN value decreased below 75%FP. This may require slight feeding during this interval (which would be a safe response to maintain an adequate pressure margin to saturation).

- The pressurizer level setpoint would then be ramped down from 6.43 meters to 5.84 meters as PLIN decreases to 60%FP.

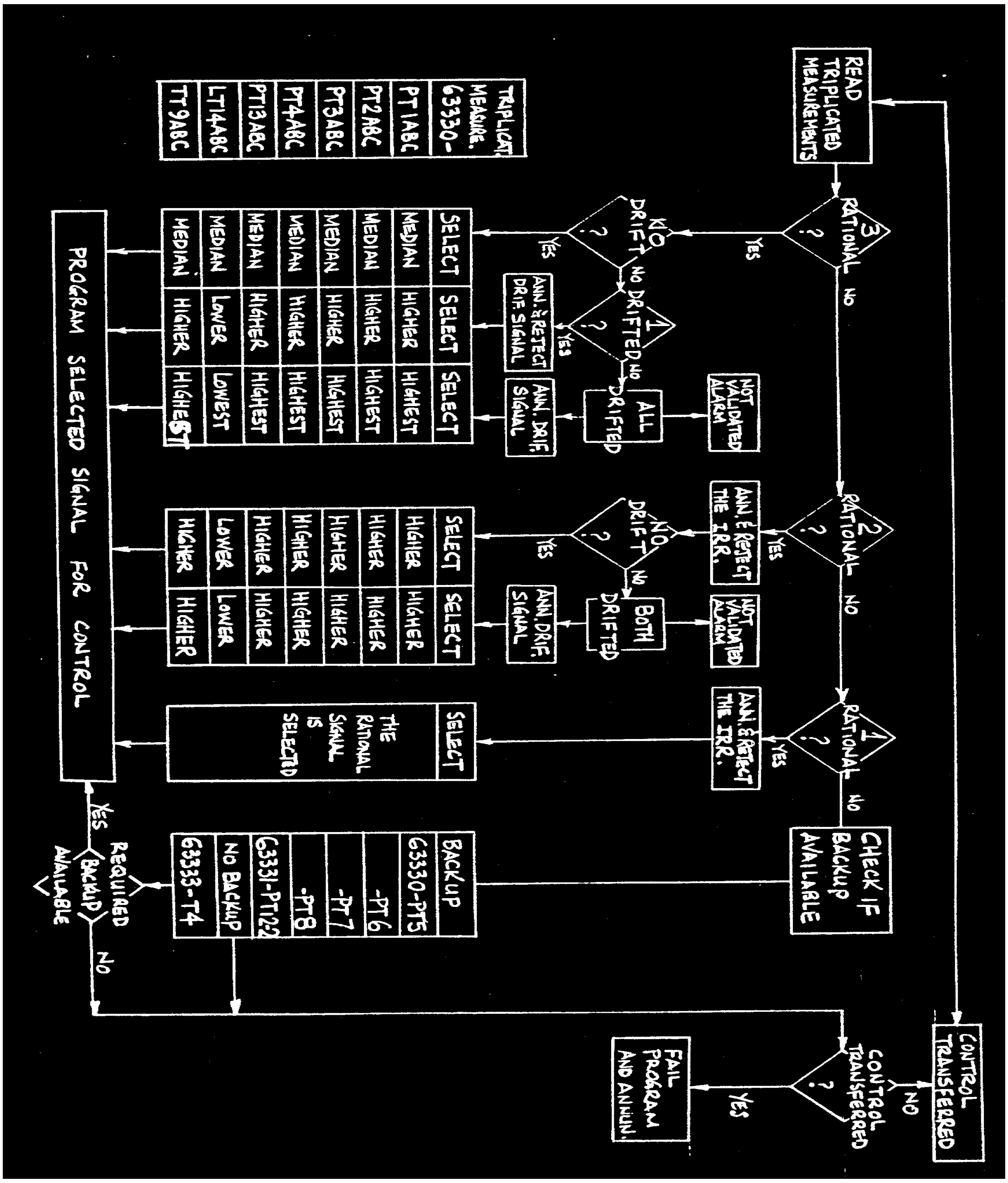
- By this time, the higher temperatures may have enough effect so that the higher pressurizer level setpoint is correct and no further feed or bleed corrections would be required.

- But even if the level setpoint had been poorly characterized, there is not much inventory that must be transferred (less than 0.6 meters) and so the HTS pressure will not be lowered due to excessive, sustained controlled bleed flows.

Normal Mode Pressurizer Level Control DCC Signal Selection

- Triplicated level transmitters LT-14A/B/C are provided for the pressurizer.
- If all three level transmitters are rational, the ***median*** level signal is selected for control.
- If one of the triplicated pressurizer level transmitters is ***drifted***, the condition is annunciated and that signal is rejected. The ***lowest*** of the remaining undrifted level signals is then selected for pressurizer level control.
- The ***drift range*** for the pressurizer level transmitters is 0.08 meters.
- If all of the triplicated level transmitters are drifted, they are alarmed as ***not validated*** and the ***lowest*** of the three rational signals is selected for pressurizer level control purposes.
- If one of the pressurizer triplicated level transmitter signals is irrational, that condition is annunciated and the ***irrational signal is rejected***. The ***lowest*** of the remaining rational signals is selected for pressurizer level control purposes.
- If two level transmitter signals are irrational, the irrational transmitter signals are rejected and annunciated and the ***remaining rational level signal*** is selected for pressurizer level control purposes.
- If all three pressurizer level transmitter signals are ***irrational***, no indication of pressurizer level exists and so the P&IC program will ***fail-off.***

FIGURE #4 P&IC SIGNAL SELECTION LOGIC



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P&IC Normal Mode Bleed Condenser Control via DCC

- The PHT control program will regulate the reflux valve CV11 to control the reflux flow to maintain the bleed condenser pressure at ***1.62 Mpa***.
- If the pressure in the bleed condenser increased , say due to an increase in bleed flow, the reflux valve would be driven more open causing the condenser pressure to drop back down toward the setpoint.
- The control of CV11 can be inhibited by the pressurizer level control - that is pressurizer ***level control can override*** the reflux pressure control decision so that bleed condenser problems do not initiate pressurizer level problems and possibly PHT pressure problems.
- If the pressurizer level is above the setpoint and the feed flow is quite low due to a low bleed bias condition, then the pressurizer does not require additional feed input to the PHT and so the reflux flow is blocked.
- In this case, the pressure in the bleed condenser would continue to rise until the ***spray control setpoint*** was reached and the back-up spray control began to take corrective control action.
- Normal bleed condenser reflux control can be resumed ***by increasing the purification bias slightly*** so that the pressurizer level drops below the setpoint and feed flow increases to match the increase in bleed flow. Now reflux will not be restricted by the pressurizer level control condition.

Bleed Condenser Pressure Control Signal Selection

- ***Triplicated*** bleed condenser pressure transmitters PT-13A/B/C are provided.
- If all three pressure transmitter signals are ***rational***, the ***median*** signal is selected for bleed condenser pressure control.
- If one of the triplicated bleed condenser pressure transmitters is ***drifted***, the condition is annunciated and that signal is rejected. The highest of the remaining ***undrifted*** pressure signals is then selected for bleed condenser pressure control.
- The drift range for the bleed condenser pressure transmitters is 0.02 MPa.
- If all of the triplicated pressure transmitters are drifted, they are alarmed as ***not validated*** and the ***highest*** of the three rational signals is selected for bleed condenser pressure control purposes.
- If one of the triplicated pressure transmitter signals is ***irrational***, that condition is annunciated and the irrational signal is ***rejected***. The ***highest*** of the remaining rational signals is selected for bleed condenser pressure control purposes.
- If two pressure transmitter signals are irrational, the irrational transmitter signals are rejected and annunciated and the ***remaining rational pressure signal*** is selected for bleed condenser pressure control purposes.
- If all three pressure transmitter signals are irrational, the back-up pressure transmitter (PT-12-2) is selected for bleed condenser pressure control purposes and the program can continue to operate.
- If all of the PT-13A/B/C and PT-12-2 transmitter signals are ***irrational,*** no indication of bleed condenser pressure exists and so the P&IC control program will ***fail-off.***

PHT Control Program Failure Conditions

- The following conditions summarize those cases which would result in the P&IC control program failing-off:

1. If all of the ***triplicated ROH pressure transmitters*** and the ***wide range back-up*** pressure transmitter for one header are ***irrational***.

2. If all the ***triplicated pressurizer temperature transmitters*** and ***backup temperature transmitter*** signals are ***irrational***.

3. If ***all triplicated bleed condenser pressure transmitters*** (PT-13A/B/C) and the ***bleed condenser back-up pressure transmitter*** (PT-12-2) signals are ***irrational***

4. If ***all triplicated pressurizer level transmitters*** (LT-14A/B/C) signals are *Irrational*

5. The ***analog output (AO) failures for both feed valves*** (CV13 and CV14) or ***both bleed valves*** (CV3 and CV4).

6. The ***analog output (AO) failures for both steam bleed valves*** (CV7 and CV8) or ***AO failures on both variable heaters*** (HTR #1 and HTR#2)

Automatic PHT Bleed Bias Removal

- The PHT ***purification bias is removed*** (by open circuiting the hand controller HC9 output circuit) automatically under the following conditions:

1. High bleed cooler outlet purification temperature (greater than 71 C)

2. Dual PHT Control program Loss (i.e. transfer to pseudo-solid mode)

3. Receipt of ECC H_2O injection valves opening signal

4. High D_2O storage tank level (level greater than 92%)

5. Loss of Class IV electric power supply

<u>P&IC Control Program Assignment</u>

1. Sketch and label a ***simple block diagram*** to show the relative control interactions and exchanges for the Heat Transport System, the Pressurizer, and the Bleed Condenser. Show how a minor disturbance in one of these systems could develop a positive feedback contribution so that all three systems become continuously cyclic.
What is one control technique that can be used to decrease this sort of resultant cyclic performance?

2. How is the feed & bleed control system designed so that feed corrections (to increase the heat transport pressure) can always ***override the bleed action*** (which attempts to lower the heat transport pressure). Why is this important from a safety persepective?

3. Explain briefly how the control logic for the pressurizer level and the bleed condenser pressure reflux control are combined to integrate and limit the reflux flow effect for the pressurizer level.

4. Make an illustrative sketch (simple line diagram) for a control signal (0-100% or 4-20 Ma) that could be used to operate the Variable Heater, the on/off heaters, and the steam bleed valves. Show and explain any necessary interlocks, deadbands, or overlaps that could be suggested for optimum control.

5. Why is the control of reflux flow preferable to spray control as the principle means for pressure control in the bleed condenser? What are some limitations or cautions that should be considered when using spray pressure control (i.e. any restrictions on the use of spray control and why)?

6. Explain a good control strategy for integrating a ***small and a large*** temperature control valve control so that the small valve can adequately handle low heat load conditions but the larger valve can quickly be brought into service as needed. What control modes should be specified for the control algorithm for this application?

7. What general signal quality check and selection method would you propose for a control application which has multiple signal inputs for a common parameter? Make a labelled logic diagram flow chart to illustrate your proposed logic.

8. What general control technique can be used to help stabilize a control application in which small, relatively unimportant perturbations are known to occur quite often and once applied these small upsets result in significant control response and cyclic recovery prior to resumed stabilization. Give examples and an explanation based on the pressurizer level control strategy.

P&IC Control Program Assignment....continued

9. Why is it important to shift the curve for the Pressurizer Level Setpoint if one of the main heat transport pumps should be tripped? Explain the rationale and make a sketch to show the approximate setpoint level curve for 3 pump and 4 pump operation to help with your answer.

10. Five conditions that would initiate automatic removal of purification bias were listed in the lecture notes. Review each of these conditions and provide a general perfromance requirement that would require the bias removal (i.e. briefly assess each condition and state the general reason why bleed purification bias should be removed in that case. then summarize your findings to state a general requirement).

11. Review the six program failure conditions presented in this lecture. In each case, identify and state the general reason why the program execution should be terminated.
Do you think that this large program could be reorganized so that individual sections could be failed while allowing other sections to continue to execute - provide an example to justify your answer (for a positive or a negative answer).