Reactor, Boilers & Auxiliaries - Course 233

HEAT TRANSPORT PURIFICATION

I. PURPOSE OF SYSTEM

The functions of the HT purification system are to:

1. Minimize the concentration of soluble (ionic) impurities. Removal of soluble ionic impurities, via IX resin, reduces;

   (a) radiation fields around HT system equipment, because these impurities become activated on passing through the core.

   (b) coolant radiolysis and hence dissolved O_2 concentration, which contributes to system corrosion and hence to piping wastage, increased activity transport and activity buildup.

   (c) the concentration of soluble fission products in the coolant. In particular I-131 is removed by the HT IX resin. I-131 is a critical isotope in case of an HT coolant escape to the environment. Specifically, the AECB sets a maximum I-131 concentration in the HT system above which the unit must be shut down and cooled down. For PNGS-A, this concentration is 1000 Ci/unit as specified in Station Operating Policies and Principles. Before this concentration is reached however, specific effort is made (above 400 Ci for PNGS-A) to reduce the I-131 by:

   - maximizing purification flow

   - locating and removing failed fuel.

   In addition, reactor power is maintained steady so as not to increase further the I-131 concentration by placing extra thermal stresses on the fuel.

   Other soluble fission products will also be picked up by purification. However noble gases such as Xe and Kr will not be removed by purification.

2. Remove particulate (insoluble) impurities. Particulate removal, via filters, reduces radiation fields around HT equipment. Particulates become activated on passing through the core and subsequently plate out in flow restricted areas, creating radiation hazards especially significant during maintenance. Deposition of crud on heat transfer surfaces, instrumentation and in pump glands will also be minimized by crud removal. This is particularly important in the HT system where 'crud bursts' may occur due to power/pH/temperature/pressure/H_2 concentration changes, which result in the release and redistribution of activated corrosion products throughout the system.

3. Control coolant pH to about 10. At pH $\sim$10, HT corrosion is minimized in system components (Zircaloy pressure tubes; carbon steel piping; monel, inconel or incoloy boiler tubes). Carbon steel is mainly the reason for the pH of 10 as:

   (a) the formation and maintaining of the magnetite layer on the steel is optimized, and

   (b) pH $\sim$10 is good compromise between caustic embrittlement by OH^- and acid attack by H^+.

   The consequences of increased system corrosion are HT piping wastage and increased activity build up in the system.

II. CHEMICAL PARAMETERS CONTROLLED BY PURIFICATION

To illustrate typical values of the specific chemical parameters which are controlled by purification, Table 1 gives a chemical analysis for a unit at Pickering A.

(i) pH

The pH is kept $\sim$10 by the use of Li^+ OD^- type IX resin to maintain a lithium concentration of $\sim$1 mg Li/kg D_2O. The resin will automatically tend to maintain the pH in the desired range. Larger variations outside the desired range can be controlled by the addition of LiOD solution to the HT D_2O or by installing and using D^+ OD^- resin. These techniques, respectively, will increase the Li^+ concentration (and pH) and decrease the Li^+ concentration (and pH). Out of specification operation of the pH will lead to increased system corrosion.

TABLE 1

CHEMICAL ANALYSES FOR PICKERING NGS-A

(September 26, 1973)

Heat Transport System	Unit 1	Unit 2	Unit 3	Unit 4
pH	10.5	10.5	10.7	10.7
Conductivity (mS/m)	2.7	2.5	2.7	2.8
Lithium (mg/kg)	1.7	1.4	1.4	1.2
Chlorides (mg/kg)	<0.1	<0.1	<0.1	<0.1
Iodine-131 (μCi/kg)	2.2	34.1	60.5	16.2
D_2O Weight %	97.8	98.2	98.0	98.3
Dissolved D_2 (cc/kg)	17.2	22.1	15.4	21.3
Dissolved O_2 (μg/kg)	<4	<4	<4	<4
Tritium (GBq/kg)	12	12	12	5.5
Tritium (Ci/kg)	0.33	0.33	0.33	0.15

(ii) Conductivity

The conductivity is higher than in the moderator due mainly to the presence of Li^+ ions for the high pH value required for corrosion control (see Table 1). The conductivity is kept below a specified operating limit by the use of the IX resin. Conductivity is a measure of the concentration of soluble ions and the consequences of too high a conductivity are therefore increased fields and increased radiolysis (see section I.1 above.)

(iii) Chloride Concentration and Fluoride Concentration.

These impurities are potentially from the same sources as mentioned for moderator D_2O and are also undesirable for the same reasons. As the HT system operates at high pressure however, corrosive damage is potentially more significant, and as a result, the upper limit of these parameters is usually specified in Station Operating Policies and Principles. The chloride and fluoride concentrations are kept below the maximum operating limit by the use of the HT IX resin, which removes the chloride and fluoride ions.

III. SYSTEM DESCRIPTION

The major purification loop is effectively a bypass flow of the main circulating system and is incorporated into the feed and bleed circuit flow.

The feed and bleed components are designed specifically to supply the required purification system conditions of temperature, pressure and flow. Hence the system is sometimes called the bleed purification system, shown in Figure 1.

IV. PURIFICATION TEMPERATURE CONTROL

A temperature below ∿60°C for purification inlet flow is provided by the bleed cooler of the feed and bleed system. Control of this temperature is required to prevent overheating the HT IX resins. This is particularly important for the HT purification system resin as the main HT system high temperature has the potential to overheat the resin so that its effectiveness is reduced, and even to melt the resin. Were melted resin to escape into the main or auxiliary systems it would cause severe problems due to increased radiolysis and activation, and pump and valve gland clogging. Removal of the resin out of system would then require a chemical cleanup.

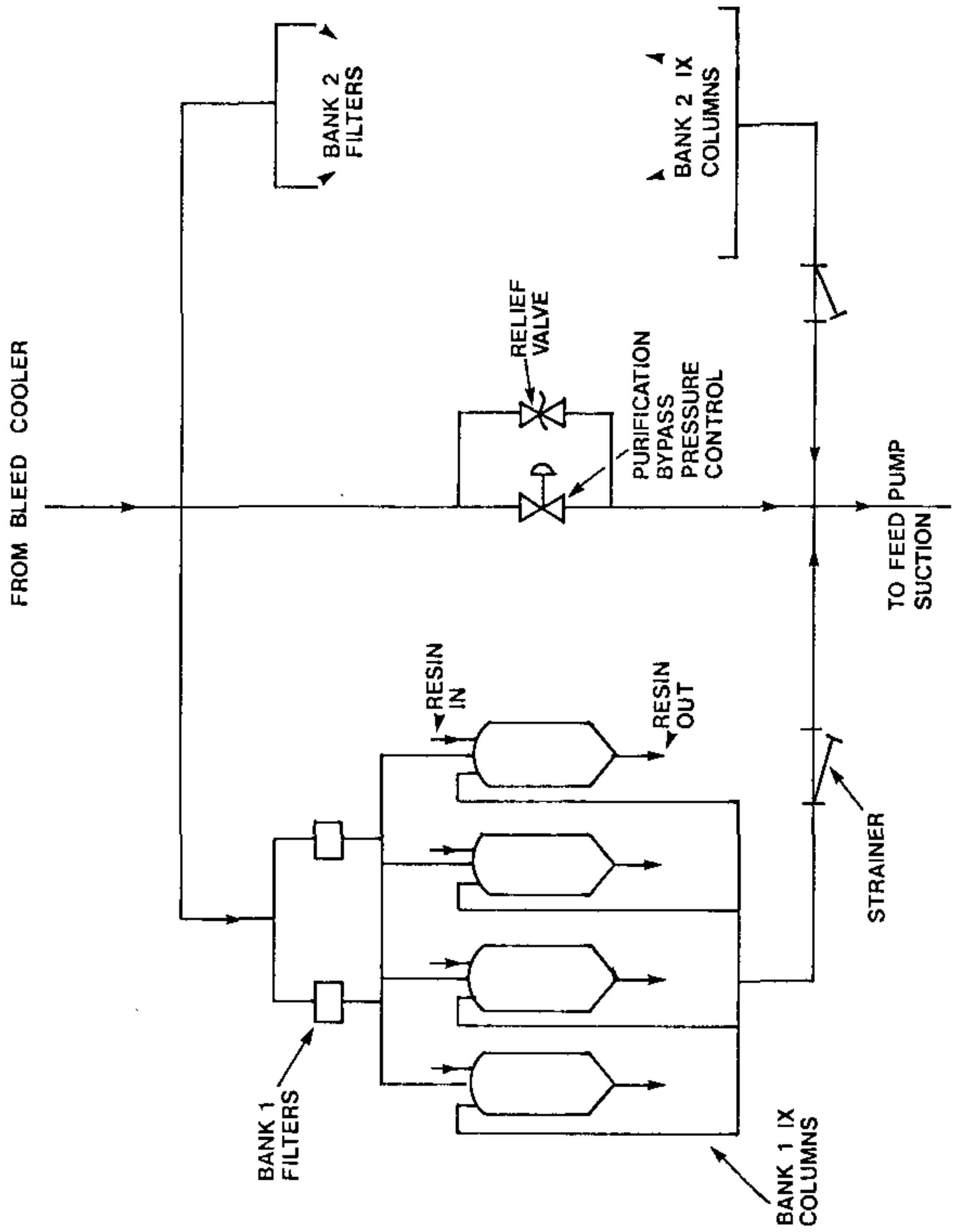


Fig. 1 TYPICAL HT PURIFICATION SYSTEM

Primary temperature control is by a control valve on the recirculated cooling water of the bleed cooler. Back up control is also provided in case of feed and bleed flow transients for which the bleed cooler cooling capacity is too small. If primary temperature control is inadequate, the bleed condenser level control is overridden. This is done by the bleed condenser level control valves (on the bleed coolant outlet) tending to close. This decreases the bleed cooler D_2O flow, and hence decreases the outlet temperature to the purification system.

V. PURIFICATION PRESSURE SUPPLY

The pressure supply varies with the HT operating state as described below, and as illustrated in Figure 2.

(a) Heat Transport System Hot Pressurized

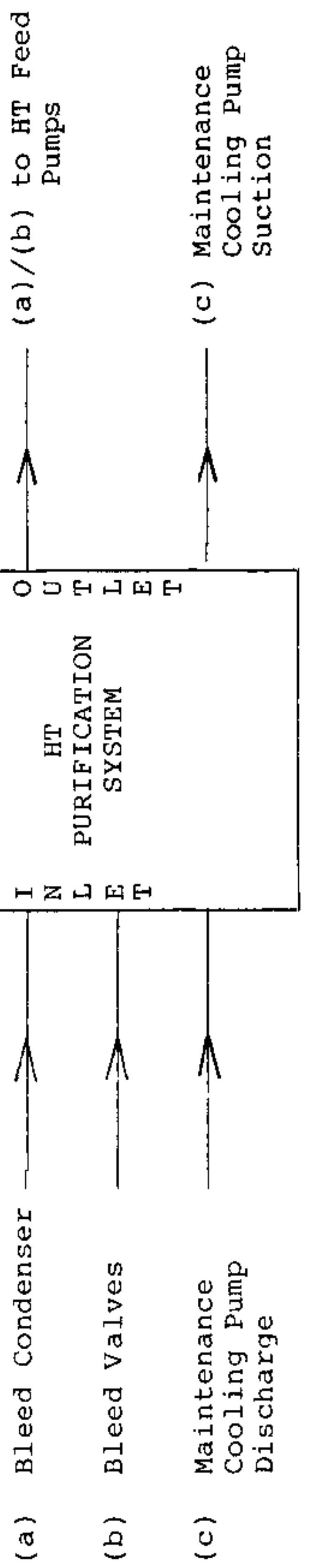
Under this condition, when the reactor may be at low or high power, the source of pressure for HT purification flow is the bleed condenser pressure (controlled at ∿2 MPa). This gives sufficient head to allow for subsequent pressure drops in the bleed cooler and bleed condenser level control valves. Purification over-pressure relief is provided by a relief valve bypassing the purification system, relieving to the outlet of the purification system, Figure 1.

In addition to relief, some stations provide a controlled purification inlet pressure by using a control valve also bypassing the purification system, Figure 1. This solves problems of high bleed filter inlet pressure and low bleed flow resulting from say, a clogged bleed filter.

As the maximum operating pressure of the purification filters and IX columns is typically ∿1 MPa then the above purification inlet pressure control features are quite important as the pressure from the hot pressurized HT bleed components is potentially much higher than this.

(b) Heat Transport System Cold Pressurized

Under this condition the bleed condenser will be isolated and out of service and so the pressure head for purification is supplied from the main system via the bleed valves which can provide a feed flow bypassing the bleed condenser.



Main System Operating States:
(a) Hot Pressurized
(b) Cold Pressurized (bleed condenser bypassed)
(c) Cold Depressurized (Bruce A/B only)

Figure 2

HT Purification System Pressure Supply Sources

(c) Heat Transport System Cold Depressurized

With the main system cold and depressurized (HT pumps not operating) no pressure head will be available from the main system via the feed valves. To obtain a purification flow, pressure has to be supplied from another source. There are differences between stations, namely:

1) Pickering A and B

No bleed purification flow is provided when the HT system is cold depressurized.

2) Bruce A and B

Flow is provided from the maintenance cooling system, which is a bypass of the main pumps and boilers. Purification inlet is from the maintenance cooling heat exchanger outlet and purification outlet is returned to the pump suction.

VI. FLOW

Maximum flow with all IX columns valved in is typically ∿40 kg/sec in newer plants. Figure 3 shows a HT system cleanup half life versus flow rate. The half life corresponding to maximum flow is seen to be ∿1 hour. HT purification flow rate capacity should be as high as possible due to:

(a) the potentially high corrosive nature of HT D_2O.

(b) the requirement to rapidly reduce crud levels in the event of crud bursts, especially likely on startups and shutdowns.

(c) the requirement to remove fission products as a result of fuel failures, as quickly as possible.

VII. EQUIPMENT DESCRIPTION

The major equipment components are:

1) IX columns

2) Filters

3) Strainers.

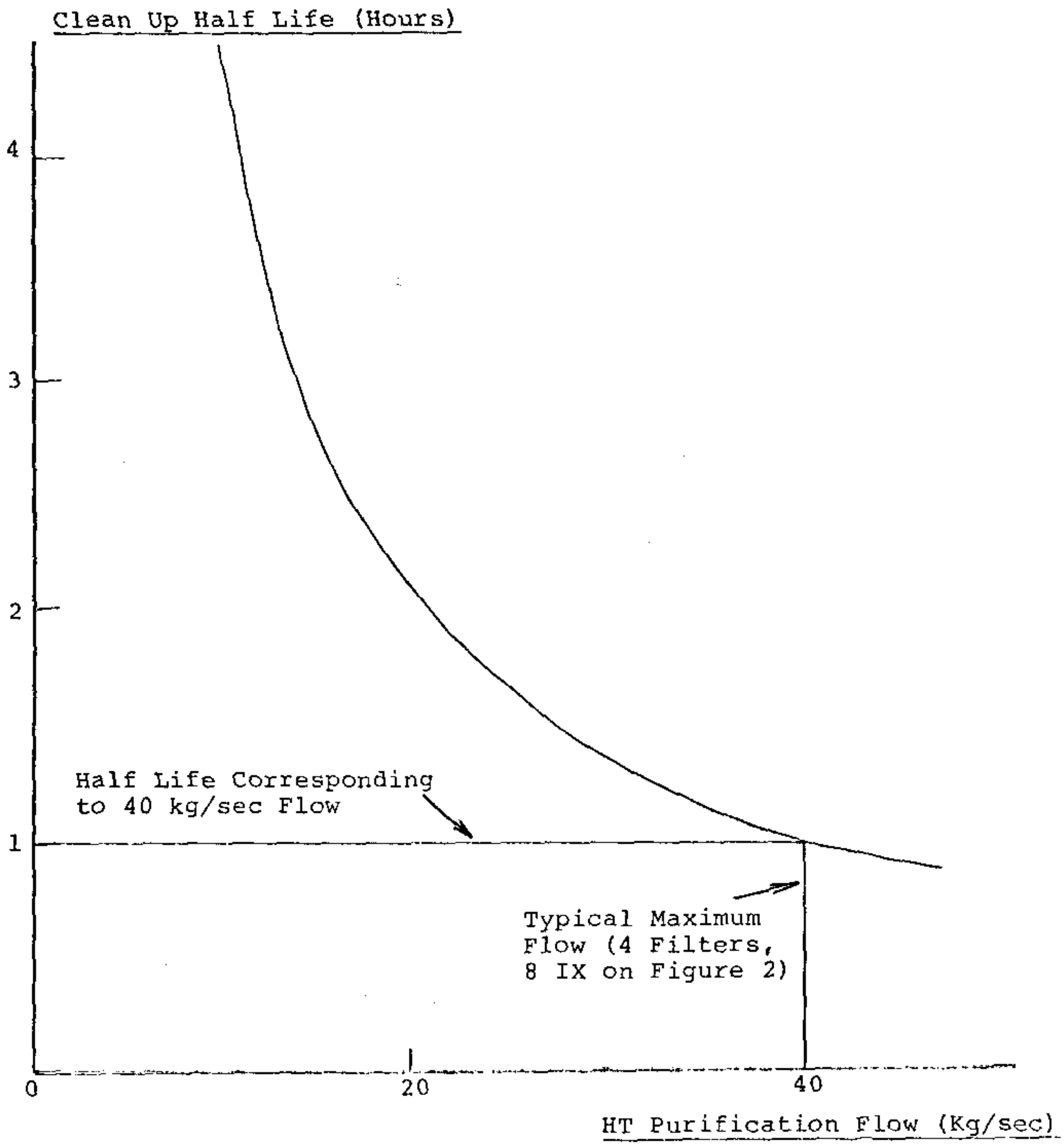


Figure 3

Typical HT System (Bruce) Purification Half Life for Different Purification Flows (HT = 216 Mg D_2O)

Usually two identical banks of the equipment are used in parallel. Either individual components or a bank of components can be isolated while some purification flow is maintained.

1) IX Columns

Typically, 6-8 columns are situated in two parallel banks. The type of resin used is Li^{+} OD^{-} for pH control. Physically the columns are similar to those discussed in the moderator purification system. (One difference at Pickering A is that the HT columns themselves are disposed of when the resin is spent).

The resin in a column would be declared spent by high conductivity and/or high chloride concentration readings in the column outlet. As the HT conductivity value is already high because of the pH requirement of the system the chloride concentration measurement is usually the most sensitive method of determining whether a column is spent. A high ΔP across the column is also an indication of a spent column, due to plugging by insolubles.

2) Filters

The purification discussed above is all incorporated into the feed and bleed system. However, various other locations have filters installed and a typical list with specific features is given below.

(a) Feed and Bleed Circuit Filters (Figure 1)

These filters do most of the filtering in the HT system as they have the highest flow rate. They are usually of the replaceable cartridge type, and last typically 6-12 months before replacement. A spent filter is indicated by a high ΔP across the filter. They are usually designed only for low temperature ($\sim 60°C$), low pressure (~ 0.5 MPa) operation. Over-pressure, which could rupture the filter element, is prevented by the purification over-pressure relief valve mentioned above.

(b) HT Pump Gland Supply Filters (Figure 4)

These filters remove from the high pressure water supplied to the glands of the HT pumps particulate matter which might otherwise damage the mechanical seals in the gland cavity.

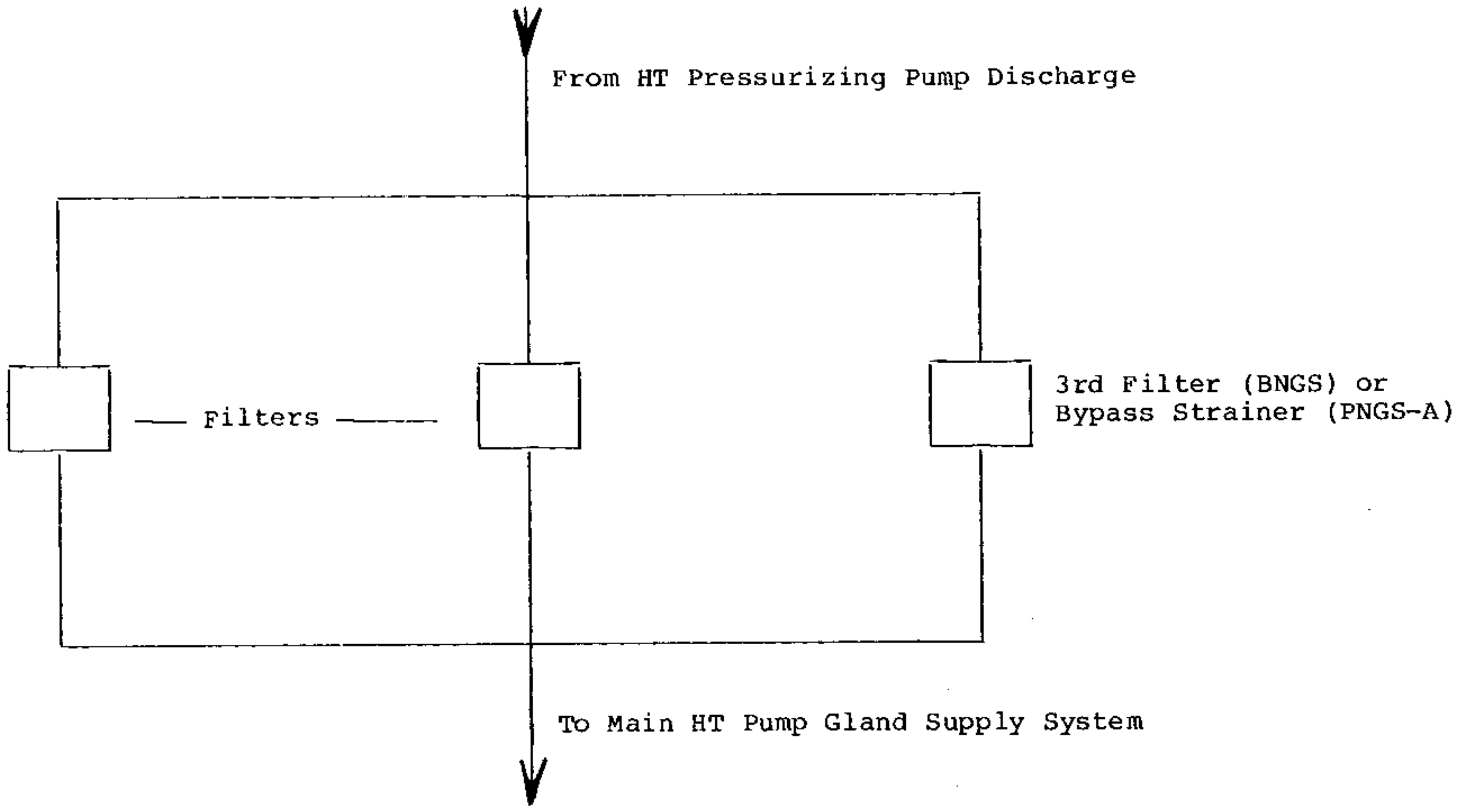


Figure 4

HT System Main Pumps Gland Supply Filter System

Two or three gland supply filters of the disposable paper cartridge type are usually used in parallel as shown in Figure 4. (Pickering A uses a bypass strainer instead of a third filter in case of filter plugging.)

Operating conditions are high pressure (∿10 MPa, supplied from the HT pressurizing feed pumps) and low temperature, ∿40°C. These filters usually last ∿1-3 years as most of the HT filtration is done by the higher flow rate bleed filters.

(c) Fuelling Machine Supply Filters (Figure 5)

For stations Pickering A and B, where the HT system can supply F/M D_2O from the feed pumps then the F/M supply filters can be considered as part of the HT D_2O clean up.

These filters are designed for high pressure (∿15 MPa) and low temperature (∿40°C), flow being controlled by F/M demand. Bypass valves are normally provided to allow continuation of flow in the event of filter blockage, as shown in Figure 5.

3. Strainers

Strainers are installed at the outlet of each bank of IX columns, Figure 1, to prevent the escape of resin into the main system. If not prevented, this would lead to increased radiolysis and possible blockage of pump gland supply lines and instrument lines due to the deterioration of IX resin into a gooey mass as a result of the high operating temperature of the main HT system.

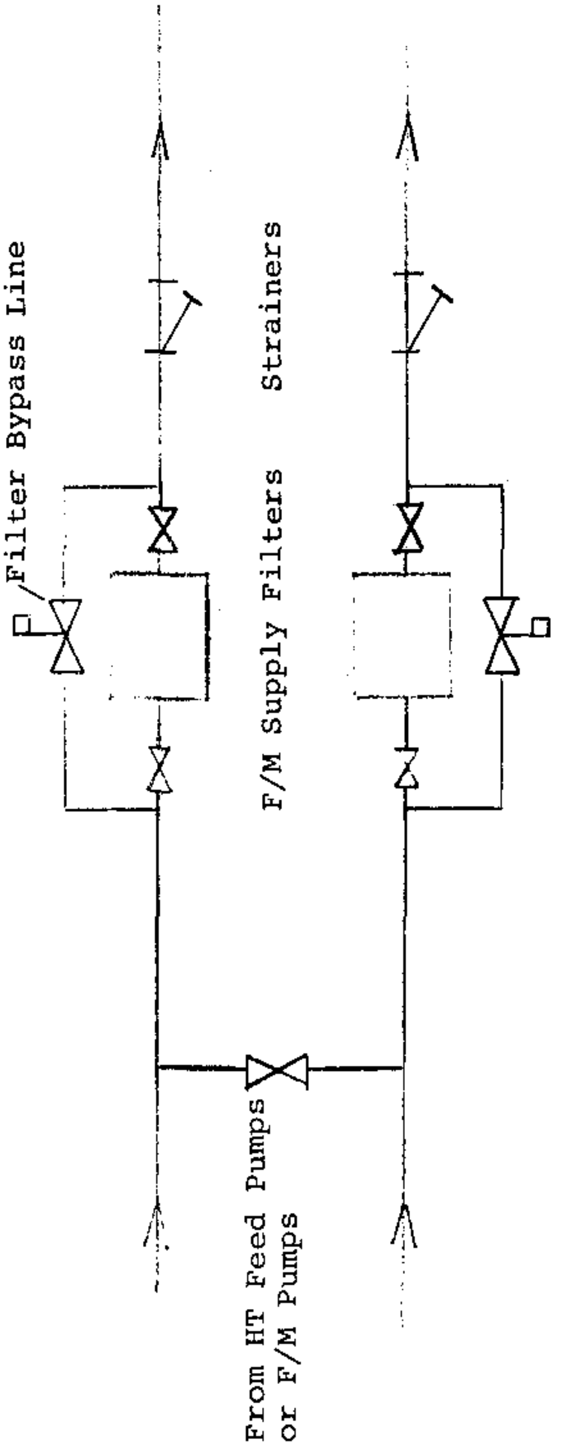


Figure 5

F/M Filter Circuit (PGS Only)

ASSIGNMENT

1. State two purposes of the HT purification system.

2. Explain how the system controls:

   (a) pH
   (b) conductivity
   (c) chloride concentration

   State consequences of not controlling each of the above satisfactorily.

3. State three locations where filters may be used in the HT system. What are the approximate operating temperatures and pressures and specific purposes of these filters in these locations?

4. State a possible cause and a likely consequence and possible action to be taken, of the following;

   (a) HT pump gland supply filter high ΔP
   (b) HT pump gland supply flow low
   (c) bleed filter high ΔP
   (d) bleed filter high inlet pressure
   (e) IX column high inlet conductivity
   (f) IX column high outlet conductivity
   (g) IX column high ΔP
   (h) IX column outlet chlorides

5. Find out in your own plant, how long:

   (a) a HT IX column will last for typically.

   (b) HT purification can be valved out by bypassing without exceeding pH, conductivity and chloride concentrations limits.

   (c) is the HT purification half life at maximum flow.

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