Reactor, Boiler & Auxiliaries - Course 133

MODERATOR SYSTEM & EQUIPMENT

The basic main and auxiliary moderator system requirements which must be met are listed and discussed in turn.

These are described in general terms to bring out the principles involved and the descriptions of each of the sub-systems are not intended to be specific to a particular station but will be applicable to most of our stations with some variations. Major differences in some systems do occur however as our units increase in size but these will be pointed out.

To provide an overall picture of complete systems, specific flow sheets (Pickering GSA) are included at the end of the text in this, and other sections, for reference if greater detail is required for a few of the major systems.

MAIN MODERATOR SYSTEMS

(a) Circulating and Heat removal system.

(b) Level Control and Helium Cover Gas System.

(c) Liquid Poison Addition System.

(d) Purification System.

AUXILIARY MODERATOR SYSTEM

(e) Reactivity Mechanism Cooling.

(f) Calandria, Dump Port and Dump Tank Spray Cooling.

(g) Emergency Transfer of Moderator to PHT System.

(h) Leakage Collection and D_2O Recovery.

(i) D_2O Addition and Transfer.

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(a) MODERATOR CIRCULATION AND HEAT REMOVAL SYSTEM

Heat Production

Heat input to the moderator is generated from the following sources:

directly from
- neutron slowing down
- γ ray absorbtion
- heat radiation from fuel channels

and indirectly from
- calandria structure heating
- calandria tube heating
- dump tank heating

The direct contribution makes up a large heat source which is unfortunately not yet practical to utilize economically for say turbine condensate reheat or building heating.

Table 1 lists the moderator heat production for all our stations together with the normal moderator operating temperature, the cover gas pressure in the calandria usually being slightly above atmosphere. The maximum and minimum temperature limits are set by the allowable thermal stresses in the calandria and its end shields.

Table 2 breaks down the various individual heat sources for Pickering GS moderator system, which is fairly typical.

TABLE 1

STATION MODERATOR HEAT PRODUCTION

	NPD	Douglas Point	Pickering	Bruce
thermal heat produced in fuel channels MW(th)*	82	657	1655	2375
Total heat appearing in moderator circuit MW(th)	6	37	89.6	155
average moderator temperature	30°C	50°C	70°C	84°C

* does not include primary pump energy appearing in PHT system.

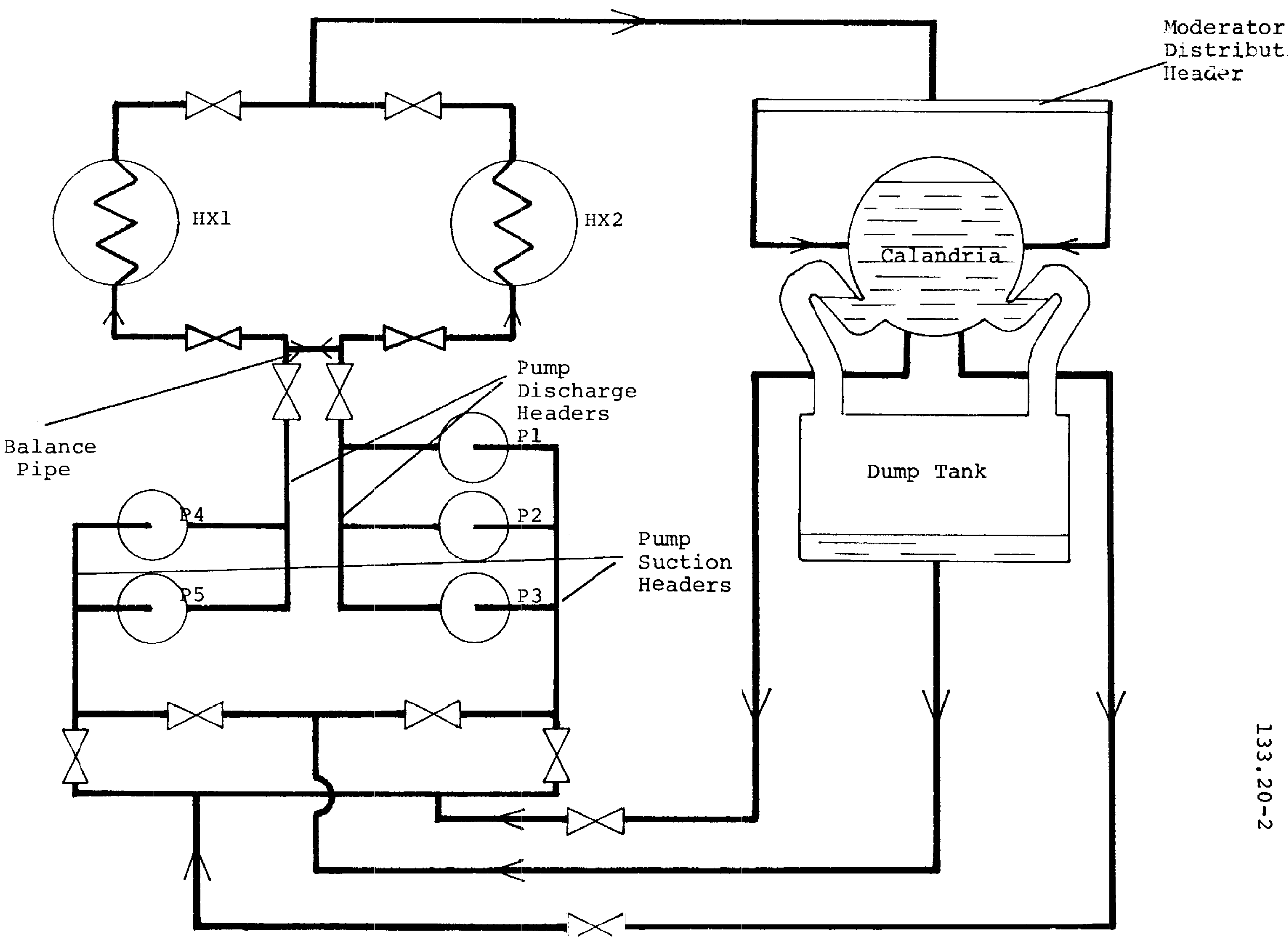

Figure 1: Basic Moderator Circulation System (Pickering G'A)

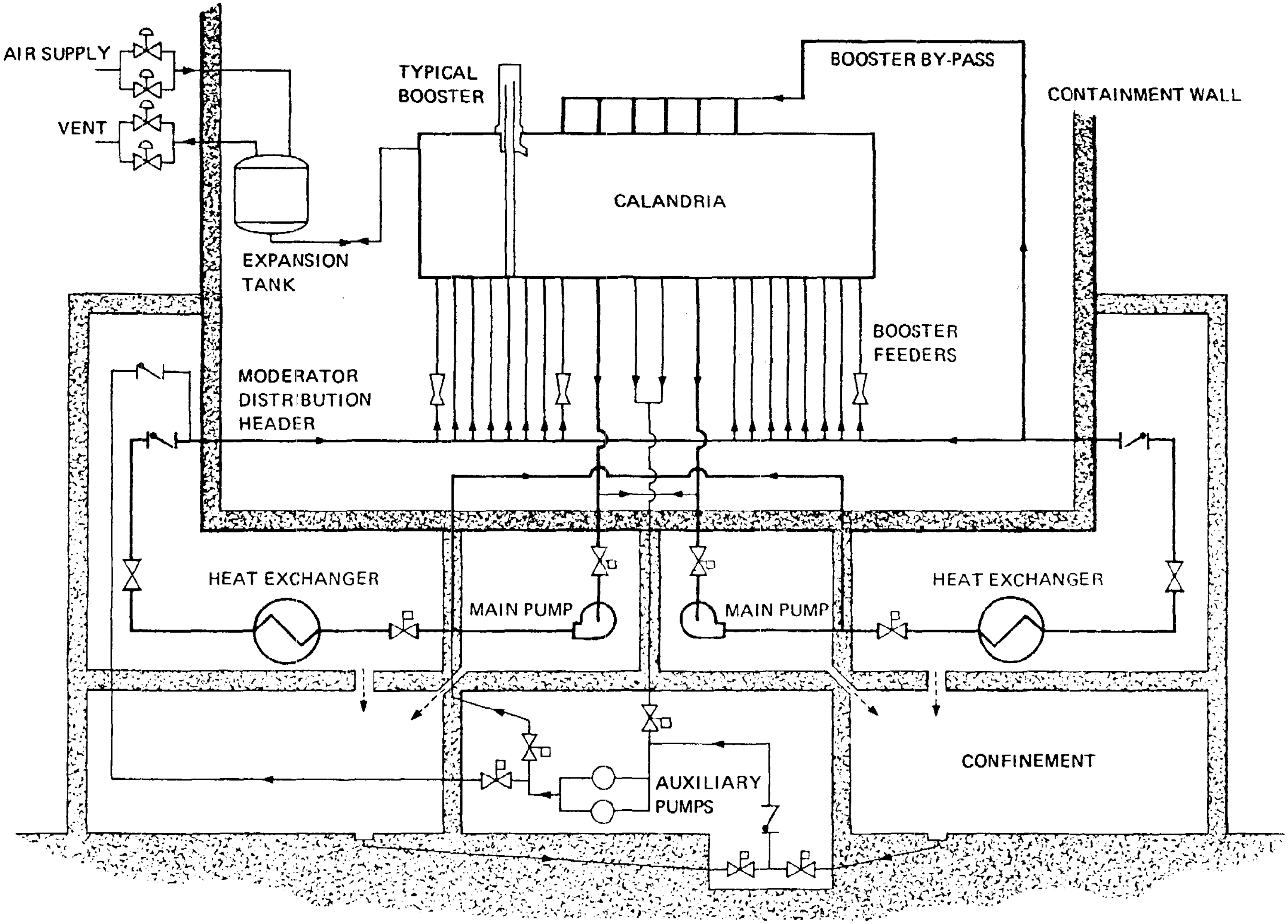

Figure 2: Moderator Circulation Circuit Without Dump Tank (Bruce GSA)

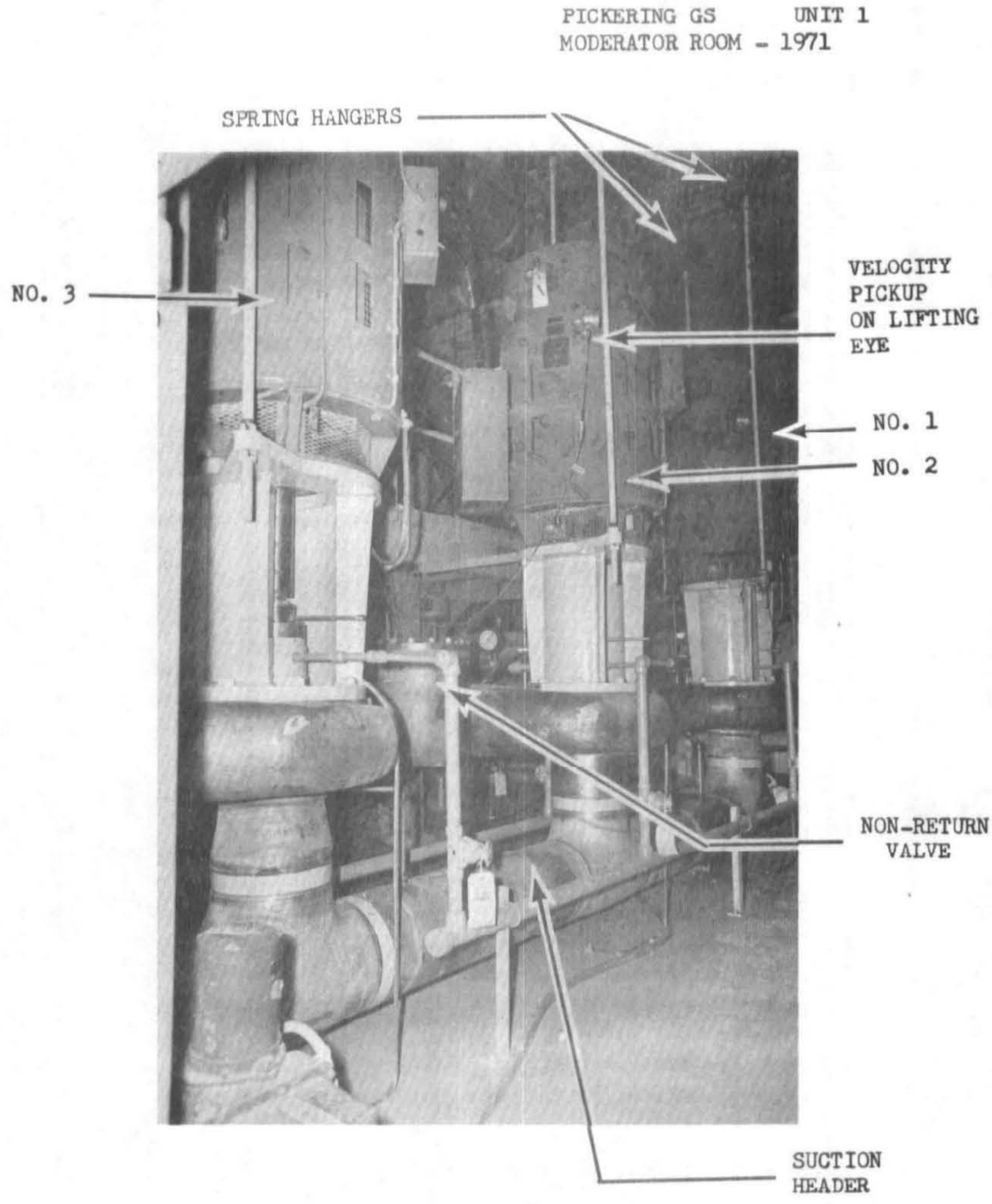

Figure 3: Pickering GS 'A' Moderator Pumps #1, 2, & 3.

TABLE 2

BREAKDOWN OF MODERATOR HEAT PRODUCTION

(Pickering GS)

Heat Source	MW(th)
neutron moderation + γ ray absorbtion	82
heat radiation from fuel channels	2.6
heat produced in calandria tubes	2.5
heat produced in calandria structure	2.4
heat produced in dump tank	0.1
total heat in moderator circuit	89.6

Basic Circulating System

A typic basic circulation system is shown in Figure 1 (Pickering A). Two pairs of pumps P1, P2 and P4, P5 are required in parallel to handle the flows involved during normal operation with one standby pump set P3 available in case of failure of one pump of either pair. Two heat exchangers HX1 and HX2 are placed after the pump outlet headers rather than on the inlets (as is done in the PHT system) to utilize the higher pressure, at the pump discharge, on the D_2O tube side of the exchangers preventing inleakage of shell side H_2O service cooling water.

In addition this arrangement enables the pump to have a higher suction head by avoiding the smaller pressure on the heat exchanger outlet due to the pressure drop in the tubes ($\sim$ 200-300 kPa) which is large compared to the pump discharge pressure required in this low pressure system.

Pump suction is from the bottom of the calandria, via two outlets, and discharge is back into the calandria via a distribution header into two inlets through upturned nozzles just below the calandria mid point. This provides good mixing and a uniform temperature distribution. Normally there is no spillage over the dump ports all the heavy water entering the calandria leaving by the dual outlets. To provide pump up after moderator dump a third line is provided from the dump tank to the pump suction headers as shown. Figure 3 illustrates pumpsets P1, P2, P3 at Pickering GSA.

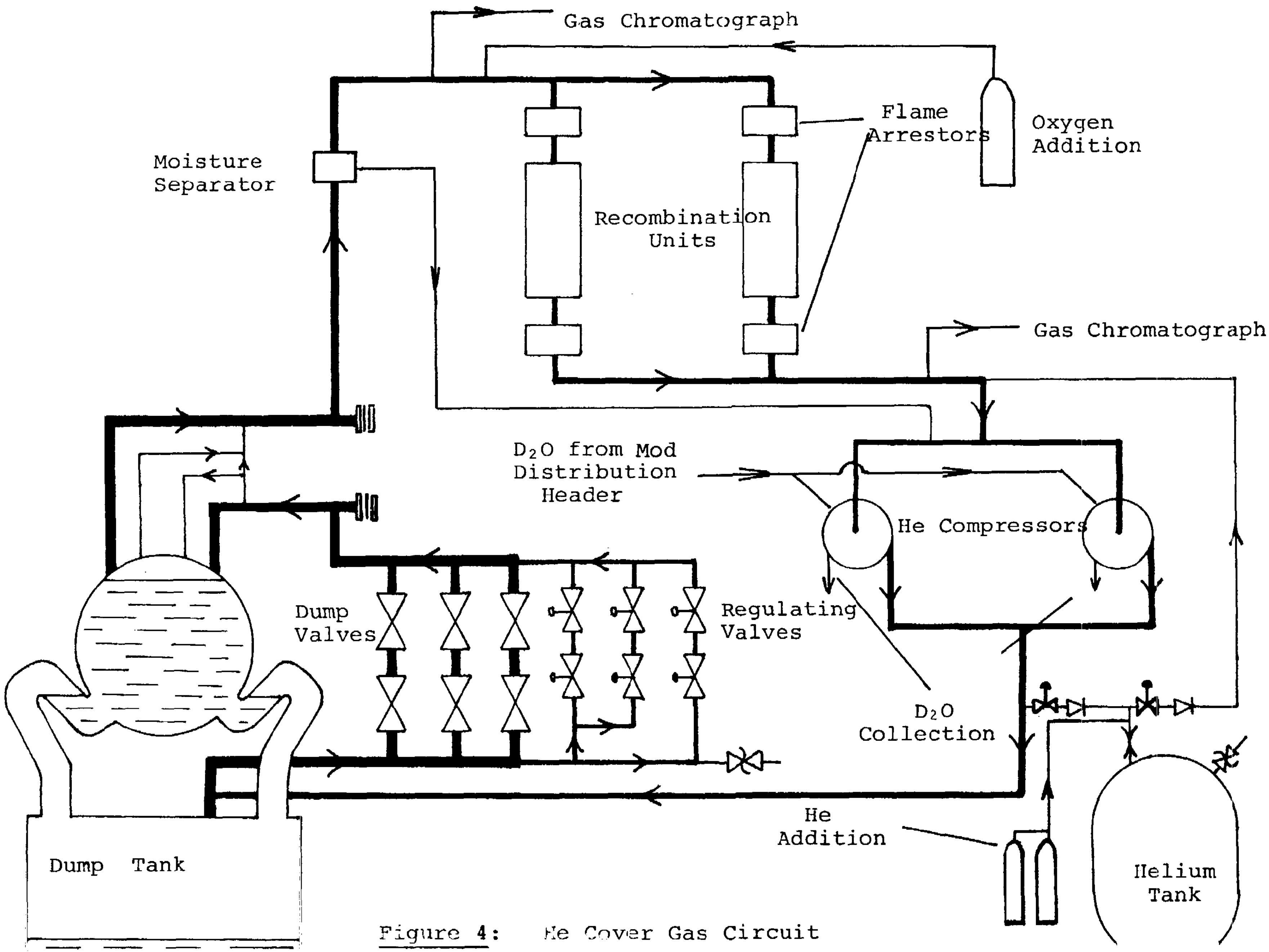

Figure 4: He Cover Gas Circuit

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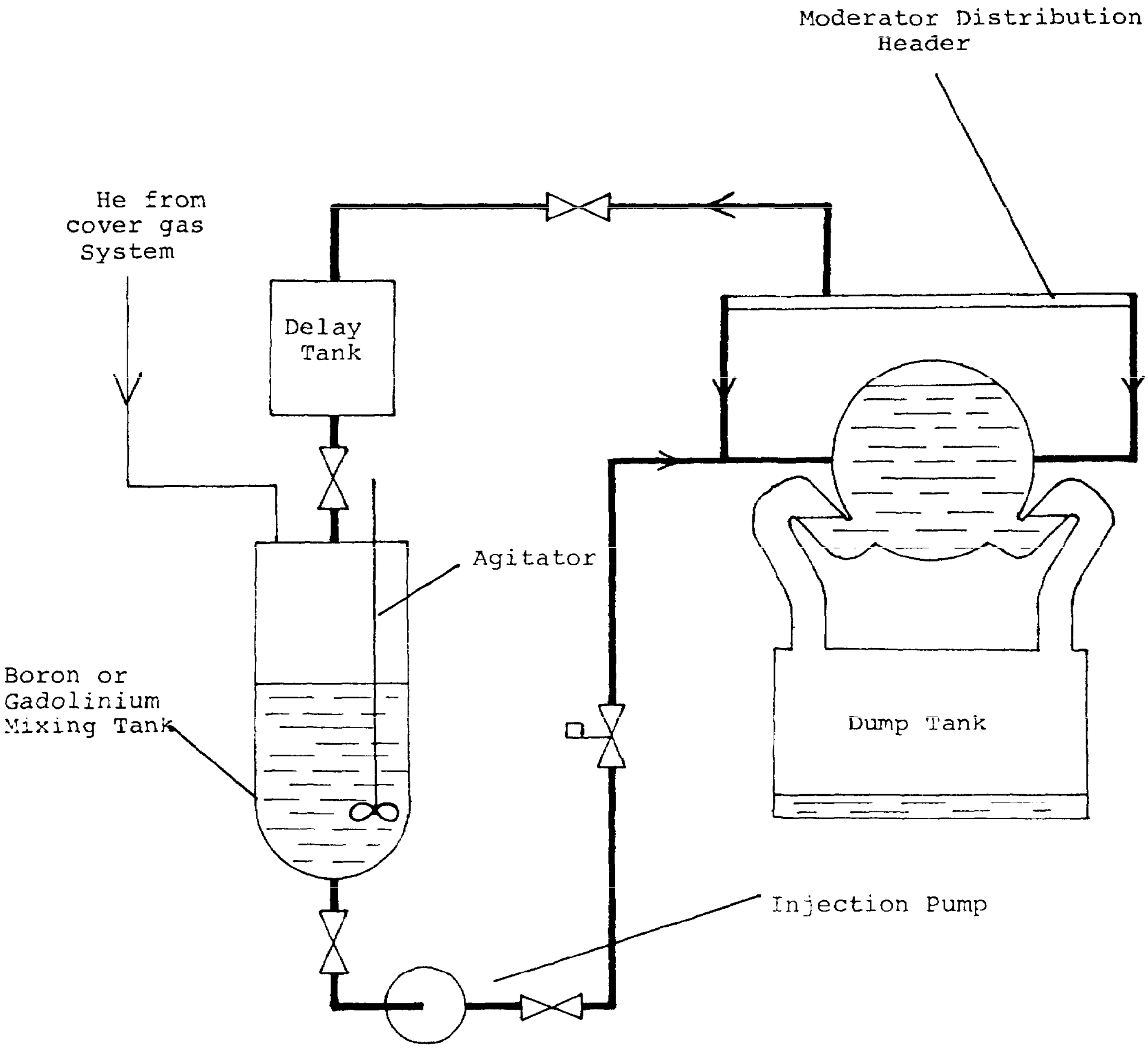


Figure 5: Liquid Poison Addition System

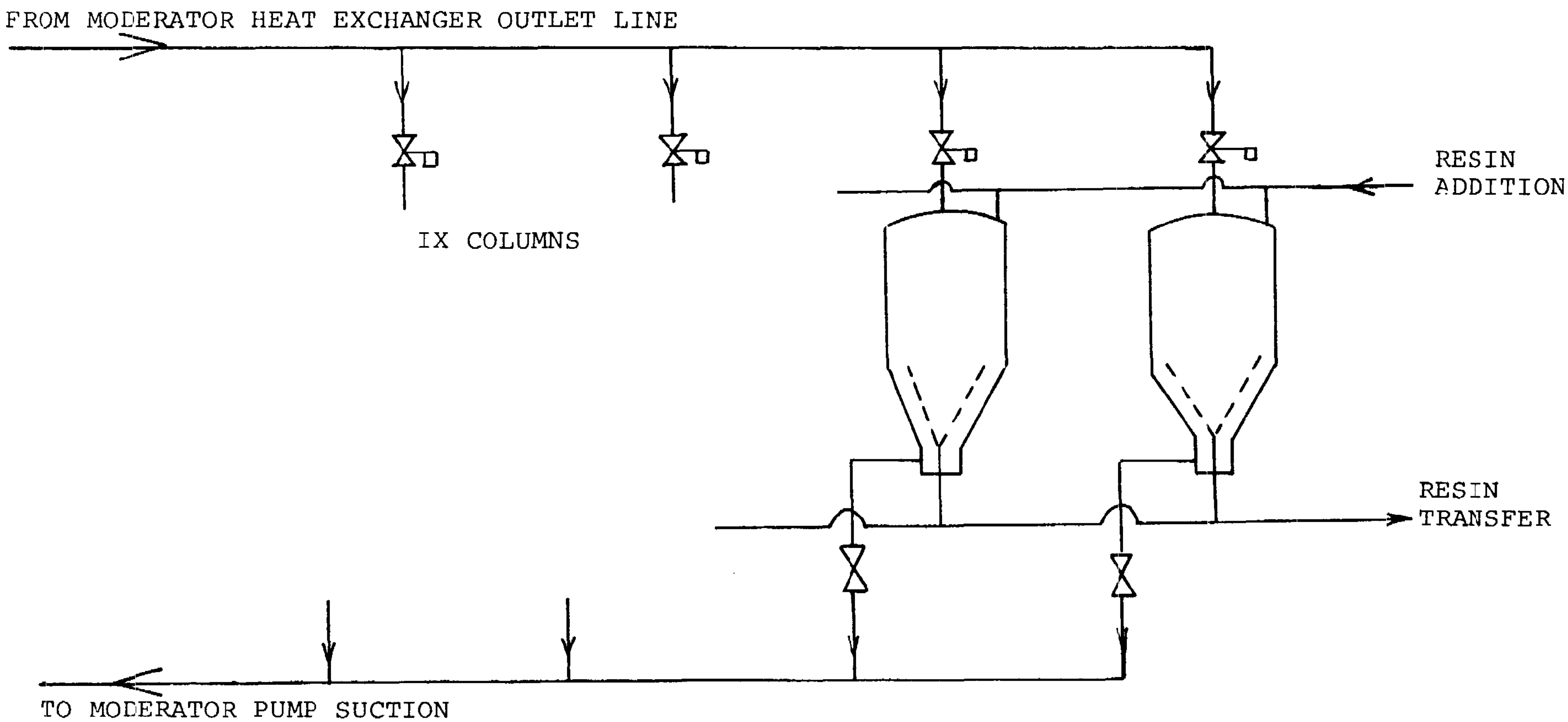


Figure 6: Moderator Purification System

Isolation Provision

It must be possible to isolate pumpsets and heat exchangers for maintenance. Figure 1 shows the position of typical gate valves provided for this purpose. Isolation, in this case, is provided for each bank of pumps and for each heat exchanger individually.

Variations on the basic circulating system.

The layout of the system described above is followed in all our stations with some minor variations. For instance, at NPD only 3 moderator pumps are used (2 x 50% and 1 on standby) and a single heat exchanger is used. Circulation here takes place by suction from the dump tank, through the pumping system, into the bottom of the calandria and a continual spillage over the dump tank port refills the dump tank to complete the circuit. Isolation is provided in this case for each pump individually.

At Bruce the differences are illustrated in Figure 2. The absence of a dump tank at Bruce and the presence of a large number of boosters necessitates the inclusion of the booster cooling in the main circuit rather than as an auxiliary cooling system. This circuit consists of 2 identical halves each comprising a pumpset and a heat exchanger with cross ties allowing for operating of either half circuit independently, normal operation being with one pump, the other being standby. The main flow distributes itself through 16 booster rod feeders into the top of the calandria and via a by pass line, limiting the maximum velocity flow through the boosters. Due to the necessity of booster cooling at all times auxiliary moderator pumps are provided in this case for booster fuel insertion and loss of the main pumpsets. Suction of these pumps can either be from the calandria or from floor drains and discharge into the main distribution headers.

An additional change at Bruce and on Pickering B, due to dump tank absence, is the inclusion of an expansion tank tied into the calandria, Figure 2. By accommodating swell and shrinkage of the moderator the moderator level is maintained and controlled at its nominally maximum value by an air feed and bleed system.

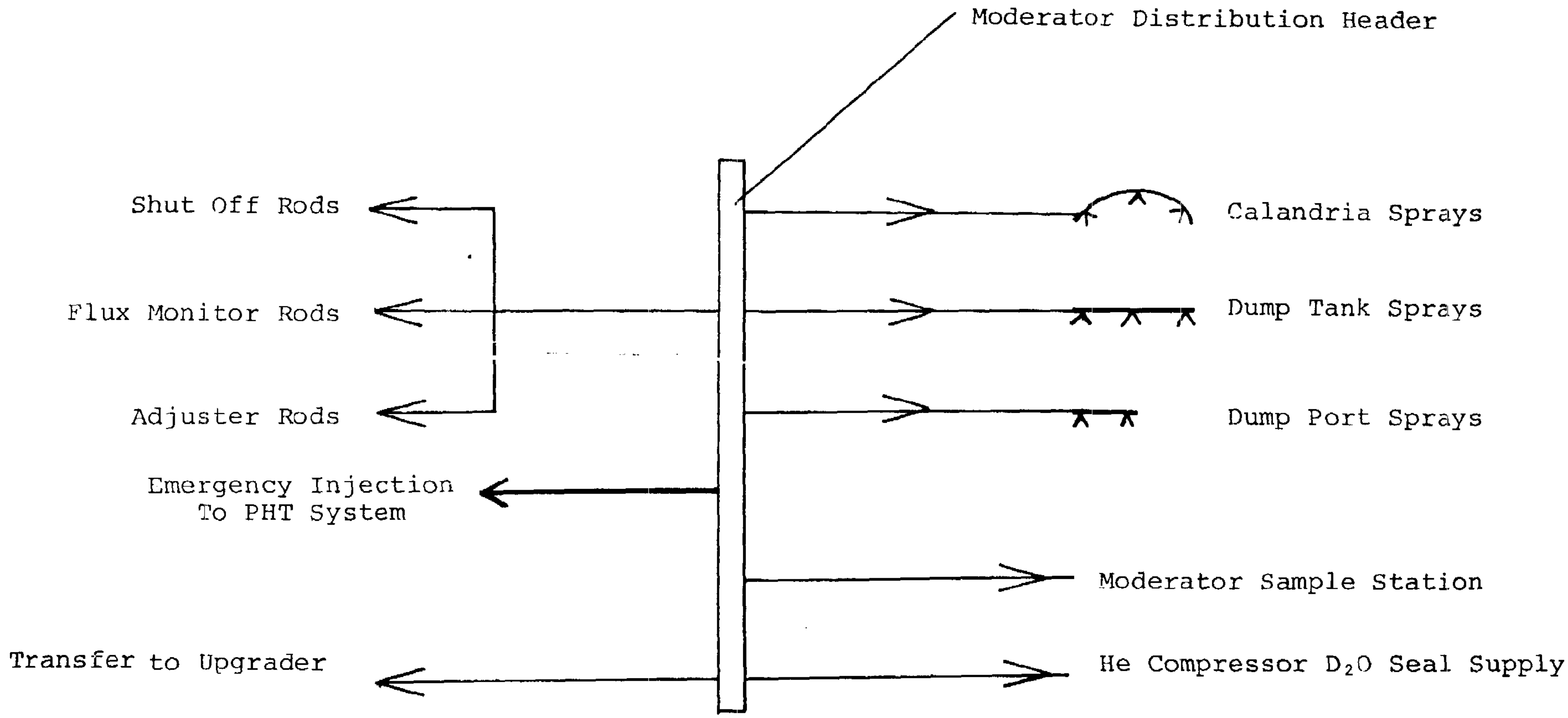


Figure 7: Moderator Auxiliary System Lines

(b) LEVEL CONTROL AND HELIUM COVER GAS SYSTEM

All our stations, up to Pickering A, are utilizing a dump tank for reactor trip and moderator level variation for reactor control.

A pressure differential is established between the dump tank and the top of the calandria (Figure 4) by drawing off a cover gas above the moderator in the calandria, compressing it to about 180 kPa(a) and returning it to the dump tank.

Gas compression is achieved using 2 x 100% blowers and moderator level control is obtained by controlling the by passed cover gas leak rate through a set of 6 control valves as shown.

For reactor trip a similar triplicated system of 6 quick acting dump valves is used to short circuit the pressure differential even when the blowers are pumping at full capacity.

Choice of Cover Gas

The cover gas used for the moderator system and also in other systems where reactor grade heavy water has a liquid/gas interface is helium. The essential properties of a cover gas to perform this function are:

- low neutron capture cross section and hence a low induced activity.
- chemical inertness
- easily maintained purity.
- no radiolytic decomposition.
- reasonable cost.

Helium satifies the above requirements better than all other gases and is used exclusively in our stations. The main problem with helium as a cover gas is air inleakage at pressures below atmosphere which increases the nitrogen content. This would lead to the production of nitric acid, with the presence of oxygen and γ radiation from the core. As a result, the system pressure in the calandria is generally kept slightly above atmospheric.

COVER GAS SYSTEM EQUIPMENT

Helium Compressors

All the stations utilize two compressors, [called blowers if the discharge pressure is less than 70 kPa (g)] usually with rotary water type seals, one running with one on standby except during pump up. (Figure 4).

The seal water supply (D_2O) for the compressors is taken from the main moderator distribution header, which being at the outlet of the heat exchangers is where the coolest water is available.

Gland leakage from the compressors is connected to the moderator D_2O collection system [section (h)].

Dump Valves and Control Valves

The six dump valves are large (~ 30 cm) butterfly valves arranged in the usual safety system triplicated manner for (a) reliability and (b) maintenance requirements. If one channel fails to operate, the dump achieved by the remaining two channels opening the two series valves, in the line not influenced by the failed channel, is still fast enough.

The six control valves are globe valves, four usually for coarse control and two for fine control.

Recombination Units

Two recombination units are usually provided, in parallel, for full flow operation in series with the blowers, situated on the inlet to the blowers. These units prevent the formation of an explosive mixture of D_2 and O_2 gases in the cover gas while at the same time preventing loss of D_2O. The units contain a palladium catalyst for the reaction and are also provided with the following equipment and services for their operation (Figure 4).

(i) heaters to start the chemical reaction and to dry out the units in case of waterlogging with D_2O.

(ii) H_2O service water cooling used if the unit overheats.

(iii) flame arrestors are placed on the inlet and outlet of each recombination unit to prevent the spread of an explosion into the calandria or dump tank.

(iv) a D_2O moisture separator used on the recombiner inlet extracts water which then bypasses the recombiner and is returned to the blower suction.

(v) gas chromatograph samplers situated typically upstream and downstream of the recombination units provide chemical analyses for D_2, O_2 and N_2 in the cover gas.

Oxygen Addition

Provision is made to add oxygen, upstream of the recombination units if the cover gas composition shows an oxygen depletion. As a result of corrosion by oxygen the D_2/O_2 ratio may be increased despite the recombination units and the oxygen addition then prevents excess deuterium build up.

Helium Storage and Addition

A helium storage tank is used to provide automatic helium bleed and feed to the cover gas system when moderator level is changing. Feed will usually be to the blower suction and bleed from the blower discharge via regulating and non return valves.

Provision is made also for the addition (manual) of helium to the storage tank from helium bottles.

The helium storage tank can also be used to store D_2O from the calandria if necessary and a tie line to the calandria outlet lines is provided as shown. In addition use is made of this tank to store D_2O from other D_2O auxiliary systems using a tie line into the bottom of the tank.

Pressure relief

Protection against overpressurizing must be provided for the major components of the cover gas system.

The calandria will usually have rupture discs (or disc) on lines on top of the calandria as shown.

The dump tank will also be protected by a relief valve situated, typically, close to the blower discharge line into the dump tank.

Overpressurization of the cover gas system at the He and O_2 addition stations will be prevented by relief valves on these addition lines.

The helium storage tank is protected against overpressure by a safety relief valve and in addition will have a vacuum breaker arrangement, drawing in building air if tank pressure becomes subatmospheric.

Auxiliary Cover Gas System Connections

Helium can be used as a cover gas for other systems where reactor grade D_2O has a liquid/gas interface for instance to the moderator poison addition tank(s) and also the D_2O collection system.

COVER GAS SYSTEMS FOR UNITS WITHOUT DUMP TANK

For units built after Pickering A moderator dump has been abandoned. At Bruce A for instance this change has meant some modifications to the basic cover gas system.

One of these changes is that low discharge pressure helium blowers are used and are of the diaphragm seal type the system now requiring only sufficient pressure to circulate the helium through the recombination units, from the top of the calandria, and directly back again.

The blowers require only H_2O service water for cooling rather than the D_2O seal water of the liquid ring type which is advantageous as far as leakage is concerned.

The second change which is apparent at Bruce and will be on later units is the provision of a surge tank to suppress calandria overpressurization on use of the liquid poison injection shutdown system which will be used on these units.

(c) LIQUID POISON ADDITION SYSTEM

In all our stations, except NPD, boric acid solution (or boric acid and gadolinium nitrate solutions) is added to the moderator main system for reactivity control. The solution is injected into the moderator distribution header as shown in Figure 5 (Pickering GSA) via a small bypass line.

Physically the boric acid (and/or gadolinium nitrate is added to a mixing supply tank (or tanks)) agitated to prevent coagulation and then introduced into the moderator by a small pump (or by gravity feed for better reliability) via a needle valve and a powered globe valve in discharge line from the supply tank.

Helium will be used as a cover gas for the mixing tank solution. A D_2O supply delay tank is also provided to permit access to the mixing tank during operation by allowing N-16 and O-19 to decay.

(d) PURIFICATION SYSTEM

In general the moderator purification, or demineralizer, system has several function:

1. to remove, or adjust the concentration of boron and/or gadolinium in response to reactivity demand.

2. to remove gadolinium after a poison injection shutdown (Bruce A and larger units).

3. pD control to minimize corrosion of the system equipment.

4. corrosion product removal which reduces the production of activated corrosion products and reduces radiolytic decomposition of D_2O.

The equipment required for B and Gd removal is a number of IX columns, Figure 6, in parallel, valved into the moderator circulation system to allow convenient resin replacement.

The pD control and the corrosion product removal is achieved by flow adjustment through the IX columns which are usually mixed bed (90% anion for boric acid 10% cation for other ions). No additions are used for the moderator pD control because impurities encourage radiolytic decomposition. As a result of the high moderator purity and low crud concentrations a purification circuit filter is not normally used. During the moderator commissioning phase a filter will usually be installed which can be valved out for normal plant operation. At Pickering, however, where filters have not been in use, high Co^{60} fields, not removable by the resins, are now being controlled by using moderator filters.

System Arrangement

All our stations, use a bypass circulating system (Figure 6), rather than a full flow system, the moderator flows being too high to permit a full flow system in series with the pumps. The circuit is connected across the moderator pumps, the pump discharge head providing pressure for the flow. To take advantage of the cooling provided by the heat exchangers the inlet to the purification system is taken from the heat exchanger outlets as the IX resins are temperature sensitive and are kept below 60°C. Table 1 shows that Bruce moderator temperature is kept hotter than in previous plants, resulting in the use of a purification system heat exchanger to prevent high temperature damage to IX resins.

Operating Features

The columns will be contained in a shielded cavity or pit as activated corrosion products accumulate on them and N-16 and 0-19 circulate through them during operation.

Before resins are added to the IX columns they must be deuterated. D_2O is passed through the resin beds until the H+ and OH- ions, normally in the resins, are replaced by D+ and OD- ions to prevent moderator downgrading. When the resins are exhausted, as determined from conductivity measurements at the inlet and outlet of the columns, the D+ and OD- ions are recovered by de-deuteration to avoid loss of D_2O.

To replace the resin in a column the column will be valved off from the purification circuit and connected to a resin drying tank. The resin is flushed out to the drying tank, the flushing D_2O passing out through screens in the tank and back to the moderator system.

Auxiliary Moderator Systems

There are a number of secondary uses of the moderator system D_2O where D_2O in particular is required. Being a low temperature low pressure system it is easier to utilize than say D_2O taken from the PHT system. Figure 7 illustrates the various take off lines to these systems, which are now discussed.

(e) REACTIVITY MECHANISM COOLING

Heat is produced in adjuster rods, absorber rods, shut off rods flux monitor rods, and booster rods during operation and during shutdown, due to neutron and γ ray absorbtion as well as decay heat from activation. This heat must be removed to prevent damage from overheating as well as for safety reasons for instance with boosters

Adjusters (Pickering A & B)

Cooling (~ 15 kW /rod) during operation is achieved by utilizing a perforated guide tube (Figure 3 section 10.2) for the rods so that there is continual contact directly with the moderator in the calandria. If the reactor is shutdown with no moderator in the calandria a small cooling flow of D_2O from a spray nozzle prevents the rods from overheating. This cooling flow, taken off the moderator system from the distribution header is also adequate to provide sufficient cooling for the rods if they are in the parked (or withdrawn) position during reactor operation.

Absorber rods and Booster rods (Douglas Point and Bruce A & B)

The greater heat production in these rods means that forced coolant circulation through the guide tubes is provided, the coolant then forming part of the main moderator coolant circuit, the boosters requiring the largest and most reliable flow (~ 3 MW/booster rod versus ~ 25 kw/absorber rod at Douglas Point).

Shut Off Rods (Pickering A & larger stations

Being out of the core for most of their life a small spray cooling supply is adequate for these rods. Heat production from activity build up in those rods will also be much less than for absorbers or adjusters for the same reason.

Flux Monitor Rods (Pickering A and larger stations)

The in-core flux monitors now in use for neutron monitoring and flux mapping may be cooled to prevent the detectors from overheating and this is achieved by using perforated zircaloy guide tubes inside which the detectors are located. Natural circulation of moderator D_2O through these tubes then provides adequate cooling. In the upper part of the guide tube, above the calandria, a moderator D_2O spray cooling flow provides cooling for the detector cables, and also for the detector when the moderator is dumped.

After PGSA however, no D_2O spray cooling is being provided for the flux monitors as it is now thought not necessary to cool the detector cables in the upper part of the guide tube.

(f) CALANDRIA, DUMP PORT AND DUMP TANK SPRAY COOLING

Heat is produced in the calandria vessel, dump ports and dump tank during reactor operation by neutron and gamma ray absorption and during shutdown by fission product radiation absorption. The cooling water will be distributed from spray headers being supplied from the moderator distribution header.

(g) EMERGENCY TRANSFER OF MODERATOR TO PHT SYSTEM

In the event of a break in a feeder pipe or a rupture of a main header, depressurizing the heat transport system, an emergency supply of cooling water is required to prevent the fuel from overheating. The most convenient and reliable source of water is from the moderator system and so this is used for the emergency injection water as described in the section on heat transport system. Take off for this supply will be from the moderator distribution header.

Apart from this type of transfer from the moderator to the PHT system, mixing D_2O between these systems is generally considered undesirable for the following reasons:

- the T^3 activity is higher in the moderator
- the moderator pD is lower
- the moderator may contain B^{10} or Gd poison
- the isotopic will probably be slightly different.

Transfer between the two systems is available at NPD however, on a continuous basis, but this facility is now avoided on the current reactors.

For reactors larger than Pickering however D_2O injection for emergency cooling has given way to light water injection, the change being made primarily to enable the moderator to be used as a heat sink. For Bruce this light water comes by gravity feed from the vacuum building dousing tank and for single unit stations from the reactor building H_2O dousing tank.

(h) LEAKAGE COLLECTION

To prevent loss of costly and tritiated D_2O from the moderator, provision has to be made to collect the heavy water from various leakage points in the system. These would include pump seals and valve stem leakage points which drain by gravity to a collection tank from which the collected water would be returned, after an isotopic check, to the moderator pump suction header, or to a drum fill station, if downgraded.

(i) D$_2$O ADDITION AND TRANSFER

Provisions must be made for the addition of D$_2$O to make up for losses from the system by leakage or sampling. A moderator D$_2$O drum addition station will be provided to add heavy water to the collection tank from where it can be pumped to the most convenient addition point, usually the moderator pump suction header.

Various D$_2$O transfer lines will be provided to supply D$_2$O to and from such facilities as the upgrading system(s), collection system and addition station.

ASSIGNMENT

1. Briefly summarize the basic requirements of the moderator system.

2. (a) Why is it necessary to cool the moderator?

   (b) Why can the heat removed not be put to some practical use?

   (c) Why are the pumps and, sometimes, the heat exchanger duplicated?

3. What reasons exist for supplying a dump tank in the moderator system?

4. (a) Explain why a moderator purification system is required and why a by-pass system is used.

   (b) What types of resin beds are used for what purpose and how is it known that the beds are exhausted?

5. (a) Why are spray cooling and booster and absorber rod cooling connections required?

   (b) Give one reason why heavy water exchange should be possible between the moderator and heat transport systems and one reason why it is not desirable.

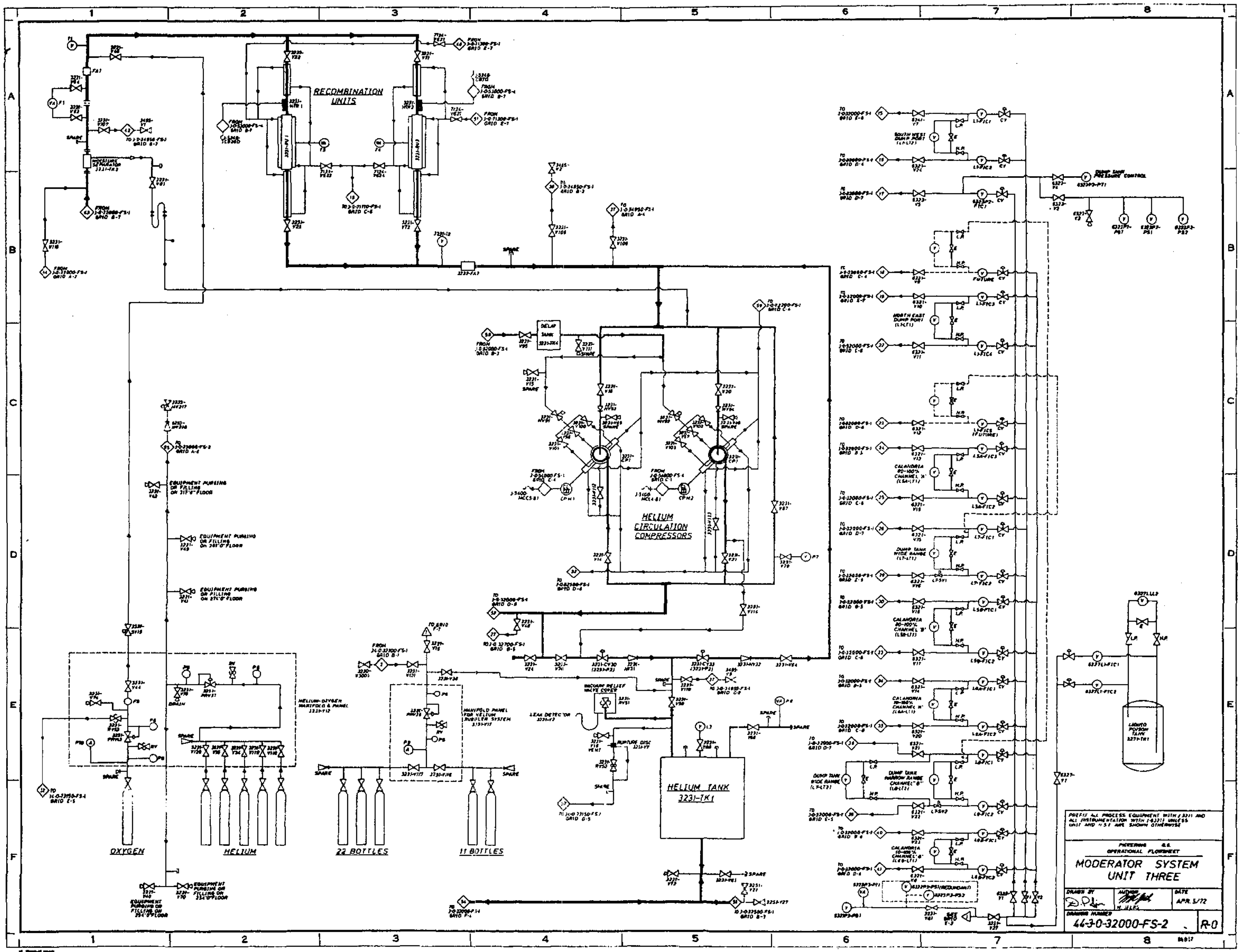
6. (a) What is the primary reason for having a cover gas system and how is it fulfilled?

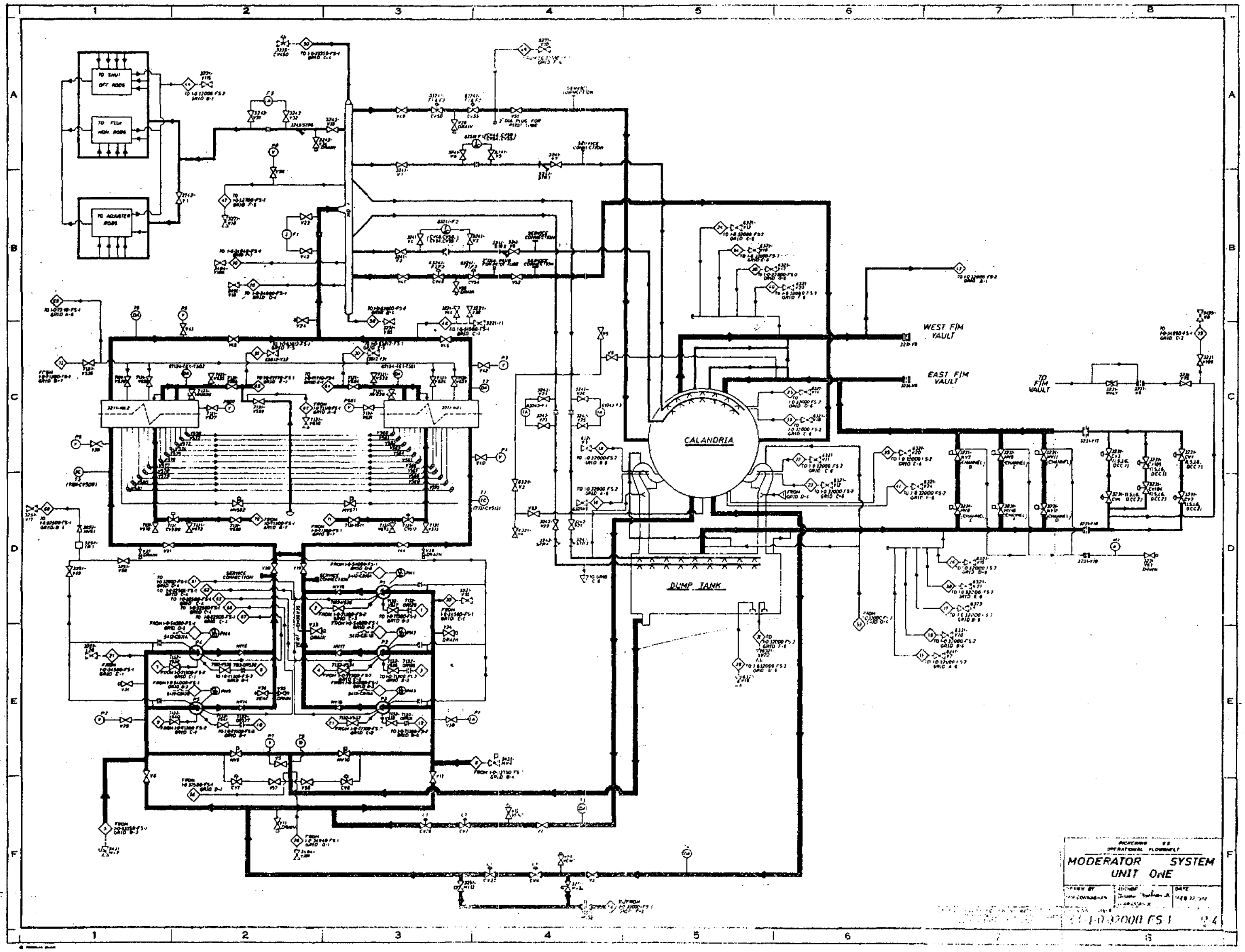
   (b) What are the other possible uses of the cover gas?

7. List the essential properties of the cover gas and explain why helium is chosen.

8. Explain why a recombination circuit is necessary and why is provision made on the recombination unit for both heating and cooling.

D. Winfield


RECOMBINATION UNITS
HELIUM CIRCULATION COMPRESSORS
HELIUM TANK 3231-TK1
OXYGEN
HELIUM
22 BOTTLES
11 BOTTLES
MODERATOR SYSTEM UNIT THREE
44-3-0-32000-FS-2
R-0


CALANDRIA
DUMP TANK
WEST F/M VAULT
EAST F/M VAULT
TO F/M VAULT
MODERATOR SYSTEM
UNIT ONE