Reactor, Boiler & Auxiliaries - Course 233

HEAT TRANSPORT PRESSURIZING SYSTEM

I. THE NEED FOR HEAT TRANSPORT PRESSURE CONTROL

The operating temperature of the heat transport system is well above the coolant's atmospheric boiling point (101°C). Therefore, an auxiliary system is required to pressurize the coolant so that it will not boil. Clearly, the operating pressure must exceed the coolant saturation pressure while remaining well below the ultimate stress limit of the heat transport piping.

The pressurizing system must control pressure at a suitable set point. Loss of pressure control is potentially disastrous: on low pressure, the coolant could boil, the pumps cavitate, the fuel channels void, and the fuel melt; on high pressure, the system could burst, initiating a Loss of Coolant Accident (LOCA), with similar hazards.

Without a pressure control system, pressure would vary wildly with T_{av}, the average coolant temperature, because of coolant expansion (swell) and contraction (shrink). Whenever T_{av} would rise, coolant swell would raise pressure, and whenever T_{av} would fall, coolant shrink would lower pressure. T_{av} varies not only during major transients such as warmup, cooldown, power manoeuvres, and trips, but also even during constant power operation, due to minor fluctuations in reactor thermal power and boiler heat transfer. Therefore, pressure control is necessary whenever the heat transport system is pressurized.

Coolant swell and shrink are large scale phenomena to be reckoned with. For example, the coolant in a Bruce unit swells by 57 m^3 on warmup, and by an additional 17 m^3 as power is raised from 0 to 100%. Now the addition of even 1 m^3 of coolant to a pressurized heat transport system - cold or hot - would raise pressure very dangerously. Therefore, it is clear that some kind of feedback control mechanism is necessary to adjust coolant inventory as T_{av} varies.

There are two types of such pressure control systems used in CANDU stations - the Feed and Bleed system, and the Pressurizing Surge Tank. These systems and the rationale for choosing between them are discussed in the rest of this lesson.

II. FEED AND BLEED SYSTEM

A simplified Feed and Bleed system, typical of that used at both Pickering and Bruce, is shown in Figure 1. It works on the straightforward principle of inventory control: coolant is fed as necessary into the main system to raise pressure to set point, and bled as necessary from the main system to reduce pressure to set point.

Feed and Bleed Operation

Hot bleed from a heat transport header is admitted via the bleed valves to the bleed condenser, where it flashes to steam. The steam cools and condenses as it gives up heat to the reflux cooling tubes in the bleed condenser, see Figure 2. Bleed condenser pressure is regulated to about 2 MPa (corresponding saturation temperature about 200°C) by varying the flow of cool D_2O from pressurizing pump discharge through these tubes, see Figure 1. However, should bleed condenser pressure rise substantially above the set point for the reflux flow controller, then cool D_2O from the reflux line is sprayed directly into the condenser (Figures 1 and 2). Spray cooling is reserved as a backup to cooling via the tube bundle because spray use has two undesirable effects:

1. Increased load on the purification system, due to recycling of previously purified water, and
2. Increased concentration of non-condensible gases in the bleed condenser due to steam 'scrubbing action' on the spray droplets (similar to deaerator action).

Note that the bleed condenser also functions as a pressure relief vessel (see lesson 233.30-8). On high pressure in the heat transport system, the motorized pressure relief valves shown in Figure 1 can open to discharge coolant from a reactor outlet header directly into the bleed condenser.

Condensate passes from the bleed condenser through the bleed cooler and purification system enroute to the pressurizing pump suction. The D_2O storage tank on the pressurizing pump suction has a helium cover gas which is pressurized slightly above atmospheric pressure, and performs the following functions:

1. It stores D_2O to make up for leakage from the main system,
2. It accommodates coolant shrink and swell, ie, tank level rises and falls with T_{av} in the main system, and
3. It provides a net positive suction head to prevent cavitation of the pressurizing pumps.

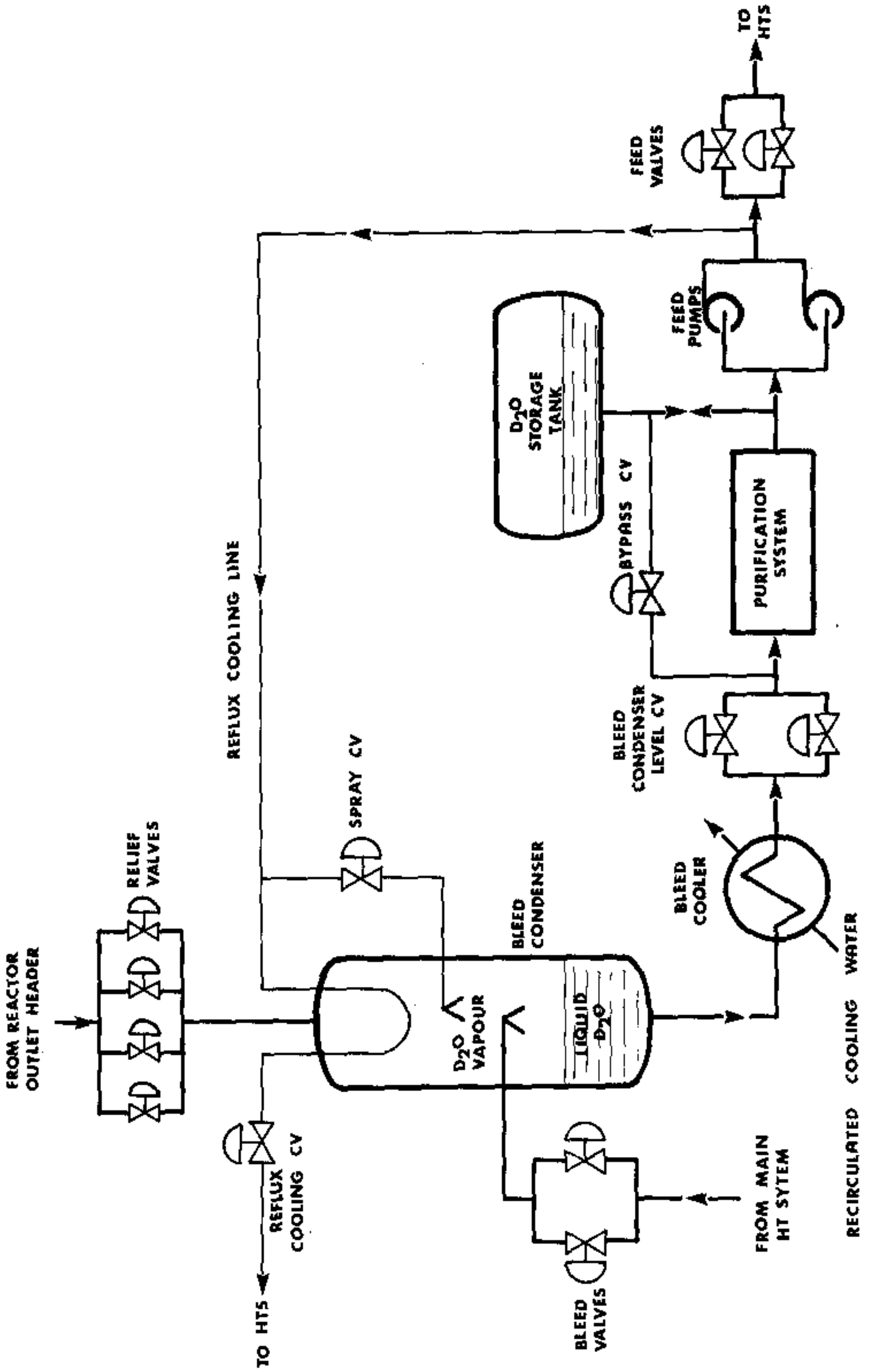

FIGURE 1: SIMPLIFIED FEED AND BLEED PRESSURE CONTROL SYSTEM

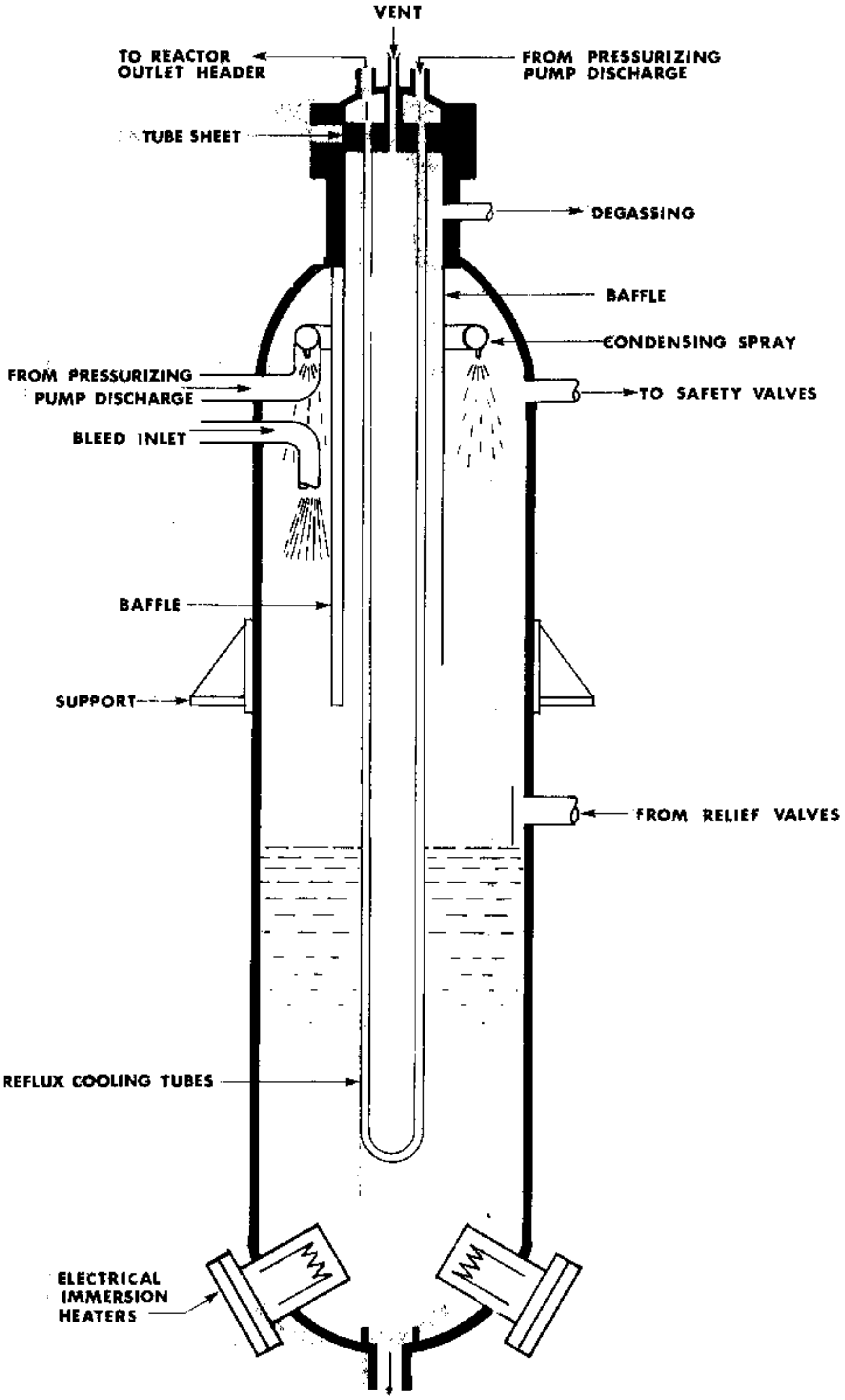

FIGURE 2: BLEED CONDENSER

The multistage pressurizing pumps (also called "pressurizing feed pumps", or simply "feed pumps") raise D_2O pressure above main system pressure, and the feed valves throttle the feed flow to the main system.

Other Heat Transport Auxiliaries Connected to Feed and Bleed System

The components of Figure 1 essential to Feed and Bleed pressure control are the feed and bleed valves, the bleed condenser (including its cooling system), the D_2O storage tank and the feed pumps. However, the Feed and Bleed system is the convenient place to incorporate three other Heat Transport Auxiliaries:

1. Purification System (see lesson 233.30-3).
2. Gland Seal Cooling for PHT Pumps (see lesson 233.30-4).
3. Fuelling Machine Coolant Supply (Bruce NGS is an exception).

The discharge of the pressurizing pumps is a convenient source of clean, cool, high pressure D_2O of the required isotopic and pH for Gland Seal Cooling and Fuelling Machine Supply.

The Purification System is placed in the Feed and Bleed System to take advantage of the cooling and depressurization available there. However, the presence of the Purification System places two important constraints on the Feed and Bleed circuit:

1. Bleed temperature must be reduced below 60°C to avoid damaging the IX resins. This explains the presence of the bleed cooler on the purification inlet in Figure 1. (The reduced pressure at bleed cooler outlet also eases the pressure vessel requirements of the IX columns.)
2. A flow must be maintained through the Feed and Bleed System in order to achieve purification. Sufficient purification flow is normally maintained during steady state operation even with the feed valves closed, because of the considerable flow to the main HT system via the reflux line, the feed valve bypass lines (not shown), and inleakage from the HT pump glands. However, the bleed flow can be increased above normal values if necessary, eg, when high I^{131} concentrations appear in the coolant, by biasing the control signal

to the bleed valves so that they open further. The pressure control loop then opens the feed valves as well, to rebalance the flows to and from the main system, so that system pressure can be maintained at set point.

Pickering-A Feed and Bleed System

Figure 3 shows how the Pickering Feed and Bleed System is connected to both heat transport loops. Note that each loop is serviced by feed, bleed and relief valves. On a LOCA, the interconnect valves are closed so that pressure can still be controlled in the good loop.

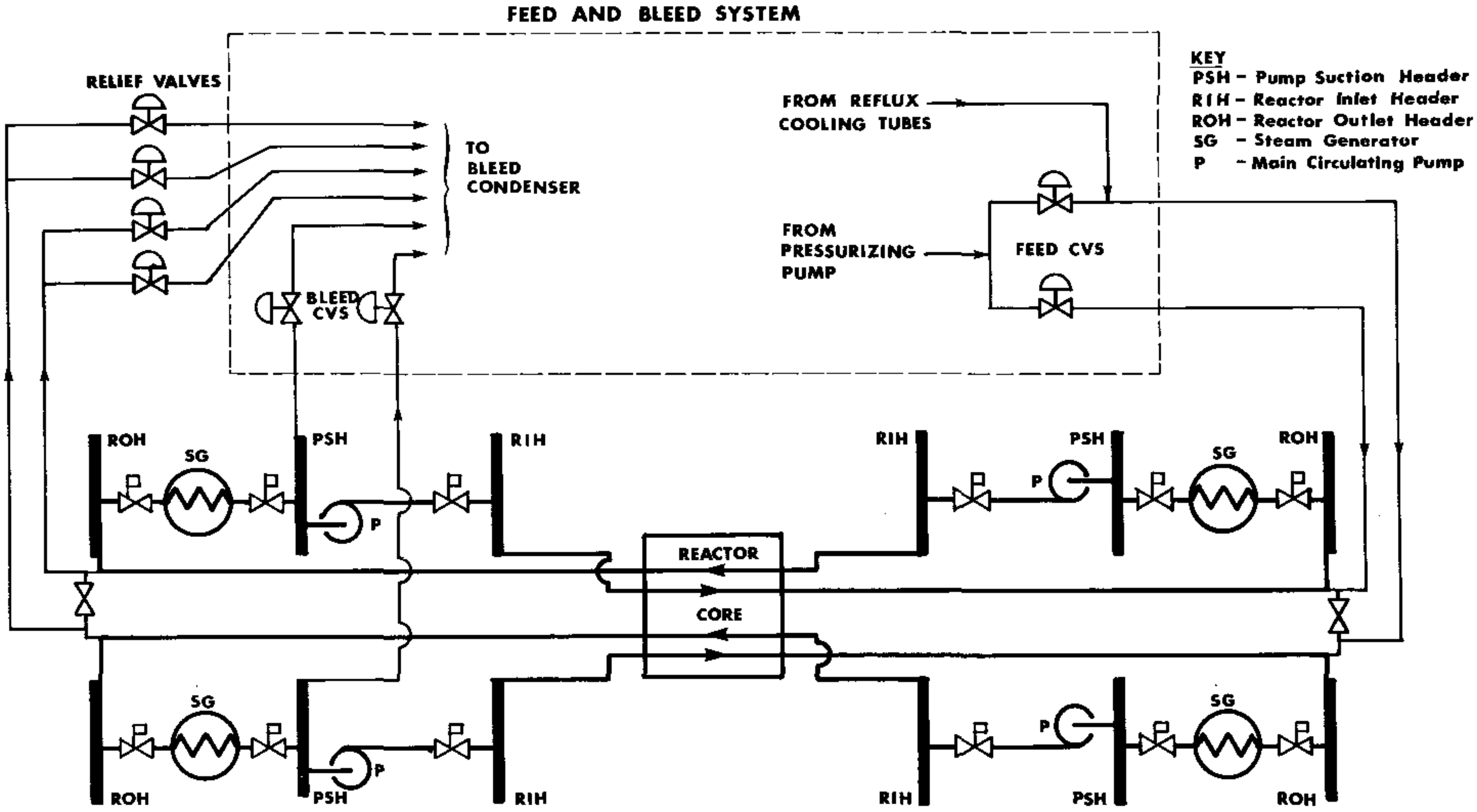

FIGURE 3: PICKERING PRESSURIZING AND PRESSURE RELIEF SYSTEM

III. PRESSURIZING SURGE TANK SYSTEM - BRUCE NGS

The Bruce surge tank system (simplified) is shown in Figure 4. The pressure in the surge tank is transmitted to the heat transport system via a large pipe connecting the bottom of the tank with a reactor outlet header. Therefore, heat transport pressure can be controlled by controlling the steam pressure in the vapour space above the water surface in the Surge Tank. To raise steam pressure, the electrical immersion heaters are switched on, converting more liquid to vapour. To reduce pressure, steam is physically discharged from the vapour space to the bleed condenser via the steam bleed valves shown in Figure 4. To summarize, heat transport pressure is returned to set point either by switching on the heaters to raise pressure, or by releasing steam via the steam bleed valves to reduce pressure.

The interconnection of the Bruce Surge Tank and Feed and Bleed systems is shown in Figure 5. Pressure control may be switched either to 'solid mode' or to 'normal mode' as described below.

'Solid Mode' Pressure Control - Bruce NGS

In this mode, the Surge Tank is isolated, and pressure control is achieved solely by Feed and Bleed action. The significance of the word "solid" in "solid mode" is that no compressible vapour space exists in the system to 'cushion' pressure transients. 'Solid mode' is selected during pressurization and depressurization of the Heat Transport system, when the Heat Transport pumps are off.

'Normal Mode' Pressure Control - Bruce NGS

'Normal mode' control is selected during normal operation. In this mode, pressure is controlled by the Surge Tank System. Meanwhile, the Feed and Bleed System performs the following functions:

1. It adjusts coolant inventory as necessary to maintain Surge Tank water level at set point (see below).
2. It condenses bleed steam from the surge tank, and returns the condensate to the system.
3. It maintains purification flow.
4. It supplies D_2O to the Gland Seal Cooling System.
5. It maintains the bleed condenser as a pressure relief vessel.

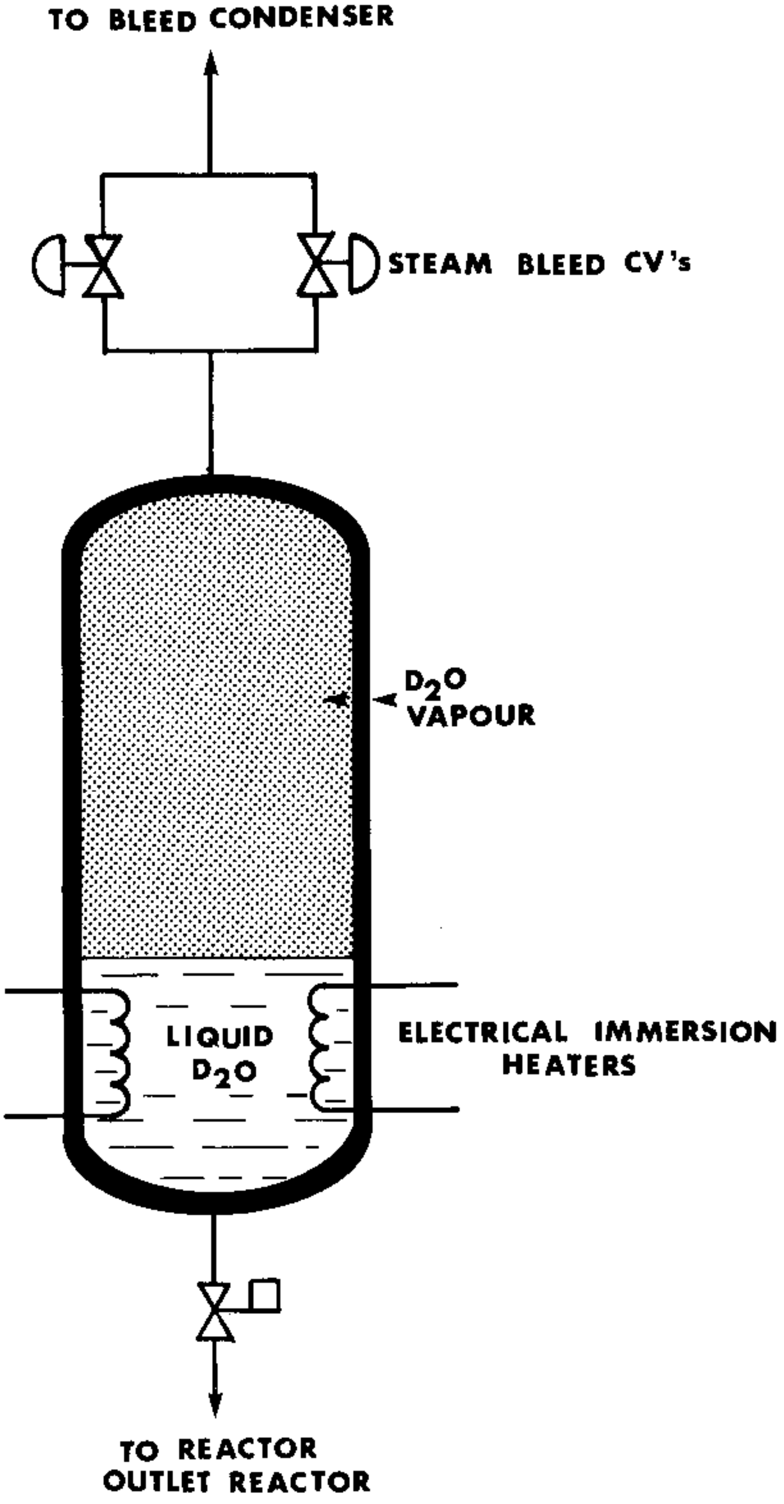

FIGURE 4: BRUCE SURGE TANK (SIMPLIFIED)

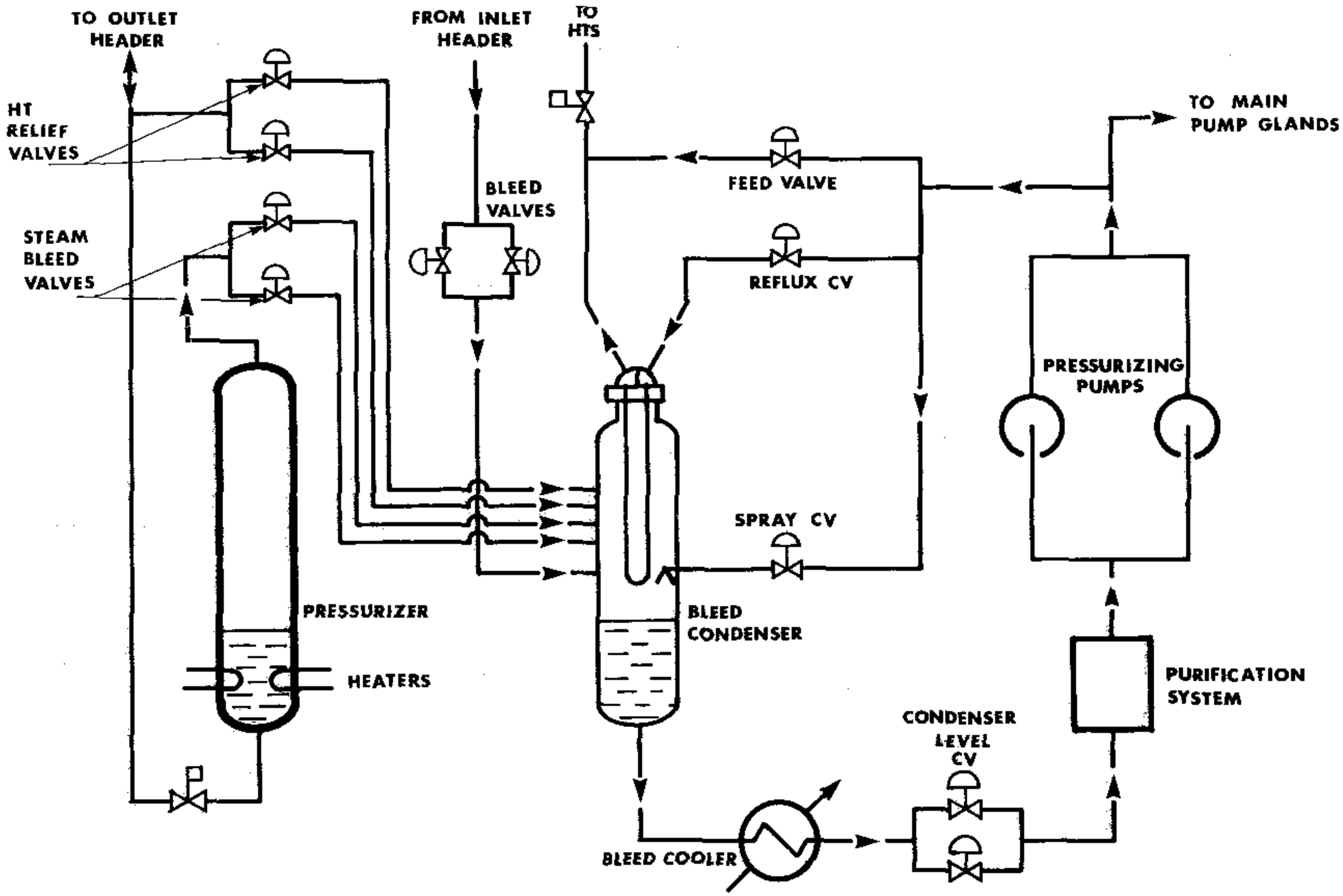

FIGURE 5: BRUCE HEAT TRANSPORT PRESSURIZING SYSTEM (SIMPLIFIED)

Note that functions #3, #4, and #5 are carried on by the Feed and Bleed system regardless of whether 'solid' or 'normal' mode is selected.

Surge Tank Level Control

Surge Tank level control is clearly necessary to prevent either of the following:

1. On low tank level, uncovering the immersion heaters, thereby risking burnout of the heating elements,
2. On high tank level, loss of the vapour space, which is essential to pressure control by the surge tank. (In this case, the surge tank is said to have "gone solid".)

An additional benefit is obtained from level control by ramping the set point up with reactor power, so that shrink or swell associated with power manoeuvres is accommodated right in the surge tank. For example, on a power rise, say, 50% to 70% full power, the Surge Tank level controller's set point is raised just enough that the controller 'expects' to see the resulting coolant swell show up in the Surge Tank, ie, the Feed and Bleed system is not then required to remove the swell in order to return the level to its set point. Therefore, during normal operation, there should be very little exchange of coolant between the main system and the D_2O storage tank, other than makeup for system leakage. (Note, however, that the enormous swell/shrink associated with warmup/cooldown is accommodated by the D_2O storage tank.)

IV. THE CHOICE BETWEEN PRESSURE CONTROL SYSTEMS

This section deals with several questions arising from the foregoing discussion on pressure control.

Question #1:	"What is the advantage of Surge Tank pressure control over Feed and Bleed control?"
Answer:	Faster response to pressure transients. It is worth emphasizing that the advantage is speed and not capacity of response. In fact, at Bruce NGS, capacity of the Surge Tank to accommodate swell or shrink is smaller than that of the Feed and Bleed system. However, the Surge Tank can accommodate a much larger swell/shrink rate than can the Feed and Bleed system. The maximum swell rate which the Feed and Bleed system can handle corresponds to the maximum allowed coolant warmup rate of 3°C/min.

Question #2: "Why is the Surge Tank response faster than that of the Feed and Bleed system?"

Answer: Because the Feed and Bleed system is more flow limited than the Surge Tank system. To begin with, the Feed and Bleed lines are typically only 10 cm in diameter as compared to 30 cm diameter for the Surge Tank line. Furthermore, the Feed and Bleed lines are throttled by the Feed and Bleed valves, which must respond to a rise in main system pressure before the Feed and Bleed system can begin to cope with the pressure transient. By contrast, the large Surge Tank line is fully opened all the time for free exchange of coolant between the Surge Tank and the main system. For example, a sudden swell of 1 m^3 in the main system could rush into the Surge Tank producing only a moderate pressure rise in the compressible vapour space before the steam bleed valves opened, whereas the same swell in a Feed and Bleed controlled system might cause a significant overpressure incident involving Heat Transport relief valve operation, or even a high pressure trip, depending on the swell rate.

Question #3: "Why is the faster responding Surge Tank necessary at Bruce NGS if not at Pickering NGS?"

Answer: The faster acting the pressure control system, the greater its scope for coping unaided with sudden pressure transients. Thus the Surge Tank is a design improvement over the Feed and Bleed system for normal operation.

There is more to the story, however. The Bruce NGS was designed to have the versatility to be a grid demand following station. To minimize the lag time in a unit's response to sudden grid demand changes, the "Turbine Leading - Reactor Following" control mode was adopted for Bruce units (see Instrumentation and Control courses for details on control schemes). One implication of this control mode is that average coolant temperature, T_{av}, varies considerably with reactor power, because the boiler pressure set point is constant (see lesson 233.60-1). Therefore, sudden power changes in response to sudden demand changes would induce sudden coolant swell or shrink. Hence the necessity for fast acting pressure control, to avoid severe pressure transients. The Pickering NGS, by contrast, was designed to be a base load station. Since time lag in a base load unit's response is not critical, the "Reactor Leading - Turbine Following" control scheme was adopted for Pickering units. The advantage of this scheme for pressure control is that boiler pressure can be ramped with reactor power in such a way as to minimize variation in T_{av}, and hence in coolant volume, during power manoeuvres. Hence Pickering units can operate satisfactorily without Surge Tank pressure control.

Question #4:	"Could the faster pressure control response required at Bruce NGS have been achieved merely by redesigning the Feed and Bleed system?"
Answer:	In principle, yes, by employing very fast acting control valves in large Feed and Bleed lines. Similarly, in principle, Feed and Bleed pressure control could have been discarded altogether by employing a Surge Tank with sufficient capacity to accommodate the shrink and swell over the entire operating range from cold shut down to full power. However, economics and reliability considered, the best choice is to employ both systems, and switch control from the one to the other as previously described.

V. WIDE RANGE VERSUS NARROW RANGE CONTROL

Coolant warmup is begun using the so-called "wide range" pressure controller, but control is transferred at some point to the "narrow range" controller, which has a higher gain. At Pickering, this transfer occurs at about 175°C. At Bruce, this transfer coincides with the transfer from "solid" to "normal" mode, and usually takes place once the Heat Transport system is fully pressurized. A higher gain controller becomes desirable as the coolant warms up because of the dramatic rise, by a factor of about 4, in coolant compressibility. A rough analogy is that the coolant becomes less like solid neoprene rubber and more like sponge rubber as the temperature rises from about 60°C to operating temperature. For example, the number of liters of coolant which must be added or removed to effect unit change in system pressure is about 4 times greater at 270°C than at 50°C. Therefore, the percentage change in bleed/feed valve opening per unit pressure deviation from set point, and hence controller/transmitter gain, must rise correspondingly in order to maintain control response as temperature rises. In practice, narrow range controller transmitter gain is more than 4 times higher than wide range controller gain so that tight pressure control can be maintained with the unit at power.

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