# 15 Heat Transport Auxiliary Systems

## 15.1 Introduction

Liquid coolant in the heat transport system (HTS) is a link in the heat removal chain. It protects the fuel by keeping it wet, and it transfers heat from the fuel to the boilers. The auxiliary systems described in the next few sections help the coolant do its job.

High pressure keeps the coolant from turning to steam. The pressure and inventory control system produces and controls coolant pressure in the main HTS circuit. High pressure feed pumps initially produce the high pressure. The pressure and inventory control system must accommodate coolant volume changes caused by thermal expansion and contraction (swell and shrink) of the coolant during operation.

The pressure may increase faster than the control system can counteract. Pressure relief valves prevent pressure from putting piping at risk of rupturing. Loss of coolant pressure and fuel failures would follow a large pipe break.

The coolant purification system protects piping and pump seals from corrosion and erosion that make ruptures more likely. It also removes fission products so that coolant, when it does escape, is less hazardous.

The gland seal system supplies cool, clean HTS $D_2O$ to cool and lubricate the pump seals. This helps prevent seal failure, which would result in pump failure and in the loss of $D_2O$ from the system.

There are many actual and potential heat transport system leaks. The fuelling machine, when connected, becomes part of the heat transport system. This creates additional places where $D_2O$ could escape.

The pressure and inventory control system uses a supply of $D_2O$ from a storage tank to keep the system full. A collection system returns leaked $D_2O$ from leakage points such as pump seals. A recovery system recovers $D_2O$ from unanticipated small breaks.

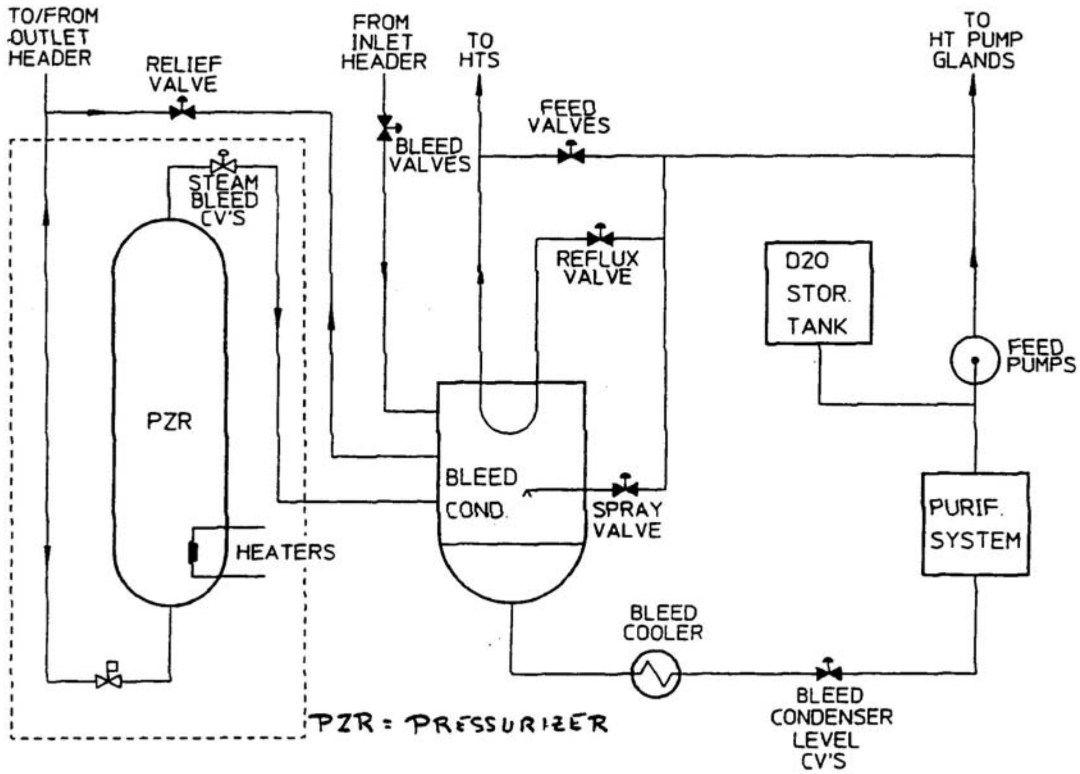


**Figure 15.1**
**Pressure Control Systems**

## 15.2 Summary of Key Ideas

- The words shrink and swell describe coolant thermal expansion and contraction.
- High pressure keeps the hot coolant in the liquid state. If the coolant pressure is too high, piping and pump seals risk rupture.
- HTS auxiliaries help maintain the quantity and quality of the coolant.

## 15.3 Pressure And Inventory Control

The pressure and inventory control system produces and controls the heat transport system coolant pressure. High pressure feed pumps initially produce the high pressure. The system then holds the pressure at the required value. In other words, the system supplies high-pressure inventory when required, and controls the pressure at the setpoint.

Low pressure and high pressure both cause problems. With low pressure, hot fuel bundle surfaces become covered with steam. This limits heat removal. Extremely high pressure can rupture piping, causing steam filled fuel channels when the pressure drops. Either way, fuel cooling suffers. Fuel bundles will likely fail, releasing radioactive fission products. If poor cooling persists, the fuel and fuel sheath could melt.

Figure 15.1 shows the pressure and inventory control systems found in most CANDU stations. Not all stations have a pressurizer, shown inside dashed lines in the figure. Some details of the CANDU 600 layout are different

We will explain figure 15.1 by describing each major piece of equipment. First we describe pressure control in a system with a pressurizer. Next, we describe pressure control with the pressurizer isolated, and then a system with no pressurizer. The next section describes the bleed condenser, bleed cooler, storage tank and the pressure relief system.

### 15.3.1 Pressure Control with a Pressurizer

The pressurizer is a large high-pressure tank, partly filled with liquid $D_2O$ and partly filled with steam. One of its purposes is to maintain the heat transport system pressure. A large pipe connects the bottom of the pressurizer directly to the reactor outlet headers at one end of the reactor. Compressed $D_2O$ steam above the liquid in the pressurizer holds the HTS pressure at the pressure setpoint.

For pressure control, there must be a steam space in the pressurizer, and nowhere else in the HTS. This condition exists when the saturated fluids in the pressurizer are hotter than the coolant elsewhere in the system.

When coolant in the main circuit heats and swells, it forces its way into the pressurizer, compressing the steam. The steam acts as a cushion, absorbing some of the pressure increase. The compressed, saturated steam, begins to condense. The steam bleed valves open as the pressure rises, lowering the pressurizer pressure to the setpoint.

When coolant in the main circuit cools and shrinks, the compressed steam in the pressurizer expands. This pushes liquid into the main circuit, limiting the pressure drop. The saturated liquid in the pressurizer begins to boil as the pressure drops. Heaters near the bottom of the tank turn on, and make more steam, raising the pressurizer pressure to the setpoint.

A pressurizer responds immediately to pressure changes. The steam space, by expanding or contracting, begins correcting a pressure error as it happens. The heaters or steam bleed valves then step in to correct pressurizer pressure and hold the system at the demanded pressure.

### 15.3.2 Inventory Control with a Pressurizer

A second purpose of the pressurizer is to accommodate volume changes of hot coolant. During power maneuvers, the pressurizer accommodates shrink and swell. Inventory control keeps the total amount of coolant in the main system plus pressurizer nearly constant. At high power, the reactor outlet temperature increases. The coolant swells and the liquid level in the pressurizer is high. At lower power, the coolant shrinks and the pressurizer level is lower.

1. Saturated liquid is at the boiling point for the given pressure. It is in equilibrium with saturated steam at the condensation temperature.

2. Five to ten metric tonnes of coolant move in or out of the pressurizer during power manoeuvres between 50% and 100% power.

Inventory control also keeps the pressurizer from completely filling with liquid, or from draining. Pressure control requires a steam space, and there must be enough liquid to cover the heaters.

Figure 15.1 shows coolant feed and bleed valves. When the pressurizer level is too high, excess inventory bleeds from the main circuit through the bleed valves. When the pressurizer level is too low, the feed valves open, allowing the high pressure feed pumps to add $D_2O$ to the main circuit.

### 15.3.3 Operation with the Pressurizer Isolated

When the reactor is shut down, the coolant temperature may be held near the operating temperature or its temperature may be cooled to below 100°C. During cooldown or warmup, the volume of coolant shrink or swell is too large for the pressurizer. The heat transport system then operates with the pressurizer isolated and the HTS $D_2O$ storage tank accommodates the large volume changes. The coolant may swell 60 $m^3$ during warmup of a large CANDU.

Figure 15.1 shows the large isolating valve in the connecting pipe between the pressurizer and the main circuit. With the pressurizer out of the picture, the inventory control system becomes the pressure control system. With no steam space anywhere in the HTS, small inventory changes have a large effect on the pressure.

The output pressure of the pressurizing pumps, labeled feed pumps in Figure 15.1, is higher than the HTS pressure. With the feed valve open, the feed pumps transfer inventory from the storage tank into the main system. If system pressure is high, the bleed valve opens to reduce pressure. Inventory from the circuit goes into the bleed condenser, reducing system pressure. This is known as feed and bleed pressure control.

### 15.3.4 Operation Without a Pressurizer

Some CANDU reactors do not have a pressurizer. Liquid coolant completely fills these reactors. Figure 15.1, with the equipment inside the dashed lines removed, shows this system. Its operation is similar to the operation just described with the pressurizer isolated, except that it is used both when the reactor is shut down and when it is at power.

A feed and bleed system controls pressure by adjusting inventory.

Pressurizing pumps increase the pressure when it drops, and the bleed condenser accepts excess inventory when the pressure is high. The feed and bleed valves control the movement of coolant in and out of the main system.

The feed and bleed system does not respond quickly to swell or shrink. Instruments must sense the pressure error and a control signal must then adjust the control valves.

Stations without a pressurizer limit the coolant shrink and swell when the reactor is running. To limit coolant shrink and swell, the coolant average temperature is kept nearly constant For example, when a power increase causes the reactor outlet temperature to increase, the temperature at the reactor inlet is lowered (by adjusting the boiler pressure).

## 15.4 Summary Of Key Ideas

- The pressure and inventory control system supplies coolant to the main circuit at the pressure required, and controls the system pressure.

- A CANDU reactor without a pressurizer controls pressure with a feed and bleed pressure control system, (pressurizing feed pumps with feed and bleed valves).

- A CANDU reactor with a pressurizer uses the feed and bleed system for inventory control. The feed and bleed system provides pressure control with the pressurizer isolated during warmup or cooldown.

- The steam cushion in the upper part of the pressurizer controls the heat transport system pressure. It expands to correct low pressure when the coolant in the main circuit shrinks. It absorbs pressure increases when coolant in the main circuit swells.

- Pressurizer heaters and steam bleed valves control the pressurizer pressure. As pressure rises, the steam bleed valves open to lower it. As pressure falls, the heaters come on to raise it.

## 15.5 Other Equipment In The Pressure And Inventory Control System

Now we will describe the role of the other equipment shown in Figure 15.1.

The bleed condenser reduces the temperature and pressure of coolant leaving the main system. $D_2O$ enters the condenser and flashes to steam. Reflux flow cools the steam, which condenses and collects in the condenser. If reflux flow cannot condense all the steam coming into the bleed condenser, the pressure will rise. Spray cooling then comes on to help bring the pressure down.

The $D_2O$ condensate flows through the bleed cooler. This drops the $D_2O$ temperature below 60°C. Hot $D_2O$ will damage the ion exchange resins and feed pump seals. The cool, clean $D_2O$ is stored in the low-pressure storage tank, or sent to the feed pumps for return to the main system.

Normally the feed and bleed valves are slightly open to supply continuous coolant flow to the purification system. The bleed condenser level control valves control the flow of liquid from the bleed condenser. The bleed condenser pressure pushes the D2O through the system to the feed pumps, or up into the storage tank. The storage tank at the pump suction has three functions.

a. It is large enough to accommodate coolant swell and shrink. The storage tank in a reactor without a pressurizer handles all inventory changes. For a reactor with pressurizer the tank handles inventory during warmup and cooldown, but not during normal operation.

b. It has a reserve supply of $D_2O$ to make up for small coolant leaks.

c. Its elevation provides pressure at the suction of the feed

The HTS coolant pressure is near 10 MPa, with a temperature near 300°C. Cooling keeps the bleed condenser temperature near 200°C. with a corresponding pressure of about 2 MPa.

The CANDU 600 coolant purification flow is separate from the feed/bleed loop. There is almost no feed or bleed flow in normal operation

## 15.6 The Pressure Relief System

The pressure relief system protects the heat transport system piping from mechanical overpressure. Overpressure could occur, for example, if the feed valves failed open, allowing the full discharge pressure from the feed pumps to pressurize the system. Relief valves that discharge coolant directly from the reactor outlet header into the bleed condenser provide the protection. The names pressure relief valves and liquid relief valves are both used.

## 15.7 Summary Of Key Ideas

- The bleed condenser collects, cools and lowers the pressure of coolant discharged from the main circuit. Coolant may enter through the steam bleed valves, the bleed valves or the liquid relief valves.

- The bleed cooler lowers the coolant temperature to protect the purification resins and feed pump seals. The low-pressure storage tank also requires cool $D_2O$.

- The feed pumps have a very high discharge pressure. Depending on the valve settings, this may pressurize the main circuit, increase the pressurizer liquid level or provide flow through the system, including purification flow.

- The feed valves supply inventory to the main system as required. In a system without a pressurizer, this raises the pressure. When a pressurizer is present, increased feed raises its level.

- The bleed valves drain inventory from the main system as required. In a system without a pressurizer this decreases the pressure. When a pressurizer is present, increased bleed lowers its level.

- The feed and bleed valves, when both open, supply purification flow.

- The storage tank accommodates coolant shrink and swell that the pressurizer cannot handle. It has a reserve supply to offset small leaks. Its elevation prevents feed pump cavitation.

- The pressure relief system protects the HTS from mechanical overpressure.

## 15.8 Other HTS Auxiliaries

### 15.8.1 The Purification System

Impurities in the system may arise from wear, corrosion and erosion. The fuel or fuelling machines also may introduce impurities. Radioactive impurities also come from fuel defects.

The purification system has two tasks. It must keep the coolant clean and it must control the coolant pH at a high value. Good chemical control is important for several reasons:

a) Protection from corrosion. Hot $D_2O$ is corrosive. The corrosion of heat transport system components is reduced when the coolant pH is kept high.

b) Protection from particulate damage. Particulates erode material, deposit on equipment and clog instrument lines. Abrasion by particulates can damage pump seals. Activated deposits are a maintenance hazard.

c) Removal of radioactive materials. Coolant may contain fission products from failed fuel and activated corrosion products. This increases radiation fields around HTS equipment, where some soluble materials plate out. Leaks are particularly hazardous when the coolant contains radioactive material. Regulations require high purification flow to remove radioactivity after a fuel bundle failure.

The layouts of the coolant and moderator purification systems are similar. Filters precede the ion exchange (IX) columns and keep the particulates from clogging up the resins. Strainers downstream of the IX columns prevent resin from entering the heat transport system.

The coolant purification system has fewer IX columns than the moderator purification system. It does not need reserve cleanup columns for removing reactivity control poisons. The ion exchange resins are also different from those used to clean moderator water. The coolant purification system resin, in addition to removing impurities, keeps the coolant pH high.

## 15.9 Summary Of Key Ideas

- The purification system keeps the coolant clean and maintains a high coolant pH.
- Good chemical control requires high pH for the coolant to minimize HTS corrosion.
- Particulates must be filtered from the coolant to limit erosion and abrasion damage. Activated particulates deposit on equipment and make it radioactive.
- The purification system removes fission products and activated corrosion products that make the coolant radioactive. These materials can escape through leaks, or when the equipment is opened for maintenance.

### 15.9.1 HTS Pump Gland Seal

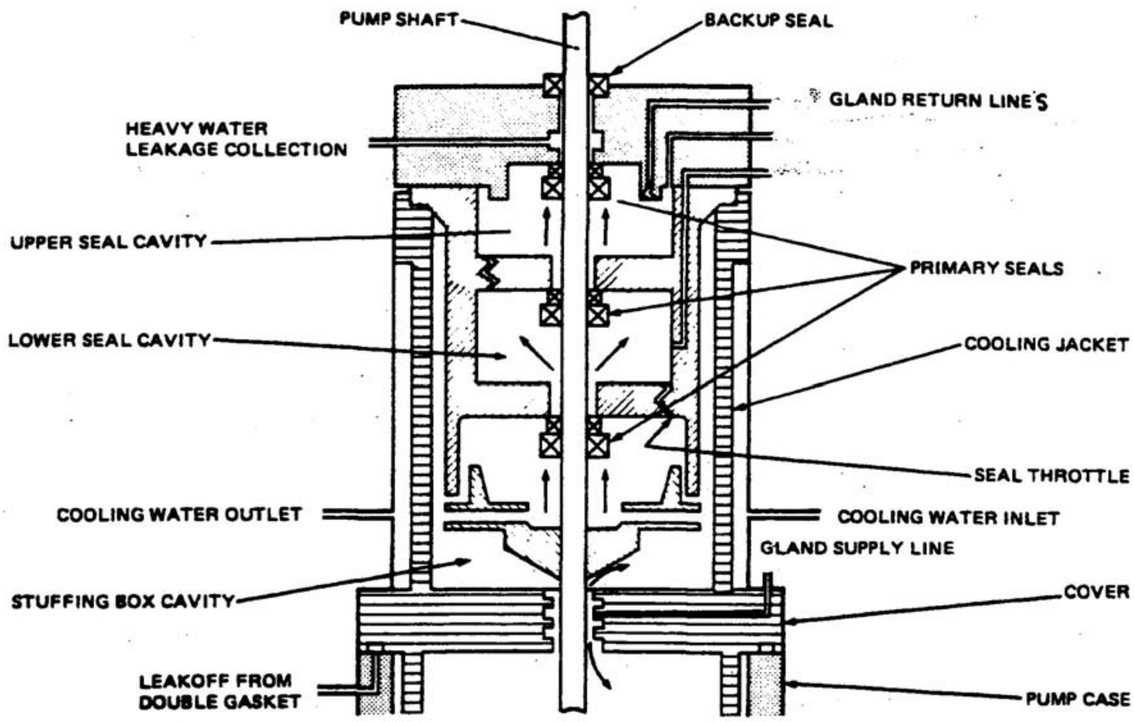


**Figure 15.2**
**Typical Heat Transport Pump Gland Seal**

The HTS pump gland and gland seal supply system protect the pump seals and bearings from damage. They also prevent leakage of radioactive coolant through the pump seals.

Figure 15.2 shows a typical pump gland seal. The pump impeller, if shown, would be at the bottom of the diagram. The bottom of the shaft is in hot coolant at almost 10 MPa pressure.

The coolant contains impurities that may be radioactive. The sealing arrangement prevents leakage of the coolant along the shaft. The hot coolant and the impurities it contains could damage pump seals and bearings. Failure of seals could release hot radioactive coolant to the reactor building atmosphere.

The gland supply line takes high pressure, cool, clean, filtered $D_2O$ from the feed pumps. The discharge pressure of these pumps is higher than the pressure in the main heat transport system. The high pressure, clean $D_2O$ keeps the hot coolant out of the seal cavities.

Some of this $D_2O$ flows along the shaft into the main HTS pump, preventing escape of the hot coolant. The rest of the gland supply flows into the seal cavities. The pressure drops from one cavity to the next. The $D_2O$ follows the gland return line to the suction of the feed pumps. A small amount of the water leaks past the primary seals, cooling and lubricating the shaft and seal. $D_2O$ that leaks past the final primary seal passes into the heat transport $D_2O$ collection system.

## 15.10 Summary Of Key Ideas

- Cool, clean, filtered $D_2O$ from the HTS pressurizing pump discharge supplies the pump glands. The high-pressure gland supply forces its way along the pump shaft, preventing hot, dirty, radioactive coolant from escaping. This prevents damage to pump seals and leakage of radioactive coolant.

### 15.10.1 The Heat Transport $D_2O$ Collection System

The heat transport $D_2O$ collection system uses a network of pipes to collect coolant that leaks from known leak points. Figure 15.3 is a line diagram of the heat transport collection system. The enclosed system lessens $D_2O$ losses, limits the escape of tritium and diminishes downgrading. Contact between $D_2O$ vapour and atmospheric $H_2O$ would cause downgrading.

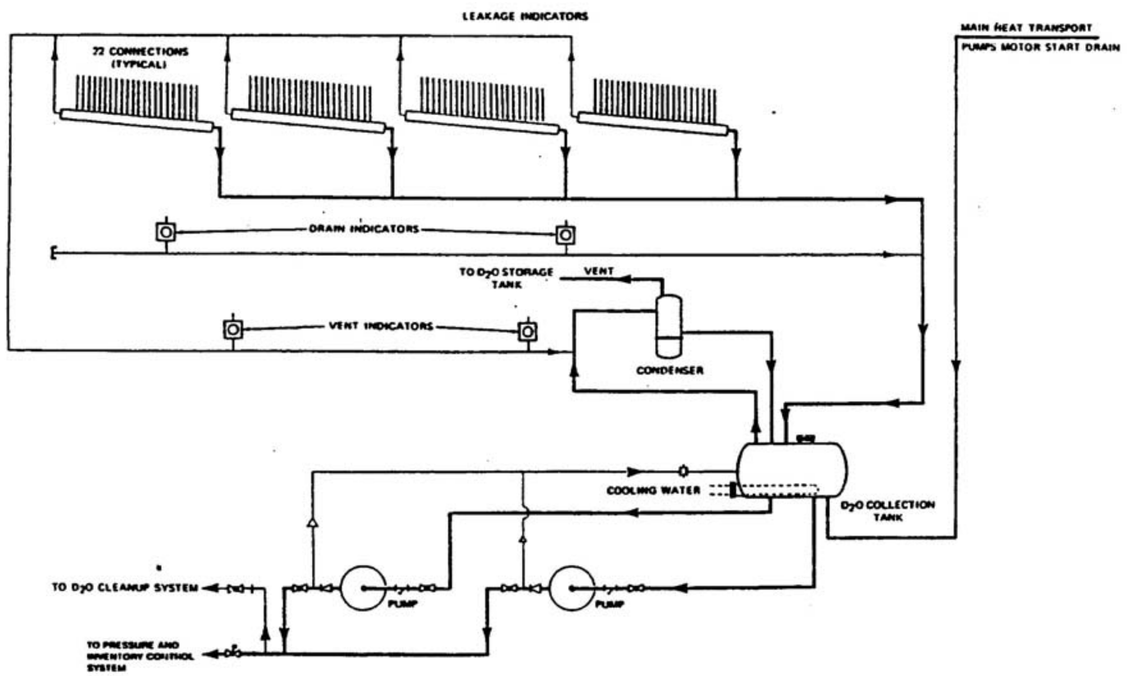


**Figure 15.3**
**HTS $D_2O$ Collection System**

The heat transport and moderator collection systems are similar in construction and purpose, but completely separate. Moderator $D_2O$ is never added to the heat transport system because tritium levels in moderator water are too high. Differences in isotopic prevent addition of coolant to the moderator system. Coolant isotopic is usually 98% to 99%, much lower than the 99.8% typical of moderator isotopic. Adding heat transport $D_2O$ to the moderator system would downgrade the moderator water. Downgrading increases fuel costs.

The heat transport collection system collects $D_2O$ from many collection points. There is more leakage from the HTS than from the moderator system. High coolant pressure makes the leak rate from many locations higher, and there are more leak points. A picture of the moderator collection system, comparable to Figure 15.3, would show fewer collection lines.

Coolant that leaks past the main HTS pump seals is the largest flow of $D_2O$ into the collection tank. Another source of $D_2O$ collection is from the inter gasket cavities of heat exchangers and other equipment. Inter gasket cavities are spaces between double gaskets used to seal the mechanical connections between the equipment and the heat transport system. Other collection lines come from valves. There is leakage along the valve stems as well as valve gaskets.

Finally, pumps, heat exchangers and other equipment have $D_2O$ draining and venting lines used for equipment maintenance. The collection system is a convenient place for collecting this drainage.

## 15.11 Summary Of Key Ideas

- Some $D_2O$ leaks are inevitable. Leakage through pump seals helps cool and lubricate the seals. There is leakage around valve stems and from gaskets on valves, heat exchangers and other equipment.

- The heat transport $D_2O$ collection system takes coolant from these known leakage points and returns it to the HTS. This system also collects $D_2O$ from drain and vent lines provided for equipment maintenance.

- The leak rate from the HTS is much higher than from the moderator system. The HTS has more leakage points and coolant pressure is much higher than the pressure of moderator heavy water.

- Moderator water, with its high tritium content, is never added to the heat transport system. The coolant, with low tritium content but high leak rate, already causes a large part of the station tritium hazard.

- Coolant isotopic is usually lower than moderator isotopic. Coolant is never added to moderator water because it would downgrade the moderator water.

### 15.11.1 The Heat Transport $D_2O$ Recovery System

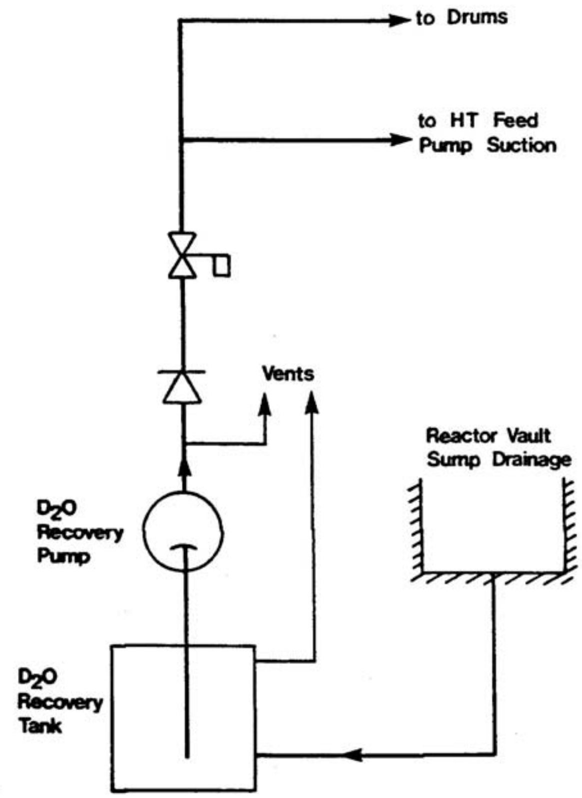


**Figure 15.4**
**Heat Transport $D_20$ Recovery System**

The $D_2O$ recovery system collects and returns coolant lost from unanticipated small and moderate leaks. If the coolant is not returned, the supply of $D_2O$ might run out. Light water injection would then be needed to keep the fuel wet, and this would downgrade the coolant.

Figure 15.4 is a line diagram of the recovery system. Leaking coolant drains to a sump. The sump drains to a recovery tank. A recovery pump transfers the coolant to the feed pumps for return to the heat transport system.

## 15.12 Summary Of Key Ideas

The HTS $D_2O$ recovery system recovers coolant from moderate leaks and returns it to the heat transport system. This allows $D_2O$ to cool the fuel. If there is not enough $D_2O$, $H_2O$ cooling is required. This causes expensive downgrading of the coolant.

## 15.13 Fuelling Machine $D_2 0$ Supply

The fuelling machine, when it is attached to a fuel channel, is part of the heat transport system pressure boundary. The fuelling machine has its own $D_2O$ supply to cool the used fuel in the fuelling machine.

Some fuelling machines inject their cool $D_2O$ into the channel during fuelling. This lessens the transfer of radioactive impurities from the heat transport system into the fuelling machine.

## 15.14 Summary Of Key Ideas

- The fuelling machines, when locked to channels during fuelling, become part of the high pressure HTS boundary.

- Used fuel in the fuelling machine must be cooled. This coolant may mix with HTS coolant during fuelling.

## 15.15 Assignment

1. State the functions of the following components for a feed/bleed pressure control system and for a system with pressurizer.

   a) feed and bleed valves,

   b) feed pumps,

   c) storage tank,

   d) bleed condenser and bleed cooler.

2. State how the pressurizer controls system pressure.

3. Compare the functions of the pressurizer steam bleed valves and the HTS pressure relief valves.

4. The moderator and heat transport purification systems both clean $D_2O$ and control its pH. Each has one specific task that is not required of the other. What are these two tasks?

5. Compare the $D_2O$ collection and $D_2O$ recovery system functions.

6. Describe how the pump gland seal works. Why is it important to filter particulates from the gland seal $D_2O$ supply?

7. Give and explain differences between the heat transport $D_2O$ collection system and the moderator $D_2O$ collection system in the following areas:

   a) Quantity of heavy water collected,

   b) Isotopic of the heavy water,

   c) Radioactivity of the heavy water.

8. Why would moderator water not be used to supply the fuelling machine?