14 Heat Transport System (HTS)

14.1 Introduction

Pressure tubes containing fuel pass through the calandria. Large pumps move heavy water coolant through these fuel channels, removing heat from the fuel. The coolant carries the heat from the core to the boilers, where it makes steam. Coolant is the main link in this heat removal chain. This module describes the heat transport system, including fuel channels, pumps and boilers. The next module describes several heat transport auxiliary systems.

The heavy water coolant removes heat from the fuel and transfers it to the boilers. In normal operation, this is a single task, but it is really two separate functions.

a) The heavy water coolant transfers heat from the fuel to the boilers. This is an essential step leading to steam production and power generation.

b) The heavy water coolant removes heat from the fuel. This task is extremely important, whether or not the reactor is making steam. Keeping the fuel wet protects the fuel. Without adequate cooling, the fuel will fail, releasing hazardous radioactive materials.

Radiation hazards in the heat transport system include the tritium,N-16 and O-19 hazards previously described for the moderator.

When the reactor is running, neutrons make N-16 and O-19. Their penetrating radiation prevents access to equipment containing circulated coolant when the reactor is running. They disappear shortly after a shutdown.

The tritium radiation hazard is always present in the coolant. Tritium releases are more common from the coolant than from moderator water because the coolant is under pressure. High pressure makes small leaks worse. A system opened for maintenance is also a tritium hazard.

Defective fuel releases a range of hazardous radioactive matter into the coolant. Some, for example iodine 131, are vapours that produce a radiation hazard around open equipment. Others, for example cobalt 60, plate out on system piping. These emit penetrating gamma radiation that persists when the reactor is not running.

The heat transport system presents two conventional hazards not seen in the moderator system. These are high pressure and hightemperature.

14.2 Summary Of Key Ideas

- The coolant is the main link in the heat removal chain.
- The coolant transfers heat to the boilers to make steam.
- The coolant protects the fuel by cooling it. This prevents massive fuel failures and radioactive releases.
- N-16, O-19 and tritium are radiation hazards common to coolant and moderator water. The coolant also may contain fission products from defective fuel.
- N-16 and O-19 are hazards that prevent access to HTS equipment with the reactor at power. Hazards from tritium and fission products persist after a reactor shutdown.
- High temperature and high pressure are conventional hazards associated with HTS equipment.

14.3 The Main Heat Transport System

Figure 14.1 shows a typical heat transport system layout The main circulation pumps take cooled D_2O from the boilers and pump it to a reactor inlet header. The header distributes the coolant through feeder pipes to the individual fuel channels.

Plate out is highest on cooler surfaces, such as the boiler outlets, and higher radiation levels are measured in these locations.

Hot coolant leaves each channel through an outlet feeder. The outlet header collects the hot coolant from these feeders and directs it to the boilers (steam generators). The hot coolant gives up its heat through the boiler tube walls. Figure 14.2, a sketch of a typical boiler, shows the boiler tubes.

This completes half the circuit shown in figure 14.2. The coolant continues from the boiler outlet to a second pump. Another inlet header, feeders and fuel channels take the coolant back to the first boiler. The complete pattern resembles a figure eight.

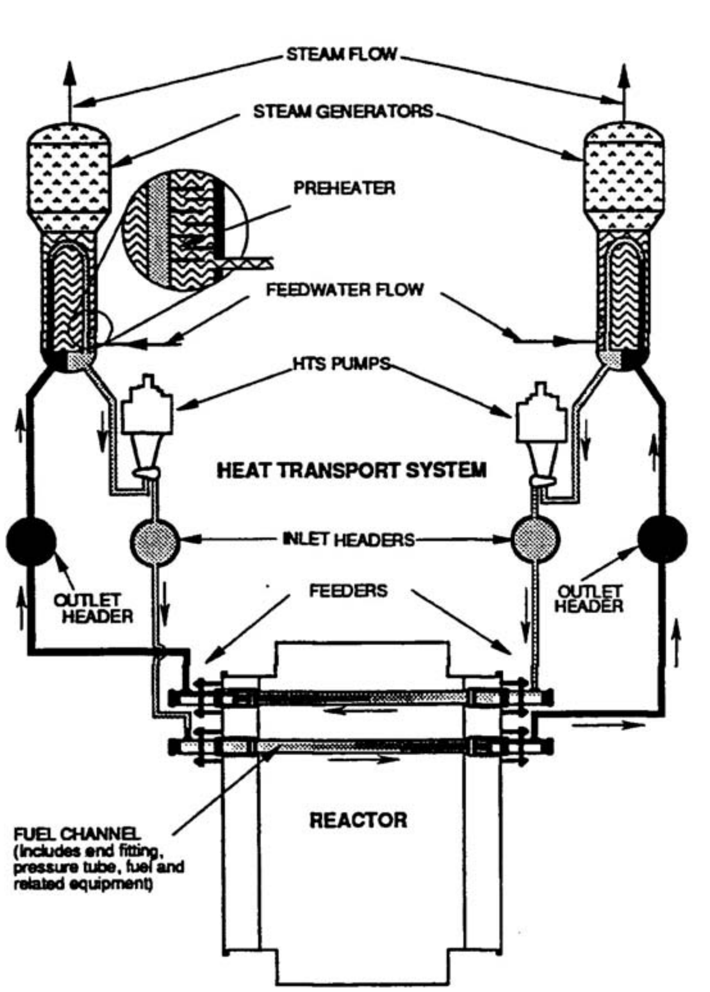

Figure 14.1
Heat Transport System

The figure eight places inlets and outlets at each end of the core. Coolant flows in opposite directions through adjacent channels. Bidirectional coolant flow keeps the temperature of the two reactor faces the same. This decreases thermal stress in the end shields, calandria and calandria tubes. If one reactor face had outlets only, it would operate about 40°C hotter than the opposite face, with inlets only.

The boiler produces steam at about 250°C for the turbine. The coolant enters the boiler somewhat hotter than this, roughly 300°C or so. Its temperature drops about 40°C as it passes through the boiler. It regains the higher temperature as it passes through the reactor core.

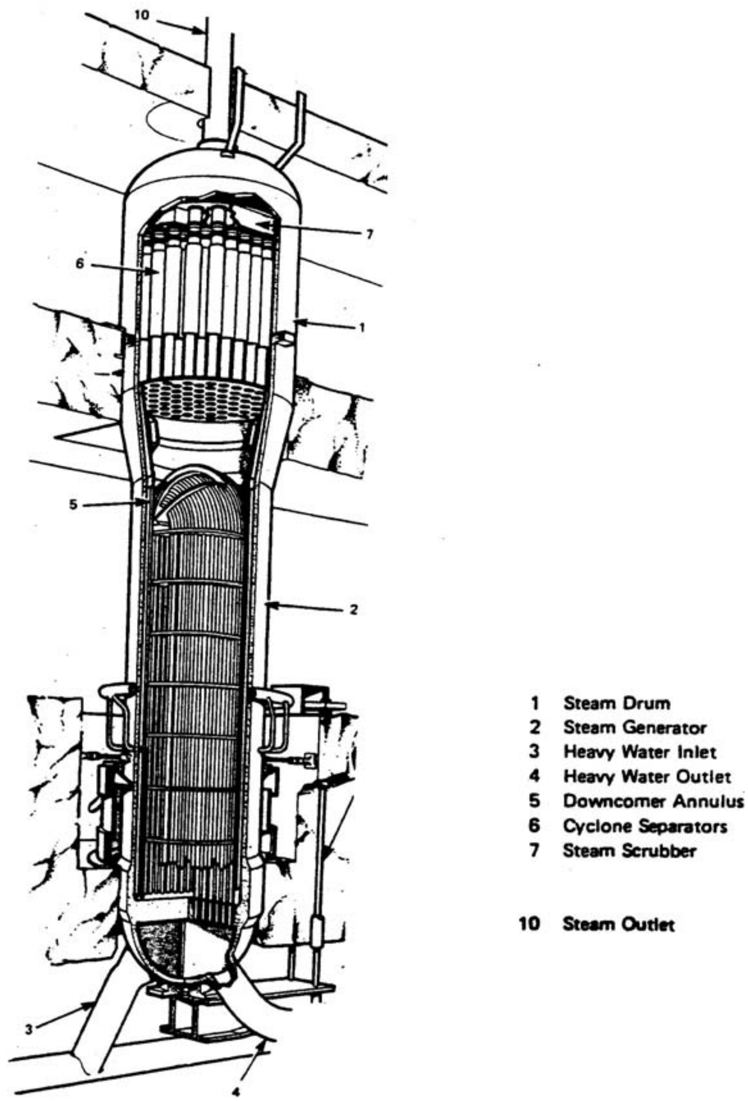

Figure 14-2
Typical Boiler

The location of the main pumps is the coolest point in the circuit at the boiler outlet. The pump location gives the largest possible margin against cavitation.

Briefly, cavitation is caused by localized boiling at the lowest pressure (highest flow) points in the fluid stream. This is immediately followed by rapid condensation of the steam bubbles on the high-pressure side of the pump impeller. Excessive HTS pump cavitation reduces the flow of coolant and may cause damaging pump vibrations. If fluid conditions deteriorate, the pump could fill with steam, stopping cooling flow to the fuel.

To prevent D_2O at 310°C from boiling, the pressure must be about 10 MPa (that is, about 100 atmospheres). The main circulating pumps do not produce this pressure; they supply coolant flow. They generate enough pressure to overcome fluid friction in the fuel channels and boiler tubes. The next module explains how the high pressure is produced and controlled.

14.4 Summary Of Key Ideas

- Pumps at the boiler outlets move coolant over fuel in the pressure tubes.
- The system has a symmetrical figure eight arrangement with boilers, pumps and headers at each end of the reactor.
- Feeder pipes take hot coolant from each channel and pass it to an outlet header. The header collects the hot coolant and supplies it to a boiler.
- The inlet headers take coolant from the pumps and distribute it to individual fuel channels through feeders.
- The pump location gives a high margin of safety against pump cavitation.
- Bidirectional flow maintains uniform temperatures across the core, reducing thermal stress on components.

14.5 Other Features Of The Hts Layout

Before you continue with this section, locate the boilers, main pumps and feeders in Figure 14.3. The figure shows the feeders at one end of the reactor only. In the diagram, the HTS pumps have double discharge and the boilers have dual inlets. That makes it easy for you to distinguish inlet headers from outlet headers in the diagram.

CANDU heat transport system designs are not all the same. The following description is typical of many newer CANDUs.

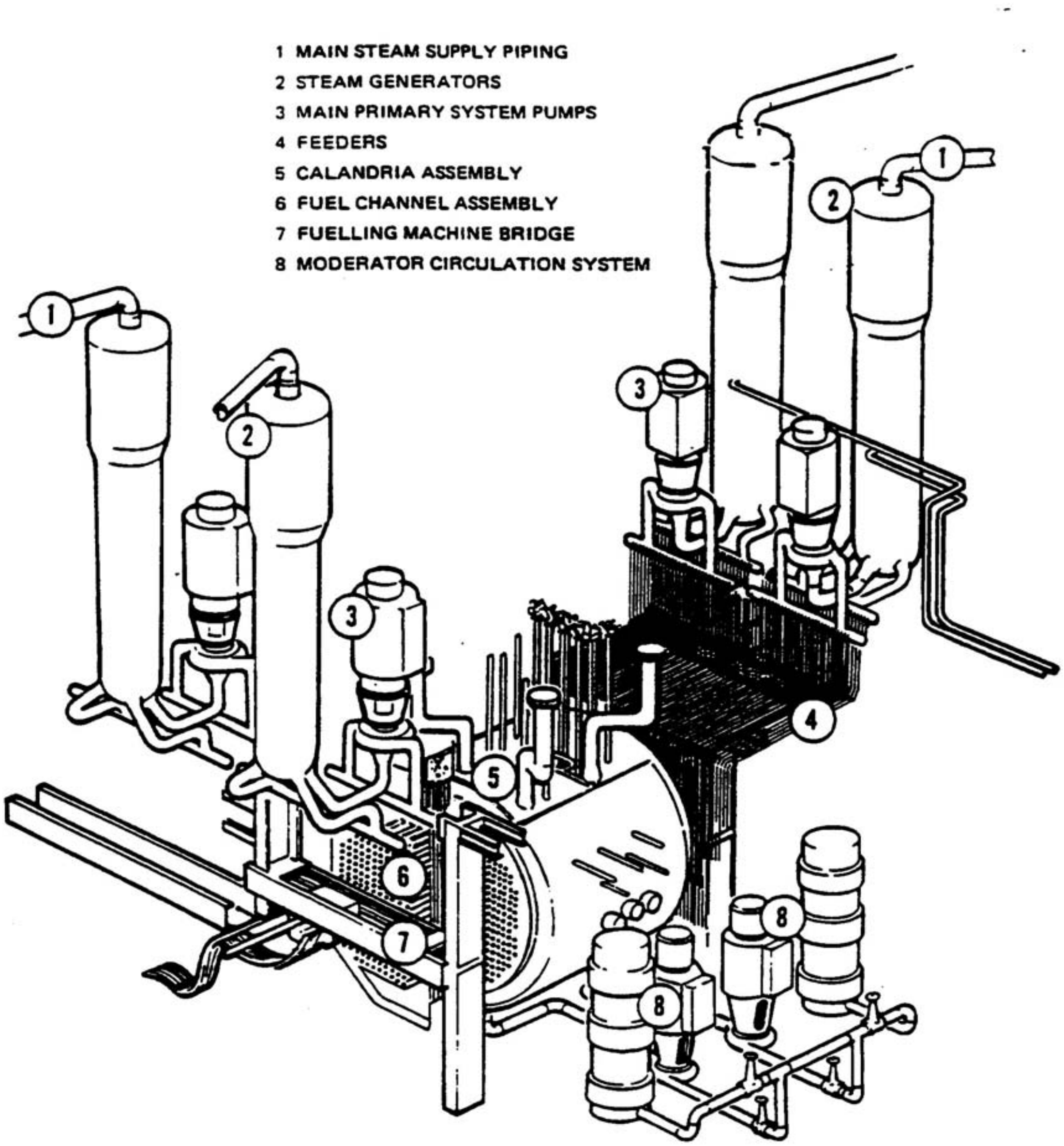

Figure 14.3
Reactor Core, Headers, Pumps and Boilers

Figure 14.3 is a view of a heat transport system with two figure eight loops. (Some plants have a single loop). Each loop supplies coolant to half the core. There are two large pumps and two large boilers in each loop. If one pump in a loop fails, it may be possible to continue operation at reduced power with a single pump.

Such large boilers and pumps were not always available. Older stations use larger numbers of smaller boilers and pumps. This sometimes includes standby pumps or boilers. Designs that are more recent do not include standby equipment in the main HTS. This saves money.

Fuel cooling must continue always, even with the reactor shut down. Without cooling, heat produced by decay of fission products in the fuel can fail the fuel, releasing fission products. A shutdown cooling system cools the fuel when the main pumps or boilers are either unavailable or not required. The size of the substitute pumps and alternate heat exchangers is adequate to remove decay heat. The actual layout differs from plant to plan.t

A feature shared by all CANDUs is the elevation of the headers and boilers above the reactor core. This permits fuel cooling by natural convection if the main pumps and shutdown cooling are both unavailable. For example, loss of electrical power could leave natural convection as the only way to cool the fuel.

Natural convection, also called thermosyphoning, does not produce high flow. It cannot remove full power heat, but is adequate to remove decay heat.

Natural convection occurs when cool D_2O in the boiler tubes falls by gravity into the core. It displaces the hot, less dense D_2O surrounding the fuel. The boilers cool the fluid pushed into them from the fuel channels, and it becomes more dense. The liquid that falls into the core expands on heating and becomes less dense. Thermosyphoning continues as long as the boilers continue to remove heat.

The elevation of the headers above the reactor and the position of the boilers above the headers has another advantage. Operating staff can drain the coolant to the level of the headers, provided it is cool and not under pressure. This drains the boilers and pumps for maintenance. The shutdown cooling system cools the fuel when the coolant does not reach the level of the main pumps. (Terminology at the Bruce site calls this system the maintenance cooling system).

There are no valves for isolating equipment in the main circuit. This eliminates the cost of the valves, reduces heavy water leakage and cuts down on radiation dose to plant staff. Reduced heavy water leakage helps reduce tritium leakage, and exposure of staff who do valve maintenance is reduced.

Early designs, uncertain of reliability, used standby pumps and boilers. Isolating valves allowed equipment maintenance.

14.6 Summary Of The Key Ideas

- A shutdown cooling system removes decay heat when other methods of cooling the fuel are not available. This is typically the case during pump or boiler maintenance.

- The elevated position of the boilers causes circulation by natural convection when the main pumps and shutdown cooling are not available. Natural convection (thermosyphoning) is adequate to remove decay heat from the fuel. It is essential when other methods of cooling the fuel are lost.

- The elevation of boilers and pumps above the reactor core eases their maintenance. Isolation valves are not needed.

14.7 Assignment

1. How are the two purposes of the coolant different from one another and how are they the same?

2. What hazards are present in the HTS that are not hazards in the moderator system?

3. Why are heat transport pumps located with their suction at the boiler outlet?

4. Why does the heat transport system layout have pumps and boilers at each end with bidirectional flow through the core?

5. What is thermosyphoning and when would it be needed?

6. What feature of the HTS layout causes thermosyphoning?

7. Why can the shutdown cooling system have pumps and heat exchangers that are smaller than the main pumps and boilers?