Module 6

HTS HEAT SOURCES & HEAT TRANSFER PATHS

OBJECTIVES:

After completing this module you will be able to:

6.1 For each of the operating states listed below, label a power flow block diagram (given) that shows the role of the heat transport system in transporting heat energy:

- a) At full power, with rated electrical output to the grid (two major pathways); ⇔ ***Pages 2-4***
- b) During poison prevent operation (major pathway only) for stations using SRV's and for stations using CSDV's; ⇔ ***Pages 4-5***

The diagrams must show:

- i) Major heat sources;
- ii) Heat carriers;
- iii) Required pumps;
- iv) Heat energy transfer points;
- v) Heat sinks.

6.2 State and explain the general constraints on HT system operation for the prevention of Delayed Hydride Cracking (DHC). ⇔ ***Page 6***

6.3 Explain the two major potential hazards associated with the HT system. ⇔ ***Page 6***

6.4 State two hazards associated with hydrogen when the HTS is cold. ⇔ ***Pages 6-7***

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INSTRUCTIONAL TEXT

INTRODUCTION

We have discussed in earlier levels of this course the main purpose of the Heat Transport System (HTS), ie. to transport the heat produced in the fission process to the steam generators by means of pressurized D_2O. The general layout of the various systems in use was also discussed as well as the three basic formats of Heat Transport Systems used in current CANDU reactors. To recap, these are:

1) Double loop, with counterflow through the reactor, and pressure control by feed and bleed;
2) Double loop, with counterflow through the reactor, and pressure control by means of a pressurizer;
3) Single loop, with counterflow through the reactor, and pressure control by pressurizer.

Also noted was the use of zirconium alloy pressure tubes for neutron economy, with the remainder of the system constructed mainly from carbon steel.

An additional function of the Heat Transport System (HTS) is to provide a barrier to the release of radioactivity to the environment.

The HTS must have the capability of removing both full power heat from the reactor and the decay heat following a shutdown. In this module we will describe the pathways by which the HTS can remove the full power output from the reactor and the alternative operational state when the unit is forced into the poison prevent mode. The shutdown operational function will be discussed in a later module.

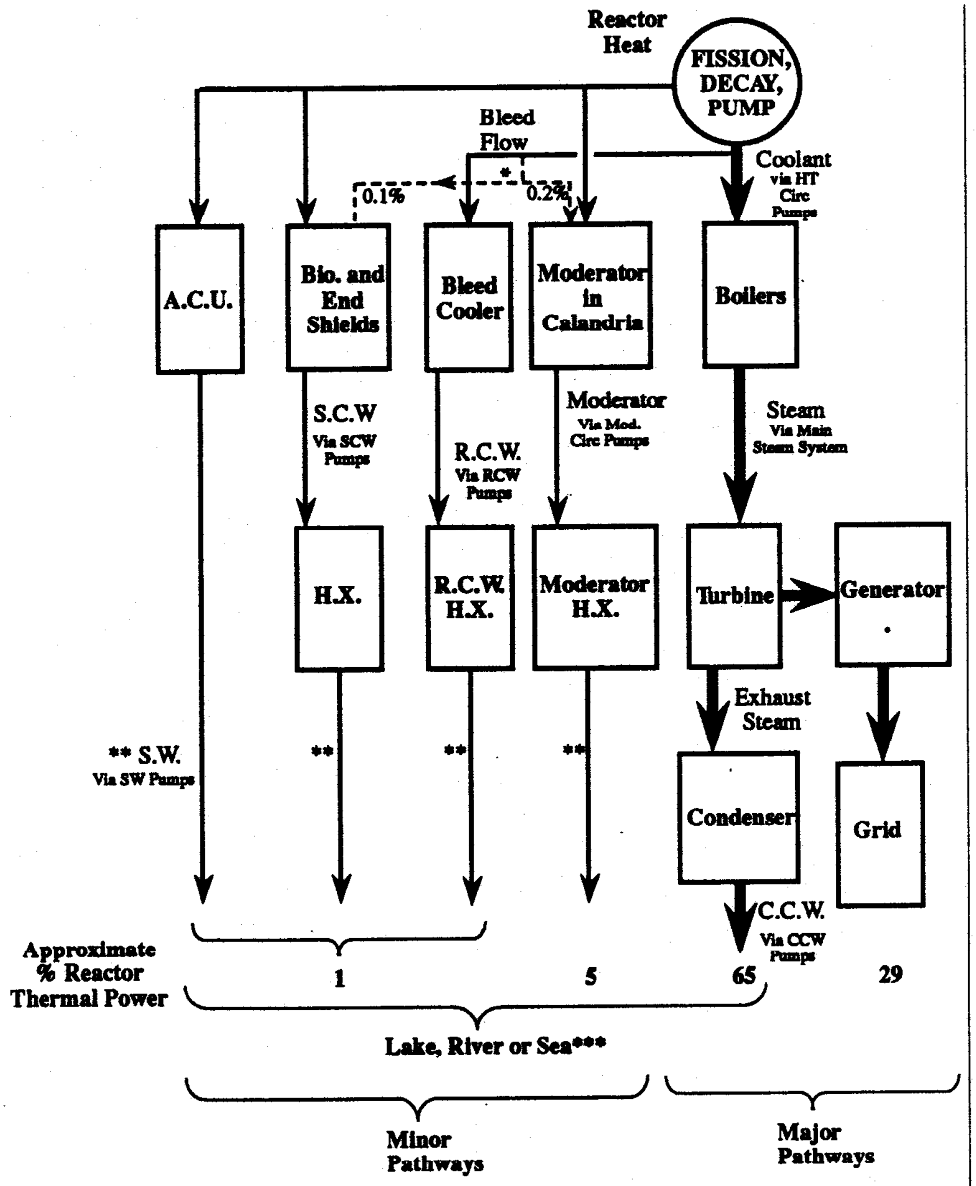
REACTOR AT FULL POWER

The approximate division of the heat produced in a CANDU reactor at full power is:

Heat from the fission process	~ 92-93%
Heat from the fission products	~ 6-7%
Heat from the HTS pumps	~ 1%

Obj. 6.1 a) ⇔

At full power, the heat from the above sources is transported by the HTS coolant (D_2O) to the boilers where the feedwater inventory, being converted into steam, provides the main intermediate heat sink (Fig. 6.1).



Key	
A.C.U.	Air Cooling Unit
S.W.	Service Water
S.C.W	Shield Cooling Water
R.C.W	Recirculated Cooling Water
C.C.W	Condenser Cooling Water

* Some channel heat will be transferred to the moderator and end shields by conduction and radiation.

*** An additional heat exchange is required for cooling to the sea, ie. Recirculated Cooling Water to Raw Sea Water

Figure 6.1 Full Power Heat Removal Chain

Steam produced in the boilers provides the driving source for the turbine generator. About **30%** of the energy **leaving the boilers** will be converted to **electrical energy** for the grid during normal operation. The remaining **70%** of the steam's thermal energy is transferred via the condenser and condenser cooling water (CCW) to the **lake, river or sea**. Note, this energy (heat) is released as the exhaust steam from the turbine is reconverted to a liquid state.

There are also other pathways, all ultimately ending at the lake (river or sea), for various auxiliary systems. As seen in Fig. 6.1, most of these pathways do not remove a large amount of heat ("minor pathway"). The only significant "minor pathway" auxiliary system is that for the moderator, which accounts for approximately 5% of reactor power output. Recall that this heat is generated by a combination of thermalizing neutrons and absorbing γs from fission, fission products, and activated core components.

Note that these "minor" heat paths will not be shown in subsequent diagrams although you should assume that they are still available for heat removal unless otherwise specifically stated.

The various shield systems at different locations (End and Biological/Thermal) have been lumped into a single category.

The circulation of the various heat transport mediums, such as Condenser Cooling Water (CCW), Recirc. Cooling Water (RCW), etc., requires the operation of circulating pumps for the overall heat transport mechanism to remain viable. The heat transfer diagrams shown in this module, and subsequent modules, will assume the correct ("normal") operation of various pumping sources.

POISON PREVENT MODE

Obj. 6.1 b) ⇔

This mode of operation is especially useful when steam flow to the turbine is lost with the reactor at power (eg, on a turbine or generator trip), and the prospects are good for returning the turbine generator to service within a few hours. As an alternative to a unit outage, this mode is used to prevent the reactor from poisoning out * due to higher than normal xenon levels.

* Recall from your Nuclear Theory course (227) that reactor power must be maintained high enough to prevent a poison outage.

Clearly, the **steam** must **be discharged elsewhere** in order to keep the boiler heat output via the steam equal to the heat input from the coolant (Fig. 6.2). At some stations, the steam is discharged to atmosphere via **Steam Reject Valves** (SRVs); at other locations, the steam is discharged directly to the condenser via **Condenser Steam Discharge** (Dump) **Valves** (CSDVs). The SRVs are rated for 100% full power and CSDVs are rated for 75-100% full power.

Ideally, reactor power could be maintained at full power to be absolutely certain that a poison outage does not occur. In practice, **reactor power**, hence steam flow, is **maintained** at the minimum - about **60% to 70%** - at which the Xe transient can be overridden. The reasons for operating at reduced power are as follows:

1) At stations using SRV's - to conserve feedwater, which is being lost to the atmosphere.
2) At stations using CSDV's having condensers with limited thermal capacity - to avoid overloading the condenser and excessive piping vibrations (note that some stations have condensers with 100% full power capacity).
3) Economic savings due to lower fuel and fuelling costs

Figure 6.2 a) depicts the Poison Prevent heat transfer chain for stations using SRV's. The coolant transports fuel and pump heat to the boiler, and steam transports the heat from the boiler to the atmosphere via the SRVs.

Figure 6.2 b) depicts the corresponding process at other stations. Steam transports the heat from the boiler to the condenser via the CSDVs, and the CCW transports the heat from the condenser to the lake, river or sea, depending on the station.

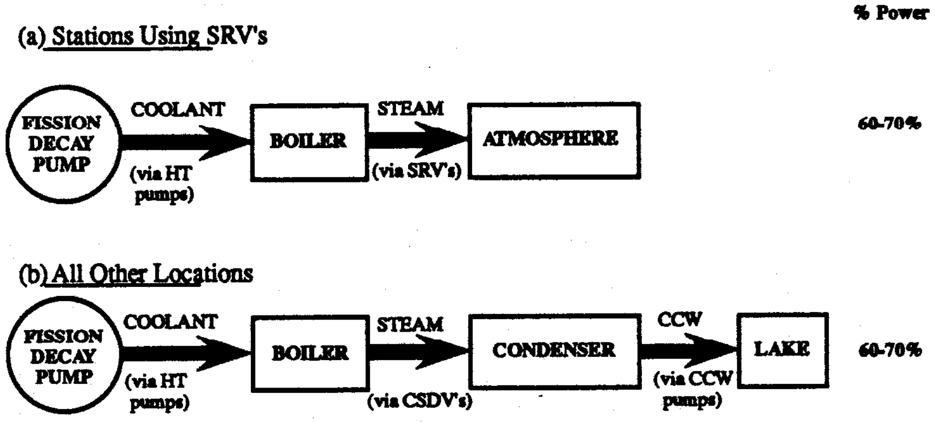


Figure 6.2
Poison Prevent Mode Heat Removal Chain

DELAYED HYDRIDE CRACKING

The movement between various reactor operating states is carefully controlled and is detailed in the various station operating manuals. One general constraint imposed on HT system operation between states is concerned with Delayed Hydride Cracking (DHC).

The phenomena of DHC has been discussed in detail in the 228 Materials course. In this course we will address only the general methods adopted to minimize the onset of DHC in the pressure tubes.

Obj. 6.2 ⇔

Experience indicates that the problem is essentially temperature/stress related. The highest risk is present when HTS temperatures are in the area **~100-200°C**. Operating procedures are, therefore, designed to **avoid operation** in this area and also to **pass through** this temperature band as quickly as possible (and in a continuous manner) both during heatup and cooldown of the unit. To further limit stress levels, this transition may also occur at pressures lower than normal operating pressure.

HAZARDS

Obj. 6.3 ⇔

The heat transport system is normally operated at **high temperature and pressure** and, therefore, has all the **"conventional"** hazards due to these effects.

In addition there are **radiation hazards** generated as a result of reactor operation. These include both activation and fission products. These materials are then distributed throughout the system resulting in:

a) Contaminated D_2O containing:

  i) Tritium;
  ii) Fission products as a result of any fuel failures or "tramp" uranium on fuel bundles;
  iii) Activation products.

b) Contaminated surfaces due to:

  i) Plating out of activation products;
  ii) Crud deposits;
  iii) Collection in IX columns and filters.

Contaminated D_2O is a significant hazard when leaks or spills occur, when the system is opened, or when adding or removing coolant.

Contaminated surfaces are hazardous when working with an open, drained system or during component maintenance.

In addition, when at power, there is a danger of elevated gamma and neutron fields around the system components (due to N^{16} and O^{19}).

Hydrogen Hazards When Cold

Obj. 6.4 ⇔

The necessary addition of **hydrogen gas** * to the system when operating can cause two major **problems when the system is cold:**

* More detail about hydrogen addition is given in Module 10

a) **Hydrogen embrittlement** of the zirconium alloy components - fully discussed in the materials course (228).

b) All the hydrogen related **explosion hazards** as the hydrogen comes out of solution following system depressurization. This is of particular concern if the system is to be opened for repairs. This is why the hydrogen addition system is isolated before the unit is depressurized during a shutdown. Purging, etc, may be required particularly if welding operations are to be undertaken.

These two problems require that H_2 additions to the HTS be limited to that required to maintain the system specifications for H_2 concentrations.

SUMMARY OF THE KEY CONCEPTS

- The two major heat removal pathways at full power are power output to grid and rejection of heat to the lake (river or sea).
- For poison prevent operation the major heat removal path is via the steam rejected directly to the condenser or to the atmosphere.
- The general operational method to combat DHC in pressure tube components is to avoid operation with the HTS in the temperature range 100°C-200°C and pass through this range quickly and continuously when required to do so.
- The HTS has potential hazards from both conventional and radiological sources.
- H_2 increases the risk of hydrogen embrittlement of zirconium alloy components when the HTS is cold. H_2 poses an explosion hazard as it comes out of solution when the HTS is cold and depressurized.

You can now **work on the assignment questions.**

⇔ ***Page 9***

ASSIGNMENT

1) For each of the operating states listed below, label the power flow block diagram that show the role of the HTS in transporting heat energy.

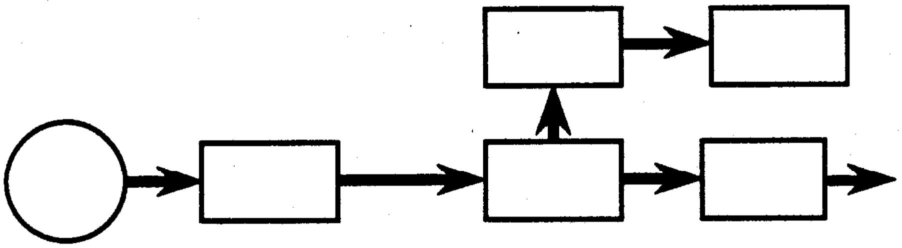
   a) At full power, with rated electrical output to the grid (two major pathways),

   b) During poison prevent (major pathway only), for a station using CSDV's and for a station using SRV's.

   The labels must show:

   i) Major heat source,
   ii) Heat carriers,
   iii) Required pumps,
   iv) Heat energy transfer points,
   v) Heat sinks.

Power Flow Diagram: Normal Operation - Major Pathways.



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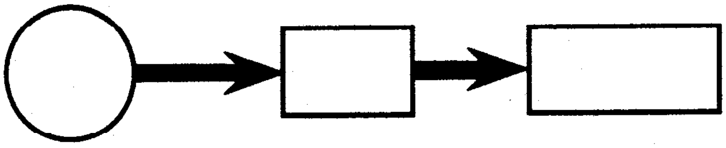
Power Flow Diagram: Poison Prevent Operation For Stations Using SRV's - Major Pathway.



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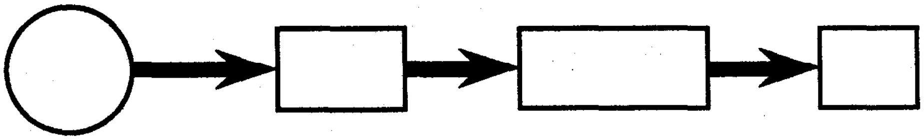
Power Flow Diagram: Poison Prevent Operation For Stations Using CSDV's - Major Pathway.



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2) The general constraints on the operation of the HTS for the prevention of DHC (Delayed Hydride Cracking) are:

a) ______________________________

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b) ______________________________

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The reason for these constraints is

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______________________________.

3) Explain the potential hazards associated with the HTS:

a) ______________________________

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b) ______________________________

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4) When the HTS is cold, H_2 causes an increased risk of __________ ______________________ of __________________ alloy components. It also poses an ________________ hazard as H_2 comes out of solution from the HT coolant at lower temperatures (and hence, lower pressures).

Before you move on, **review the objectives** and make sure that you can meet their requirements.

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