E. HEAVY WATER PRODUCTION AND MANAGEMENT

ENABLING OBJECTIVES:

5.14	State where D_2O is produced and describe the production process.
5.15	Describe how D_2O is managed in a CANDU station to minimise the need for continual makeup.
5.16	Describe the purpose and process of the tritium removal facility.

A CANDU reactor contains about 1 metric ton (1 Mg) of heavy water for every megawatt of electrical output. For example, a 540MW reactor at Pickering A has about 300 Mg of D_2O in the moderator and about 160 Mg of D_2O in the heat transport system. Currently Ontario Hydro has 20 CANDU reactors. To meet this very large need, Ontario Hydro constructed the **Bruce Heavy Water Plant** (BHWP) on the site of the Bruce Nuclear Power Development. It is the largest producer of heavy water in the world and has been supplying heavy water to Ontario Hydro and other customers since 1973.

HEAVY WATER PRODUCTION

Deuterium is found in any body of water in very small percentages. The production of heavy water involves nothing more than extracting and concentrating the deuterium naturally occurring in the lake water. Figure 5.7 is a simple schematic of the heavy water production process. The process is divided essentially into two parts: **enriching** and **finishing**.

ENRICHING

The **enriching process** used is known as the Girdler version of a sulphide process and is carried out in three stages. Natural lake water, after pretreatment to remove any solids and dissolved gases, is saturated with hydrogen sulphide gas. In the first stage of enriching (I in figure 5.7), this sour water is fed into the top of a process column. As the cool water flows down the column, it falls through a number of trays. Hydrogen sulphide gas blown into the bottom of the column rises upward through many little holes in each of the trays. This forces the gas into very close contact with the falling sour water to facilitate an efficient hydrogen/deuterium exchange.

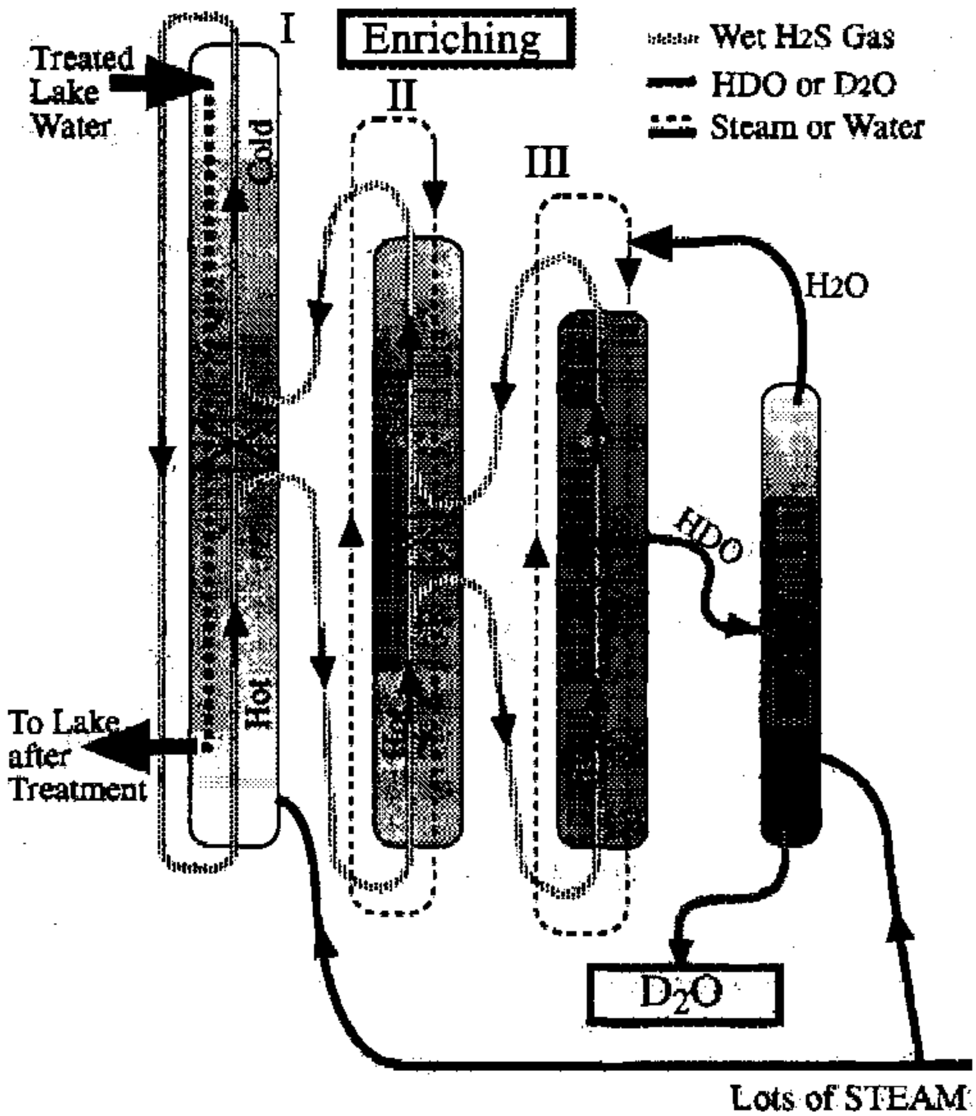

Figure 5.7
Heavy Water Production

The top half of the column is relatively cool and this encourages the falling water to exchange its hydrogen for the deuterium in the rising gas. The concentration of deuterium in the sour water reaches a maximum about the mid-point of the column. At the bottom of the column steam is used to heat the process. The heat in the lower part of the column encourages the rising gas to exchange its hydrogen for the deuterium in the falling water. The concentration of deuterium in the gas reaches a maximum about the mid-point of the column.

At the bottom of the column, the falling water has given up about 17% of its natural content of deuterium. This depleted sour water is stripped of hydrogen sulphide gas, cooled and returned to the lake. About 1000 kg of lake water is processed this way through an enriching unit every second.

In the second stage of enriching (II in figure), a portion of the deuterium enriched gas from the mid-point of the first stage column is blown into the bottom of a second smaller column. The sour water in this column is recirculated in a closed loop. Similar to the process in the first column, deuterium is further concentrated about the mid-point of this column.

In the third stage (III in figure), a portion of the gas from the middle of the second column is diverted into the bottom of a third and smallest column. Here in this column the deuterium is concentrated to over 900 times the natural content of lake water. From the mid-point of this column, a small flow of deuterium enriched sour water is drawn off and stripped of hydrogen sulphide gas. This is the product of the enriching process.

FINISHING

The **finishing process** involves taking the water from the enriching process and concentrating it in a large distillation column. The top product of the column is light water which is recycled back to the third stage column of the enriching process. The bottom product is heavy water which is over 99.9% pure.

HEAVY WATER MANAGEMENT

Heavy water is very expensive to produce and when it is used in a reactor it becomes radioactive largely due to the production of tritium. It is therefore critical that we manage our heavy water in such a way as to:

- minimize permanent losses;
- reduce our environmental emissions;
- minimize the chronic hazard to personnel.

Figure 5.8 shows the systems used for managing D_2O in a CANDU station.

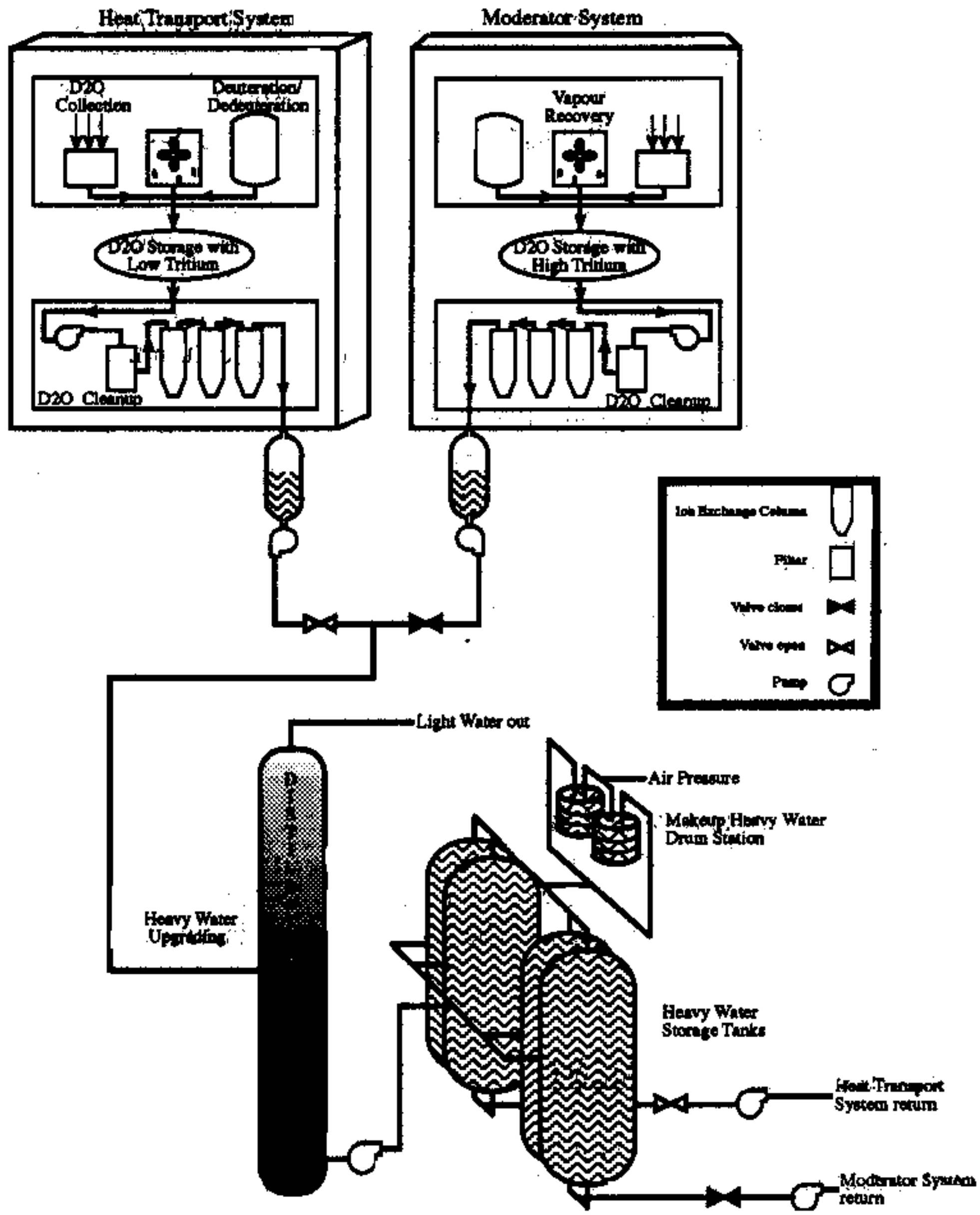

Figure 5.8
CANDU Station D_2O Management Systems

LOSS RECOVERY

Part of the cost of operating a CANDU station is the D_2O upkeep cost. This consists both of replacement costs for D_2O lost permanently to the station, and the cost of upgrading D_2O that has been downgraded (isotopic below limit).

D_2O can be lost permanently through:

- vapour losses (the largest factor);
- discharge of wet fuel bundles to the irradiated fuel bay;
- resin deuteration and dedeuteration[10] which produces some downgraded D_2O that is not recoverable;
- D_2O sampling and analysis;
- component decontamination;
- the top product from the upgrader which contains a small percentage of unrecoverable D_2O;
- moderator heat exchanger leaks.

To minimize D_2O losses, vapour recovery and special collection systems are employed. The areas where vapour losses are most likely have closed loop ventilation systems containing vapour recovery driers which reclaim most of the vapour. The recovered D_2O is always downgraded due to mixing with moisture in the air. Despite this recovery system, vapour loss makes up the largest fraction of permanent heavy water loss.

There are two types of D_2O liquid collection system. The **open method** uses drip trays under potential leak points such as flanged joints. The **closed system** conveys leakage directly to collection tanks without it coming in contact with the atmosphere to prevent downgrading from moisture in the air. This type of leakage generally occurs from double packed valve stems or bellows-sealed valves.

UPGRADING

If D_2O is downgraded below a certain isotopic then it is not worth recovering.[11] If it is economical to recover the D_2O then it is passed through a station upgrader. The upgrader is essentially the same as the finishing unit at BHWP. It uses distillation to separate the heavy water from the light water.

TRITIUM REMOVAL

The **Tritium Removal Facility** (TRF) located at Darlington NGS forms a part of our heavy water management system. It provides the capability to

[10] Deuteration is a process of exchanging the light water in IX column resins with heavy water to ensure no downgrading when the columns are placed in service. The resin must be dedeuterated prior to disposal to recover the heavy water.

[11] A group at Head Office works out the isotopic level below which upgrading is not economical.

reduce the tritium levels in the moderator and heat transport systems at our nuclear plants thereby reducing the chronic hazard to personnel. As a side benefit, the tritium extracted by the TRF is marketed commercially bringing extra revenue into the corporation.

Figure 5.9 provides a schematic of the TRF. In simple terms the TRF transfers the tritium from the heavy water to a deuterium gas stream. The gas stream is then distilled to concentrate the tritium. Finally, the tritium is immobilized to minimize the potential hazard.

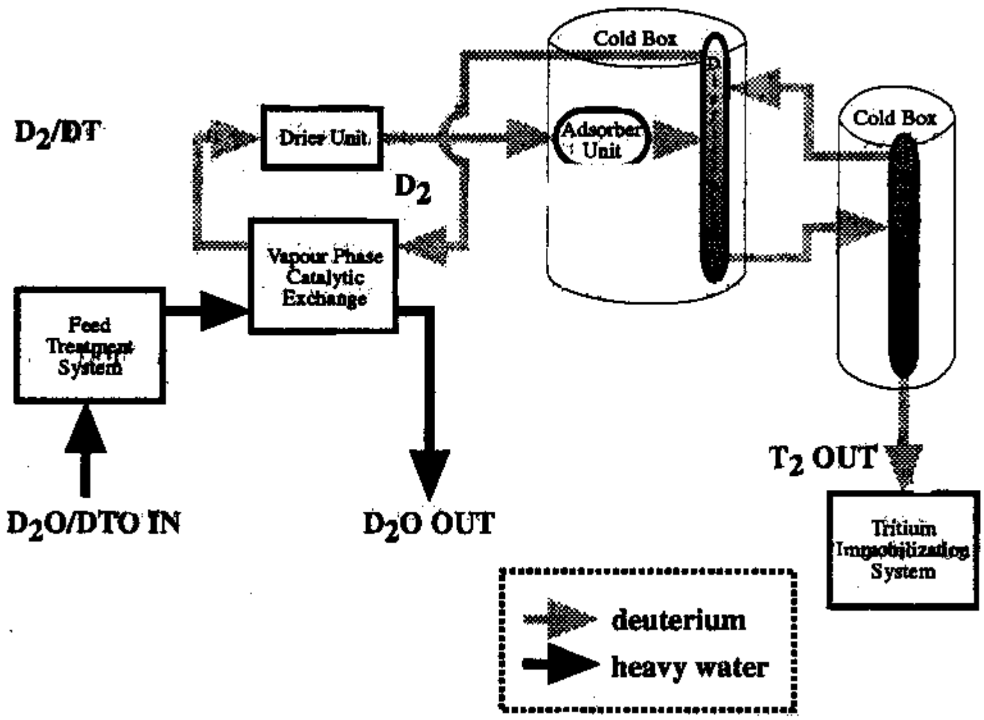

Figure 5.9
Tritium Removal Process

The **Feed Treatment System** receives highly tritiated heavy water (a mixture of D_2O, DTO and T_2O) from the stations and cleans it up to prevent impurities from fouling the TRF systems. The **Vapour Phase Catalytic Exchange** (VPCE) combines the heavy water with deuterium gas. The transfer of tritium from the water to the gas is facilitated by superheating the heavy water and deuterium and passing it over a catalyst. The heavy water leaving this system will have been detritiated by a factor >10 and is ready to be returned to the station. The deuterium gas stream leaving the VPCE passes through a **Drier Unit** where moisture is removed to prevent fouling of the distillation columns.

To concentrate the tritium that has been collected in the deuterium gas stream, the TRF relies on cryogenic distillation (at ~25 K[12]). To provide insulation to allow operation at such a low temperature, the distillation process is enclosed in **Cold Boxes** which are maintained at a near perfect vacuum. The **Adsorber Unit** strips the gas stream of any residual moisture as well as any gases (eg., oxygen and nitrogen) that freeze at temperatures higher than 25K. The distillation process relies on gravity to separate the heavier tritium from the lighter deuterium.

Finally, the concentrated tritium is drawn from the bottom of the last distillation column into a **Tritium Immobilization System**. This system is located in a glovebox to provide containment in the event of a process leak. The tritium is immobilized as a tritide on a titanium metal sponge in a sealed container. Because it is immobilized, the containers are at normal pressure and temperature and can be safely stored in a bank vault in the basement of the TRF building. Over time the tritium will decay (half life of twelve years) into a non-radioactive isotope of helium and will escape from the sponge. The slight pressure buildup is bled off periodically.

ASSIGNMENT

1. What is the process used to produce heavy water?

2. Where is heavy water produced in Ontario?

3. Why is D_2O managed so carefully?

4. Where might losses of D_2O occur and what systems are in place to keep these D_2O losses to a minimum?

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[12] K (Kelvin) is a temperature scale measured from absolute 0 (~-273°C). The gradations in the scale are identical to those used in Celsius.

5. What function is served by the Tritium Removal Facility?