13 Moderator Auxiliary Systems

13.1 Introduction

The moderator must slow neutrons and not absorb them. We previously examined moderator properties related to this function. This module describes several systems that support moderator system operation.

The last section described the heating caused by fast neutrons slowing down. Temperature changes cause thermal expansion and contraction of the heavy water. Expansion in a moderator system full of liquid could raise the calandria pressure, which is not a pressure vessel. A gas cushion, the moderator cover gas, protects the calandria structure from high pressure. This module describes the moderator cover gas system.

Fast neutrons split the water molecules that slow them down. Gamma rays also fragment D_2O. The gases D_2 and O_2 form from the fragments. The cover gas system removes these gases from the calandria so they will not collect and explode. Equipment in the cover gas system combines the gas molecules, making them into heavy water again.

The cover gas system keeps the pressure a little higher than the surrounding atmosphere. This prevents air from leaking into the system and contaminating it. The moderator purification system removes chemical contaminants and corrosion products from the moderator water.

Air is 78% nitrogen (N_2), 21% oxygen (O_2) and 1% argon (Ar) with traces of other things. O_2 is corrosive. N_2 makes the moderator acidic and Ar becomes radioactive.

Because the system is above atmospheric pressure, leaks that occur are outward. The D_20 collection system collects and returns D_2O that leaks from moderator equipment

It has already been stressed how important high isotopic is to keep absorption low. Reactor regulation sometimes needs changes in neutron absorption. The liquid poison addition system adds neutron-absorbing chemicals and the moderator purification system removes them.

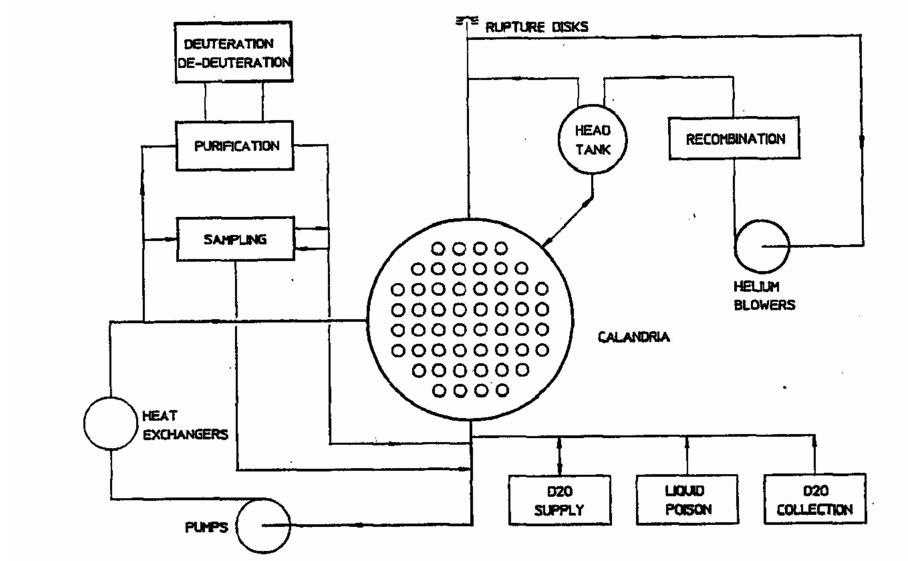

Figure 13.1
Moderator and Auxiliary Systems

Figure 13.1 shows the connections between the auxiliary systems and the main system. Notice how moderator pump pressure provides flow through the purification system.

Holes in heat exchanger tubes cause D_2O and tritium leaks into the service water. Finding and fixing leaks costs less than downgrading moderator water with service water.

Figure 13.1 is not a realistic drawing. Systems differ from station to station. For example, some stations connect the purification system downstream from the heat exchangers, taking advantage of the cool D_2O they provide. Other stations connect the purification system at the pump discharge to get better flow, and then provide a separate purification system heat exchanger.

13.2 Summary Of The Key Ideas

In a moderator system full of heavy water, that is, without a cover gas, thermal expansion could raise the pressure and damage the calandria.

Cover gas above atmospheric pressure allows heavy water and helium to leak out. It stops air from leaking in to contaminate the system.

Fast neutrons and gamma rays split water molecules. This produces hydrogen D_2 and oxygen gases that could collect and explode.

Reactor control uses neutron absorbing chemicals added to and removed from the moderator water as needed.

The main moderator pumps supply purification flow.

13.3 The Moderator Cover Gas System

13.3.1 Purposes

Figure 13.2 and the upper right hand corner of Figure 13.1 show the cover gas system. Figure 13.3 shows the layout for a system with a dump tank.

Dropping the moderator out of the reactor core stops the fission chain reaction.

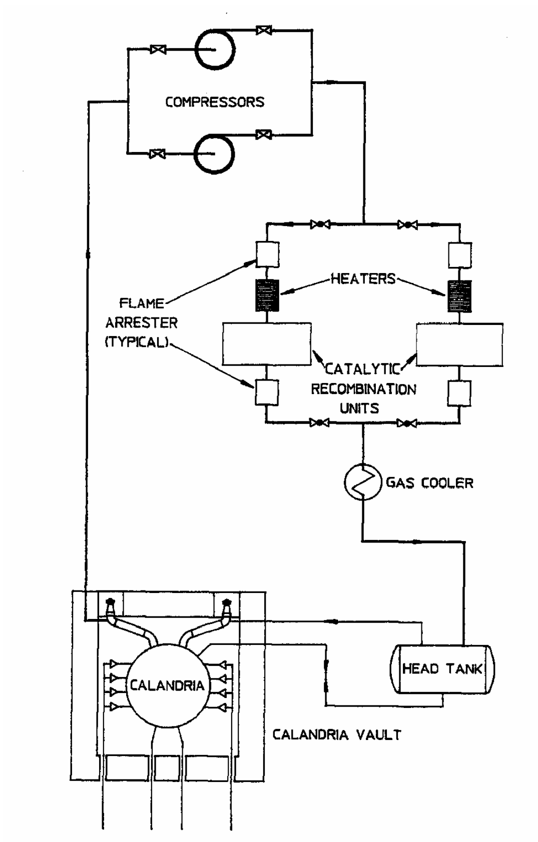

Figure 13.2
Moderator Cover Gas System for a Reactor Without Moderator Dump

The moderator cover gas system fulfils several functions.

The cover gas system controls pressure in the calandria.

The cover gas keeps a cushion above the moderator. This allows for expansion and contraction of the heavy water. It also absorbs transient high pressure caused by the liquid injection shutdown system.

Recall that rupture disks also protect the calandria from high pressure. Figure 13.1 shows these.

The cover gas provides a non-corrosive, non-radioactive atmosphere in parts of the system not filled with water. The cover gas is helium.

It is chemically inert, does not break down when radiation bombards it and neutrons cannot activate it.

Helium is, for a gas, a good heat conductor. It cools components not cooled by moderator water. The cover gas system removes D_2O and O_2 gases from the calandria.

Gamma rays and fast neutrons fragment water molecules, a process called radiolysis.

D_2O (RADIATION INDUCED)➔$D_2 + O_2$

The mixture of hydrogen and oxygen becomes an explosion hazard as the gases collect. Oxygen corrodes system components.

13.3.2 Description

Figures 13.2 and 13.3 show several common features. We will describe these first, and then discuss additional functions for the moderator cover gas system for reactors with moderator dump.

The helium compressors keep the pressure in the gas space above the calandria at about 110 kPa(a). The pressure is high enough to keep air out at the lowest pressure point of the system, the compressor suction.

The compressors also circulate the cover gas through the recombination unit.

Do not confuse the liquid poison injection system, an automatic shutdown system, with the liquid poison manual addition system described in this module.

13.3.3 The Recombination Unit

The recombination unit takes the radiolysis products, deuterium and oxygen gases, and combines them to make D_2O. The recombiner uses a catalyst that promotes a controlled chemical reaction at low levels of the reactants. This keeps the concentration of D_2 and O_2 in the system low enough that they cannot explode.

The chemical reaction between hydrogen and oxygen produces heat. This keeps the catalyst hot and dry. A small heat exchanger cools the hot gas.

When the system is not used, the catalyst becomes wet and will not work. On restarting, the heater at the inlet to the recombiner warms the cover gas, drying the catalyst.

Flame arrestors on the inlet and outlet prevent propagation of flames that might arise in the recombination unit.

Small lines can take a cover gas sample upstream or downstream from the recombination unit. The sample passes through a gas chromatograph.

The gas chromatograph finds the concentrations of O_2, D_2 and N_2. (N_2 shows there is air leaking into the system). If the deuterium concentration is high, the operator must act and shut down the reactor.

Oxygen is corrosive and some of it will combine with other elements in the system. There may not be enough oxygen in the cover gas to combine with the D_2. Oxygen addition lines introduce oxygen to the recombination units, if required.

Some helium will leak in normal operation. High-pressure cylinders supply makeup helium through a helium addition line connected to piping into the head tank.

Normally the concentration of reactants will be low and there will be no flame. Operating conditions could increase the concentration unexpectedly, however.

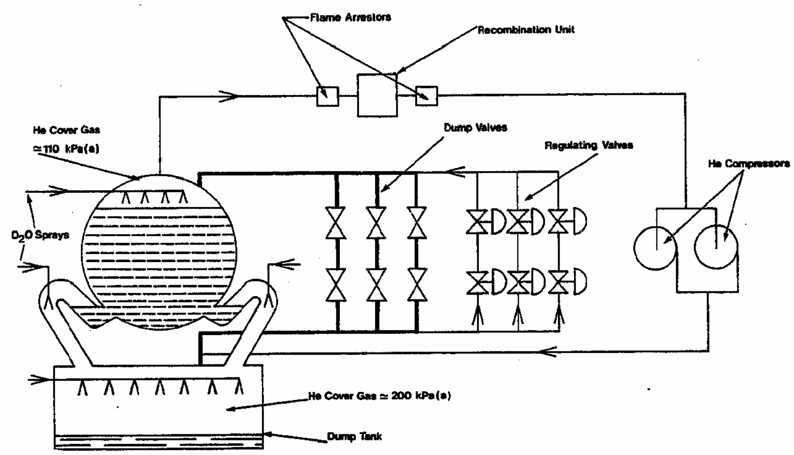

Figure 13.3
Cover Gas System for a Reactor with Dump Tank

At Pickering A, the cover gas system is part of the moderator dump emergency shutdown system.

A reactor malfunction may require a rapid shut down. With moderator dump, the cover gas system dumps the moderator from the calandria, shutting down the reactor. Future sections describe reactor protection by shutdown systems.

Large liquid ring compressors apply a pressure of about 200 kPa(a) to the dump tank. The regulating valves adjust the pressure in the gas space at the top of the calandria. A differential pressure of about 100 kPa supports the water in the calandria. The gooseneck design of the dump ports allows the dump tank pressure to prevent the water from draining into the dump tank.

Pickering A uses 2 x 100% (one operating and one standby) compressors. They take their seal water from the moderator, as light water would downgrade the D_2O.

Six dump valves trigger a reactor shut down. These valves, closed during normal operation, open quickly in an emergency. This equalizes the pressure in the calandria and dump tank. The moderator falls through the dump ports into the dump tank, shutting down the reactor.

At Pickering A, the cover gas system helps regulate reactor power.

The cover gas system at Pickering A maintains and regulates the moderator level in the calandria. Lowering the level increases neutron leakage from the core, and this reduces power.

Six regulating valves control moderator level by adjusting pressure in the dump tank. The height of heavy water that can be supported depends on the dump tank pressure. To lower moderator level, the valves go to a more open position. This lowers pressure in the dump tank. To raise moderator level the valves go to a more closed position.

13.4 Summary Of The Key Ideas

- The cover gas acts as a cushion, absorbing high pressure that could damage the calandria. Helium compressors keep the pressure slightly above atmospheric pressure.

- The helium cover gas is an inert atmosphere, neither radioactive nor corrosive, in parts of the system not filled with water.

- The cover gas removes O_2 and D_2 from the calandria and carries them to the recombination unit. The compressors circulate the cover gas.

- The recombination unit safely converts O_2 and D_2 to D_2O. The recombination usually produces a lot of heat. Flame arrestors prevent propagation of flames that might arise in the recombination unit. A heat exchanger cools the hot gases as they leave the heat recombiner.

- Dampness can prevent the catalyst from working. If the recombiner catalyst becomes damp through lack of use, an inlet heater warms the gases, drying the catalyst.

- A head tank helps maintain a full calandria in the system without dump. The cover gas fills ducts above the calandria. Figure 13.2 shows head tank and ducts.

- A gas chromatograph samples the cover gas for O_2, D_2 and D_2O. If there is not enough O_2 to combine with the available D_2, oxygen can be added through oxygen addition lines.

- Helium leaks from the system, high-pressure He cylinders replace it.

- At Pickering A, the cover gas system is part of the reactor control systems. This includes power regulation and emergency shut down.

13.5 Moderator Purification System

13.5.1 Purpose

Figure 13.4 shows the purification system. The purification system has two tasks. First, it must remove insoluble and soluble corrosion products and other impurities from the moderator water. Secondly it must remove unwanted neutron absorbing chemicals (called poisons), used for reactor regulation.

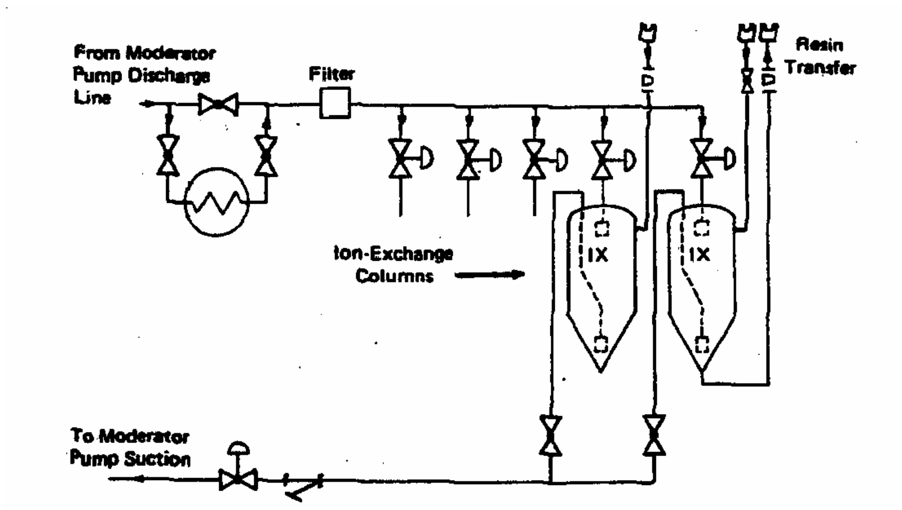

Figure 13.4
Moderator Purification System

Typical impurities include pump-lubricating oil and small particles produced by wear.

The purification system must keep the moderator water very clean for several reasons. Impurities cause corrosion and erosion damage. Neutron activation converts some impurities into radiation hazards. Impurities increase D_2 and O_2 gas releases from the moderator water.

13.5.2 Description

The ion exchange (IX) columns hold chemical resins that remove the soluble impurities. There are several IX columns in parallel. Purification flow increases if two or more columns operate simultaneously. The operator can valve in a fresh column to replace one that is used up. A filter removes insoluble particles. The filters precede the IX columns so the IX resin does not become clogged. Downstream from the IX columns, the strainer keeps resin from entering the moderator system.

The purification cooler in Figure 13.4 drops the moderator water temperature before cleaning. High temperature damages the resin, causing it to release trapped impurities back into the system. At some stations, this cooling is done by the main circulation system heat exchangers.

The chemical resins and filters concentrate activated impurities from the moderator. Heavy shielding protects workers from this equipment

Replacement of filters or resins requires exceptional care because of the radiation hazard.

13.6 Summary of Key Ideas

- The moderator purification system has two uses. It cleans the moderator water and helps regulate the amount of neutron poison.
- High chemical purity of moderator water curtails corrosion, diminishes the hazards of activated substances and reduces releases of D_2 and O_2.
- The moderator circulation pumps provide purification flow.
- Before purification, the moderator water is cooled. In some stations, the main circulation system heat exchanger provide this function. In other stations, there is a separate purification cooler.
- A filter removes particles from the moderator water and ion exchange columns clean it. A strainer prevents resins from escaping into the main system.

13.7 Other Moderator Auxiliaries

13.7.1 Moderator Liquid Poison Addition System

Boron and gadolinium are strong neutron absorbers used for reactor regulation. The liquid poison addition system adds soluble compounds of these elements to the moderator water. Figure 13.5 shows a typical system.

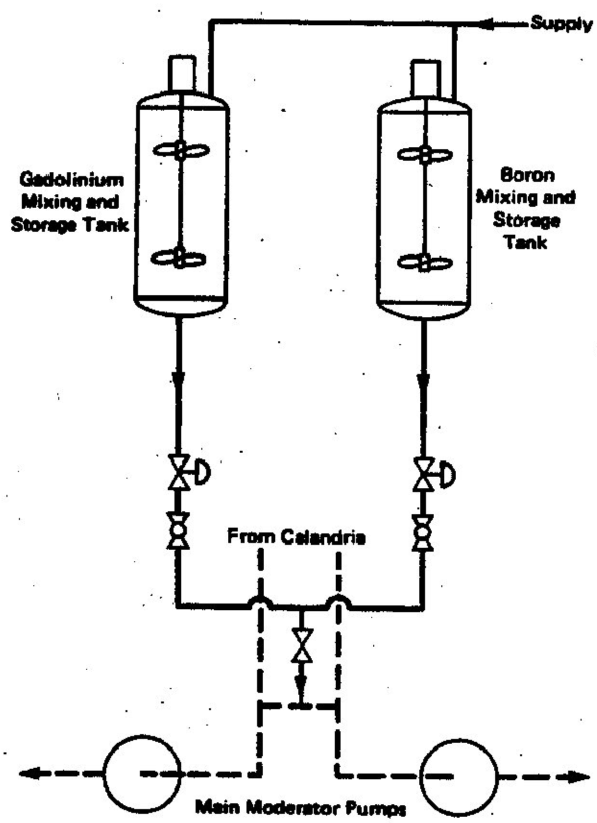

Figure 13.5
Moderator Liquid Poison Addition System

A poison addition pump introduces the selected solution at the moderator pump suction, the lowest pressure point in the main circuit. The control room operator regulates the pump and addition valves. Poison is added for coarse control of the reactor.

Some stations have a gravity feed instead of a pump.

Addition is not directly into the moderator so the effect is not immediate. After addition it stopped, poison continues to enter the system from holdup, in the pipes.

13.7.2 Moderator D_2O Collection System
The moderator D_2O collection system collects moderator water from known leak points. These typically include pump seals, gaskets, and packing around valve stems.

The collection system also accepts drainage from vent lines, from heat exchangers and from pumps. Maintenance workers drain and vent a pump or heat exchanger before opening it for maintenance.

The collection system consists of piping from the collection points, drained by gravity into a collection tank. Sight glasses or flow gauges reveal the leakage rate from various sites. A sample station is used to check isotopic. A pump returns high isotopic, clean water to the main system. Downgraded or dirty D_2O goes for upgrading or cleaning as needed.

A closed collection system lessens the loss of expensive D_2O. It also reduces the release of tritium to the plant atmosphere and diminishes downgrading, as it blocks mixing with atmospheric H_2O.

There is a figure in the HTS sections that shows a similar system that collects heat transport D_2O leakage. There are two separate collection systems to prevent mixing of heat transport coolant and moderator water.

13.7.3 Auxiliary Cooling Systems

Some stations use moderator water to cool certain equipment. A brief description of these auxiliary cooling facilities follows.

13.7.4 Reactivity Mechanism Rod Cooling

Rods to control the reactor need to be cooled. These rods include s adjuster rods, control absorber rods, and shut off rods. Their function will be discussed later. Gamma rays and neutrons heat these rods even when they are out of the core. Some stations cool the out of core rods with a spray of moderator water. Others circulate cover gas past these devices to cool them.

13.7.5 Calandria, Dump Port and Dump Tank Spray Cooling (Pickering A only)

Figure 13.3 shows calandria spray nozzles that cool the exposed calandria, calandria tubes and guide tubes. The figure shows similar sprays for the dump port and dump tank. The sprays operate continuously, both when the moderator is in the calandria and when it is in the dump tank.

During reactor operation, absorption of neutrons and gamma rays heats these components. Without cooling, thermal stress could distort the equipment Spray cooling continues during shutdown, to remove heat produced by decay gamma radiation.

13.8 Summary of Key Ideas

- Some pieces of mechanical equipment (gaskets, seals, valve stems) inevitably leak. The moderator D_2O collection system routes the leakage to a collection tank, keeping it out of contact with the surrounding atmosphere.

- The D_2O collection system also collects drainage from pumps and heat exchangers before they are opened for maintenance.

- The reactor power control scheme includes manually controlled addition of boron or gadolinium to the moderator by the poison addition system.

- Some CANDUs use moderator water to cool out-of-core reactivity devices and calandria components. Other CANDUs use the cover gas to cool them.

13.9 Assignment

1. Why is helium used as a moderator cover gas?

2. Why does a leak in the moderator main system or cover gas system produce a radiation hazard?

3. What is the purpose of:

   a) a recombination unit?

   b) the flame arrestors?

   c) the gas chromatograph?

4. Why is the recombination unit inlet heater not normally needed?

5. Give two uses of the moderator purification system and describe how the purification system equipment carries out these functions.

6. What problems arise if the moderator water is not kept clean?

7. a) What harmful effect does oxygen have on moderator system parts?

   b) Why is oxygen sometimes added to the cover gas? Why is helium added?

8. What are the sources of heat in the reactivity mechanism rods, the calandria tubes and the calandria shell?

9. Describe how the poison addition system is used.

10. Explain why a moderator D_2O collection system is needed and why a closed pipework system is used.

11. What is the role of the strainers in the purification system?